Operational scheduling with business modelling and genetic algorithms

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Submitted in fulfilment of the requirement for the degree of

Doctor of Philosophy
May 2020

Abstract

Development and maintenance of effective schedules is paramount to the overall success of project management. Scheduling in complex and large problem domains is resource consuming and challenging, and becomes especially difficult when project conditions often change within relatively short periods. This research contributes to knowledge in the program management area by putting forward a new approach that entails automation and optimisation of operational scheduling to enable organisations to run their workstreams in a controlled and predictable fashion to achieve the desired outcomes within expected timeframes and resource constraints.

The approach put forward in this research combines theoretical knowledge, technology-based scheduling implementation and genetic algorithm optimisations in a single framework to generate optimised schedules. The approach entailed the development of a new planning and scheduling method based on business modelling and genetic algorithms. This new method, called Operational Scheduling with Business Modelling and Genetic Algorithms has been recognised with the award of an Australian Standard Patent, and offers an integrated operational scheduling approach that allows its users to follow a clear path and address their day-to-day problems at the level of complexity required.

This method allows for artificial intelligence implementations based on genetic algorithms, which develop the initially proposed scheduling solutions to the optimal schedules that could be generated for given problem scenarios. The method starts from essential planning and scheduling where relatively simple scheduling is performed and then moves into domain-specific scheduling, which requires unrestricted, customised and complex implementations. In doing so, it constructs business models of the problem domain, identifies hard and soft constraints, implements automatic scheduling procedures to generate initial schedule samples, and performs genetic algorithms' crossover, mutation, fitness valuation to produce optimal scheduling solutions.

The method was applied in a number of case studies where it was found the optimisation delivered efficiency gains of between 8 per cent and 20 per cent of the total operational costs, which some cases resulted in significant monetary savings.

Keywords

Operation Management, Artificial Intelligence, Genetic Algorithms, Optimisation.

DECLARATION

I, Boris Petukhov, declare that the PhD thesis entitled Operational Scheduling with Business Modeling and Genetic Algorithms is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature Date

Acknowledgments

I would like to thank my academic supervisors because without their expert advice and support this PhD project would not have been possible.

Professor Yanchun Zhang, who is a Professor of Applied Informatics the VU Institute for Sustainable Industries & Liveable Cities.

Professor Terry Hallahan, who is an Honorary Professor at the VU College of Business.

I would like to thank all Victoria University working groups and staff who contributed to this study and who supported me administratively and academically on this journey.

I would like to thank the owners, executives and staff of Matthews Steer Accountants Advisors (MS), Melbourne, for participating in this study.

We would like to thank the owners and staff of Argo Computing Services Pty Ltd, Melbourne, for supporting this study both financially and technically.

I would like to thank my family for their support in this endeavour. If it were not for them, I would not have been able to complete this work.

Copyediting was provided by professional editor Sophie Dougall in accordance with IPEd's *Guidelines for editing research theses.*

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Chapter 1 – Introduction

1.1 Problem Description and Motivation

Operational management is a mature discipline. It defines how a given function is performed and it can be split into the following main components: all activities that need to be complete to achieve the desired objectives; dependencies related to those activities (i.e. what is the valid order of execution and related lead and lags.); resource types required to complete those activities; estimated durations of those activities; and anticipated costs and overall completion times of logically completed outcomes. Operational management is complex and challenging. It spans across financial management, people management, time management, scope management, issues and risks management. Operational management failures result in significant loss of capital and negative impact on all involved groups, including customers, delivery teams, and sponsoring bodies. To mitigate the risks of such problems, operational managers from different industry sectors employ various methods and techniques to manage the delivery of their initiatives more effectively. Over the last few decades, several methodologies were widely adopted. They have introduced a level of discipline and supported the development of a significant body of knowledge supporting operational delivery predictably.

Opportunities and threats of the operational management domain have motivated extensive research and development effort to make sure that advances in science and technology help the industry participants to achieve their objectives and achieve their strategic goals.

The author has spent more than seventeen years managing the delivery of various projects and programs in many industry sectors. During that time, he has made the observation that despite the effort from all parties involved, the success rate of project delivery is still very low. He thought more research in the space could be completed to develop new methods and techniques and help operations managers to face challenges of the modern era. Such a new approach could bring an end-to-end integration of management processes, based on advanced quantitative method. This method would keep track of all aspects of the delivery in near real-time. The author felt that the emergence of artificial intelligence could contribute to automation and optimisation of managerial processes, which in turn should result in timely responding to dynamic delivery conditions and optimal allocation of resources across working groups, among other improvements.

1.2 Research Objectives

With the above-described problem brief and desire to bring improvements, the research commenced and the following objectives and research questions were taken into the scope of this PhD project.

- Can a new operational management method be proposed that allows planning and scheduling professionals to always have valid, current and optimised operational schedules?
- Can operational scheduling optimisation be implemented using genetic algorithms within the larger operational planning and scheduling method?
- How can the known approaches be modified so that the new method does not employ encoding/decoding when performing optimisation operations and therefore improves performance and illuminates creation of invalid solutions altogether?
- How can the known approaches be modified so that search and optimisation is implemented in SQL?
- How can the known approaches be modified so that the new method uses the native DB storage structures (database tables)?
- How operational planning and scheduling techniques can be applied to an accounting, taxation and compliance practice to achieve operational efficiencies with so-called projectisation and productisation.
- How operational planning and scheduling techniques could be applied to information technology projects and programs to achieve operational efficiencies.
- How the earlier developed Operational Scheduling with Business Modelling and Genetic Algorithms method can be used to achieve the desired outcomes by automating and optimising scheduling process.
- Can the Operational Management Optimisation method and its techniques be applied to telecommunications network provisioning where resource allocation has to be optimised to offer those who run the network to utilise the most optimal planning of the available resources possible?
- We believe that a newly developed operational scheduling method (Petukhov 2016) can be employed to reduce resource consumption across enterprises around the world in various industry sectors. Will doing so drive the delivery on the climate change Sustainable Development Goals (SDGs)?

1.3 Research Methodologies

This study was performed in the form of a few different initiatives. Firstly, it completed qualitative analysis to explore existing operational management methods and to propose the new one. It also performed a quantitative analysis to understand how the application of the new method can improve efficiencies of operational management.

Following that, a new optimisation method was introduced, which while using popular genetic algorithms concepts, introduces novelties that help the optimisation module of the planning and scheduling method to perform better.

One of the main objectives of the research was to not only develop a body of theoretical knowledge but also to develop technology that implements the method and allows for integration with modern enterprise resource management systems. To meet this requirement, a certain way to abstract and model business and technology problems and solutions has been adopted by the author. Static models are presented in Unified Modeling Language (UML) format. They describe how business entities relate to each other and what attributes they have. Dynamic modelling is built using Microsoft .NET framework. It provides an opportunity to compile functions and procedures, implementing processing logic (e.g. automatic schedules generation and genetic operations like mutation and cross over). This choice of modelling tools and techniques brings outcomes of this research closer to the industry standards related to business process architecture, information architecture and technology architecture. Finally, it opens many opportunities to utilise the results when building industry strength operational management and optimisation solutions.

The end-to-end planning and scheduling method has been called Argo AI – OMO, also known as Argo Scheduling 2015.

A case study was conducted to show how strategic objectives of a given accounting firm, Matthews Steer Accountants and Advisors (MS), can be achieved when modern methods of service delivery are applied. The study and proposed method will be considered a success if, when completed, some tangible positive outcomes can be observed.

Another case study was performed to show the feasibility of the new development optimisation method in the information technology projects and programs domain to achieve operational efficiencies.

Finally, the automated scheduling and optimisation approach was tested in a telecommunications network resource allocation domain.

Given the current interest in the space of climate change and related challenges, the team completed analysis to see if the approach to operational management can indirectly impact the developments there. We have analysed the climate change challenge, reviewed its impact on human life, assessed actions that should be taken to tackle the problem and evaluated the feasibility of applying AI optimisation techniques to achieve some positive outcomes.

Ultimately a new end-to-end scheduling and optimisation method was developed with some original inclusions into its search module implemented with genetic algorithms. Several completed case studies proved that it could be applied to different industry settings.

In line with Victoria University policies, the Human Research Ethics Committee has approved this research (Reference Number: HRE20-154).

1.4 Novelty

The new optimisation approach introduced in this study was granted a status of Standards Australian Patent in January 2017. This invention is titled: ‘Operational Scheduling with Business Modelling and Genetic Algorithms’.

This study helps managers to address the challenges they experience in their day-to-day work when they run their operations. The proposed approach employs a new planning and scheduling method developed by the research team: Argo AI – OMO.

The new method shows how genetic algorithms (GA) are implemented to meet requirements specified by the soft constraints in the operation scheduling scenarios. The proposed method does not use the normally employed encoding and decoding techniques. It performs its GA operations on the domain model and therefore, never generates invalid solutions.

The study has demonstrated that some components of this method can be applied in accounting, taxation and compliance practice to achieve operational efficiencies. It has confirmed that the newly developed method can be applied to IT project and programs delivery successfully, as it allows to optimise project resource allocation.

This initiative has confirmed that the newly developed method can be applied to network resource allocation optimisation successfully.
This work has confirmed that the newly developed method can also be applied to optimise resource utilisation in organisations of various industry sectors across the globe and by doing so support the climate change agenda in a very predictable, pragmatic and productive way.

1.5 Practical Value

In the very beginning of this PhD project, it was agreed that it has to present new theoretical knowledge and also show how it applies to the business domains to help practitioners in their day-to-day work. It is because of this objective that the team conducted a number of industry case studies to see how the method will behave in real-life scenarios.

As shown in one of the case studies, the method supported the implementation of ideas of projectisation and productisation for an accounting organisation. It allowed the organisation to record a positive and tangible change.

The performed case studies confirmed that the method could be used to automatically create and optimise operational schedules in complex and large domains across different industry sectors, including IT projects and programs delivery, and telecommunications resource allocation.

This tested approach can now be taken into other professional services organisations in Australia and internationally to help them in achieving their medium- and long-term strategic objectives.

1.6 Thesis Structure

This thesis consists of the following chapters.

- Chapter 2 - Operational Planning and Scheduling with Argo AI – OMO. Defines the body of a new operational planning and scheduling method.
- Chapter 3 - Operational Planning and Scheduling with Argo AI – OMO – Genetic Algorithms. Describes how genetic algorithms is used to implement optimisation module of the method and proposes some innovative modifications to the existing body of knowledge (recognised by an Australian Standard Patent in 2017).

- Chapter 4 - Projectise and Productise Accounting Practice with Operational Management Optimisation. This chapter presents the first case study showing how professional services organisations can benefit from some of the components of the study's method.
- Chapter 5 - IT Projects and Programs Scheduling with Operational Management Optimisation. This part of the thesis demonstrates how the new method can be applied to the project and program scheduling in Information Technology.
- Chapter 6 - Telecommunications Network Resource Allocation with Operational Management Optimisation. This chapter shows how resource allocation in the telecommunications network domain can be optimised.
- Chapter 7 - Climate Change and Operational Management Optimisation. Views on how the method can positively impact climate change issues are presented in this chapter.
- Chapter 8 - Thesis Conclusions. In the final chapter, significant outcomes of the research and proposed areas for future work are outlined.

Chapter 2 - Operational Planning and Scheduling with Argo AI- OMO

2.1 Introduction

As an experienced professional project manager in the Australian technology and business environment, the author witnessed many business and technology initiatives being delivered with various success rates. Critical management decisions were often made based on 'gut feel', influential stakeholders' opinions and/or previous experience in similar projects. These decisions were seldom made based on the current advances in science, technology and delivery methods available in the wider professional and academic community.

While many different factors contribute to the success or failure of project deliveries, we strongly believe that effective planning and scheduling of relevant resources and activities is critical to a project's success overall. Operational scheduling, as a discipline, is responsible for maintaining an acceptable quality of operational plans and schedules. These operational plans define what needs to be done, in what sequence, and by what resources.

Organisations employ various methods to solve planning and scheduling problems. These methods are not taking advantage of the latest advances in science and not allowing for a rapid change which is common in the current project delivery eco-systems.

When the maturity of given operational management practice is assessed, the following qualities play a vital role in understanding how effective their planning and scheduling is.

- Are their schedules valid?
- Are their schedules current?
- Are their schedules optimised?

A valid schedule will have a collection of all activities required to achieve the operational objectives. It will also reflect all the relevant dependencies (start-to-finish, start-to-start, etc.). It will also show what type of resources are required to finish a given activity.

A current schedule will be in line with the resource pool, and it will always reflect on the actual progress of activities, effectively being responsive to all the changes in the delivery space.

An optimised schedule will take operational management maturity to the next level. In addition to schedules being valid and current, they will also be optimised to see if a more optimal scheduling solution can be employed to save delivery costs and completion time.

The data analysis shows that only about 70–80% of operational schedules are valid, about 20–30% are current and only 2–3% of those schedules are optimised.

In this study, the question is asked: 'Can new operational management methods be developed and implemented that will be effective enough and allow users to always have valid, current, and optimised plans and schedules?'

The question is answered in this study. A new operational management method is introduced. It allows its users to manage their project deliveries on time and within budget. It helps them to respond to change in the surrounding environment in a timely fashion.

The study will show how operational management can be automated and optimised. A new optimisation method will be developed and described in this study. This project will show how the proposed operational management approach helps businesses to run their workstreams in a controlled and predictable fashion to allow their sponsoring bodies to achieve the desired outcomes within expected timeframes and resource constraints.

This method is called Argo AI – OMO, also known as Argo Scheduling 2015.

The term 'Argo' signifies the contribution of Argo Computing Services to this development. AI stands for artificial intelligence. OMO is an abbreviation of Operational Management Optimisation. This method was first invited in 2015. It was filed as an invention with the Australian Patent Office in 2016; it was granted an Australian Standard Patent in 2017.

This study was performed in the form of the invention. It completes quantitative analysis to explore existing methods and to propose the new one. It also performs quantitative analysis to understand how the application of the new method can improve efficiencies of operational management and draw conclusions on its effectiveness. Several key studies are performed to prove the usefulness of this method in real-life business scenarios.

This chapter includes the following sections:

1. Introduction. This section helps to understand why the study was undertaken, how it was performed, and how the chapter is structured.

2. Background and Key Concepts. The operational management eco-system is described here and its main principles and concepts identified.
3. Problem Statement and Known Solutions. The problem will be stated here and available solutions will be explored.
4. Methodology and Proposed Solution. The new method will be described here.
5. Case Studies. Examples of the applications of the new method will be listed here.
6. Findings and Related Work. The outcomes of this study will be presented and analysed. Future directions for continuing research will be considered.
7. Conclusions. Confirmation of the study's objectives being achieved.

2.2 Background and Key Concepts

2.2.1 Operational management discipline

Organisations around the world run operations to fulfil their function and to achieve the desired outcome.

A truck company would run a fleet of vehicles transporting goods for the clients to generate profits for the owners. Their operation would involve a multiple of trucks and other transportation equipment carrying the loads around a particular geographical area. Goods would be picked up at a source location and dropped off at a destination. Human resources, as well as supporting IT systems, would also be involved in such an operation to fulfil relevant roles and make the operation run.

A university will execute an operation around their educational process, running lectures, tutorials, examinations, and other teaching events to take the students through the end-to-end learning. Operational resources will include academic staff, supporting groups, lecture theatres, laboratories and required equipment. Outcomes of that operation would comprise of qualifications achieved by the students who attend this university.
A software development company runs an operation that delivers IT solutions to its clients. Requirements are gathered, designs are completed, source code is written then an executable package is compiled and testing is performed to ensure the quality of the deliverables is satisfactory. This work is normally very resource-intensive and requires multifunctional subject matter experts being involved in the product delivery. Here too, many other resources, making the operation run, would be allocated, and a significant consideration would be given to ensure the delivery company generates profit and the clients get value for money.

The above listed and other operations need to be executed efficiently to fit into the constraints applicable to a given economic domain. It is a responsibility of the operational management discipline to devise a solution to all operational challenges and help the organisation that runs this operation to achieve their strategic goals.

Existing academic literature pays significant attention to describing relevant concepts, (Chase & Zhang 1998; Demeter 2017). It analyses processes and techniques that help to make operational management more effective and operations themselves more robust and profitable. Marion (2018) talks about how researchers and practitioners alike negotiate the famous management triangle: the scope of work that has to be complete, the timing and resources involved with the function delivery.

2.2.2 Operations run as projects or collections of projects (programs/portfolios)

Increasingly the majority of activities organisations run today are delivered as projects. This approach helps to stay focused on outcomes and have a clear view of the resources allocated to achieve those results. In their case study, Cerne and Jansson (2019) show how projectification can be applied to process the global organisation using a sample of the Catholic Church's initiative. The spectrum of this arguably oldest and largest international organisation is wide. A multitude of various projects is being carried out daily. The authors show this approach had a positive impact on the success of the Catholic Church's operation.

An example of applying key project management principals to collaborative research projects is described in the study by Lippe and vom Brocke (2016). They look at projects that deliver innovations by industry, academic, and public partnerships. They are challenging due to vaguely defined objectives and the often conflicting priorities of the stakeholders. They developed a graphical framework to present and analyse project models. Application of this situational project management approach has led to significantly improved management practice of collaborative research projects.

Trenkner (2019) explores the adoption of the project management principles for the benefit of a given continuous improvement (CI) initiative. The idea of CI implementation has become popular in enterprises. It relates to the on-going positive change improvement of a given operation, implemented via many relatively minor enhancements, to make a given company more competitive (Trenkner 2019). Service providers specialising in transport, freight forwarding, and logistics (TFL) seek to optimise their processes. Optimisation criteria include levels of customer satisfaction, processing and competition time, quality of outcomes, and

delivery costs. Trenkner's (2019) study identified the strengths and weaknesses of related continuous improvement initiatives. Continuous improvement is now widely recognised and adopted in all types of organisations and is still a very challenging undertaking. Given the associated risks, it is important to have visibility of related impacting factors, and with that knowledge to have a solid implementation plan, allowing for the successful delivery of the strategic outcomes.

The author argues that the most crucial aspect of the CI implementation in the surveyed organisation was the identification of common goals related to all stakeholders involved with the implementation. As with similar project delivery initiatives, this CI implementation required detailed planning and analysis of the related risks and issues, as well as active management of all the delivery aspects to lead to the completion of all improvement activities within anticipated timeframes.

We continued the study into how various project delivery techniques are applied to different industries. A study by Pareliya (2019) is explored that investigates the implementation of agile project management in real estate initiatives. Increasingly, IT departments adopt the agile project delivery approach. It works better for projects, where it is challenging to specific customer needs and final products features during planning phases. The study has researched the positive outcomes of implementing an agile delivery method in infrastructure development. One of the many benefits of using the agile delivery method in that scenario was increased involvement of the delivery group in all activities.

Additionally, this approach improves the level of the client’s engagement with the delivery groups. On the other side, it reduces delay and delivery risks during the construction stage. It also advocates for effective time management and regular meetings, which helps to track the project’s progress. Jim Highsmith (in Pareliya 2019) said: ‘A traditional project manager focuses on following the plan with minimal changes, whereas an agile leader focuses on adapting successfully to inevitable changes.

The author claims that the main benefit of implementing the agile delivery method in the construction stage of the project was the increased level of communication between the team members. It gave them the freedom to demonstrate their initiative and to work independently. The agile project management method helps each team member to realise their abilities and contribute to the project outcomes productively. The agile approach enhances their professionalism as they are given more accountability for their work and an increased level of decision power. While being involved with this delivery method, the clients have also been

encouraged to increase their participation in delivery activities. Adopting agile project management has also resulted in clients' satisfaction with the project outcomes. This has happened mainly because the product log was used as the main requirements and prioritisation document, and clients were participating in its grooming regularly. The study concludes that the implementation of an agile project management approach in the researched domain has decreased ambiguity and uncertainty. It has also helped with planning activities and decreased delays.

Project management offices (PMOs) are critical functions of any organisation that chooses to run their activities in a project/program/portfolio delivery fashion. They can help organisations to increase the project success rate and the overall organisational performance. Kaul and Joslin (2019) have completed an extensive literature review on how adopting projectification has transformed the way project management practices are considered. The literature review has examined how the research of PMOs in organisations has evolved and found trends in the different areas of project management research over the past 20 years. Ultimately that research helps to understand how to make PMOs more successful. The increasing success rate of PMO functions directly impacts the success rate of project delivery overall and results in organisations achieving their strategic objectives sooner and at lower costs.

In the context of IT consulting delivery, customer needs for management consulting projects are subject to rapid change (McKinsey 2017; Sywottek 2018, cited in Kerscher & Günzel 2019). As the nature of consulting operations transforms from the development in silos to cooperative and transparent participation by many working groups and frequent discussions of initial partial outcomes, and a higher number of short-term change requests during development work, the need to adopt a robust project management method eventuates. Traditional project management techniques of waterfall-like methods, including Project Management Body of Knowledge (PMBOK) (PMI 2008) or PRINCE2 (Commerce 2009) work well in some environments. More modern management techniques such as Lean Startup (Ries 2017, cited in Kerscher & Günzel 2019) or Design Thinking (Lewrick & Link 2018, cited in Kerscher & Günzel 2019) demonstrate the current tendency towards iterative and adaptable methods (Denning 2018, cited in Kerscher & Günzel 2019). In their article Kerscher and Günzel (2019) researched implementation of Scrum for management consulting projects. The authors have developed and validated the concept called Scrum4Consulting. Their work shows how modern project management techniques can be successfully applied to IT consulting service delivery.

Business process improvement (BPI) is a way to evolve a given organisation's way of working to introduce efficiency, provide better customer service and to better a variety of key performance indicators (KPIs). Process improvement could be delivered by radical change. Also, the enhancements could be brought about by incremental transformations (Brajer-Marczak 2018). The paper presented by Brajer-Marczak (2018) considers the project structure as a vehicle for process improvement. The author stated that improvements implemented as part of projects took into account the entire complexity and scope of the target domain, and, most importantly, selection of various management approaches including Lean, Kaizen, Six Sigma and finally business process management (BPM).

2.2.3 What are the projects and how are they normally run?

As defined by PMBOK, a project is a temporary structure established to deliver a given packaged product, service offering or outcome *(*PMI 2008). Projects have a definite beginning and end.

In modern business, world projects drive business activities (Gründler & Butterfield 2019) and define organisational evolution (Gründler & Butterfield 2019).

Projects are tangible demonstrations of investments. In modern business, world sponsors would not commit to any significant spends without having established projects to run and deliver to their expectations in a predictable fashion.

Normally, projects are temporary structures. They are created to achieve the required organisational goals. They must satisfy the following qualifications:

- They need to meet the needs of the sponsors.
- They must have priority relative to portfolio projects, which compete for project resources.
- They must generate a positive change.

Project risk management is a significant part of any project delivery method. Effective management of the uncertainties, which (if eventuated) will result in projects being negatively impacted, is critical to the overall project success.

In their paper, Suárez (2018) researches a scenario when under extreme conditions project managers needed to take drastic measures as part of their risk management work to reduce losses of time, money and creditability when things do not go according to the original plan. They demonstrate one example of such a project that had a good chance to complete and

realise the significant benefits. The author described in detail the risk management activities related to the project in question. They noted that while it was obvious how project responsibilities were allocated according to the PMBOK Guide (PMI 2008), the framework did not provide actionable guidance on how to help project managers to deal with situations compromising a project.

Suárez (2018) suggest establishing clear, transparent and timely communication to manage the risks. Once risks are identified in a project, they recommend alerting the project stakeholders as soon as it is practically possible. A set of valid, feasible and sound alternatives should be presented for consideration to the project committee. Based on the information provided, they will be able to take corrective actions, which in turn will result in projects either getting into the clear delivery path or (in extreme situations) project closures that reduce losses associated with project failure.

Earned value management (EVM) is a technique employed by many professionals to measure the performance of project delivery relative to time and resources. It allows stakeholders to complete quantitative analysis of projects in question and derive a view on whether a project is progressing well, and also (even more importantly) on whether the project is likely to complete its activities on time and within budget.

In their study, Morad and El-Sayegh (2018) explore critical impacting aspects for earned value techniques in building infrastructure developments. The authors state that to achieve sponsors' objectives, operational managers need to complete these projects on time and within budget. The use of EVM would help with that due to its practicality and quantitative nature. Their paper analysed the integration of EVM in building in the United Arab Emirates (UAE). They conclude that the integration of EVM helps to establish a history of projects delivered earlier. This information can be used for comparative analysis to improve management of the in-flight projects. In addition to that, they warn that top management buy-in is crucial for successful implementation of EVM. In their opinion organisations need to develop well-working processes for EVM implementation and resource these undertakings sufficiently.

2.2.4 Project Scheduling and Planning

As noted by Kerzner (2017), 'a project plan is fundamental to the success of any project' (Kerzner 2017). Kerzner thinks that the development of project plans could be time-consuming

and expansive, and for it to succeed all levels of the organisation have to participate. For a lot of projects, particularly large ones, comprehensive scheduling is required for all activities.

Delivering the outcomes on time is the main objective of many projects (Haniff & Salama 2016). Creating project schedules involves specifying the duration of project activities, calculating the best start and end dates of all activities and estimating the cost of fast-tracking projects. Stages of compiling a project schedule include developing and analysing a project plan and creating the Gantt charts. Active management of projects schedules may cover the following:

- Activity specification—defying all the activities needed to complete each project.
- Activity sequencing—deciding the order in which each activity should be completed and identifying the dependencies between various components of the work breakdown structure.
- Activity timing—defining the duration of each activity, defining resource assignment and determining the resource loads required to execute each activity.
- Schedule control—to monitor modification relevant to a project schedule. Project schedules can be represented via either project network diagrams or Gantt charts.

A network diagram is a schematic depiction of the project plan, developed from the work breakdown structure (WBS). It shows all the activities for a given initiative.

Gantt chart notation is widespread as the main form of representing project schedules. It employs bar charts plotted across the timeline. Each bar demonstrates a project activity indicating its start and finish times. Still, there are several limitations in the use of Gantt charts. Among other issues, Gantt charts do not provide the level of detail that is available in network diagrams.

According to Adeli and Karim (2001), the network diagram is the most popular medium for the graphical presentation of project schedules. Network diagrams include nodes, arrows and lettering to reflect both task attributes and dependencies.
They defined this approach as follows:

> There are two different ways of representing schedules as a network of nodes and arrows. In an activity-on-arrow (AOA) diagram, arrows are used to represent tasks whereas nodes represent events or times of importance such as the start and finish time of tasks. In an activity-on-node (AON) diagram, on the other hand, nodes represent tasks and arrows between tasks establish precedence relationships. The

AOA and AON diagrams are equivalent in their modelling capabilities; a schedule that can be represented by an AOA diagram can also be represented by an AON diagram and vice versa. The AON diagram, however, is more general, compact, and displays more information than the AOA diagram. AON diagrams are used more broadly (Adeli & Karim 2001).

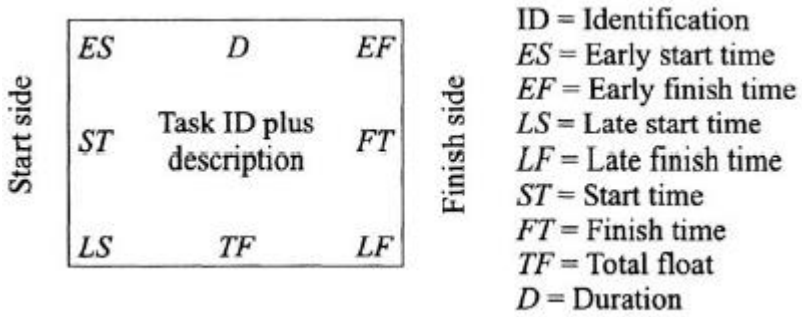

Figure 2.1 Representation of Activity Using AON Notation

The route along the project network related to the longest duration is called the critical path.

The critical path method (CPM) (Lockyer & Gordon 2005) determines the minimal time in which a project can be delivered by analysing tasks on the critical path. The following attributes are important when discussing this method:

- Earliest start (ES) shows the soonest time a task can commence when all activity dependencies are respected.
- Earliest finish (EF) shows the soonest time an activity can be completed when all activity dependencies are respected.
- Duration is an amount of time required to complete a given task.
- Latest start (LS) shows the latest point in time when an activity can commence without delaying the project.
- Latest finish time (LF) shows the latest point in time when an activity can be completed without delaying the project.
- Float is a span when an activity can be postponed without delaying the project.
- Lag is a delay between the first and second activities when the second succeeds the first.
- Forward pass calculates the total duration by calculating the ES and EF for all tasks as EF = ES + task duration.
- Backward pass calculates the LS and LF of all tasks as LS = LF – task duration.
- Activities with a zero float define the critical project path.

In the project governance discipline, the use of probabilistic analysis to define the duration of project activity is called the project evaluation and review technique (PERT). Recently the terms CPM and PERT are used as synonyms. They are represented by an AON network. The latter adopts the following qualities of the project to calculate a project length:

1. The optimistic time calculation option assumes everything goes according to the plan, and activities are delivered without delays.
2. The pessimistic time calculation option assumes that the project is experiencing some major issues and activities are delayed.
3. The most likely time calculation options assume that the project would have some issues close to how initiatives are run in normal working environments.

The PERT method is not widely used in the industry.

In an endeavour to further explore aspects of PERT, Goman (2019) have conducted a study on practical verification of central limit theorem (CLT) assumption for PERT application. This is about applying a CLT to calculate length using standard normal distribution (SND). CLT assumes that some pre-requisites are met. The author summarised some problems with existing probabilistic assessments and proposed a chance constraint optimisation model for a probability-based project examination. They concluded that managers should update their time estimations using the Bayesian method.

2.2.5 Projects/Programs/Portfolio

It is important to realise that operational activities are often structured hierarchically to allow for more granular management. Such structures can be represented by projects, programs and portfolios.

In their study, Jiang, Klein and Fernandez (2018) research the main differences between project portfolios, project programs, and projects as units of work. They state that a project has a defined delivery scope and expected outcomes. A program is a collection of related projects and activities formed to realise a given benefit (e.g., better financial outcomes or new value creation). An organisation portfolio is comprised of all active programs and projects.

Once this structure is defined, it is easier to look at different management aspects which apply to the delivery across the enterprise as described in Table 2.1 Project, Program, Portfolio - Managerial Aspects.

Table 2.1 Project, Program, Portfolio - Managerial Aspects

Management Area	Project	Program	Portfolio
Planning	Project-specific.	Derived from projects which belong to one program.	Organisation wide, based on strategic objectives.
Scope	All the tasks that need to be done to complete the project.	Derived from the scope of projects which belong to one program.	The anticipated change reflected in some measurable KPIs.
Timeframes	The specified completion date for a given project and all the related activities.	Derived from the timeframes of projects which belong to one program.	Described by organisational roadmaps, managing dependencies between all programs.
Resources	Focus on related suitability of anticipated resources and tasks to be performed.	Planning resources across multiple projects within a program to allow timely completion of all projects.	Manage the efficiencies of resource allocation across the organisation.
Scheduling & Execution			
Scope	Micromanage progress of activities completion and react to change in a timely fashion.	Derived from the scope of projects which belong to one program.	The anticipated change reflected in several measurable KPIs.
Timeframes	Micromanage progress and react to change in a timely fashion. Report on status.	Derived from the timeframes of projects which belong to one program.	Manage organisational roadmaps based on the actual progress, manage dependencies between all programs.
Resources	Enable resources. Remove blockers. Manage suitability, availability and allocation of the resources to the activities to be done.	Manage resource allocation across multiple projects in the most effective way.	Manage the efficiencies of resource allocation across the organisation.
Risk Management	Actively manage risks related to project scope, timing, resources.	Manage project risks when they are escalated to the program level. Manage program-specific risks.	Manage risks associated with strategic objectives delivery.
Issue Management	Actively manage issues related to the project to unblock delivery of project activities.	Manage project issues when they are escalated to the program level. Manage program-specific issues.	Manage issues associated with strategic objectives delivery.
Overfall Management Role	Micromanage the delivery of the scope within the timeframes with available resources.	Macromanage delivery of the related projects' outcomes within the timeframes with available resources.	Ensure the organisation works well as a whole. Actively manage road maps to meet the KPIs.
Main controls	Project plans/schedules; risks and issues register.	Program plans/schedules; risks and issues register.	Roadmaps, KPIs.

2.2.6 Project Managers Drive Operational Management Discipline

A project manager plays a critical role in the project delivery process. Their competencies across various qualities of the required skill set have been highlighted as decisive factors contributing to project success.

According to Araújo and Pedron (2015), these project management professionals 'can develop competence that will allow them to build a productive environment for team members to perform well, ensuring project success' (Araújo & Pedron 2015).

In their research paper, the authors have asked a question: 'What are the most relevant competencies that IT project managers should possess to achieve IT project success?'
In their attempt to answer, the following competencies were identified as critical:

- Team Management
- Business domain knowledge
- Communication
- People skills
- Technical
- Project Management
- Personal Characteristics
- Organisational
- Problem-solving
- Professionalism

We agree with the authors; these qualities are important and do contribute to the overall project success.

2.2.7 How different project methods implement project management principles

The waterfall approach is extensively described in PMBOK – PMI (2008) and PRINCE2 – Office of Government Commerce (2009).

Naturally, once these methods found their space in the industry, several tools were made available to support their specific processes.

Microsoft Project (Chatfield 2010; Stover 2011) is a well-recognised and widely adopted tool that project management practitioners around the world have adopted as their tool of the trade. It helps to implement planning, scheduling, execution and monitoring steps of the larger

operational management process. It is very intuitive and user-friendly. Its drawback has always been a lack of multiuser concurrent access to a single data repository. This weakness was somewhat addressed by the introduction of the project server (Quiring 2011). This technology allowed its users to maximise the resource management capabilities and 'obtain better information on resource usage, costs, and future needs, and in turn, gain better planning, scheduling, awareness and control of your scarce resources' (Quiring 2011). It is a multiuser application and allows a single repository accessed by many team members as they each participate in the delivery process.

PMBOK

According to Marion (2018), project plan and project schedule are different entities. They claim that a project plan differs from a project schedule in many ways. For instance, project schedules do not address risk, communications, resources, quality, and procurement to the same degree as an overall project plan. The two are managed by separate controls to achieve the overall project success.

The PMBOK (PMI 2008) method prescribes several tools and techniques to control project schedule. The most common are:

- Performance Reviews
- Variance Analysis
- Resource Levelling
- What-If Scenario Analysis
- Adjusting Leads and Lags
- Schedule Compression

Performance reviews analyse schedule performance such as 'actual start and finish dates', 'percentage complete', and remaining duration for 'work in progress'. If earned value management (EVM) is employed the schedule variance (SV) and schedule performance index (SPI) are analysed to assess the magnitude of schedule variations. If using the critical chain method, comparing the amount of buffer remaining to the amount of buffer needed can help indicate the project status.

This delivery approach utilised the critical path method with all of its attributes extensively; this helps to complete the scheduling phases of project management. Gantt chart diagrams are also conveniently employed to visually represent current project schedules to stakeholders.

Overall, classic PMBOK can be described as a collection of well-defined controls which allow management professionals to conduct planning and execution monitoring on a very low level with a good certainty about expected outcomes. Strict change management processes are usually adhered to when managing scope change. Because of this well-defined process design to largely prevent changes to disrupt project delivery, this method is often considered as rigid and not suitable for deliveries in domains subjected to frequent change.

According to the PMBOK Guide, 'there are five phases of project management: initiation, planning, execution, monitoring & controlling phase, closing' (Esposito 2015, in Banica et al. 2017). During the initiation stage business cases are developed, and required stakeholders buy-ins are achieved. Planning focuses on establishing a clear view of how the project objectives will be achieved. As execution commences, those responsible will drive the project activities to allow a smooth delivery. Project management practitioners monitor project progress and assess if adjustments are required to re-align priorities and resource allocation. Banica et al. (2017) state, 'Project closure represents the completed project, the stage when the team delivers the software product, and the project manager along with the customer representatives evaluates the performances of the entire project' (Banica et al. 2017).

PRINCE2

PRINCE2 stands for 'PRojects IN Controlled Environments'. It is a structured project management method that emphasises dividing projects into manageable and controllable stages such as :

- Starting Up a Project
- Directing a Project
- Initiating a Project
- Controlling a Stage
- Managing Product Delivery
- Managing Stage Boundary
- Closing a Project

It highlights the importance of communication plans and relies on principals of management by exception.

Initial business case development at the start of a project and effective business case management for the rest of the project duration is a significant characteristic of this method.

In their paper Vaníčková (2017) provides an example of how PRINCE2 can be employed to deliver projects used in an enterprise service industry. They describe the advantages of the methodology applicable to this use case. While this method prescribes a well-defined process of phase project implementation, which reduces risks and increased stakeholders' confidence in successful outcomes, it has to be said that this method works better in very structured domains. In such environments, long-term plans can be compiled and executed without being exposed to constant change. This approach, however, is not very effective in domains where constant change around project scope, priorities and business rules is a fact of life and is considered as business as usual (BAU).

As PMBOK, PRINCE2 and other waterfall methodologies became more and more criticised due to their inflexibility, another approach emerged in software development: agile methodology.

Agile

As the industry has become largely accepting of constant change in many delivery domains, PMBOK Version 6 included support for agile methodology (Marion 2018). Agile is intended to provide the means for quickly and flexibly providing incremental project deliverables with a minimum of process overhead.

The agile approach (Banica et al. 2017) applied to software delivery introduces some risks.

> The most common cause of project failure being that the final product does not meet the client requirements. Another significant risk refers to exceeding project deadline and budget, due to the inexperienced team and, especially, to an inexperienced project manager (Banica et al. 2017).

To manage these risks and improve the chances of successful delivery, teams use agile project management software. This software normally implements functionality supporting sprint planning, progress reports, prioritisation and backlog grooming.
This century has seen agile delivery methods commence, which 'combine adaptable and highly flexible methods designed to help teams to develop applications faster and safer (Mihalache 2017). In their paper, the author analysed several technical tools enabling agile delivery. That analysis was focused on effective management of resource management and delivery timelines, as well as the ability of various approaches to support effective scope management and requirements documentation. Mihalache (2017) stated, 'Regarding the tools comparison, VersionOne and Rally provide the highest level of features for managing multiple

agile projects for established and mature teams' (Mihalache 2017). In the modern IT world, 'developers in many teams work remotely, and these tools also make working in such teams as comfortable as possible' (Mihalache 2017). Atlassian Jira is a proven tool for agile project management. It can be integrated with a large number of plugins. Mihalache (2017) claims that 'visual Studio Team Services is also a powerful integrated tool, having a lot of effective features easy to use' (Mihalache 2017). Microsoft being a provider and consumer of this technology constantly improves this package and Google Docs and Microsoft Project are both effective tools for relatively simple agile project management.

In their paper Banica et al. (2017) presents the concept of DevOps (Development & Operations), as an early-stage project management methodology, built on the agile principles. They think that it contributes to project management for IT solutions delivery and support. The authors 'experienced this methodology by developing a small project in the academic environment by three teams of master students, using VersionOne software' (Banica et al. 2017).

According to Banica et al. (2017) VersionOne defines DevOps as 'an IT mindset that encourages communication, collaboration, integration and automation among software developers and IT operations to improve the speed and quality of delivering software'. Banica et al. (2017) define as 'DevOps has the same Agile principle, stated in Agile Manifesto' (Banica et al. 2017; *Manifesto for agile software development* 2019) and 'Individuals and interactions over processes and tools'. Another interesting practice area of DevOps defines concepts and helps to implement automation in the software delivery procedures. Banica et al. (2017) claim that 'DevOps uses the same principles as Agile methodology, adding further the operation and functionality of the deliverables' (Banica et al. 2017). To support DevOps, VersionOne has a collection of tools 'to track the progress of the project: story planning boards, burn-down, burn-up and velocity charts' (Banica et al. 2017).

While it is common to have project delivery governed by one of the available methods, it is not unusual to see how a combination of a few approaches is adapted to meet specific requirements of a given organisation and its operational eco-system. In their paper, Rosenberger and Tick (2019) are researching the adaption of classical PMBOK framework to cope with Scrum.

As it is known in the field of operational management, some of the project management frameworks like PMBOK demand a detailed level of planning and scheduling and solid change management. Others like Scrum rely on team self-management and delivery flexibility and are

open for change. In their article, the authors have proposed five PMBOK components that are accepted as crucial for Scrum delivery model. Such integration of these two methods might be challenging. Roles of driving each of the methods are very different. In agile, the project manager assumes overall responsibility of the project success but cannot actively manage the execution by the agile development team. In PMBOK, the project manager controls all the project activities at every stage. Also, developing project work structures and estimating the timing of activities is complex in agile due to conflicting concepts of predictable planning performed in traditional delivery management methods and agility that needs to support ever-changing priorities and scope. Still, their study showed that gaps between traditional project management and agile development could be closed. Two candidate solutions were proposed. 1) Integration of Strike System for project governance (Rosenberger & Tick 2019). This approach helps to share responsibility assigned to Scrum teams and managers. 2) Project manager assumes a role as Scrum master when they are comfortable working 'inside' of a team which delivers agile sprints.

2.2.8 Project Success Factors

In their paper, Abylova and Salykova (2019) analyse critical success factors in project management. In their opinion, 'project management is a broad subject with different knowledge areas that embrace a variety of issues a project manager, a team, organizations and experts have to deal with to succeed in project implementation' (Abylova & Salykova 2019). When researchers discuss the factors of project success, they normally focus on two different concepts: successful project delivery and successful project management. It is challenging to separate the two. In our opinion, successful project delivery results in all the objectives being achieved. Successful project management is assessed using the prescribed project management processes and controls.

We think that it is interesting to witness how the concepts of project success have evolved over time, what models emerged, and what methods are used to analyse and manage project success.

There are many considerations related to project management success. They include system integration, delivery scope, human resources management, communication with teams and stakeholders, risks and procurement management. Morris and Hough (cited in Abylova & Salykova 2019) mentioned four other success factors which should also be considered as part of success including health and safety, positive experience for the stakeholders, positive impact on the owner-organisation and positive impact on the overall delivery eco-system.

Kejun and Fenn (2019) analyse success factors and performance indicators of construction projects. The construction industry is a very influential industry sector in world economies. It attracts significant investment funding and presents many opportunities for infrastructure development. Recently, the challenging business climate and complex delivery models have made it difficult to measure the success of projects in that space (Neely 2005, cited in Kejun & Fenn 2019). Kejun and Fenn (2019) think that it is crucial to measure performance accurately. Their study has developed a 'hierarchical model of construction project performance measurement (HMCPPM)' (Kejun & Fenn 2019) to analyse the status of the projects. That model was structured to better link measurement benchmarking and project objectives. The Analytical Hierarchy Process (AHP) as a decision-support approach was utilised to construct the model and determine the scores via pairwise evaluations and recommendations of subject matter specialists.

The key performance indicators were calculated via related parameters including 'time (SPI), team satisfaction (TSI), communication (CMI), client satisfaction (CSI), cost (CPI), profitability (PPI), billing (BPI)' (Kejun & Fenn 2019). These are calculated using techniques introduced in PMBOK.

According to Kejun and Fenn (2019), quality and safety should be used for performance measurement. Other factors (e.g. time, team satisfaction, communication, client satisfaction, cost, profitability, and billing) will help to assess success from three facets, including internal, customer, and financial points of view.

More analysis of the project success criteria, in this case, focused on the IT services industry, was undertaken by Gründler and Butterfield (2019). In their study, they wanted to check if the existing performance measures were effective, how success can be defined, and whether the agile or waterfall method could be used to measure a project's success. Traditional project delivery methods use quantitative analysis to measure project success. This technique ignores the specifics of the domain. The current method adopted by the Information Technology industry focuses on qualitative analysis of project environments and outcomes. Their study claimed that both qualitative and quantitative techniques are important.

Projects fail because their supporting structures are not arranged in time, and they cannot achieve the expected delivery velocity. Some causes of project fiasco include inadequate planning, financial issues, weak business cases, or the oversight of sustainability, appropriateness, and practicability. Csiszárik-Kocsir (2018) completed an examination of the above-described success factors using Hungarian organisations. They claim that the

enterprises considered projects planning to be critical regardless of their size. In other words, if a project is well planned, then it would probably meet the expectations and deliver to the anticipated scope. Their paper highlights the importance of the following factors:

- Appropriate risk management
- Availability of well qualified and committed project managers
- High quality of project deliverables
- Outside factors like economic policy and impact on the environment

Ágnes Csiszárik-Kocsir (2018) thinks that 'the success of a project also highly depends on how well it can be implemented into the project promoter organization' (Csiszárik-Kocsir 2018).

We largely align with classifications of project delivery success factors stated in the existing literature and can present its view on important contributors to the project success in the list below.

- Time management
- Resource management
- Scope management
- Quality management
- Risks management
- Issues management
- Other projects in the portfolio and relevant dependencies management
- Adoption of innovative delivery method and techniques
- Legal and compliance
- Opportunities management
- Wins management
- Successful integration with other technology/processes/people
- HR management
- Effective communication
- Procurement management
- Safety (internal and external)
- Stakeholders satisfaction
- Customer satisfaction
- Tangible benefits to the organisation
- Non-tangible benefits to the organisation
- Long-term impact on project environment
- Project management process

- Knowledge management (documentation)
- Change management (human factor)
- Controls to drive, measure, report, monitor all the success factors (above)

The project management target domain is very dynamic and the number of project models is constantly increasing; the list of such critical factors is therefore subject to constant evolution This dynamic nature is also driven by the change in customer organisation, which is also impacting how the delivery projects need to be managed.

2.2.9 Many projects fail

According to some industry sources, 'on average, large IT projects run 45 per cent over budget and 7 per cent over time, while delivering 56 per cent less value than expected' (Bloch, Blumberg & Laartz 2012). Also 'one in six IT projects have an average cost overrun of 200% and a schedule overrun of 70%' (Bloch, Blumberg & Laartz 2012). Based on these statistics, it can be concluded that software development projects run at a very high risk of budget and timing overruns.

2.2.10 Why do projects fail? Risks and issues that lead to failure

According to Auer and Rosenberger (2018), project delivery in the information technology field is steadily increasing, and the budgets of IT groups grow. They state that 'only 16.2% of all projects are successful' (Standish Group 2015, cited in Auer & Rosenberger 2018). In their view, the so-called 'hybrid projects', which adopt a combination of principals from both waterfall and agile methods, have specific risk factors, which, if neglected, lead to failures and financial loss. In particular, they discuss how when projects become more agile it is sometimes difficult to measure their success using the KPI simply because those are not available. They also state that not having a dedicated project manager who is normally responsible for project management end to end, but now not available in agile delivery structure, adds to the risk of successful project completion.

This hybrid management style is an approach that combines traditional and agile governance techniques (Auer & Rosenberger 2018). That approach utilises the best components from those two methods, while keeping the organisational structures and procedures largely intact (Komus et al. 2015, cited in Benjamin & Philipp 2018). It is challenging because a robust script of how hybrid initiatives are delivered does not exist.

Most of the time, projects are evaluated using key performance indicators (KPIs) (Auer & Rosenberger 2018). Unfortunately, there is no clear definition of which parameters constitute a key performance indicator and which does not. Therefore, it is often challenging to calculate these KPIs. (Parmenter 2015). Due to this uncertainty, project delivery risks are more likely to eventuate. Project accomplishment is also threatened (Csiszárik-Kocsir et al. 2017). The literature review reveals numerous project failures. Out of the subject matter experts' interviews, eight reasons were listed, and the view was expanded to add another four reasons (Coolman 2016, cited in Auer & Rosenberger 2018).

1. Inattentive management
2. Insufficient project management
3. Poor communication
4. Lack of collaboration between the working groups involved
5. Human factors and technologies that make things more difficult
6. Important decisions were not made
7. Missing goal definition
8. Underestimate deadlines
9. Unreasonable expectations set up in the planning phase
10. Under-resourced management groups
11. Under qualified management groups
12. Failure to recognise the vital details

Auer and Rosenberger (2018) presented an assessment system which can be applied to hybrid projects. It allows verifying if initiatives were unsuccessful because of acknowledged issues. Also, two definition representations for hybrid projects were considered thoroughly. They presented possible results of each delivery stage (start, execution and completion). Using a literature review and participants' interviews, the team has recognised uncertain components leading to projects' failures. Following that, key objectives were established for a retrospective valuation technique. Focusing on these objectives, a given professional would be able to assess if the project issue matches with one of the earlier established problems.

In their study, Flyvbjerg and Budzier (2013) state: 'A $5 million project that leads to an almost $200 million loss is a classic 'black swan''. They described how one of the IT projects at Hong Kong's airport suffered a loss of $600 million in 1998 and 1999.

They assessed 1,471 initiatives, analysing their budgets and estimated performance benefits against the actual expenditure and delivered outcomes. That review showed that the average budget overrun was 27%.

The list of observed failures continues as they reviewed how in other countries companies collapse due to failed technology implementations.

> In 2006, for instance, Auto Windscreens was the second-largest automobile glass company in the UK, with 1,100 employees and £63 million in revenue. Unsatisfied with its financial IT system, the company migrated its order management from Oracle to Metrix and started to implement a Microsoft ERP system. In the fourth quarter of 2010, a combination of falling sales, inventory management problems, and spending on the IT project forced it into bankruptcy (Flyvbjerg & Budzier 2013).
>
> The German company Toll Collect—a consortium of DaimlerChrysler, Deutsche Telekom, and Cofiroute of France—suffered its own debacle while implementing technology designed to help collect tolls from heavy trucks on German roadways. The developers struggled to combine the different software systems, and in the end the project cost the government more than $10 billion in lost revenue, according to one estimate. 'Toll Collect' became a popular byword among Germans for the woes of their economy (Flyvbjerg & Budzier 2013).

These examples may seem like an unfortunate once-off failure. But, as the literature shows, such disasters do happen frequently.

Wisianto (2019) assessed the risks associated with a refinery project. They studied how one of their organisations implemented the Refinery Development Master Plan (RDMP). This plan was to refurbish four parts of standing refineries and building two components of a new refinery. They researched risks related to different projects stages, namely project development and project execution. That given project had 170 risk items logged with 46% in the categories of strategy and planning, 2% related to compliance and the remaining 22% accounting for the operations and infrastructure domains (Wisianto 2019). These figures are in line with the understanding that the planning phase would normally have a relatively high risk. The highest number of risks fall into the business strategy area. These include the business operation model, partner relationship, financial management and land management. These risks are mostly owned by the Project Development Department. The study confirmed that the sample projects had a very large number of risks. The analysis of the risk log has confirmed that risks associated with strategy and planning were the biggest contributors in the Megaproject Directorate. To improve the chances of successful delivery, risk analysis and mitigation plans should be completed at the beginning of every initiative.

As seen in these examples, the reasons projects fail (risks that will potentially become issues) span not only along with various project components, but also across project phases, where some are specific to the project starting times, and others relate to implementation and completion.

2.2.11 Success factors in the scope

While the existing literature identified quite a broad set of factors which impact the success of projects delivery in the modern world, this list needs to be narrowed to only those items which are relevant to the scope in the context of this study dedicated to Operational Management Optimisation (OMO). These in-scope factors will be looked at in more details as the study progresses.

In the context of business process management (BPM) and business process improvement (BPI), the following levels of maturity are shown:

- Ad hoc approach
- Streamlined process
- Automated process
- Optimised process

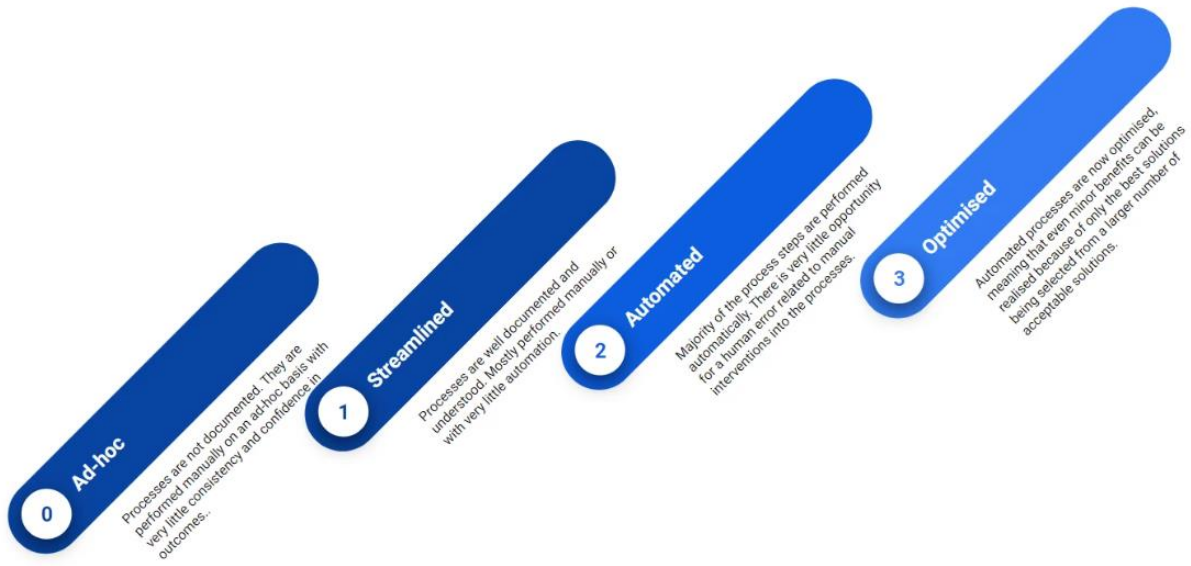

Figure 2.2 Argo AI - levels of operational process maturity

To allow for a better success rate, organisations should automate and optimise operational management processes.

In the context of operation planning and scheduling maturity, the following levels are observed:

- Ad hoc planning and scheduling
- Streamlined planning and scheduling
- Automated scheduling
- Optimised scheduling

Figure 2.3 Argo AI - Operational Planning / Scheduling Maturity

In summary, the success factors in scope can be listed below.

- Operational management process should be automated
- Operational management process should be optimised
- Operational plans should be valid
- Operational schedules should be current
- Operational schedules should be optimised

The author thinks that for the project delivery to be successful, the associated processes have to be automated and optimised. Also, the operational schedules have to be optimised to allow managers to select that solution that meets their needs as close as possible.

For the rest of this thesis, we will consider scheduling automation and optimisation as the major in scope project delivery success factor.

2.2.12 Practical AI

Based on existing literature and industry experience, the following applications of artificial intelligence in the business process improvement field are observed by the author:

- Machine Learning
- Deep Learning
- Robotic Process Automation
- Chatbots
- Optimisation

2.2.13 What practical AI techniques are in scope and how they help now

The main success factor in scope is Operational Management Optimisation. How do the various industry participants and academic researchers achieve the objective of having their operations run as close to optimal as possible?

To deliver projects (be it construction of an apartment block or delivery of a major upgrade to an enterprise financial management system) in predictable fashion management, professionals in various industry sectors employ planning and scheduling techniques to know what is being delivered when and at what cost and deliver projects outcomes on time and within budget. This approach is very well supported by methods, industry standards and technologies.

To deliver initiatives effectively, valid plans and current schedules are needed. It is also beneficial if schedules are optimised to allow initiatives to be run in the most optimal fashion.

Project management discipline is a mature field of knowledge. Like many other areas of human activities, it progresses in time and experiences various levels of adoption and technological support. The paper-based recording has been replaced by electronic Gantt charts, following by Scrum Boards, supporting multi-user, multi-device access to the same consistent set of data governing projects and programs of work.

It could be said that, while the project management practice goes through major technological transformations, the community has been somewhat overwhelmed by the rapidness of the change and started questioning the underlying concepts of this field.

Additionally, the spaces being managed are also subjected to rapid transformations, change and uncertainties.

All these experiences raise questions:

- If the domain being managed changes so rapidly that the existing tools cannot cope with that pace, and project schedules are never current, should the planning activities be dropped altogether?
- If the agile delivery method are now being adopted and long-running Gantt Charts are no longer relevant, should the planning activities be dropped altogether?
- If a given tool does not provide full visibility of project-related information by all involved in a very effective and suitable fashion, should the planning activities be dropped altogether?

The author's answer to all of these questions is: 'Of course not!'

Anyone who desires to deliver their initiative predictably (on time, on budget and to the agreed scope) must apply a robust method and supporting technologies to plan and execute successfully.

The way forward would probably be to not focus on details of the available technologies or, indeed, related problem domain, but instead pay attention to the underlying principles of the managerial practice. Regardless of which industry sector being operated in, or the current status of technological advances supporting the management process, plans must be valid, current, and (if possible) optimised.

2.3 Problem Statement and Known Solutions

2.3.1 Problems

Multiple problems with project management delivery

According to Katunina (2018), low-level maturity of the project management discipline significantly reduced success rates of project delivery. The author discussed and categorised 'the main problems with organizational project management development. These problems are concerned with poor support of organizational enablers. Organizational project management development should be considered in the context of strategic governance and management' (Katunina 2018).

Additionally, as discussed in section 2.2.8, many other factors contribute to project delivery success or failure. It is the responsibility of the project manager to manage these factors adequately to achieve better performance outcomes of their project delivery efforts.

The focus is only on the effective management of plans and schedules.

As agreed in section 2.2.11, the success factors in scope only include operational scheduling automation and optimisation. Problems related to those will be analysed.

Operational schedules are large

As organisations scale up the sheer amount of initiatives they do, the size of those initiatives also steadily increases. Project schedules with thousands of items listed and managed are the norm. Tens of internal and external resources are involved with project delivery; they vary in their skill sets and costs to the project. This volume of information that needs to be managed presents a challenge for those responsible operational managers. It simply becomes difficult from a cognitive load point of view to apply management principals effectively to operational domains with large schedules and resource pools.

Operational schedules also grow in size when the aim is to combine plans of various projects and programs into one concise artefact. This approach is often used to show how a larger resource pool is allocated to many initiatives across the entire organisation (e.g. project portfolio).

Operational schedules are complex

Botchkarev and Finnigan (2015) claim that ‘complexity is an inherent attribute of any project. The purpose of defining and documenting complexity is to enable a project team to foresee resulting challenges in a timely manner and take steps to alleviate them’ (Botchkarev & Finnigan 2015). They look at complexities in operational management by modelling relevant business domains. A ‘complexity taxonomy’ is delivered and analysed in three levels: ‘the product, the project and the external environment’ (Botchkarev & Finnigan 2015).

For five decades, ‘complexity has been acknowledged as a critical project dimension’ (Botchkarev & Finnigan, 2015).

The authors claim that if project managers identify complexities early, they will have a better chance to delivery their initiatives successfully. They suggest that a systematic approach should be applied to assess complexity qualities. Identified problems are then mapped and

managed accordingly. The proposed method could be applied to project management in many business domains, while they focus their discussion on the delivery of information systems.

In their case study, Cerne and Jansson (2019), while confirming a positive impact this projectification had on the success of the Catholic Church's operation, have identified several challenges related to this approach. It was difficult to coordinate cross-project resources, technical development and learning. This resonates with our current understanding that effective resource allocation across a large number of activities is challenging.

It is difficult to respond to rapid change

As seen from the literature review, operational management is not equipped to respond to change in a timely fashion. On the contrary, a few management methods introduce controls to prevent change form disputing project and to surround the projects with the process which make it hard to accept the change.

At the same time, the business environment where projects deliver becomes increasingly competitive and dynamic. It does change constantly and significantly. In this ecosystem, the inability of managerial function to adapt to the change and effectively adjust the way things are done, has become a major obstacle.

Plans and schedules are not valid

Many project plans compiled with Microsoft Project (Stover, Biafore & Marinescu 2011) are taken into execution with some critical information still missing. Not all the project activities and relevant dependencies are accounted for and not all the information about the estimated durations and required resource skillset is present. Such plans and schedules are considered as not valid. As execution using invalid plans progresses, the delivery teams experience challenges related to pure planning and this may result in project failures.

Schedules are not current

When projects and programs prepare for their initiatives to start, they invest many resources/hours to compile valid and current schedules. Once these are done, and the initiatives commence, the work follows these well-prepared scheduling artefacts. Naturally, not long after that start things change (someone gets fired, someone starts with the organisation, things get delayed, things complete earlier, etc.). All of these events cause the schedule to ‘break’. In other words, it simply does not reflect the reality on the ground. It is not current. It is very hard to re-create another schedule that is aware of all the things that

happened previously in the project. Often managers have no choice but to continue running their project with that 'old' schedule by applying some fixes to keep it more or less workable.

Schedules are not optimised

A lot of organisations do not even attempt to have optimised schedules, as they simply do not have expertise and technical capacity to take their operational management practice to that level.

Industry data

Based on our professional experience, about 70% of industry projects have valid plans. Thirty per cent of all projects have current schedules, and 2% attempt to optimise their operational schedules.

#	Category	%
A	All projects	100
B	Valid	70
C	Current	30
D	Optimised	2

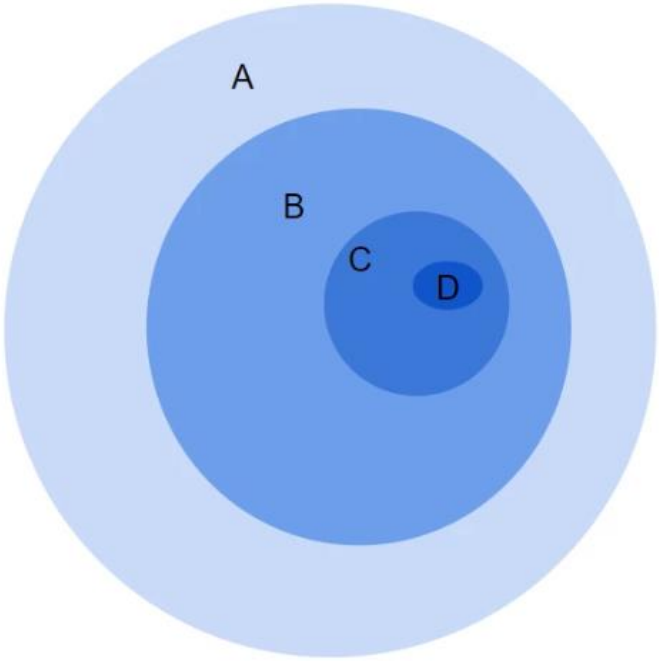

Figure 2.4 Argo AI - OMO Industry Data

2.3.2 Known solutions

If 100 project managers are stopped on the street and asked if they have valid, current and optimised delivery plans, it would be discovered that about 70% have valid plans, about 30% have a current schedule, and perhaps not more than 3% would have optimised schedules.

At the time of writing, several approaches are used to solve the project planning and scheduling problem. It is often seen that various industry sectors tend to adopt a particular method and supporting technology suitable to address their operational needs in a given time and geography. Such selection is likely to become the best practice, and participants adopt the selected approach to be aligned with other industry players.

Such approaches vary from more traditional waterfall-like methods (i.e. PMBOK, PRINCE2) to more modern agile alternatives (i.e. Scrum, DevOps, Lean, etc.).

These frameworks allow project management practitioners to streamline planning and scheduling processes. Sometimes they even take the maturity to the next level and allow these processes to be automated.
Very rarely optimisation of proposed scheduling solution is performed to not only show that a solution is available to solve the problem and complete a set of operational activities predictably but also to see how out of many such solutions some demonstrate improvements across various qualities. They can therefore be considered as optimised concerning relevant parameters.

How different project methods solve the problem

Maturity of project management (PM) practice will allow for a better success rate of project delivery. Also, the larger and the more complex the organisation is, the more critical it is to have good PM practices in place.

In their study, Katunina (2018) analysed the current state and dynamics of project management in the organisations in a given geography. They have identified problem areas and explored ways for improvements. The research has confirmed that high-performing delivery groups appreciate the value of the art of project governance better than the under-performing teams. Only a small percentage of organisations involved in that study demonstrated a high level of project management maturity.

Katunina (2018) emphasises that nowadays, ‘the main objective of organizational PM is to tie the PM practices to business processes and organizational strategy in order to develop the integrated process as the sustainable strategic advantage’ (Katunina 2018). If the project managers could achieve that alignment, the organisation would become more successful in their project delivery.

PMBOK

Several techniques are employed to actively manage project schedules in the context of 'traditional' waterfall delivery methods. Following are some examples, tabled by Haniff and Salama (2016).

Fast-tracking is a technique where the project delivery time is reduced by introducing parallel execution of activities that would normally be run in sequence. Rather than waiting for a dependent activity to be completed, the successor activity commences at the same time as the dependent activity.

The author states that sometimes it is beneficial to change the priorities of the project objectives. For example, a compromise can be made between delivery cost and product quality, delivery time and product quality or delivery cost and total project duration. The author does not agree with allowing quality to be compromised. It should always remain acceptable and ensure that deliverables are fit for purpose. The author allows for trade between the three dimensions of the project management triangle (time, scope, resource). If time and resources are constrained, the scope could vary to allow for delivery of minimum viable product (MFP), which still meets a 'must-have' set of customer requirements.

In summary, issues with project delivery time can be managed by applying fast-tracking when activities planned to be executed consecutively are completed in parallel. Project managers can also apply project crashing when resources are added to the project for the least cost possible.

Agile

Nowadays, an exponential growth of information technology development is being witnessed that requires specialists to bring the ability to this domain and to rapidly accommodate the changes that occur in a very dynamic business environment. If the delivery of information technology initiatives (either enhancing an existing system or introducing new ones) cannot transform and allow for such agility, the customer organisations won't be able to keep up with the change in the markets and will lose their competitiveness. agile delivery approach is not a new concept, and its principles are relatively simple and very easy to follow to warrant the positive impact on the delivery teams. Based on existing research, there is an increasing number of agile project management technological tools on the market that should help users to manage their agile initiatives more effectively.

In their recent research Mihalache (2017) show how the success of software delivery projects relies on the usage of an effective toolset supporting agile project management. Some technologies available on the market are assessed, and their strong features and weaknesses are presented for considerations. Interestingly the set of evaluated tools is only designed to support existing management processes. This means that if the process does not try to find an optimised solution to a management problem, the tool will not attempt to solve this problem either.

Atlassian Jira (Lynda.com 2015) offers a technology that implements project management in an agile fashion. It allows all project participants to interact with this web application and effectively manage their own and other team members' workloads. This tool is very well integrated with other applications offered by Atlassian (Confluence, Bitbucket, Bamboo) and helps to streamline project delivery activities end to end (project management, workflow management, requirements elicitation and management, coding, testing and deploying).

Trello (Johnson 2017) is a Kanban tool, which very much like Jira, helps organisations to deliver their initiatives in collaborative and agile fashion. While being an easy-to-use web application, relative to Jira, it lacks a robust implementation of the workflows, helping project participants to understand the status of all the delivery components. At the moment, because of its simple and intuitive interface, it is recognised as one of the best free offerings in the agile management tools market.

As Manole and Avramescu state 'Asana is one of the best tools on the market' (Manole & Avramescu 2017). It comes with a wide range of strong integration features and can run on PCs and mobile devices, either in iOS or Android environments. It is a technology that helps to manage agile teams, and also allows them to collaborate and communicate effectively. Agile project managers use Asana to manage initiatives at a very granular level. They can create tasks that belong to the project and assign tasks to available resources for workloads. Project stakeholders can follow the task and provide comments in their context to keep the project audience informed and engaged.

Literature review shows that none of the above-described agile project management solutions offers optimisation functionality.

Critical Chain

Critical chain project management (CCPM) was introduced in 1997 by the Israeli physicist Eliyahu Goldratt who wrote the book 'Critical Chain' (1997) to describe the concepts and application of the method. It was developed in response to projects that were marred by poor performances and failure to deliver to stakeholders' expectations. The method applies Goldratt's 'Theory of Constraints' (TOC) to resolve scheduling and delivery problems. In their paper Luiz at al. (2019), when analysing state of the art in CCPM Luiz et al. (2019) conducted a review of existing literature related to this approach. The CCPM controls the project performance using 'buffer management' (BM). The buffers are normally split into three components, including 'expected variation,' 'normal variation' and 'abnormal variation' (Luiz et al. 2019). This approach helps with the timing management of the projects.

Automated Scheduling

Project management is well described in PMBOK – PMI (2008), PRINCE2 - Office of Government Commerce (2009) and agile (Journal 2013) methodologies. While these delivery methods help project managers to form, plan and deliver projects, they do not prescribe a way for effective scheduling of project activities.

This problem was addressed by several studies and technical advances, resulting in the availability of numerous project-scheduling techniques and instruments.

Based on several research and development (R&D) initiatives conducted by Argo Computing (2019) and others such as Jiang (2004), it can be said that scheduling in large and complex resource-intensive domains is challenging. It is not unusual for a large or medium size organisation to spend $10M + per annum on operational activities. Very often, scheduling is implemented manually or with very limited automation. Below are just some of the problems experienced in the scheduling area.

While a significant effort has been made to research various separate areas of operational planning and scheduling, it is often not clear how to apply these methods and approaches to given industry scenarios in a single well-defined fashion. PMI (2008), Office of Government Commerce (2009) and agile (2013) only proposed a theoretical body of knowledge and did not offer a technically supported implementation method. Available scheduling automation technologies like MS Project, SAP Project Services and others only solve problems that fit into a very strictly defined model, prescribed by the respective solution providers. The reviewed optimisation methods are also limited to simplistic managerial structures. Operational

managers are left with the task of having to select from these known techniques to accommodate their particular circumstance. This path may lead to the proposed solutions being far from optimal.

It takes a long time to generate a schedule for a large project (Argo 2019). It is often impossible to regenerate the schedule when project conditions change. Usually, only one schedule is generated. Only a given set of hard constraints is implemented. Often soft constraints are not even considered. It is often difficult to calculate the ideal number of project resources required. Ad hoc changes cannot be validated. Resource allocation (full/partial and single/multiple) can be challenging. Equipment allocation (single/multiple) can be challenging. Internal and external participants' availability for windows implementation can be challenging.

Organisations around the world are facing scheduling problems for a long time now. As problem domains get larger and more complex, these challenges become more difficult to address. At the same time, the benefits that effective solutions present are ever more attractive. These difficulties and potential benefits from successful implementation have attracted researchers from around the world to this problem space. The most known research in scheduling was done for transport, educational timetabling, and software development project management. These initiatives have resulted in significant improvements and benefits realised in the scheduling domain.

In modern project management history, two main approaches to deliver initiatives are waterfall and Agile. While Microsoft Project does address some of the resource-levelling and optimisation functionality, it does not truly implement searching of the whole solution domain to investigate a large number of suitable schedules and see which one is more optimal concerning one quality or another.

Another planning and scheduling tool, widely accepted in enterprise project management organisations, is Oracle Primavera (Williams 2012). Similar to other capabilities suitable for waterfall-like project delivery, it offers a robust technology to support planning, scheduling and execution aspects of the operational management. It also integrates well with enterprise tools and ERP systems (i.e. Oracle EBS, JD Edwards, and PeopleSoft) and offers scalability across varies delivery structures (project, program, portfolio). Similar to Microsoft Project, it still lacks optimisation features.

CA Clarity PPM (Velpuri 2011) is another major player in the larger enterprises planning field. It implements functionality to manage multiple projects in one workspace and allow for that

broad view across the whole of the organisation. This view shows how activities are progressing and how resources are utilised. Again, it does not cover the optimisation very well and does not offer stakeholders to see what opportunities they have to achieve benefits related to different qualities of the delivery when more than one solution is presented for selection and is taken into execution.

SAP Project Services (Zupsic 2003) is a fully-featured project management instrument. Its functionality supports a number of project management processes including budget planning, activities scheduling, procurement of materials and labour.

Among other functionality, it offers the ability to manage a pool of available resources which can be assigned to activities based on their primary or secondary suitability. For example, the primary role of a given resource is a software developer. They can also perform software testing, but it is not their preferred function. The system will be able to track them as a software developer and also allocate testing activities when no other resources are available.

The inability of the so-called 'Waterfall' method to respond to change effectively resulted in practicians around the world starting to look for alternatives.

In recent years organisations have adopted agile delivery method to deal with complexities and pace of change specific to software delivery operations.
Various flavours of this method were developed:

Requirements Driven Development
Test-Driven Development
Scrum
Kanban

General principles of the agile approach are described in Project Management Journal (2013).

While initial planning and scheduling was used for operational management widely for some time now, in more recent times, both industry and academia wanted to see if scheduling solutions could be optimised. They thought that if the solution domains could be searched for better variants, users could be rewarded with better outcomes.

Two main methods commonly used in solving scheduling optimisation problems are:

- exhaustive search (aka brute-force search) method (Pearl 1984)
- heuristic search

The first method evaluates all the possible solutions to a given problem and the second only does it relative to a subset of possible solutions. The second approach sometimes is the only feasible option, since for a large and complex problem domain, the number of possible variations might be too big, and their processing might be prohibitively expensive.

The genetic algorithm (GA) has been known since the 1970s as one way of implementing heuristic searches when tackling scheduling problems. Holland (1992) defined the main principals of this technique in 1975. It applies the selection of the fittest concept used by Mother Nature in the engineering discipline to computerise search and optimisation.

A literature review reveals that there is access to some specific implementations of GA related to the scheduling and optimisation domain described in scientific and other resources. They tend to focus on only one type of problem. It would be difficult to modify them to meet the needs of another industry sector or a given organisation.

The known implementation of GA needs to perform a cross over and mutation operations on sample solutions to create new chromosomes, and effectively search the problem space for alternatives. Before such operations are executed information that describes a given sample (i.e. a set of activities with allocated timeslots and resources) is encoded (converted to a binary format). The operation (cross over or mutation) is then performed on encoded data. When these operations are done, the encoded data is decoded back to the format describing the solution (i.e. classes, attributes, relationships, etc.). The decoded information can be evaluated to see if the newly generated solutions are valid (i.e. they do not violate hard constraints). Needless to say, this is a limitation; it negatively impacts the qualitative and quantitative performance of the search process.

As they are implemented in C++ (Jiang 2004) or Delphi (Argo 2019) or they require the implementation of data structures specific to these languages (data classes), this may result in doubling both development and execution efforts when the input data is already stored in well-defined native database structures.

The reviewed solutions do not implement programme scheduling (more than one project-scheduling problem).

2.4 Methodology and Proposed Solution

2.4.1 Method Context

This new method supports an end-to-end implementation of solutions to scheduling problems in complex domains. It includes both theory and the actual technology to guide the operational manager through preparation, planning, scheduling and optimisation phases of their operational management effort.

This project-scheduling method combines current advances in different fields with industry experience, and it helps to address project-scheduling challenges better. Planning and scheduling problems in complex and resource-intensive domains can be solved using business modelling and genetic algorithms (GA) using this method.
This new method offers an integrated operational scheduling approach, allowing its users to follow a clear path and address their day-to-day problems at the level of complexity required. It will start from essential planning and scheduling where relatively simple scheduling is performed and will move into domain-specific scheduling, which offers unrestricted, customised and complex implementations. Finally, this method will also allow for artificial intelligence implementations based on genetic algorithms, which take the initially proposed scheduling solutions to the most optimal schedules that could be generated for given problem scenarios.

Split the plans and schedules

Significantly the method splits the operational management artefacts into two main categories:

- Operational Plans
- Operational Schedules

Plans usually describe what tasks are performed within a given initiative and in what order (e.g. what dependencies are present). They also specify expected task duration and resource types required to complete those.

Schedules specify what actual resources are being allocated to planned tasks for what periods. In other words, a plan, aligned across actual resource and time dimension, becomes a schedule.

Resources – suitable and available

For the method to work and for the resources to be allocated when schedules are generated, a pool of valid and available resources is maintained. This pool is used by the scheduling

engine to create schedules and should have sufficient resource capacity to meet the demand specified in the plan; if not, the user will not be able to create schedules. Importantly, in addition to resources' skill sets (suitability), the system uses calendar functionality to specify when a resource can be assigned to projects tasks (availability). Resource costs relative to units of time are also managed to understand the overall cost of delivery when the schedules are compiled.

Valid plans

According to the method, a plan is valid when the following conditions are met:

- All the tasks are listed
- Durations are specified
- Required resources' skill sets are specified
- All the tasks dependencies are captured
- There is only one starting task
- There is only one finish the task
- Percentage complete is specified to allow for those scenarios when some tasks are complete partial or in full

Current schedules

Operational schedules are current when they reflect the true situation on the ground. This applies to the currency of resources assigned (they are still available and suitable, they have not left the organisation or changed their expertise). The list of tasks is still in line with what needs to be done. This includes related dependencies and percentage complete.

Optimised schedules

Schedules are considered optimised when the operational managers can select from a population of valid and current schedules, which all meet what is called 'hard' constraints fully, but fare differently in relation to 'soft' constraints or 'nice to have' qualities. For example, one schedule candidate may offer 5% cost reduction and others will allow efficiencies in delivery timeframes. The method allows running optimisation across multiple constraints. It also allows for weighting applied to various qualities. This is used to calculate the overall fitness of a given solution and its place in the list of possible candidates for execution.

The method covers the process of managing plans and schedules E2E

Any project management method will have at least three phases described and implemented:

- Project Planning

- Project Scheduling
- Project Execution

Project planning focuses on understanding what tasks/activities will have to be completed to achieve the overall project outcomes and how they related to each other (i.e. does one need be fully completed before the next task starts). This phase also describes what kinds of resources are required to complete the project tasks and what resources are available to the project in question. One such list of activities, their dependencies and required skillset is complemented with a pool of available resources who possess the required quality to suit the skillset needs; it can be said that the project plan is now complete and can be taken to the scheduling phase.

The project-scheduling phase will take inputs from the project planning and will allocate all the activities into the actual time dimension (i.e. assign start and end times to each task) and specify which resources will be assigned to these tasks for their duration and complete the work. Such schedules have to be initially compiled and published before the project starts its execution phase. They will also need to be modified every time plans change, for instance when resources are no longer available, or other resources have become engaged with the project.

When a good schedule is compiled and published the project execution starts. Information about actual completion times, allocated resources and project progress is recorded. Project execution is being monitored by project management professionals and may trigger changes in planning and/or scheduling.
The proposed method will streamline and automate the above-mentioned phases of the overall process. It will optimise its scheduling component to see if out of already valid and current schedules, more optimal ones can still be generated.

The study answers the research question

Ultimately the method helps operational managers to always have valid plans and current schedules. It allows them to still progress and has their schedules optimised.

The method solves the problem

As will be shown later in the paper, the proposed method addresses the problems in scope and makes operational management more effective. It can be equally successfully adopted in large, complex domains where change is a norm.

2.4.2 The Implementation

Delivering an advanced scheduling solution requires a set of expert knowledge in various related areas such as project management, scheduling, timetabling, mathematical modelling, business intelligence, and business process management. The fact that the author possesses this expertise will allow this research project to be delivered successfully.

This method will construct business models of the problem domain, identify hard and soft constraints, implement GA procedures, generate initial schedule samples, perform crossover and mutation and perform the fitness valuation and selection.

This method will allow for specific scheduling problems to be addressed predictably.

This method will combine theoretical knowledge, technological scheduling implementation and GA optimisations in a single framework which, when implemented, offers operational managers a new end-to-end solution to their scheduling problems.

The business modelling component allows the user to manage complexities and dynamics of various business domains and having the problem structures ready as an input into the implementation phases of scheduling and optimisation. This solves a major issue that many alternative methods have, where the solution model is locked in during the method design and implementation and cannot fit with a real-life business problem model. Such scenarios often lead to a business having to adjust their structures and process to fit with what the selected method and technology offers. Such compromise may lead to that business losing their competitiveness and their unique value proposition, followed by the loss of revenue and reduced profitability.

GA implements the optimisation component of this method and allows the achievement of optimal outcomes without applying expositive searching techniques. It implements the artificial intelligence component of the method, which makes the optimisation engine possible and applicable to the method overall.

Classic business/technology initiatives delivery methods, typical to the software development life cycle (SDLC), will be adapted to the delivery of this research. These will be complemented with pure research and scientific techniques described in the existing literature on the topic of genetic algorithms (Grefenstette 2014; Hartmann 1998; Haupt 2004; Holland 1992; Rutkowski et al. 2014).

Since every problem domain needs to have its model designed and developed, advanced mathematical models specific to a given business domain will be built. The Unified Modeling Language (UML) design tools and RDBMS systems will be used to analyse and implement the project/programme/ portfolio management system model. The known implementations are employing computer languages like Java, Delphi, C++ and C# to construct these models. Native RDBMS data implementation components – database tables – will be used to store data within this study project.

Search and optimisation algorithm – GA will be designed, and hard and soft constraints will be identified. The main components to be designed include population initialisation operations; GA crossover; GA mutation; fitness function for each constraint; fitness-related function for each schedule; and elitism related procedures.

Custom configured scheduling and optimisation modules implementing the earlier defined algorithms will be developed. This will be coded using native MS SQL server data structures and procedures. This should allow the user to avoid using Java, Delphi, C++ or C# computer languages because the main schedule generation procedures will be written in SQL and T-SQL. The main components to be developed include population initialisation operations; GA – crossover; GA – mutation; fitness function for each constraint; fitness-related function for each schedule; and elitism related procedures.

Within this research and with the support of a sponsoring organisation (Argo Computing Services Pty Ltd), a technology was built to implement the Method and run some case studies to validate its applicability in various problem domains.

Here and beyond that, technology is called Argo AI – OMO (Argo artificial intelligence – Operational Management Optimisation). This technology is protected and unconditionally remains the property of Argo.

Figure 2.5 Argo AI - E2E Scheduling Process shows how the end-to-end scheduling process is implemented.

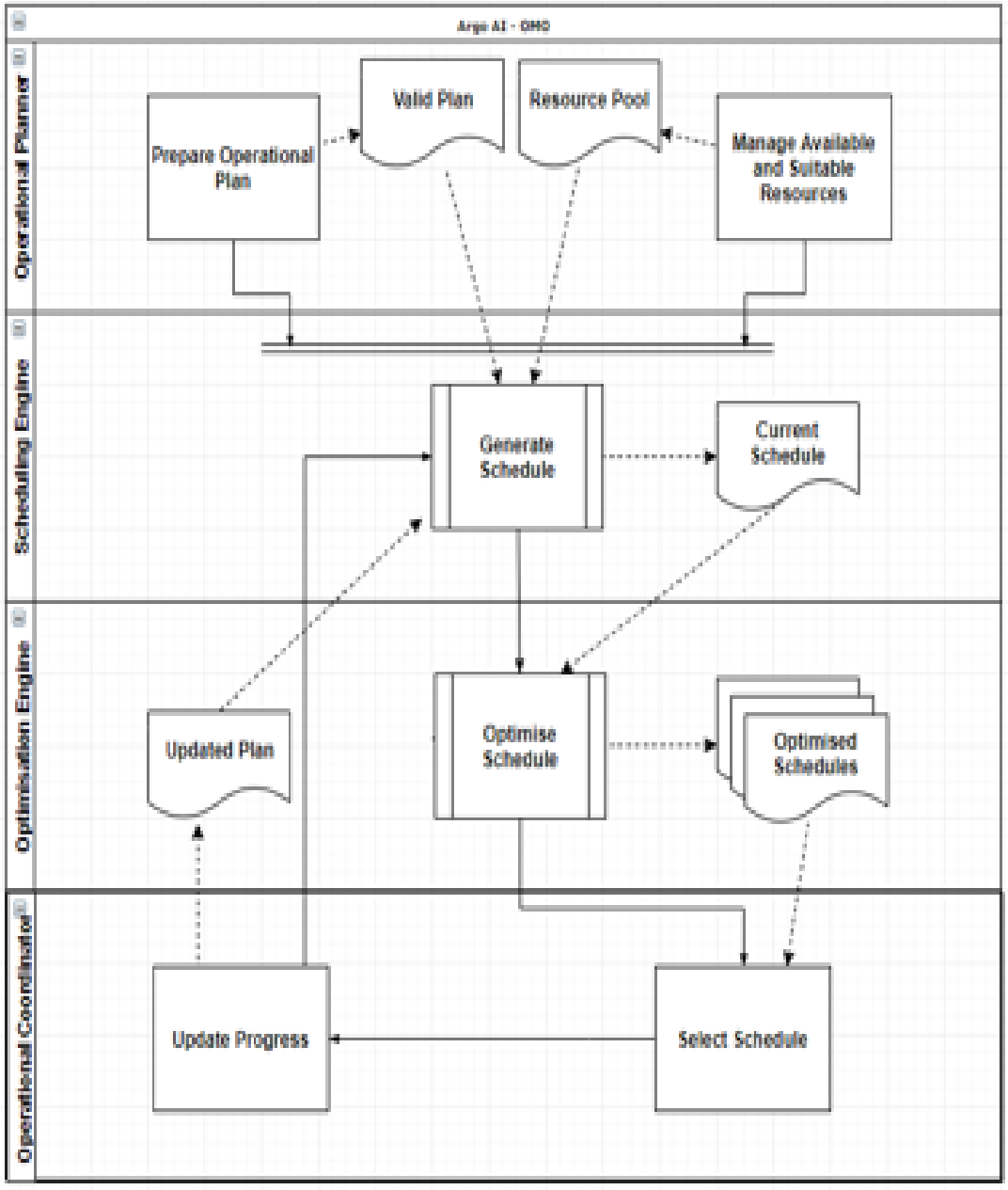

Figure 2.5 Argo AI - E2E Scheduling Process

How the plans and resources are managed

Figure 2.6 Project Planning below shows how the planning phase focuses on the specification of activities that need to be performed, their dependencies and estimated required effort. Each activity has to be completed by a specific role (skill set). The plan also includes a list of resources available to fulfil each role related to planned activities and their availability in the form of the working calendar.

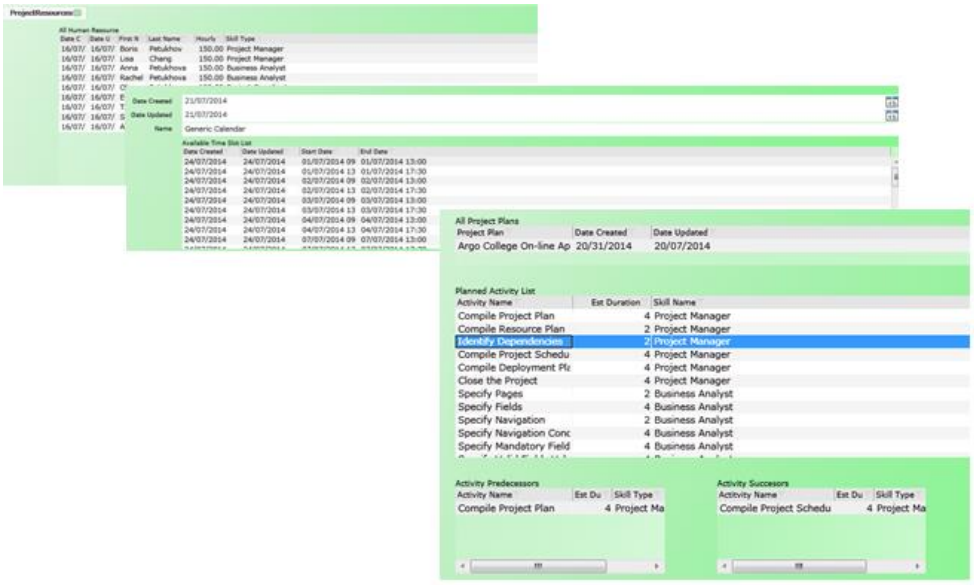

Figure 2.6 Project Planning

Hard and soft constraints relevant to a given plan are defined and specified in detail to allow their implementation in the scheduling phase. A hard constraint is effectively a requirement that if not satisfied, would make the whole schedule invalid. Examples of such constraints may include a requirement to ensure that a given resource is not allocated to more than one activity at a given moment in time, or a rule requiring that one teacher cannot teach more than one class at the same time. Soft constraints, on the other hand, specify requirements that could be violated (nice to have) or only implemented partially. For instance, a project coordinator would prefer to work on activities related to the same project for a full day without interruptions. If a proposed schedule does not fulfil this requirement, it will still be considered to be valid. The table below lists several such constraints relevant to IT Project scheduling.

#	Description	Hard/Soft
1	One resource cannot be allocated to more than one activity at the same time	Hard
2	Activity dependencies have to be implemented (i.e. start-finish)	Hard
3	Planned activity duration has to be implemented as scheduled duration	Hard
4	Planned activity skill set has to be implemented as scheduled skill set	Hard
5	Resource availability specified in planning cannot be violated in schedules	Hard
6	All planned activities must be scheduled	Hard
7	Project duration should be minimised	Soft
8	Project cost should be minimised	Soft
9	Resource load / load deviation / load distribution should be even	Soft
10	Milestones – external dependencies should be considered	Hard

Figure 2.7 Hard and Soft Constraints Specific to Project Scheduling

It is important to understand that the plan does not stipulate the actual allocation of activities to calendar time slots and human resources. This will be implemented in the scheduling step of the process.

To allow the system to automatically generate current schedules, valid plans and pools of available and suitable resource as input need to be provided into the scheduling process. A plan needs to meet several requirements to ensure all the information is present in acceptable shape and form to be considered as valid.

One way to meet those requirements would be to implement an upload and validation function via a web front end. Figure 2.8 Argo AI - OMO - Sample Plan Upload shows how validation is enforced when a plan is uploaded into the system.

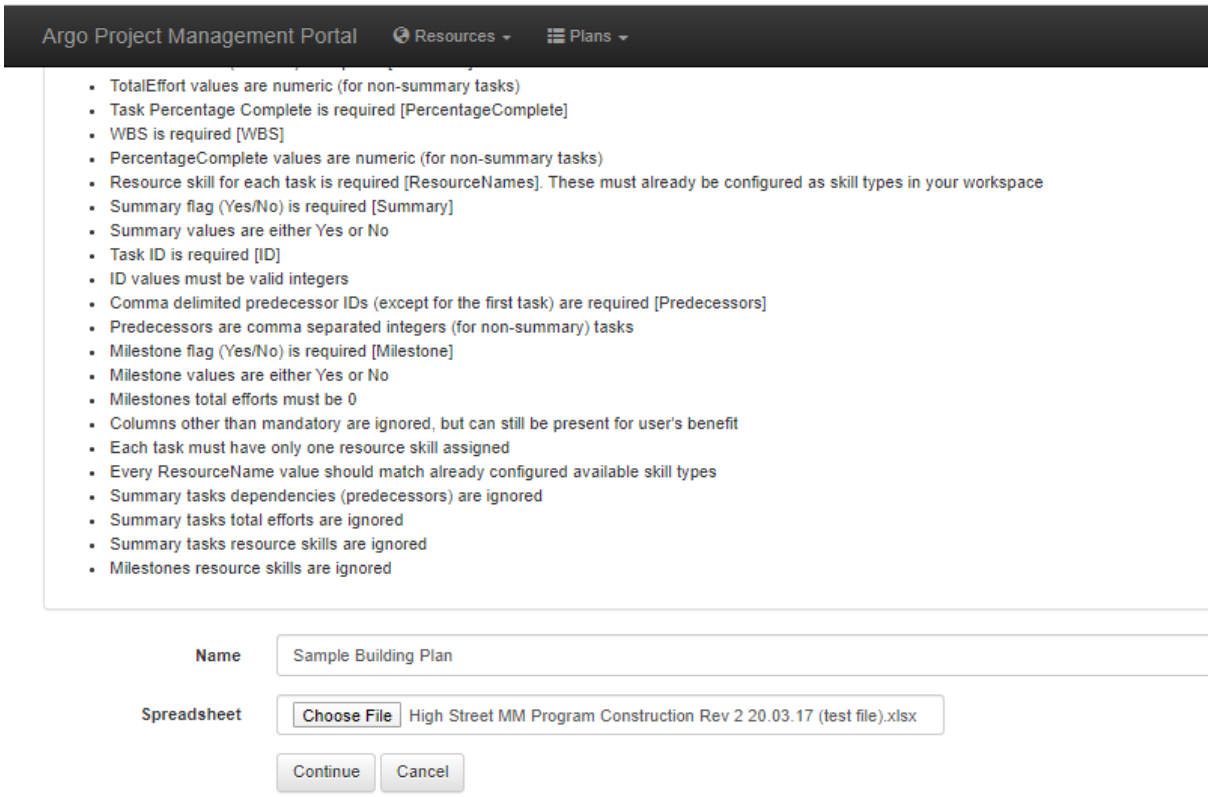

Figure 2.8 Argo AI - OMO - Sample Plan Upload

When a valid plan is uploaded, the users can see all the details of that plan in the system, as shown in Figure 2.9 Argo AI - PMP - Sample Valid Plan

ID	Activity	Skill	Estimate (hours)	Percentage Complete	Created	Last Updated
10	Formwork	Building Contractor	160	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
100	Excavate and Shotcrete Walls to Pit	Excavation Contractor	48	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
101	FRP Car Stacker Slab	Concrete Contractor	24	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
102	FRP Ground Floor Slab (rear)	Concrete Contractor	32	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
106	Formwork	Building Contractor	32	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
107	Reo	Steel Contractor	8	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
108	Pour	Steel Contractor	8	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
11	Concrete Supply	Concrete Contractor	160	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
110	Install Columns Walls and Lift Shaft	Building Contractor	96	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52
112	Formwork	Building Contractor	32	0.00	01 Nov 2017 08:10:52	01 Nov 2017 08:10:52

Figure 2.9 Argo AI - PMP - Sample Valid Plan

As mentioned earlier, the Method requires all the tasks to be linked and start in one point while finishing in one endpoint as shown in Figure 2.10 AI - OMO - Sample Valid Plan - Critical Path.

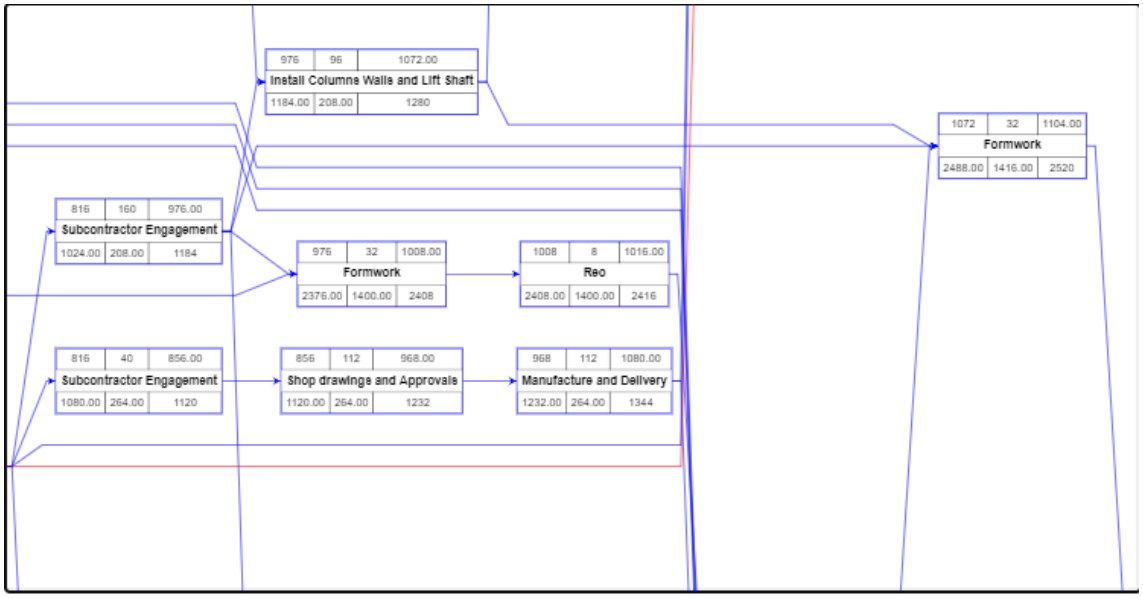

Figure 2.10 AI - OMO - Sample Valid Plan - Critical Path

Managed resource pool

A pool of suitable and available resources and their costs is managed as per Figure 2.11 Argo AI - OMO - Sample Resource Pool

#	Name	Skill	Hourly Rate	Is Active	Created	Last Updated
34	Boris Petukhov	Construction site management contractor	100	YES	30 Jun 2015 23:14:17	22 Oct 2018 20:54:27
35	John Smith	Project Manager	100	YES	01 Jul 2015 03:55:35	01 Jul 2015 03:55:35
83	Demolition C	Demolition Contractor	110	YES	08 Jan 2018 15:16:27	08 Jan 2018 15:16:27
84	Concrete C	Concrete Contractor	90	YES	08 Jan 2018 15:17:17	08 Jan 2018 15:17:17
85	Steel C	Steel Contractor	135	YES	08 Jan 2018 15:18:03	08 Jan 2018 15:18:03
86	Plumbing C	Plumbing Contractor	70	YES	08 Jan 2018 15:18:40	08 Jan 2018 15:18:40
87	Landscape C	Landscape Designer	60	YES	08 Jan 2018 15:19:21	08 Jan 2018 15:19:21
88	Masonry C	Project Manager	140	YES	08 Jan 2018 15:20:13	01 Nov 2018 17:43:03
89	Manufacture W	Manufacture Worker	130	YES	08 Jan 2018 15:21:03	08 Jan 2018 15:21:03
90	Facade C	Facade Designer	120	YES	08 Jan 2018 15:21:38	08 Jan 2018 15:21:38
91	Constraction C	Building Contractor	50	YES	08 Jan 2018 15:22:16	08 Jan 2018 15:22:16
92	Architect A	Architect	70	YES	08 Jan 2018 15:22:53	08 Jan 2018 15:22:53

Figure 2.11 Argo AI - OMO - Sample Resource Pool

Automatically created schedules

Scheduling will take the previously defined plan and convert it into an executable list of tasks allocated to actual resources and calendar time slots. In this phase, hard and soft constraints will be implemented. In project management, this is the most labour-intensive and challenging component.

Figure 2.12 Project Scheduling shows how scheduling is implemented for an IT project.

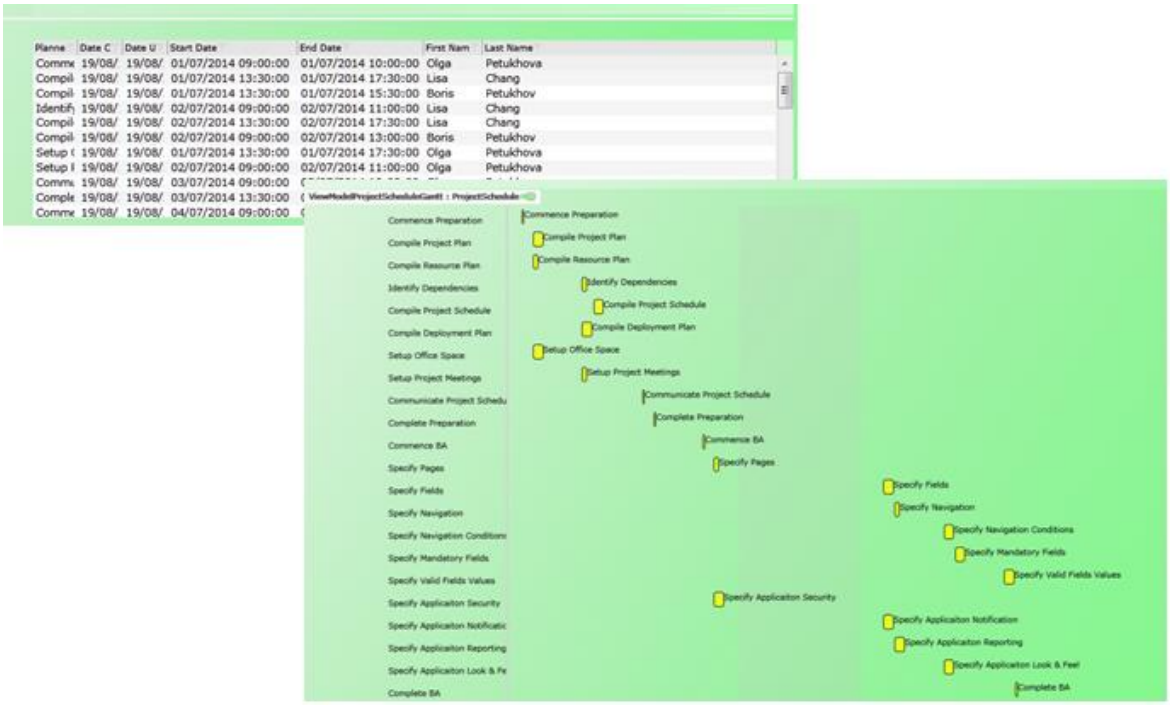

Figure 2.12 Project Scheduling

This research study will attempt to address scheduling problems by automating the scheduling phase.

To approach the solution, the problem domain needs to be defined and modelled.

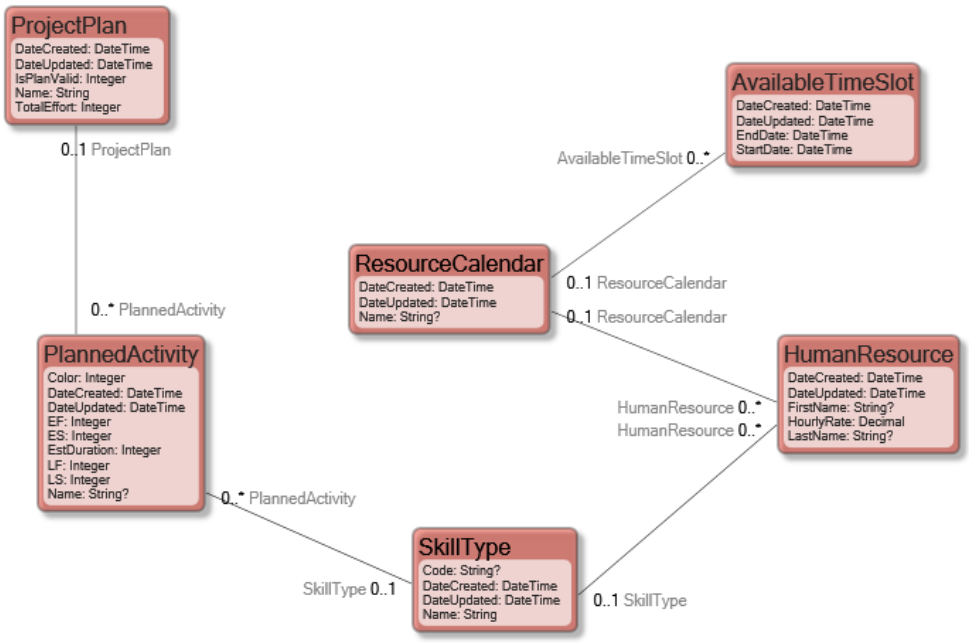

Figure 2.13 Problem Domain Model

The solution domain then needs to be defined and modelled.

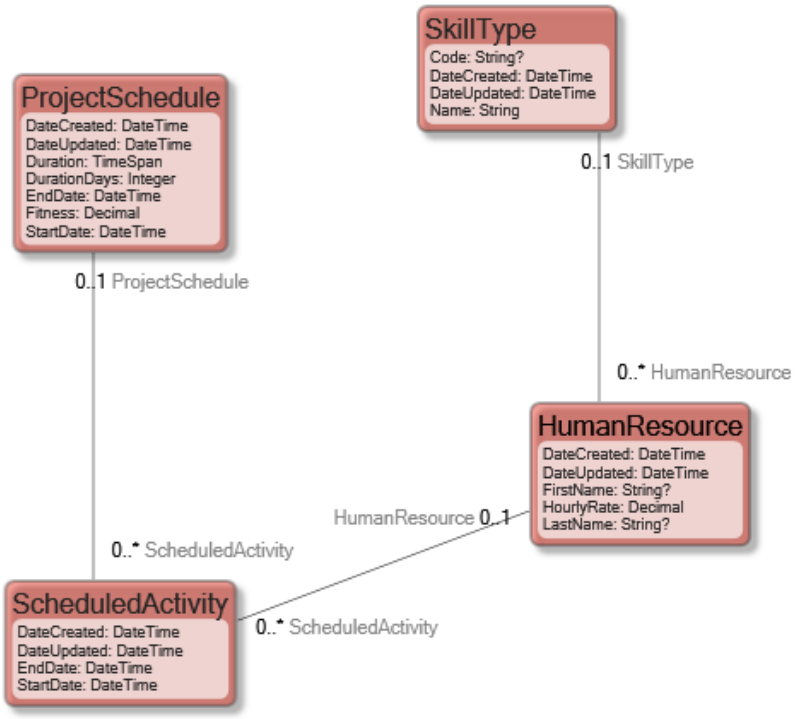

Figure 2.14 Solution Domain Model

When both problem and solution domains are fully modelled, the automatic scheduling processed will be developed to generate a valid solution(s) for the problem. This will be used to create initial pupation of valid schedules.

When the system is presented with a valid plan and a resource pool, schedule generation can be performed by the scheduling module and outcomes of that step can be presented as a project schedule in line with Figure 2.15 Argo AI - OMO - Sample Current Schedule.

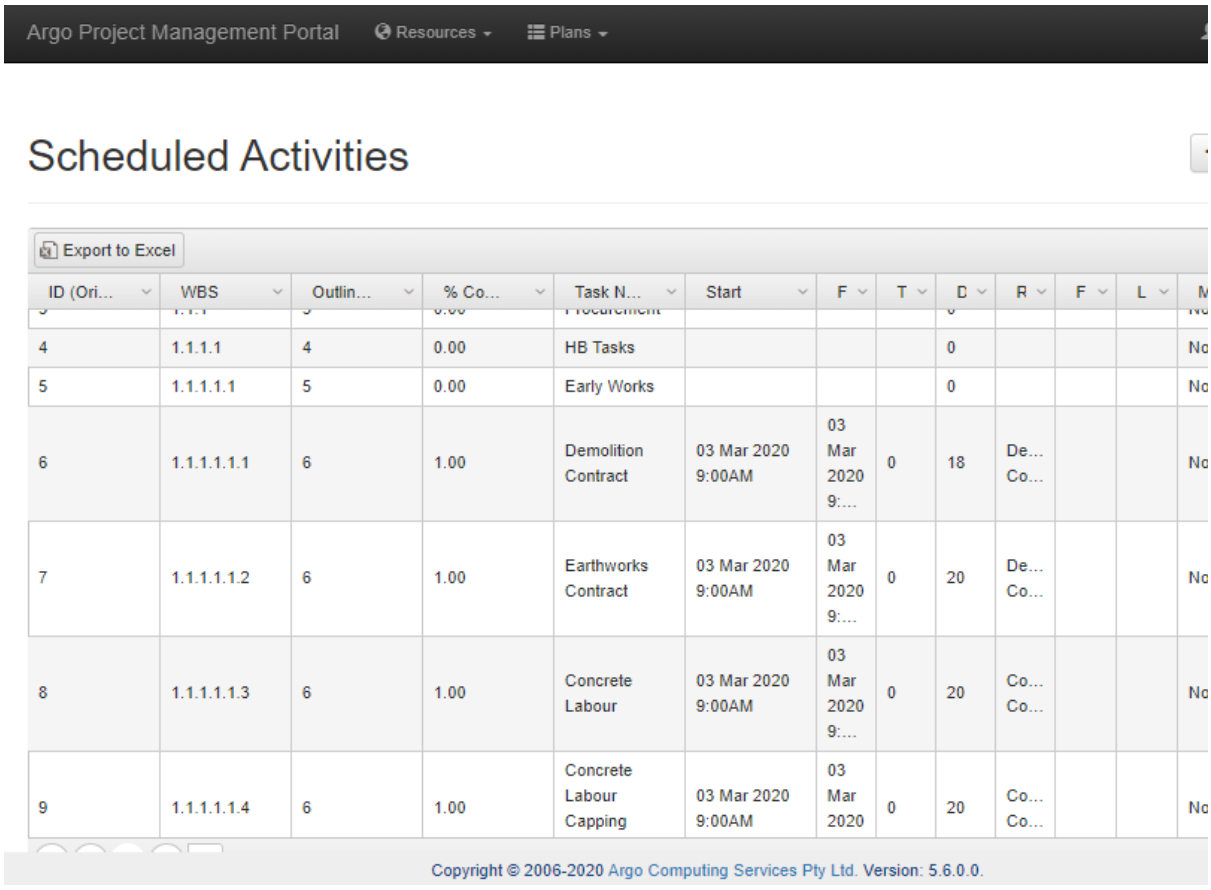

Figure 2.15 Argo AI - OMO - Sample Current Schedule

The same schedule can be shown in a Gantt Chart view as shown in Figure 2.16 Argo AI - OMO - Sample Current Schedule - Gantt Chart.

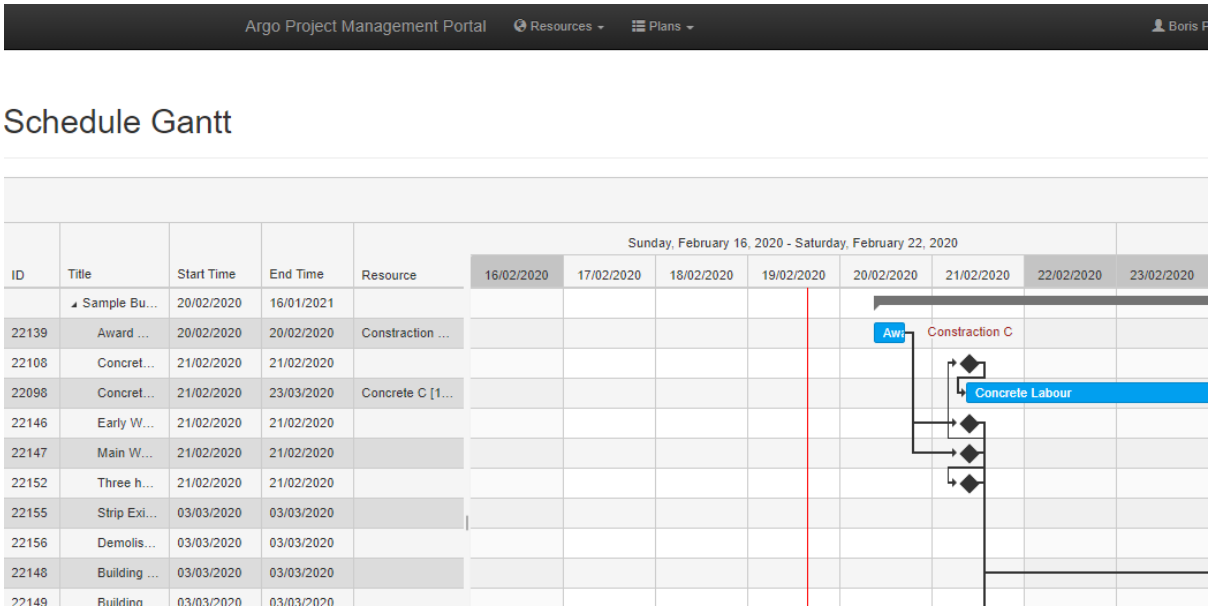

Figure 2.16 Argo AI - OMO - Sample Current Schedule - Gantt Chart

That newly generated current schedule can now be imported in Microsoft Project tools for further referencing and distribution (see Figure 2.17 Argo AI - OMO - Sample Current Schedule - MS Project).

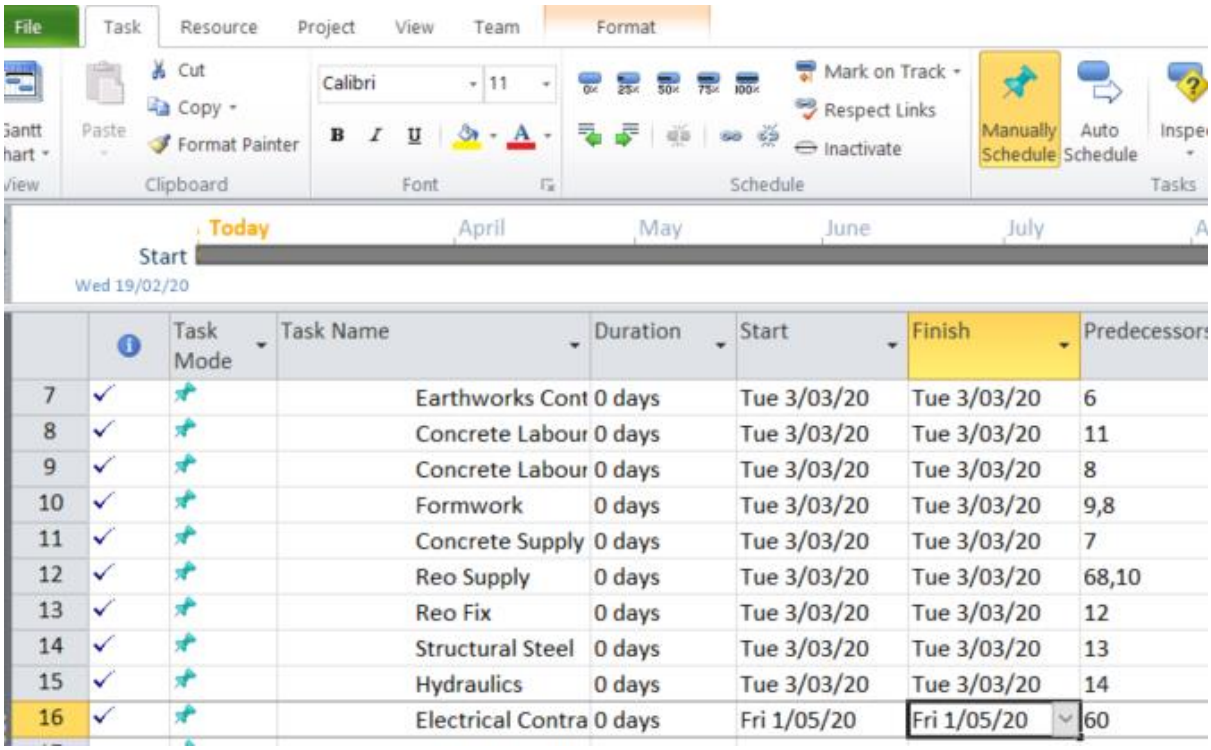

Figure 2.17 Argo AI - OMO - Sample Current Schedule - MS Project

Updated progress

A selected schedule is taken into the operational execution. When teams have their tasks completed (partially or in full), the operational manager would update that progress using appropriate tools (i.e. MS Project) and would compile schedules reflecting those updates. When they need to proceed to the next iteration of schedule creation and optimisation, they will provide this updated plan as an input into the overall schedule generation and optimisation process. The system will be intelligent enough that resources and tasks duration will need to be allocated with the percentage complete in mind.

How the schedules are created automatically with current progress in mind

Figure 2.18 Argo AI - OMO - Sample Current Schedule – Excel shows how a new schedule is created with the known current progress.

A	B	C	D	E	F	G	H	I
ID	WBS	Outline_Level	PercentageCon	TaskName	StartDate	EndDate	TotalEffort	Duratic
1	1	1	0.00	1268 High Street				0
2	1.1	2	0.00	Project Summary				0
3	1.1.1	3	0.00	Procurement				0
4	1.1.1.1	4	0.00	HB Tasks				0
5	1.1.1.1.1	5	0.00	Early Works				0
6	1.1.1.1.1.1	6	1.00	Demolition Contra	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	18
7	1.1.1.1.1.2	6	1.00	Earthworks Contra	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
8	1.1.1.1.1.3	6	1.00	Concrete Labour	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
9	1.1.1.1.1.4	6	1.00	Concrete Labour C	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
10	1.1.1.1.1.5	6	1.00	Formwork	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
11	1.1.1.1.1.6	6	1.00	Concrete Supply	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
12	1.1.1.1.1.7	6	1.00	Reo Supply	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
13	1.1.1.1.1.8	6	1.00	Reo Fix	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20
14	1.1.1.1.1.9	6	1.00	Structural Steel	03 Mar 2020 9:00A	03 Mar 2020 9:00AM	0	20

Figure 2.18 Argo AI - OMO - Sample Current Schedule – Excel

How the schedules are optimised

The next step after scheduling component is complete is to look at the optimisation engine. As mentioned earlier, its objective will be to find solutions that offer a more optimal usage of project resources, complete work in shorter timeframes, or allow users to do the same work but spend less money. This improved solution will be known as the fitter ones related to the soft constraints discussed earlier.

Genetic algorithm (GA) operations will be employed to search the solution space for a more suitable solution.

Figure 2.19 Argo AI - OMO - Optimisation Process shows how the schedules are optimised. Initially created schedules undergo GA operations (crossover and mutation), the fitness of the

candidate solutions is measured and after ranking, best-fit candidates make it into the next optimisation cycle. The optimisation process continues until the objectives are achieved.

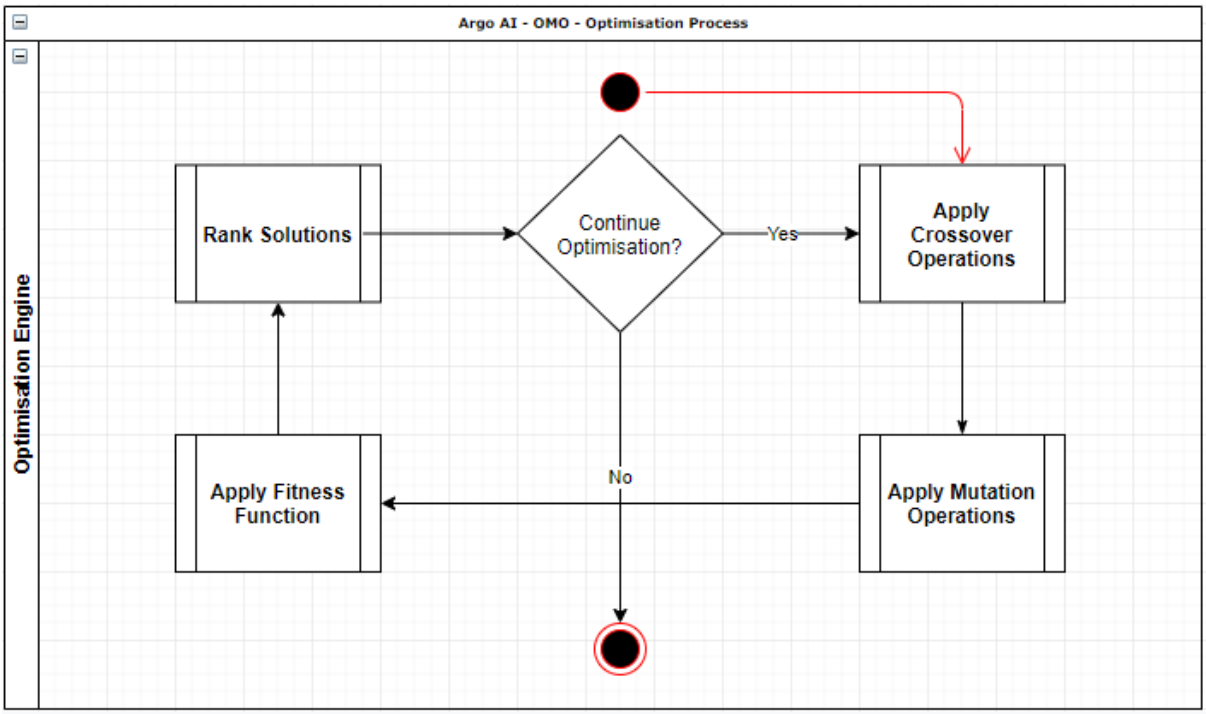

Figure 2.19 Argo AI - OMO - Optimisation Process

Genetic Operations

Figure 2.20 Sample GA Operation – Crossover shows how the first GA operation is performed.

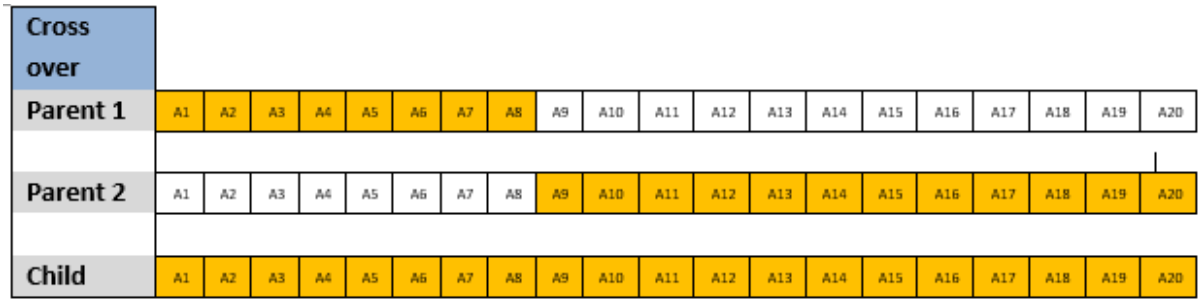

Figure 2.20 Sample GA Operation – Crossover

Figure 2.21 Sample GA Operation – Mutation shows how the second GA operation is performed.

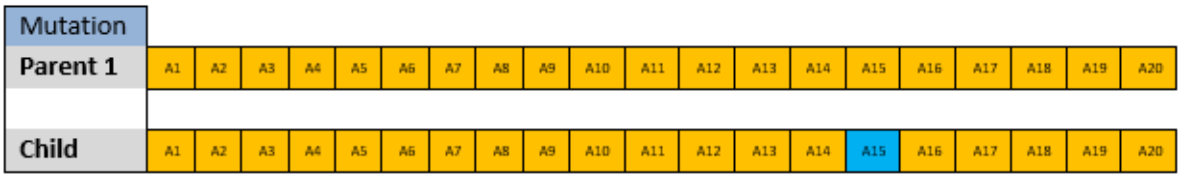

Figure 2.21 Sample GA Operation – Mutation

Fitness Function (also known as Objective Function) is used in genetic algorithm operations to measure the strength of a given solution. It can be simple or complex when some simple functions are combined to take into account more than one quality of a sample. In our method, a complex measuring approach will be used to allow the fitness function to be a sum of scores calculated relative to soft constraints considered in the optimisation.

Schedules selection for execution

When human beings are presented with a population of valid and current solutions, they will select the most optimal one to be taken into the execution phase of their operation.

2.5 Case Studies

Several case studies were conducted under the overarching umbrella of this PhD project. Their detailed designs and outcomes are presented in separate chapters related to this method, including the following:

2.5.1 Accounting Practice – Projectise and Productise

A case study showing how operational planning and scheduling techniques can be applied to an accounting, taxation and compliance practice to achieve operational efficiencies. This technique is called projectisation. The implementation of projectisation is achieved through the application of a proprietary system, Argo Scheduling.

Additionally, this study reflected on how the packaging of a practice's service offerings into a product, an approach known as productisation, is implemented to make the company more competitive and appealing to current and prospective clients.

2.5.2 IT Program and Portfolio Delivery Optimisation.

This case study shows how operational planning and scheduling techniques were applied to a software development company to achieve operational efficiencies.

The earlier developed Operational Scheduling with Business Modelling and Genetic Algorithms method was used to achieve the desired outcomes. It helped to automate and optimise scheduling process.

2.5.3 Telecommunications Network Resource Allocation Optimisation.

This case study shows how an operational management optimisation method and its techniques can be applied to telecommunications network provisioning where resource allocation has to be optimised to offer those who run the network to utilise the most optimal planning of the resource possible. Given optimisation benefits often reach 5 to 10% across different qualities of the considered solution, applying such an approach to a domain where tens of thousands of devices need to be included in the plan promises to deliver some significant savings opportunities.

2.5.4 Climate Change and Operational Optimisation.

This research component analysed the climate change issue. It presented the known facts about climate change and its impact on the planet. If offered a detailed discussion of possible applications in climate change, and opportunities for future research. It assessed actions that could be taken to respond to the challenge and checked if AI techniques in general and Argo AI – OMO, in particular, could be utilised to bring about some desirable outcomes.

2.6 Findings and Related Work

2.6.1 Data Analysis

The proposed method implementation and its testing in the case studies have shown positive outcomes. We were able to significantly automate the main phases of operational management (i.e. planning, scheduling, optimisation). Cross-industry case studies prove that the method can be adopted by multiple types of organisations.

Table 2.2 Data Analysis

#	Industry Sector	Problem Domain	Most Significant Outcome
1	Telecommunications	IT environment management	Implemented automated allocation to testing needs
2	Professional Services	Delivery of the tax and compliance function	Write-offs for a given financial year reduced by 9.60%
3	IT Consulting	Implement web application	Project cost can be optimised by 11.87%
4	Building & Construction	Running a building project	Delivery time can be optimised by 7.60%
5	Telecommunications	Network resource allocation optimisation	CPU utilisations can be optimised by 12.96%

2.6.2 Summary of findings and benefits

Domain complexity

This method can be used to solve scheduling problems in complex, large resource-intensive and heavily constrained project/program/portfolio management domains. More streamlined and optimal schedules will be generated and optimised to achieve a nearly 'perfect' solution.

Practicality

This method provides an end-to-end solution to real-world scheduling problems.

Multi-industry sector

This method can be implemented in different industry sectors:

- IT solution delivery
- Transport and logistics
- Building and construction
- Accounting services
- Educational services
- Retail and wholesale trade

Various management structures

This method can be used in operations with various types of management structures:

- Project level management
- Programme level management (many projects)
- Portfolio level management (many programmes)
- Enterprise-level management (many portfolios)

Financial benefit

For any operation not currently using advanced artificial optimisation of its scheduling, the method will bring at least 5% costs reduction in the first year of implementation. The less streamlined operation will experience up to 30% of costs reduction in the first year of implementation.

Hard constraints and soft constraints implementation

This method will be able to implement an unlimited number of non-mutually exclusive hard and soft scheduling constraints.

Suitability for organisations with various levels of maturity

This method can be implemented in organisations that have different levels of project management maturity relative to project management discipline, starting with initial levels to fine-tuned operations using advanced forms of scheduling.

Suitability for service-oriented delivery operations

Operations that previously utilised functional delivery model can be projected when this method is implemented to manage their operation.

Various implementation extends

This method can be implemented fully or partially, ensuring that at least some benefit can be achieved even for implementations not covering all the prescribed components.

2.6.3 Related Work

Other industry sectors

The conducted case studies have shown how this method can be applied to some industry sectors and optimisation problems. The author has presented many case studies showing

how the method can be applied in IT projects and program delivery, telecommunications and professional services industry sectors.

Further research in this space can check how other domains can also benefit from similar implementations in various industry sectors. The probability of this method is applicable and success in other areas is very high; exploratory efforts in that direction are strongly recommended by the author.

The following industry sectors' operational management dilemma could be tackled by complete or partial application of the developed method.

- Electricity supply. The utilisation of infrastructure and equipment
- Professional services (i.e. HR, legal)
- Manufacturing. Can more optimal resource allocation in the manufacturing processes be achieved?
- Transport and logistics. Can storage capacity and workloads of all parties participating in loads delivery processes be optimised?
- Building and construction

While this study has laid out a solid foundation and solved several problems, each of the above-specified scheduling domain dimensions opens numerous opportunities for further research.

Other technical dimensions

As in the core of this study's method, the equilibrium is managed between hard constraints and soft constraints relevant to a particular problem domain. In the currently implemented method, tasks and resources assigned to their completion are managed. Because of how the method is envisaged to be fairly generic and easily adaptable to enhancements, it is possible to add other definitions to the problem model and have the method of addressing those. One of the more significant such new dimensions is the geographical positioning of operational activities and their participants. When someone runs a truck company, they are very aware of complications arising from goods and services being scatted across towns, cities, states and countries which their transportation services cover. Our method would be extended to have this dimension included when plans and schedules are compiled. With that in mind, the new research question would be:

- Can Argo AI – OMO be adjusted and utilised in geographic aware operational management?

Other AI techniques

The method can also be used in combination with other AI approaches like machine learning, deep learning and predictive analytics. Such additions would potentially allow historical knowledge to be utilised when optimising operational schedules.

Chatbots are another AI technology that could potentially benefit this operational management. The author anticipates utilising this technique when capturing inputs from human operators to build a full view of operational plans and resource pools.

What about agile?

Traditionally, an agile delivery method does not establish strict planning and scheduling controls. The majority of agile teams use planning where tasks are managed via Scrum Sprint Boards, only to understand what needs to be done next and how the project is progressing to the completion. Still, with sizes of such delivery groups reaching 40 and 50 human resources in given product development, it is obvious that resource expenditure would reach $8M per annum and more. With that in mind, responsible and accountable managers ask themselves a question: 'Do we utilise our delivery resources in the most efficient way possible?' If the answer is 'Probably not', then several new research questions arise:

- Can similar implementations of streamline, automated and optimised planning and scheduling process in agile delivery ecosystems be explored?
- Do strongly defined planning and scheduling contradict somewhat loosely defined agile delivery principles?
- Would the planning and scheduling method complement agile delivery approach and help delivery teams to get things done more effectively and meet sponsors' expectations?

Extend the optimisation approach to risks and opportunities management

In this study, we have largely shown the optimisation of allocation between resources and activities that needs to be completed to deliver an initiative. This work can be taken further into the more challenging areas of the operational management field. Similar modelling and optimisation techniques could be applied to risks and issue management, and, given these are just one side of managerial uncertainties, to opportunities and wins. With that in mind, we would like to propose the following new research question:

- Can Argo AI take advantage of related uncertainties management with Bayesian networks to achieve the most optimal way to manage risk and opportunities.

Chapter 3 - Operational Planning and Scheduling with Argo AI – OMO – Genetic Algorithms

3.1 Introduction

As a seasoned professional project manager in the Australian technology and business environment, the researcher has seen many business and technology initiatives delivered with various success rates. Very often, critical management decisions were made based on 'gut feel', influential stakeholders' opinions and/or previous experience in similar projects. Not very often, these decisions were made based on the current advances in science, technology and delivery methods available in the wider professional and academic community.

While many different factors contribute to the success or failure of project deliveries, we strongly believe that effective planning and scheduling of relevant resources and activities is critical to a project successful overall. Operational scheduling, as a discipline, is responsible for maintaining an acceptable quality of operational plans and schedules.

Methods, currently utilised to solve planning and scheduling problems, are not taking advantage of the latest advances in science and not allowing for a rapid change which is common in the current project delivery ecosystems.

When the maturity of given operational management practice is assessed, the following qualities play a vital role in understanding how effective their planning and scheduling is.

- Are their schedules valid?
- Are their schedules current?
- Are their schedules optimised?

A valid schedule will have a list of all activities required to achieve the project objectives. It will also reflect all the relevant dependencies (start-to-finish, start-to-start, etc.). It will also show what type of resources are required to complete a given activity.

A current schedule will be in line with the resource pool, and it will always reflect on the actual progress of activities, effectively being responsive to all the changes in the delivery space.

An optimised schedule will take operational management maturity to the next level. In addition to schedules being valid and current, they will also be optimised to see if a more optimal scheduling solution can be employed to save delivery costs and completion time.

The data analysis shows that only about 70–80% of operational schedules are valid, about 20–30% are current and only 2–3% is optimised.

We ask the following questions:

- How can the known approaches be modified so that the new method does not employ encoding/decoding when performing optimisation operations and therefore improves performance and illuminates creation of invalid solutions all together?
- How can the known approaches be modified so that our search and optimisation is implemented in SQL?
- How the known approaches be modified so that the new method uses the native DB storage structures (database tables)?

In this study, the research team answers these questions. The team introduces a new optimisation method, which while using popular genetic algorithms concepts, introduces novelties that help the optimisation module of the planning and scheduling method to perform better.

The End-To-End (E2E) planning and scheduling methods are called Argo AI – OMO, also known as Argo Scheduling 2015.

The new optimisation approach introduced in this study was granted a status of Standards Australian Patent in January 2017. In the paper, complete quantitative analysis is completed to explore existing methods, and the new one is proposed. Several case studies are performed to prove the usefulness of this method in real-life business scenarios.

This chapter includes the following sections:

1. Introduction. This section helps to understand why the study was undertaken, how it was performed, and how the chapter is structured.
2. Background and Key Concepts. The author will describe the optimisation of operational management here and identify its main principles and concepts.

3. Problem Statement and Known Solutions. The problem will be stated here and available solutions will be explored.
4. Methodology and Proposed Solution. The new method will be described here.
5. Case Studies. Examples of the applications of the new method will be listed here.
6. Findings and Related Work. The outcomes of this study will be presented and analysed. Future directions for continuing research will be considered.
7. Conclusions. Confirmation of the study's objectives being achieved.

3.2 Background and Key Concepts

According to Haupt (2004), optimisation 'is the process of making something better' (Haupt 2004). When there is a robust and satisfactory solution to a given problem that needs improvement, optimisation techniques are applied. The optimisation involves finding variations of an initial approach and using available knowledge to improve. As creating alternative approaches and analysing them is a tedious task requiring intensive analysis, computer systems are often used to perform effective optimisation. For this process to work domain models and related data have to be available in electronic format and loaded into the processing system components. Optimisation practitioners know very well that when a 'good' solution is found for a given problem, it is most likely not the most optimal one. They know that generally significant improvement can be achieved if optimisation is performed. It is when aiming to realise those better qualities of a final proposed solution that the researches and practitioners are ready to invest their knowledge, expertise and commitment.

Optimisation problems have fascinated scientists from antiquity to the present. Since the beginning of our existence, civilisation had to face many 'challenges, such as finding the optimal solution of various problems including control technologies, power sources construction, applications in economy, mechanical engineering and energy distribution amongst others' (Zelinka, Snasael & Abraham 2012). Extensive research was completed to explore various applications of artificial intelligence in various domains (Graña et al. 2013; Taylor 2007; Teguh, Murakami & Igarashi 2014; Wang & Wets 2013; Man, TANG & Kwong 2012).

In their book titled 'Optimal resource allocation' (Ushakov 2013), the authors bring attention to the importance of optimal resource allocation. Operational managers of all eras wanted to achieve a maximum outcome with limited expenses. The book helps the reader with basic knowledge of optimisation theory as it presents examples of optimisation implementations.

Albert Einstein was quoted in one of the reviewed literatures (Okuno & Ali 2007) as saying: 'The true sign of intelligence is not knowledge but imagination'. It is that imagination that keeps many scientists and engineers striving to introduce a new way to apply artificial intelligence concepts and theoretical knowledge to the real-life problem in many industry domains.

In the field of human health science, a considerable body of knowledge was built on understanding how genetics work. Padyukov (2013) presented an investigation on the current status, relevant problems and opportunities in the domains of genetic epidemiology and human genetics. As they put it, advances in technology and ambitions of many brilliant geneticists and biologists resulted in the development of outstanding methods to study the human genome. The main objective of that work is to improve human health and life expectancy.

Humans have always been captivated by nature's biological variety and its evolutionary progression (Bansal et al. 2012). For centuries scientists studied the way nature improved the living inhabitants of this planet to make them live longer and adapt to challenging surroundings. The question has arisen: 'Can we apply similar improvement logic to optimisation of business processes?' These explorations have led to the development of a new paradigm of computation known as natural computing. Generally speaking, it tries to replicate the way nature deals with the evolution of its species into human-created products and services.

In their volume Gandomi and others (2015) analysed genetic programming applications. Their case studies include solving real world problems, such as energy conversion and management, financial analysis, engineering modelling and design, and software engineering.

Process engineering is a good research field, and researchers have created a significant body of knowledge, allowing for advances in that space. Valadi, and Siarry (2014) demonstrates how metaheuristics can be applied to achieve even better outcomes. Metaheuristics are upper-level heuristics. Several process engineering optimisation problems are addressed in their book, such as 'heat and mass exchanger network synthesis, static and dynamic optimization of chemical and bioreactors (batch/semi-batch/continuous), supply chain optimization, etc.' (Valadi, & Siarry 2014).

Jarboui extensively covered optimisation of production scheduling in manufacturing in their book 'Metaheuristics for production scheduling' (Jarboui 2013). This volume shows how effective scheduling needs to be established to produce high-quality and reliable goods

without time delays. In their opinion, heuristic scheduling methods would be able to provide good solutions with reasonable computation time.

Those audiences concerned with financial risk management can find relevant discussions presented by Rubinson and Yager (1996). They show how fuzzy logic and genetic algorithms can be applied to a better understanding of stakeholders in finance perceive applicable risk factors, and how to better mitigate those risks to help those involved to achieve better returns on their investment. They employ genetic algorithms to calculate the qualities of a 'fuzzy multi-criteria ranking problem' automatically. This new approach offers a substitute to 'fuzzy rule-based systems' for management of negative uncertainties.

Liang and Lv (2009) continued research in the field of financial applications. They focused on 'detecting technique of financial statement fraud based on fuzzy genetic algorithms' (Liang & Lv 2009). Their paper described 'fraudulent characteristics analysis and significant testing and factor analysis'. Their work developed an indicator system which includes 'eight main factors and 21 feature indexes' for fraud-detection. Based on those factors and indexes, a fraud-detection model called Fuzzy Genetic Algorithms BPN FGABPN was designed. This new tool supporting fraud management was the outcome of that.

Relevant to the financial industry sector, El Hachloufi, Haddad, and Attar (2016) worked on minimisation of 'value at risk of financial assets portfolio using genetic algorithms and neural networks'. Their paper has proposed an approach for minimisation of a shares portfolio invested in a market where the fluctuations follow a normal distribution based in an explicit mathematical formula for calculating value at risk (VaR) for portfolios of linear financial assets invested. The considered approach was the Black-Scholes stochastic process, assuming that the portfolio structure remained constant over the considered time horizon. The technique minimised the VaR using neural networks and genetic algorithms.

Recently Ha (2013) looked at how to optimise 'insurance risk allocation with the steepest ascent and genetic algorithms'. They conducted 'a numerical experiment to evaluate the relative performances of the Steepest-Ascent method and Genetic Algorithm in the solution of an optimal risk-allocation problem in primary-insurance portfolio management' (Ha 2013). The outcomes demonstrated that 'the steepest-ascent way was found to be functionally dependent on but not overly sensitive to the choice of initial starting policy' (Ha 2013). The genetic algorithm produced a superior solution to the steepest-ascent method at the cost of increased computation time.

To present a modern approach for ‘pairs trading using genetic algorithms (GA)’ Huang and other researchers (2015) published a paper where they proved that the ‘GA-based models’ could perform better than the benchmarked techniques and their method can produce robust models to deal with specifics of financial optimisation. To come to this conclusion, they had to conduct ‘a statistical validation on the learned models to account for the temporal order and dynamic characteristics of the stock data, which is critical for the real-world investment’ (Huang et al. 2015).

In 2017 a team of researchers published a paper presenting ‘a new technique to portfolio selection using a genetic algorithm (GA) and fuzzy synthetic evaluation (FSE)’ (Nayebpur & Bokaei 2017). In their opinion, portfolio prioritisation is ‘a multi-objective/criteria decision-making problem in financial management’ (Nayebpur & Bokaei 2017). They utilised FSE and a GA for portfolio management in the Tehran stock exchange. The experimental results showed that ‘valuation perspective criteria, growth potential criteria, profitability criteria, liquidity criteria, asset utilisation criteria and leverage condition criteria have the highest importance, respectively, of investors’ perspectives’ (Nayebpur & Bokaei 2017). The main outcome of that study was the realisation that the proposed approach can support the investor decision making for the most optimal financial performance of their portfolio. They do not need to rely on human expert knowledge when completing this work. Instead, the computerised optimisation algorithms do tedious and advanced analysis.

In their paper titled ‘Computing value-at-risk using genetic algorithm’ (Sharma, Thulasiram & Thulasiraman 2015), Sharma and others described how value at risk (VaR) could be evaluated with genetic algorithms (GA). The authors proposed two modifications to the standard GA: normalised population selection and strict population selection. They assessed the outcomes of this approach relative to the performance of the ‘conventional VaR techniques’. They suggest ‘two modifications to the standard GA: normalized population selection and strict population selection’ (Sharma, Thulasiram & Thulasiraman 2015). The empirical data collected based on the performance of a number of market indices demonstrated that ‘by adjusting the volatility, the VaR computed using GA is more conservative as compared to those computed using Monte Carlo simulation’ (Sharma, Thulasiram & Thulasiraman 2015). Financial planning discipline advocates for a more conservative approach to financial investment management so the outcomes therefore of this study are useful to industry practitioners.

The ‘genetic algorithm (GA) is the most widely known type of evolutionary algorithm’ (Eiben, & Smith 2003). It was originally introduced by Holland (1992) as a way of exploring ‘adaptive

behaviour'. Holland (1992) defined the primary principals of this technique in 1975. It applies the selection of the fittest concept used by Mother Nature in the engineering discipline to computerise search and optimisation.

Since the publication of Holland's book, interest in GAs has spread from the University of Michigan to research centres throughout the US, Canada, and Great Britain (Grefenstette 2014). GAs were used in striking diversity of problem domains, from machine learning to image processing to combinatorial optimisation.

Genetic algorithms (GA) as a technique for exploration and optimisation is currently in an established phase of its lifecycle (Wall 1996). Over the last decades, it has been very useful in various academic and commercial fields. Due to its need to process large datasets and perform complex computational logic, its feasibility is often relying on the processing power and costing of underlying computing infrastructure. As the recent advances have been made in solid-state microelectronics manufacturing, the genetic algorithms have become more successful and more widely adopted.

According to some researchers, 'genetic algorithms are one of the more effective machine learning methods' (Martin, Spears, & Martin 2001). Derived from the biological concept of the 'survival of the fittest', this optimisation approach searches the available solution domain, assesses fitness of each candidate solution and finds more optimal variances by replacing not so fit members of the populations with the fitter ones.

Application of genetic algorithms in optimisation research is widely adopted across various problem domains. In their book 'The practical handbook of genetic algorithms: Applications' Chambers (2001) explores practicalities of the genetic algorithm applications. The authors address a broad range of issues, including:

- selection and scheduling of road projects
- transportation optimisation
- job-shop scheduling constraint satisfaction
- radiotherapy treatment scheduling
- optimisation of power electronic circuits

Other applications of genetic algorithms were researched, and their practicality was summarised (Liepins & Hilliard 1989). Successful applications included: image management, Aegis observation, network arrangement, prisoner's predicament, and gas pipeline controller.

The ‘deadlock control problem in Automated Management Systems (AMSs)’ has been addressed in a study (Xing et al. 2011) that integrated a ‘deadlock control policy’ using genetic algorithm and developed a new ‘deadlock-free scheduling algorithm’.

Review of these use cases shows the versatility of this relatively novel method of optimisation.

Genetic algorithms are technically complex to implement (Riolo, Vladislavleva & Moore 2011). A number of exploratory papers available in the existing literature and related to genetic programming (GP) (Riolo et al. 2011), looked at ‘the synergy between theoretical and empirical results on real-world problems, producing a comprehensive view of state of the art in GP’ (Riolo et al. 2011). They focused on ‘modularity, scalability; evolvability; human-competitive results’.

‘Evolutionary optimization algorithms’ (Simon 2013) embarks on the journey of providing some technical definition of several techniques around evolutionary algorithms and genetic algorithms. Some of the topics the authors discuss include ‘steepest ascent hill climbing’, ‘random mutation hill climbing’, ‘roulette wheel selection’ and ‘cycle crossover’ for the travelling salesman. This engineering text aims to help practitioners and researchers to understand the state of the art better.

As stated by Nguyen and others (2013), ‘designing an effective scheduling policy is challenging and time-consuming because it needs to take into account multiple scheduling decisions and conflicting objectives in a manufacturing system’ (Nguyen et al. 2013). In their paper, they developed ‘hyper-heuristics for automatic design’ of scheduling methods via genetic software design. They employed an evolutionary search approach to deal with many scheduling complexities and often conflicting priorities in the development of scheduling solutions. Four ‘hyperheuristics’ built on genetic programming were described in that paper.

> The performances of the proposed methods are examined by training and testing the evolved scheduling policies on various simulation scenarios. The results show that the evolved scheduling policies outperform the existing scheduling policies created from combinations of popular dispatching and dynamic or regression based due-date assignment rules on both the training and testing scenarios (Nguyen et al. 2013).

In the study, the authors have developed a ‘diversified multi-objective cooperative coevolution method’ (Nguyen et al. 2013) that demonstrated improved performance relative to other known evolutionary scheduling approaches.

More research on the topic is offered by Tavana and others (2014). They proposed two multi-objective approaches to solve the 'preemptive generalized precedence discrete-time–cost–quality trade-off PGP-DTCQT problem' (Tavana, Abtahi & Khalili-Damghani 2014). One of the proposed solutions was called 'the efficient e-constraint method'. 'The calculation of the range for the objective functions over the efficient set was accomplished with a lexicographic payoff table' (Tavana, Abtahi & Khalili-Damghani 2014).

> The other one is based on a dynamic self-adaptive multi-objective evolutionary algorithm. A special chromosome structure was designed for the problem. Customized evolutionary operators were designed for PGP-DTCQT model. The proposed algorithm was also equipped with a self-adaptive penalty function and a dynamic parameter-tuning function. The dynamic self-adaptive penalty function penalized the violated chromosomes according to the status of the chromosome, the status of the entire population, and the iteration of the algorithm. Through dynamic parameter-tuning, the crossover, mutation and penalty parameters were modified based on the iteration number in favor of a better exploration and exploitation. In order to provide a basis for comparison and investigating the efficiency and applicability of the two procedures, we systematically simulated a series of random problems. The generated Pareto fronts of both methods were compared against reference sets (i.e., the best-known Pareto fronts of instances) based on two sets of diversification and accuracy metrics. The proposed dynamic self adaptive multi-objective evolutionary algorithm represented relative dominance in comparison with the efficient e-constraint method (Tavana, Abtahi & Khalili-Damghani 2014).

Recent studies confirm the effectiveness of genetic algorithms. In their book, Carson (2017) take a deeper dive into the world of opportunities this method presents. In one of the chapters, they described 'the genetic algorithm-based calibration procedure for a microscopic traffic simulation model, focusing on freeways and modern roundabouts'. They demonstrated how a calibrated model was applied to calculate the passenger car equivalents for heavy vehicles that represent the starting point for the operational analysis of roads and intersections.

Another example of applying the GA method to solve optimisation problems is presented by Lin et al. (2018). They have designed optimisation of the thermal load of the buildings.

Gobetto (2013) have focused their research on optimisation of operations management in automotive engineering. It explores the supply chain management and procurement techniques. It covers several components in the overall end-to-end manufacturing process,

including decision-making strategies, the manufacturing tools and equipment, analysis of the materials to support production and the 'supply chain management' and the procurement.

It is interesting to see that the financial sector is also covered by research in the optimisation space. Pan (2012) have confirmed how genetic programming could be employed to help with the creation of a financial management structure. They applied 'grey relational analysis' to analyse the operational success of 600 companies in China. They then used a more novel categorisation method to divide enterprises in China into two groups. In the end, three models (i.e. 'genetic programming', 'Back-Propagation Neural Network' and 'Logistic Regression'), were employed to create an 'Enterprise Operational Performance' model and an 'Enterprise Finance Characteristic' model. It was concluded that genetic programming produced the best cataloguing and prediction outcomes.

In 2008 Lai published a book describing how the 'mean-variance model and genetic algorithms are utilised to find the optimised weights of a portfolio of funds' (Lai 2008). They choose seventeen funds of fidelity covering eight economic areas to be their research subjects. The time period of this study was from January 1998 to November 2006. They used the past sixty monthly returns to decide the holding weights of the next month. They rolled the data period a month forward to decide the next period's holding weights of each underlying target each time. Based on the results, the authors suggested that the investors can use the GA to optimise the weights of funds portfolio since the results indicate that GA outperforms the Mean-Variance Model (MV) and equal weight method.

In their book, Yang and others (2012) examined the 'latest developments of metaheuristics and their applications in water, geotechnical and transport engineering offering practical case studies as examples to demonstrate real-world optimisation applications' (Yang et al. 2012). They remind us that optimisation problems are often very challenging to solve for many reasons. The problem business domains are complex, and simulating models are large. The objective factions can take many forms, and therefore some methods could be better suited for required calculations than others. Volumes of data that the optimisation engines need to process is also constantly increasing, which puts pressure on computational times and expected levels of scenario coverage. Their discussion covered a range of areas within the theoretical approach, including implementations of 'optimisation algorithms, artificial intelligence, cuckoo search, genetic programming, neural networks, multivariate adaptive regression, swarm intelligence, genetic algorithms, ant colony optimization, multiobjective evolutionary optimisation' with diverse applications in engineering such as 'the behaviour of materials, geotechnical design, flood control, water distribution and signal networks'.

Gen, Cheng and Lin (2008) discuss network models and optimisation with multi-objective genetic algorithm approach. This work describes how to represent real-life business models using network models to establish a framework for the following manipulation of this model using genetic algorithms operations to achieve objectives of optimisation initiatives.

Chan, Lettice and Durowoju (2012) wrote a book to demonstrate the latest advances in decision-support for the supply chain management. It presented several case studies showing the successful implementation of numerous decision-making practices. One of its chapters looks at the scheduling issues where the products are shipped 'from suppliers to cross-docking' destinations within a given time. The author has adopted genetic algorithms to solve this complex problem, and they were able to prove the effectiveness of this approach in transport and logics scenarios.

In 2014 more work was completed by Demirel and others (2014) to develop 'a genetic algorithm approach for optimising a closed-loop supply chain network with crisp and fuzzy objectives' (Demirel et al. 2014). They demonstrated the usefulness of 'a mixed-integer programming model for a closed-loop supply chain (CLSC) network with multi periods and multi-parts' (Demirel et al. 2014).

In a volume called 'Medical applications of artificial intelligence,' Agah (2013) demonstrated how an artificial intelligence (AI) tools set has had been applied in the medical sector. Such implementations are intended to improve health care by helping health professionals to deliver better services to the population via improved 'effectiveness, productivity, and consistency'.

Based on some R&D initiatives conducted by Argo Computing (2015) and others such as Jiang (2004), Wall (1996) and Dean (2008), it can be said that scheduling in large and complex resource-intensive domains is challenging. It is not unusual for a large or medium size organisation to spend $10M+ per annum on their operational activities. Very often, scheduling is implemented manually or with minimal automation. Below are just some of the problems experienced in the scheduling area.

It takes a significant effort and time to generate a schedule for a large project (Argo 2019). It is often impossible to regenerate the schedule when project conditions change (Argo 2019). Usually, only one schedule is generated (Argo 2019). Only a given set of hard constraints is implemented (Argo 2019). Often soft constraints are not even considered (Argo 2019). It is often difficult to calculate the 'ideal' number of project resources required (Argo 2019). Ad hoc changes cannot be validated (Argo 2019). Resource allocation (full/partial and single/multiple)

and equipment allocation (single/multiple) can be challenging (Argo 2019). Internal and external participants' availability windows implementation can be challenging (Argo 2019).

The reviewed optimisation methods are also limited to simple managerial structures. Operational managers are left with the task of having to select from these known techniques to accommodate their particular circumstance. This path may lead to the proposed solutions being far from optimal.

This method will also allow for artificial intelligence implementations based on genetic algorithms, which take the initially proposed scheduling solutions to the most optimal schedules that could be generated for given problem scenarios.

3.3 Problem Statement and Known Solutions

3.3.1 Problems

The optimisation is rarely applied to the operational management processes.

3.3.2 Known Solutions

Organisations around the world have been facing scheduling problems for a long time now. As problem domains get larger and more complex, these challenges become more difficult to address. At the same time, the benefits that effective solutions present are ever more attractive. These difficulties and potential benefits from successful implementation have attracted researchers from around the world to this problem space. The most known research in scheduling was done for transport, educational timetabling, and software development project management. These initiatives have resulted in significant improvements and benefits realised in the scheduling domain.

Two main methods commonly used in solving scheduling problems are:

- exhaustive search (aka brute-force search) method (Pearl 1984)
- heuristic search

The first method evaluates all the possible solutions to a given problem, and the other only does it relative to a subset of possible solutions. The second approach sometimes is the only feasible option, since for a large and complex problem domain, the number of possible variations might be too big, and their processing might be prohibitively expensive.

The genetic algorithm (GA) has been known since the 1970s as one way of implementing heuristic searches when tackling scheduling problems.

A literature review reveals that there is access to several specific implementations of GA related to the scheduling and optimisation domain described in scientific and other resources.

In their paper Hartmann (1998) have proposed:

> a genetic algorithm (GA) for solving the classical resource-constrained project scheduling problem (RCPSP). The representation is based on a precedence feasible permutation of the set of the activities. The genotypes are transformed into schedules using a serial scheduling scheme. Among several alternative genetic operators for the permutation encoding, we chose a ranking selection strategy, a mutation probability of 0.05, and a two-point crossover operator which preserves precedence feasibility (Hartmann 1998).

Their study confirmed that the considered GA approach worked better than the methods presented in the existing literature.

According to Xiao and others (2013), ‘software project scheduling problem (SPSP) is one of the important and challenging problems faced by software project managers in the highly competitive software industry’ (Xiao, Ao & Tang 2013). In their paper, they proposed an ‘ant colony optimization (ACO) approach’, which is called ‘ACS-SPSP algorithm’. In their experiment, six problem domain-specific heuristics were introduced to analyse the variations of activity efforts, assigned human resources and activity priority. Out of these six methods, the ‘heuristic of allocated dedications of employees to other tasks’ (Xiao, Ao & Tang 2013) performed well.

More work to solve scheduling problems was done by Zamani (2013). They utilised genetic algorithms for resolving the ‘resource-constrained project scheduling problem’ (Zamani 2013). The advanced addition to the algorithm was the use of a ‘magnet-based crossover operator’ that can pre-serve up to two connected parts from the receiver and one ‘contiguous part from the donator genotype’ (Zamani 2013).

> For this purpose, a number of genes in the receiver genotype absorb one another to have the same order and contiguity they have in the donator genotype. The ability of maintaining up to three contiguous parts from two parents distinguishes this crossover operator from the powerful and famous two-point cross- over operator, which can

> maintain only two contiguous parts, both from the same parent. Comparing the performance of the new procedure with that of other procedures indicates its effectiveness and competence (Zamani 2013).

Zhu, Li, and Shen (2011) have implemented a genetic algorithm for 'resource-constrained project scheduling with limited preemptions' (Zhu, Li, & Shen 2011). The objective was to minimise the duration of a targeted initiative, 'different from the traditional method to represent a feasible schedule, a resource-fragment chain was constructed to restore all the information, including starting times and resource distribution' (Zhu, Li, & Shen 2011). A 'resource allocation algorithm' was proposed to produce a valid schedule for a sample plan, and the schedule optimisation method was delivered to better the available variances further. A different fitness function was designed to calculate the quality of the obtained solutions.

> Combined with the resource allocation algorithm and the schedule enhancement method, a genetic algorithm was constructed for RCPSP with pre-emption allowed at most M times. Genes were abstracted from the complete resource-fragment chain of a schedule, and the chromosome was represented as a set of genes. During the genetic process of the proposed GA, an offspring generator was introduced to generate a feasible activity list from parent chromosomes. The algorithm has been tested on the well-known benchmark instances. For each instances, the computational results were compared to the one of the best current available algorithm for RCPSP. The experimental results showed that pre-emption can decrease the completion time of RCPSP greatly and the proposed algorithm is effective for the considered problem. (Zhu, Li, & Shen 2011)

Yannibelli and Amandi (2012) have looked at the project-scheduling problem and presented 'a multi-objective evolutionary algorithm that optimizes the effectiveness of human resources and the project makespan' (Yannibelli & Amandi 2012). They have proposed a 'multi-objective evolutionary algorithm'. In their opinion 'this algorithm designs feasible schedules for the project and evaluates the designed schedules in relation to each one of the defined optimization objectives' (Yannibelli & Amandi 2012). In particular, the evaluation is established to measure the project effectiveness parameters. For each prepared plan, the algorithm calculates the efficiency of human resources allocated to the scheduled tasks. Their method allowed a project manager to obtain several schedules with different levels of optimisation. At that stage, they can choose the solution(s) in line with their current preferences.

Elloumi and Fortemps (2010) proposed a solution to the 'multi-mode resource-constrained project scheduling problem (MRCPSP)' (Elloumi & Fortemps 2010). They present a new

method to implement the ‘multi-objective evolutionary algorithm (MOEA)’. Their study explores several techniques to improve on previously known approaches, including evaluation of the candidate solutions by the ‘ranked-based fitness assignment method’, ‘clustering algorithms’ to compute densities and the ‘forward-backward’ improvements, among others.

In their paper titled ‘An efficient hybrid algorithm for resource-constrained project scheduling’, Chen and others (2010) proposed an effective ‘hybrid algorithm‘, known as ‘ACOSS’, for solving ‘resource-constrained project scheduling problems (RCPSP)’ in real-time. That technique combined a ‘local search strategy’, ‘ant colony optimization (ACO)’, and a ‘scatter search (SS)’ in a repeatable procedure. The outcomes indicated that ‘with a limited number of generated schedules, ACOSS was capable of providing near-optimal solutions for a small scale RCPSP. It outperformed other heuristic algorithms for large scale problems‘ (Chen et al. 2010).

In another paper focused on a genetic algorithm for the ‘Resource-Constrained Project Scheduling Problem (RCPSP)’ (Montoya-Torres, Gutierrez-Franco & Pirachicán-Mayorga 2010) published in 2010, the authors proposed different modelling of the candidate solutions using a ‘multi-array object-oriented structure’. This approach would allow the team to capitalise on programming structure available in most computer programming languages for the development of decision management capabilities. The required experiments were performed to conclude the outcomes of this study. The relevant information was analysed. Outcomes demonstrated that the proposed approach was effective enough in the context of processing time and quality of the deliverables. It outperformed the previously studied implementations.

In 2011 Gonçalves, Resende and Mendes (2011) demonstrated how a ‘biased random-key genetic algorithm’ with ‘forward-backward’ improvement could help to resolve the ‘resource-constrained scheduling problem’. Within the proposed method solutions are created using a procedure that automatically generates valid schedules. The authors tested their approach extensively on a large set of data processed by many other algorithms. They concluded that their ‘algorithm compared well with the other algorithms and produced new best-known solutions for a number of benchmark test instances. Overall, the experiments confirmed the effectiveness of the proposed algorithm’ (Gonçalves, Resende & Mendes 2011).

In their work titled ‘Multi-mode resource-constrained discrete-time–cost-resource optimization in project scheduling using non-dominated sorting genetic algorithm’ Ghoddousi et al. (2013) employed ‘non-domination based genetic algorithm (NSGA-II)’ to reduce project time and cost. Significantly they addressed resource-levelling issues. We can see how, in this work, they

addressed three optimisation objectives – reduce cost, reduce time, achieve better resource levelling.

Artigues and others (2013) present a diversity of solutions to the 'resource-constrained project scheduling problem (RCPSP)'. They want to achieve a reduced project duration while maintaining the requirements related to activity dependencies and resource availabilities. The readers are brought on a journey of 'constraint programming' and 'integer linear programming' formulas, exact and heuristics methods, and computational trials. They also demonstrate industry case studies. 'Applications are presented in various domains such as assembly shop and rolling ingots production scheduling, project management in information technology companies and instruction scheduling for VLIW processor architectures' (Artigues, Demassey & Néron 2013).

In 2013 a team of authors including Afshar-Nadjafi, Rahimi, and Karimi published a book titled 'A genetic algorithm for mode identity and the resource-constrained project scheduling problem' (Afshar-Nadjafi., Rahimi, & Karimi 2013). The objective of their work was to minimise project duration when a set of activities has to be completed within that initiative. They applied a genetic algorithm, including a smart 'local search' to achieve that objective. Interestingly, the learning module gets the intelligence from the candidates created using standard genetic programming operations and feeds it back into the optimisation process. They employed the 'Taguchi experimental design' to set the required GA measurements and make the process more productive. The experimental results showed improvements in computation time performance. Also, it was observed that the GAs with local search, were better than the normal GAs.

Recently, Werner (2011) shared a survey on 'some genetic algorithms for shop scheduling problem'. In that scenario, some activities were performed using some machinery with a given optimisation goal in mind. According to the constraints on the 'technological routes of the jobs', they distinguished a 'flow shop' (each job is defined by the same technological route), a 'job shop' (each job has a specific route) and an 'open shop' (no technological route is imposed on the jobs). They have also considered some variations of 'shop scheduling problems' such as 'hybrid' or 'flexible shops' or the addition of 'processing constraints' such as 'controllable processing times', 'release times', 'setup times' or the 'no-wait condition'.

> We discuss some computational results and compare them with those obtained by other heuristics. In addition, we also summarize the generation of benchmark instances for makespan problems and give a brief introduction into the use of the program package 'LiSA - A Library of Scheduling Algorithms' developed at the Otto-

von-Guericke-University Magdeburg for solving shop scheduling problems, which also includes a genetic algorithm (Werner 2011).

The table below outlines the main characteristics (i.e. objectives, implementation language, approach to encoding/decoding, etc.). It also shows if a given implementation addresses more complex initiative management structures (i.e. project, program, and portfolio). Strengths and weaknesses of each approach are presented.

Table 3.1 GA Implementations

Reference	Argo (2019)	Jiang (2004)	Wall (1996)	Dean (2008)
Objective	Implement an education organisation's timetable of teaching activities.	Develop a genetic algorithm approach for large-scale multiple resource-constrained project-scheduling problems.	Defined genetic algorithm approach to resource-constrained scheduling using a direct, time-based representation.	Implementation of Staff Scheduling by a genetic algorithm with a Two-Dimensional Chromosome Structure.
Data structure implementation	Delphi Classes	C++ Classes	C++ Classes	Java Classes
Implementation Language	Delphi	C++	C++	Java
Encoding / Decoding Operations	Yes	Yes	Yes	Yes
Positive outcomes	A fully automated scheduling solution in the space where manual development of an academic timetable for a large organisation is simply not possible.	A fully automated scheduling solution for large-scale multiple resource-constrained projects using genetic algorithm.	A solution for resource-constrained scheduling using a direct, time-based representation.	A scheduling solution using genetic algorithm with Two-Dimensional Chromosome Structure.
Multiple Project Schedule Creation	No	No	No	No
Shortcomings	- Solution specific to one problem domain. - Double handling of data structure. - Invalid solutions generated when GA operations are performed. - Solution provided does not implement programme scheduling.	- Solution specific to one problem domain. - Double handling of data structure. - Invalid solutions generated when GA operations are performed. - Solution provided does not implement programme scheduling.	- Solution specific to one problem domain. - Double handling of data structure. - Invalid solutions generated when GA operations are performed. - Solution provided does not implement programme scheduling.	- Solution specific to one problem domain. - Double handling of data structure. - Invalid solutions generated when GA operations are performed. - Solution provided does not implement programme scheduling.

Other resources were analysed:

- Optimisation of Logistics by Yalaoui et al. (2013)
- Conference on Genetic Algorithms and their Applications by Grefenstette, J. J. (2014)
- Handbook of optimisation by Zelinka, Snasael, & Abraham (2012)

The literature review has confirmed that all the assessed solutions have a set of common weaknesses:

They tend to focus on some problems. It would be difficult to modify them to meet the needs of another industry sector or a given organisation.

The known implementation of GA need to perform a cross over and mutation operations on sample solutions to create new chromosomes and effectively search the problem space for alternatives. Before such operations are executed information that describes a given sample (i.e. a set of activities with allocated timeslots and resources) is encoded (converted to a binary format). The operation (cross over or mutation) is then performed on encoded data. When these operations are done, the encoded data is decoded back to the format describing the solution (i.e. classes, attributes, relationships, etc.). The only decoded information can be evaluated to see if the newly generated solutions are valid (they do not violate hard constraints). Needless to say, this is a limitation. It negatively impacts the qualitative and quantitative performance of the search process.

As they are implemented in C++ (Jiang 2004), Delphi (Argo 2019) or Java (Dean 2008), they require the implementation of data structures specific to these languages (data classes); this may result in doubling both development and execution efforts when the input data is already stored in well-defined native database structures.

The reviewed solutions do not implement programme scheduling (more than one project-scheduling problems).

From the business domain perspective, the analysed works only offer a very specific solution to one problem at a time. It would be beneficial to have a solution which, while still addressing given domain needs, could be easily modified to solve other industry sectors' issues.
From the technology perspective it can be seen that analysed solutions were implemented in computer languages that required double effort relative to both development and execution work. This occurs when data structures specific to those languages needed to be constructed

and used while performing optimisation operations. Another technical issue with the analysed literature was that they used encoding/ decoding heavily. This leads to several proposed solutions violating hard constraints and therefore being invalid.

3.4 Methodology and Proposed Solution

3.4.1 Implementation Design and Methodology

Classic business/technology initiatives delivery methods, typical to the Software Development Life Cycle (SDLC), will be adapted to the delivery of this research. These will be complemented with pure research and scientific techniques (Grefenstette 2014; Hartmann 1998; Haupt 2004; Holland 1992; Rutkowski et al. 2014).

Requirements phase

We will compile the domain model, learn about hard constraints (the ones that when violated make the solution invalid) and understand the nature of the soft constraints (the ones that when violated do not deem the solution invalid). Project plans will be compiled, and existing operational schedules will be sourced. Any relevant non-functional requirements (NFR) will also be agreed upon.

Implementation phase

In this phase, all the deliverables will be produced. Since every problem domain needs to have its model designed and developed, advanced mathematical models specific to a given business domain will be built. UML design tools and RDBMS systems will be used to analyse and implement the project/programme/portfolio management system model. The known implementations are employing computer languages like Java, Delphi, C++, C# to construct these models. Native RDBMS data implementation components – database tables – will be used to store data within this study project.

Search and optimisation algorithm—GA—will be designed, and hard and soft constraints will be identified. The main components to be designed include population initialisation operations; GA crossover; GA mutation; fitness function for each constraint; fitness-related function for each schedule; and elitism related procedures.

Custom configured scheduling and optimisation modules implementing the earlier defined algorithms will be developed. This will be coded using native MS SQL Server data structures and procedures. This should allow us to avoid using Java, Delphi, C++, C# computer

languages because the main schedule generation procedures will be written in SQL and T-SQL. The main components to be developed include population initialisation operations; GA – crossover; GA – mutation; fitness function for each constraint; fitness-related function for each schedule; and elitism related procedures.

This approach will allow us to introduce a new method of solving scheduling problems. The team have found that the earlier reviewed existing implementations require storing data in both core database and temporary structures implemented in Java (Dean 2008), Delphi (Argo 2019), C++ (Jiang 2004; Wall 1996), computer languages. It is also known that existing implementations are using a so-called encoding/decoding technique during the GA operations (i.e. crossover and mutation). Because of such management of the domain data, situations are often presented where generated problem solutions are not valid (they violate hard constraints). We anticipate that our solution will not use such an approach and therefore, will be more effective from both run time performance point of view and the development time perspective.

It is also known that such an approach should allow for our solution to be easily customisable for specific problem domains across different industry sectors.

Quality assurance

In this phase, the project team will assess the quality of findings and deliverables produced so far. It will check how the planning is performed, analyse how the integration works, confirm if constraints are implemented correctly, assess how the schedules are used, perform statistical analysis of schedule generations and, finally, ensure that the desired quality of the scheduling solutions has been achieved.

Figure 3.1 describes the delivery approach.

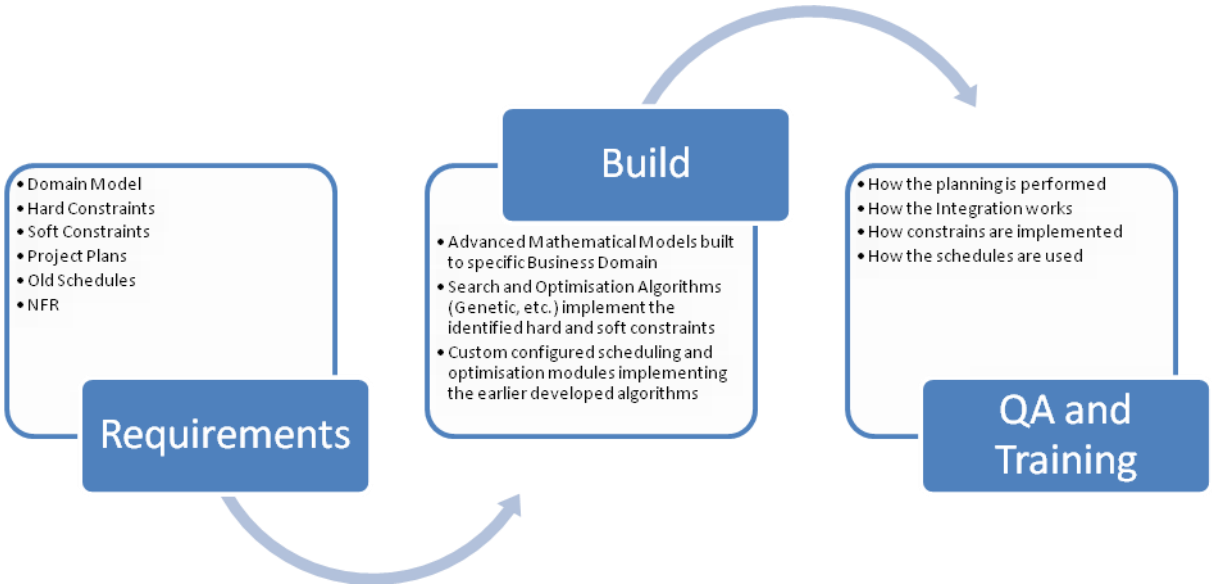

Figure 3.1 Delivery Approach

We anticipate that this approach would allow the objectives of this study to be achieved, as the advanced technology and delivery methods will be used to implement this solution.

This method will construct business models of the problem domain, identify hard and soft constraints, implement GA procedures, generate initial schedule samples, perform crossover and mutation and perform the fitness valuation and selection. This method will allow for specific scheduling problem to be addressed predictably.

This method will also combine theoretical knowledge, technological scheduling implementation and GA optimisations in a single framework which, when implemented, offers operational managers a new end-to-end solution to their scheduling problems.

3.4.2 Implementation

Planning and scheduling process

We can see how the end-to-end scheduling process is implemented in Figure 3.2 Argo AI - E2E Scheduling Process.

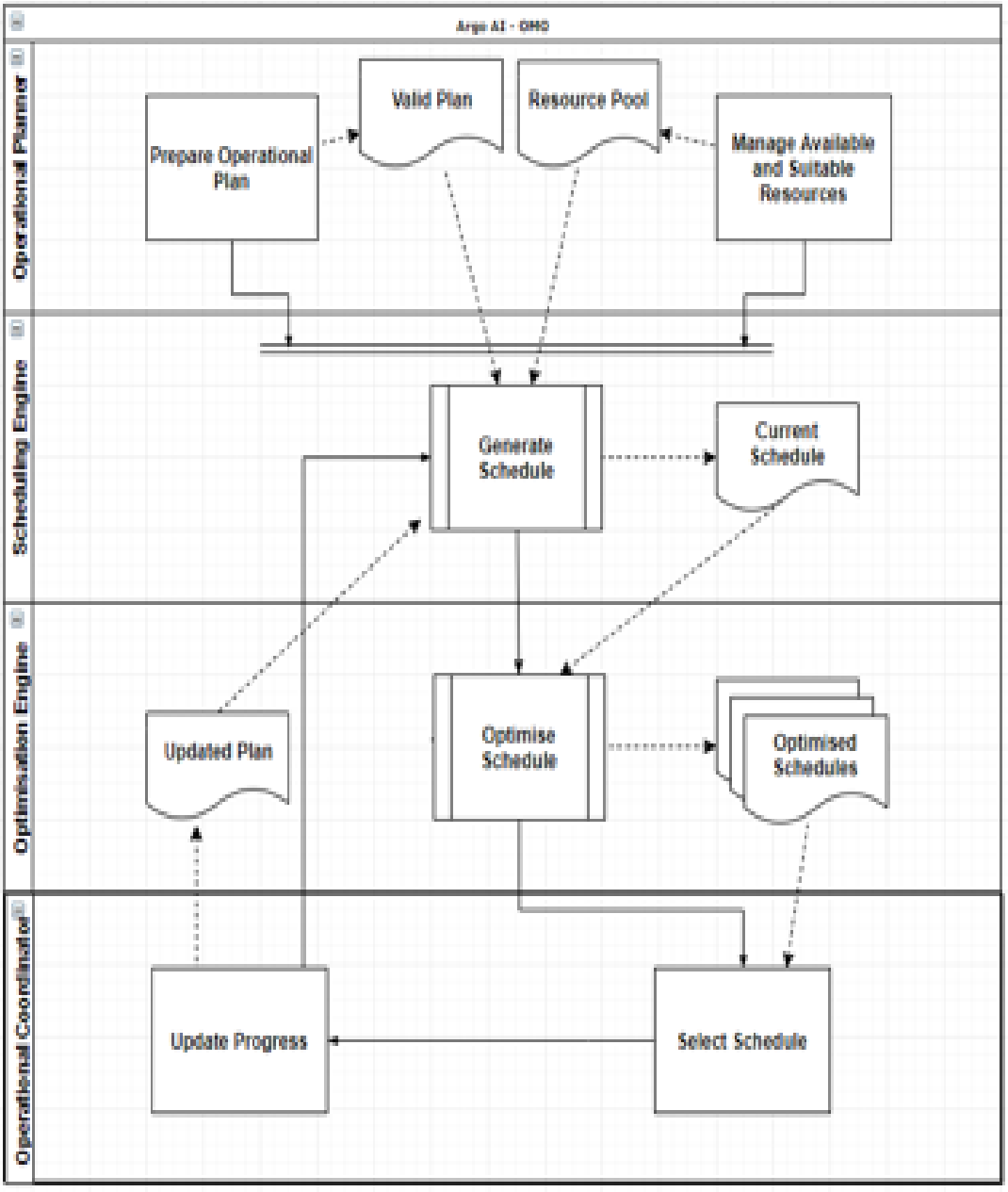

Figure 3.2 Argo AI - E2E Scheduling Process

When the scheduling component is complete, the optimisation engine can be looked at. As mentioned earlier, its objective will be to find solutions that offer a more optimal usage of project resources, or complete work in shorter timeframes, or yet again allow the users to do the same work but spend less money. This improved solutions will be called as the fitter ones concerning the soft constraints discussed earlier.

Genetic algorithm (GA) operations will be employed to search the solution space for a more suitable solution.

Figure 3.3 Argo AI - OMO - Optimisation Process below shows how the schedules get optimised. Initially created schedules undergo GA operations (crossover and mutation), the fitness of the candidate solutions is measured and after ranking best-fit candidates make it into the next optimisation cycle. The optimisation process continues until the objectives are achieved.

Optimisation process

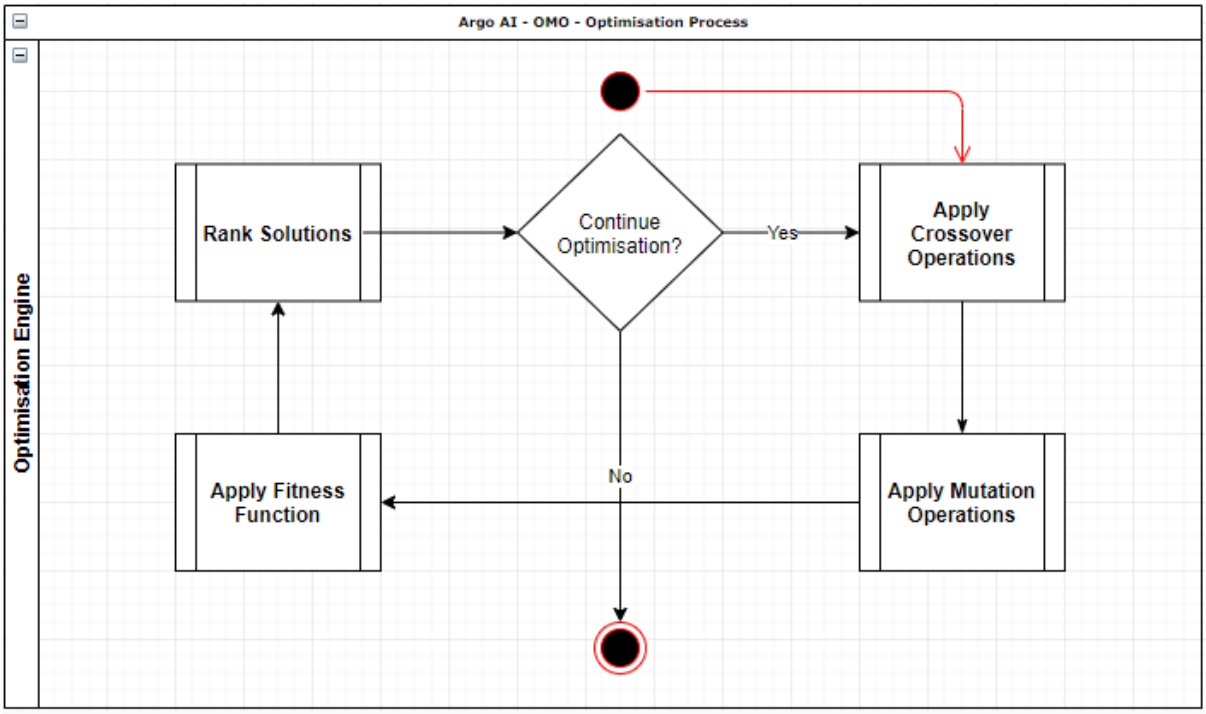

Figure 3.3 Argo AI - OMO - Optimisation Process

Genetic operations

Figure 3.4 Sample GA Operation – Crossover shows how the first GA operation is performed.

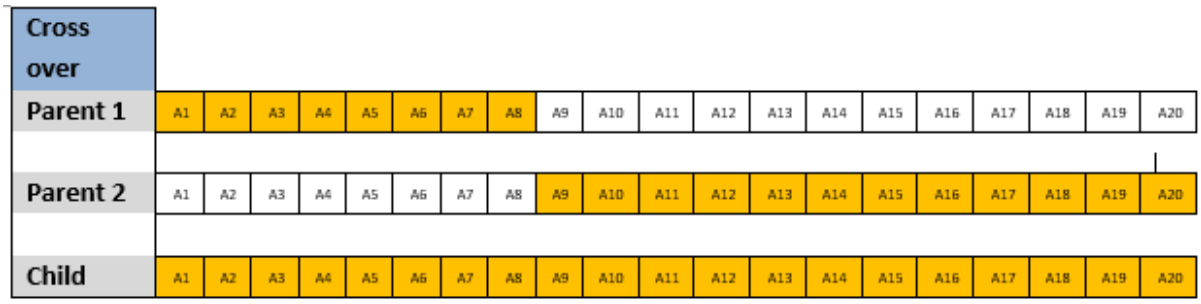

Figure 3.4 Sample GA Operation – Crossover

Figure 2.21 Sample GA Operation – Mutation shows how the second GA operation is performed.

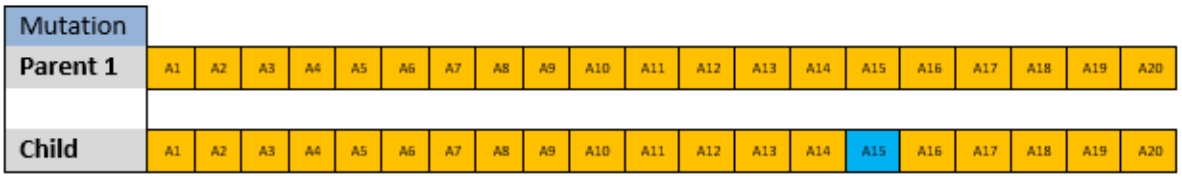

Figure 3.5 Sample GA Operation – Mutation

Fitness function

Fitness function (also known as objective function) is used in genetic algorithm operations to measure the strength of a given solution. It can be simple or complex when some simple functions are combined to take into account more than one quality of a sample. In this study's method, a complex measuring approach will be used to allow the fitness function to be a sum of scores calculated relative to soft constraints considered in the optimisation.

SF = PDF + PCF + ALF + RUF + RLF

Where:
SF – Solution Fitness
PDF – Project Duration Fitness
PCF – Project Cost Fitness
ALF – Activity Load Fitness
RLF – Resource Load Fitness
RUF – Resource Utilisation Fitness

PDF – Project Duration Fitness. Ideally the actual project duration would want to be the same as the planned total effort of all project activities. In reality, it will always be longer. The fitness value is calculated using the following formula:
PDF = 1000 * PE / AD

Where:
1000 – Perfect Score
PF - Planned Effort
AD - Actual Duration
PCF – Project Cost Fitness. Ideally, the actual project cost would want to be the same as minimal cost calculated for all planned activities when they are performed by the most cost-

effective resource. In reality, it is likely to be higher. The fitness value is calculated using the following formula:

PCF = 1000 * LC/AC

Where:
1000 – Perfect Score;
LC – Lowest Cost;
AC – Actual Cost;

ALF – Activity Load Fitness. Ideally, the activity load would want to be spread evenly across working days. In reality, the spread is uneven. The fitness value is calculated using the following formula:

ALF = 1000 * (AAL – SDAL) / AAL

Where
1000 – Perfect Score
AAL – Average Activity Load
SDAL – Standard Deviation of Activity Load

RLF – Resource Load Fitness. Ideally, the resources load would want to be spread evenly across different resources. In reality, the spread is uneven. The fitness value is calculated using the following formula:

RLF = 1000 * (ARL – SDRL) / ARL

Where
1000 – Perfect Score
ARL – Average Resource Load
SDRL – Standard Deviation of Resource Load

RUF – Resource Utilisation Fitness. Ideally, resource utilisation would want to be 100%. In reality, it would be less. The fitness value is calculated using the following formula:
RUF = 1000 * RATS / WTS
Where
1000 – Perfect Score;

RATS – Resource Allocated Timeslots;

WTS – Working Timeslots.

The above formulas demonstrate that the anticipated fitness function implements evaluation of each candidate solution across several soft constraints relevant to a given problem domain.

3.5 Mathematical Model

This section will outline the general mathematical model. It will provide a list of constants, variables, and calculations used within the operational optimisation method.
The operational optimisation process flow will be presented in the second part of this section.

Constants

PS	A perfect score is used in the fitness function
N	Number of evaluated solutions is used to build and evaluate candidate solutions
M	Number of optimisation cycles to complete for each optimisation initiative

Variables

OA	Operational Activity
n	Number of activities in the Operational Plan
OP	Operational Plan $OP = \{\mathrm{OA}_1, \mathrm{OA}_2 \ldots \mathrm{OA}_\mathrm{n}\}$
OR	Operational Resource
l	Number of resources in Resource Pool
RP	Resource Pool $RP = \{\mathrm{OR}_1, \mathrm{OR}_2 \ldots \mathrm{OR}_\mathrm{l}\}$
RS	Resource Skill
i	Number of skills in Skill Set
SS	Skill Set $SS = \{\mathrm{RS}_1, \mathrm{RS}_2 \ldots RSi\}$
HC	Hard Constraints. If these are violated, the schedule is not valid
SC	Soft Constraints. These are scheduling preferences.
ST	Scheduling Time Slot
k	Number of slots in Scheduling Calendar
SC	Scheduling Calendar SC= $\{ST_1, ST_2 \ldots ST_\mathrm{k}\}$
SA	Scheduled Activity
m	Number of activities in Operational Schedule
OS	Operational schedule $OS = \{\mathrm{SA}_1, \mathrm{SA}_2 \ldots \mathrm{SA}_\mathrm{m}\}$
SF	Solution Fitness
PE	Planned Effort
planduration	Duration of planned Operational Activities
AD	Actual Duration of a given solution candidate
actduration	Duration of scheduled Operational Activities
PDF	Project Duration Fitness
AC	Actual Cost of a given solution candidate
actcost	The actual cost of completing one scheduled activity
LC	Cost of completing the scheduled operational activities using the cheapest suitable resources
mincost	Minimum cost of completing one scheduled activity
PCF	Project Cost Fitness

ALF	Activity Load Fitness
AAL	Average Activity Load
SDAL	Standard Deviation of Activity Load
RLF	Resource Load Fitness
ARL	Average Resource Load
RUF	Resource Utilisation Fitness
SDRL	Standard Deviation of Resource Load
RATS	Resource Allocated Timeslots
WTS	Working Timeslots
j	Number of Operational Schedules in a given population $j = N$
POS	The population of Operational Schedules $POS = \{\mathrm{OS}_1, \mathrm{OS}_2 \ldots \mathrm{OS}_\mathrm{j}\}$
OC	Optimisation Cycle generates a population of solution candidates
i	Number of Optimisation Cycles in Optimisation Imitative $i = M$
OI	Optimisation Initiative $OI = \{\mathrm{OC}_1, \mathrm{OC}_2 \ldots \mathrm{OC}_i\}$

Calculations

SF	$SF = PDF + PCF + ALF + RUF + RLF;$
PDF	$PDF = PS * PE \,/\, E\mathrm{D};$

PE $\quad PE = \sum_{x=1}^{n} \mathrm{planduration}_\mathrm{x}$

AD $\quad ED = \sum_{x=1}^{n} \mathrm{actduration}_\mathrm{x}$

PCF	$PCF = PS * LC \,/\, AC;$

LC $\quad LC = \sum_{x=1}^{m} \mathrm{mincost}_\mathrm{x}$

AC $\quad AC = \sum_{x=1}^{m} \mathrm{actcost}_\mathrm{x}$

ALF $\quad ALF = PS * (AAL - SDAL) \,/\, AAL;$

RLF $\quad RLF = PS * (ARL - SDRL) \,/\, ARL;$

RUF $\quad RUF = PS * RATS \,/\, WTS;$

Process Flow

Manage Operational Plan (OP)
Manage Resource Pool (RP) and Operational Resources (OR)
- Manage resources' costs
- Manage resources' skill sets - suitability
- Manage resources' availability

Manage Scheduling Calendar (SC)

Manage Hard Constraints (HC)
Manage Soft Constraints (SC)

Run Optimisation Cycle (OC)
- Imitate Solution Population (POS)
  - Generate Operational Schedules (OS)
  - Optimise Operational Schedules (OS)
    - Perform Genetic Algorithms Crossover (OS)
    - Perform Genetic Algorithms Mutation (OS)
    - Measure Actual Duration (AD)

Measure Actual Cost (AC)
Measure Solution Fitness (SF)
Select schedules for the next optimisation iteration (OS)
Complete optimisation process when the goal is achieved (POS)

Select Operational Schedules for execution (OS)
Complete Optimisation Cycle (OC)

3.6 Case Studies

3.6.1 IT Projects and Program Delivery

A case study was undertaken to see how the optimisation can be applied to IT projects scheduling. The team implemented an end-to-end planning and scheduling solution. It included an automatic scheduling module and also the optimisation module. The latter took advantage of the proposed GA technique. The outcomes have confirmed that the new method can be applied in that given domain successfully.

3.6.2. Telecommunications Networks Resource Allocation

A case study was undertaken to see how the optimisation can be applied to telecommunications network resource allocation domain. The team implemented an end-to-end planning and scheduling solution. It included an automatic scheduling module and also the optimisation module. The latter took advantage of the proposed GA technique. The outcomes have confirmed that the new method can be applied in that given domain successfully.

3.6.3. Building and Construction

A case study was undertaken to see how the optimisation can be applied to building and construction projects scheduling. The team implemented an end-to-end planning and scheduling solution. It included an automatic scheduling module and also the optimisation module. The latter took advantage of the proposed GA technique. The outcomes have confirmed that the new method can be applied in that given domain successfully.

3.7 Findings and Related Work

3.6.1 Data Analysis

The proposed method implementation and its testing in the team's case studies have shown positive outcomes. We were able to significantly automate the main phases of operational management (i.e. planning, scheduling, optimisation). Cross-Industry case studies prove that the method can be adopted by multiple types of organisations.

Table 3.2 Data Analysis

#	Industry Sector	Problem Domain	Most Significant Outcome
1	Telecommunications	It environment management	Implemented automated allocation to testing needs
2	Professional Services	Delivery of the tax and compliance function	Write-offs for a given financial year reduced by 9.60%
3	IT Consulting	Implement web application	Project cost can be optimised by 11.87%
4	Building and Construction	Running a building project	Delivery time can be optimised by 7.60%
5	Telecommunications	Network resource allocation optimisation	CPU utilisations can be optimised by 12.96%

3.6.2 Summary of Findings and Benefits

Domain complexity

This method can be used to solve scheduling optimisation problems in complex, large resource-intensive and heavily constrained project/program/portfolio management domains. More streamlined and optimal schedules will be generated and optimised to achieve a nearly 'perfect' solution.

Practicality

This method provides an optimisation approach to real-world scheduling problems.

Multi-industry sector

This method can be implemented in different industry sectors:

- IT solution delivery
- Building and construction
- Telecommunications

Financial benefit

For any operation not currently using advanced artificial optimisation of its scheduling, the optimisation method will bring at least 5% costs reduction in the first year of implementation.

Encoding/decoding during genetic operations.

This method does not employ encoding/decoding when performing optimisation operations and therefore improves performance and illuminates creation of invalid solutions altogether.

SQL language.

This method is using SQL as the primary implementation of computer language.

RDBMS tables

This method is using the native DB storage structures (database tables) for its data manipulation operations.

3.7.3 Related Work

Other industry sectors

The conducted case studies have shown how this method can be applied to some industry sectors and optimisation problems. We have presented many case studies showing how the technique can be used in IT projects and program delivery, telecommunications and building and construction projects.

Further research in this space can check how other domains can also benefit from similar implementations in various industry sectors. The probability of this method is applicable and success in other areas is very high, and the author strongly recommends exploratory efforts in that direction.

The following industry sectors' operational management dilemma could be tackled by complete or partial application of the developed method.

- Electricity supply. The utilisation of infrastructure and equipment.
- Professional services (i.e. HR, legal).
- Manufacturing. Can more optimal resource allocation in the manufacturing processes be achieved?
- Transport and logistics. Can storage capacity and workloads of all parties participating in loads delivery processes be optimised?

While this study has laid out a solid foundation and solved several problems, each of the above-specified scheduling domain dimensions opens numerous opportunities for further research.

Other technical dimensions

As in the core of this study's method, the author manages the equilibrium between hard constraints and soft constraints relevant to a particular problem domain. In the currently implemented way, tasks and resources assigned to their completion are handled. Because of how the method is envisaged to be relatively generic and easily adaptable to enhancements, it is possible to add other definitions to the problem model and have a way of addressing those. One of the more significant such new dimensions is the geographical positioning of operational activities and their participants. When one runs a truck company, they are very aware of complications arising from goods and services being scatted across towns, cities, states and countries that their transportation services cover. The method of this study would be extended to have this dimension included when plans and schedules are compiled. With that in mind, the new research question would be:

- Can Argo AI – OMO optimisation module be adjusted and utilised in geographic aware operational management?

Chapter 4 - Projectise and Productise Accounting Practice with Operational Management Optimisation

4.1 Introduction

Accounting practices in general and their compliance groups, in particular, are facing a number of challenges in the current marketplace.

While these challenges are numerous, the focus of this case study is on some operational characteristics common across the industry sector:

- Job handling times can span across weeks and months
- Write-off levels are high
- The delivery process is long and complex
- Entry-level accounting work is being sent off-shore to countries with lower labour costs. This has subjected accounting practices to increased price competition as practices using off-shore labour are able to aggressively price their offerings to attract new clients.

This study was conducted to show how strategic objectives of a given accounting firm can be achieved when modern methods of service delivery are applied. The study and proposed method will be considered a success if, when completed, some tangible positive outcomes can be observed.

This research implements improvements to the existing process and organisational strategy in a given accounting firm. It shows how these improvements allow capitalising on the organisation's strengths and opportunities while addressing weaknesses and mitigating risks.

This case study involves an Australian accounting firm, Matthews Steer Accountants and Advisors (MS), as the subject of the study. The objective of this firm is to provide professional services to their clients and help them be compliant with Australian taxation regulations. They do this by collecting financial information related to each entity's business transactions in a reporting year and compiling a set of financial reports that are later used by both external (i.e. Australian Tax Office, auditors, banks) and internal (i.e. staff, senior management.) stakeholders.

We have decided to implement the required change using some of the components from the newly developed operational planning and scheduling method - Operational Scheduling with

Business Modelling and Genetic Algorithms (also known as Argo AI – OMO). These components were complemented by some innovative techniques applicable to this problem domain.

The following innovations were proposed and implemented within this case study:

- Projectise compliance operation
- Productise compliance operation
- Implement a client reward programme to provide an incentive to those Matthews Steer clients choosing to accept the new approach

Projectisation is an approach where the entire job pipeline is structured in a project-like way, and each client job becomes a project with its own timeframes, scope, and allocated resources. These well-defined initiatives are completed following all the known project management principles by actively managing related plans, risks and issues.

Productisation is an approach where a professional services firm packages its offerings and presents a complete solution for the client without exposing the clients' decision-makers to complexity and challenges of how each delivery component is costed and managed.

This case study chapter is structured as follows:

Section 2 provides background information on the accounting sector in Australia. Section 3 states applicable problems and provides a literature review. Section 4 presents the proposed solution. Implementation of the solution is discussed in Section 5. Section 6 summarises the case study outcomes and discussed possible future work.

4.2 Background and Key Concepts

Existing literature defines accounting as ‘recording, classifying and summarising a financial report’. This makes accounting procedures a process of collecting, recording, analysing and summarising relevant data into financial statements.

According to Chaplin (2013), ‘it is difficult to determine precisely the number of accounting firms currently operating in Australia’. The three professional accounting organisations in ‘Australia include CPA Australia (CPAA)’, the ‘Institute of Chartered Accountants in Australia (ICAA)’ and the ‘Institute of Public Accountants (IPA)’.

A typical Australian accounting practice would provide services around tax and compliance, business advice, financial planning and auditing. The 'largest income-producing service for accounting firms was business taxation which accounted for approximately 36.7 per cent of the total accounting practice income' (Chaplin 2013). 'Personal accounting and taxation represented 18 per cent of the income, and auditing and assurance represented 16.5 per cent' (Chaplin 2013). The rest of the revenue comes from other services acknowledged by the Australian Bureau of Statistics (ABS) and contains consulting (12.1%); liquidation related services (6.2%); wealth management (2.8%); and everything else (7.7%).

Accounting in Australia is heavily regulated and extensively described in academic texts and regulatory literature (Lehmann & Coleman 1991; Baker, Cliff & Deaner 2016; Dagwell et al. 2012; Dowling & Leech 2014).

Hasseldine and others (2007) claims that 'Tax systems such as those found in Canada, the United States and the United Kingdom mostly rely on the concept of voluntary compliance by taxpayers' (Hasseldine, Hite & Toumi 2007). Data collected in the UK shows that 'taxpayers frequently engage the services of paid preparers, who play a key role in the tax environment with responsibilities for both their clients and the state' (Hasseldine, Hite & Toumi 2007).

According to Pragoddee and others. (2015), the strategic accounting practice processes include accounting function excellence, accounting information quality, accounting practice effectiveness, financial report quality, information value and accounting success' (Pragoddee,, Boonlua & Muenthaisong 2015). They think that the only way organisations can perform well in the complex and ever-changing conditions of today's business environment, is to keep delivering quality outcomes in a timely fashion to the highest quality possible. With this in mind, most firms aim to get a technological advantage to achieve efficiency in decision making and other business processes.

Methods and techniques supporting efficient accounting processes go back to the times of double-entry bookkeeping and the system of bound records in 1494 (Charles & Carel 2000). Economic growth and the need to increase the productivity of accounting work resulted in the introduction of the loose-leaf accounting systems in 1885. As a critical component of day-to-day business operations, accounting processes have always been subjected to the latest advances in technology and science. Today they are supported by cloud-enabled, near real-time computer systems that allow the accounting firms to streamline and automate business processes significantly.

In an attempt to save on human labour costs accounting firms, following the lead of other industry sectors, started looking at overseas outsourcing. The evolution of digital technology and information distribution using the Internet has led organisations to seek cost savings by outsourcing services to cheaper geographically remote labour markets. These services were previously performed within the organisation (Chaplin 2013). Firms are outsourcing relatively simple and labour-intensive tax and compliance work and focusing on other offerings like financial auditing and business consulting.

Varajão (2018) says: ‘Project Management (PM) as a discipline has gained remarkable recognition in the last decades. This is clearly reflected by the high number and size of projects that are being carried out in organisations in various industries and areas of business’ (Varajão 2018). Ever since project management evolved as a business-related discipline, many procedures and technologies have been developed to cover all phases of projects and increase efficiencies of those teams who manage and perform operational activities, all with the aim of increasing the success rate of the projects.

A number of guides and standards like PMBOK (PMI 2008), PRINCE2 (Commerce 2009), and others were introduced to allow for some consistency in measuring how efficiently projects are delivered.

One of the research questions considered in this study is: ‘Can the rigour and maturity of the project management discipline help to streamline processes in accounting organisations?’ This thesis will confirm that the answer to that question is ’Yes’.

In 2015 a new method to optimise operational scheduling was developed. It is called Operational Scheduling with Business Modelling and Genetic Algorithms and forms the basis of the Argo Operational Management Optimisation (OMO) approach. That method is based on two main concepts. Firstly, business modelling (implying that any operational domain needs to be modelled first to make sure the problem and the solution are described correctly); and secondly, genetic algorithms, which provide a scientific basis to the optimisation steps of that process. This method comprises of a number of various components which cover many areas of the operational management, including planning, scheduling, execution, et cetera. It is considered that it would be feasible to utilise some of the components from this method to improve efficiencies in an Australian accounting practice.

4.3 Problem Statement and Known Solutions

4.3.1 Problems

While accounting practices in Australia face a number of challenges, it was agreed that the following two issues would need to be addressed by this research:

- Average job handling time at around eight weeks is too long.
- Write-off level in the tax and compliance group, at 7%, is too high.

4.3.2 Known Solutions

‘Companies have long sought ways to streamline processes so that accountants can spend less time collecting numbers and more time analysing them for the organisation's benefit’ (Farr 2018).

The most recent trend in the industry is to employ off-shore labour and by doing so, significantly reduce the costs of completing clients’ jobs. This approach typically requires the more senior and customer-facing roles to remain in Australia, while allowing for more junior positions to be outsourced to a cheaper overseas workforce. The immediate savings on labour costs are easily achieved. Yet there are quite a few negative impacts that come with this method of cost reduction. Cultural, geographical and skill level disconnect often results in work taking a long time and the quality of the deliverables being sub-optimal. This means that if Matthews Steer were to follow this path, they would need to modify their processes to allow for additional training, quality control and re-work. Another significant drawback associated with the off-shoring would be the breakdown in the organic professional development of staff from the junior level to more experienced senior levels and consequently to executive staff members. Additionally, MS management felt responsible for giving young Australian talent an opportunity to start their careers, professionally develop and become well-recognised members of the accounting profession locally. Although, as described in (Chaplin 2013), ‘not all tax practitioners are adhering to codes of conduct in relation to client confidentiality’—MS takes privacy and confidentiality issues very seriously. Management of such privacy and confidentiality concerns becomes much more complex when organisational resources span across on-shore and off-shore. This method of sending accounting jobs overseas was not suitable for MS.

In academic literature, approaches to tackle issues related to this study are described extensively.

These are the questions the author would like to find the answers to in the literature review:

- How can accounting practices be managed more effectively?
- How can their write-offs be reduced?
- How can the average job handling times be reduced?

Some of the main principles of corporate accounting in Australia are defined in detail by academic texts (e.g. Dagwell et al. 2012). While this literature provides a good understanding of these principles in general, it does not help to understand how the stated issues could be addressed.

A few accounting practices in Australia follow processes as described by Bragg (2004), Gregoriou and Finch (2012), and Stenzel (2007) are also covering some of these concepts. While these principles help to deliver outcomes regulated by the law, they do not propose a clear direction on how we could address issues related to this case study.

Project management literature describes agile (Journal 2013), PMBOK (PMI 2008), and PRINCE2 (Commerce 2009), as wildly adopted in IT and other industry sectors traditionally aligned with project-oriented delivery. However, it does not define a method of applying these project management principles to an accounting practice.

It appears that the nature of changes to how MS should work is somewhat related to the business process improvement exercise. Indeed, if the activities related to the preparation of tax returns could be streamlined, the expectation could be to achieve some desired benefits. Following this logic, the existing process could be reverse engineered using some kind of business process definition notation and see if areas for improvements could be identified. The compilation of new 'To Be' process flows could then proceed, which would be used later to implement the improvements. In line with this, the 'Flowcharting business processes: a new approach' (Reding et al. 1998) shows how the flowcharting technique 'provides a means of comprehensively documenting and evaluating the wide spectrum of business process controls utilized by world-class organizations'. The authors argue that good quality flowcharts are a powerful instrument helping management to evaluate correctness and robustness of business processes in a given organisation.

Similarly, in (Farr 2018), we see how the accounting process can be streamlined so that staff spends less time collecting numbers and more time analysing them. Still, the authors claim that 'a recent survey by software provider FloQast reported that 88% of accounting and finance

professionals were negatively impacted by the pressure' (Farr 2018) to close client jobs at the end of a reporting period. In their opinion, efficiencies could be gained from the following techniques:

- developing and documenting a set of standard procedures
- automating as much as possible
- communicating the importance of speedy close
- spreading the work
- considering materiality for estimates
- cross-training for critical steps.

The other option to deal with complexities of the accounting process, particularly related to private companies, would be to reduce the number of statements prepared at the end of the year (Cary et al. 2015). The authors propose that accounting standards should be simplified and the flowchart methods broadly utilised. Once again, this paper's researchers do not see a clear opportunity for applying the described method to solve the issues in question.

In their article about project management (PM) improvements Varajão (2008) explores an opportunity to apply business process definition and flowcharting to the project management discipline. Their hypothesis is that by applying business modelling to project management, the success factor of project activities, executed by organisations, could be increased. Their research proposes improvements in PM practices by presenting a systematic process model for success management.

A medium-sized accounting firm with 140 employees (Thompson 2015) was looking to create efficiency and meet the needs and expectations of their executives. The organisation employed 'COBIT (Control Objectives for Information and Related Technologies) - framework created by international professional association ISACA for information technology (IT) management and IT governance' (Thompson 2015) to achieve the desired objectives of their improvement initiative. This approach required a seven steps implementation effort. One of the challenges experienced during the described implementation was the fact that the method was more suitable to a larger organisation. The sampled accounting firm could not quite easily map their available resources to the roles and responsibilities prescribed by the framework. This was due to the comparatively small size and nature of the services provided to its clients.

Barrar, Wood and Jones (2002) perform an analysis of the outsourcing model, employed to achieve efficiencies in the delivery of accounting services. In line with broader industry views

they highlight that when applying the off-shore resourcing model, the organisation will exchange fixed price of internal labour for gaining flexibility and cost-effectiveness of a variable pool of resources. This research provides a detailed qualitative and quantities analysis of the proposed model across various sizes of accounting organisations. This was accomplished by using a procedure called data envelopment analysis (DEA). It allowed comparing internal and external (outsource) efficiency in the delivery of finance function. While this model does present a number of attractive qualities, the author knew from the beginning that their study participants did not want to follow that path.

A mid-sized regional accounting firm was using COBIT® framework to establish and manage controls and techniques to implement significant improvements to their operation (Thompson 2015). As a result, the firm has put into place more definable processes, better aligned with the business goals.

Rodríguez (2007) describes how Aquino de Córdova is using technology to streamline booking operations. The emphasis here is put on heavy IT-driven solutions, which automates processes well. The staff are constantly trained to use computer applications effectively to contribute to the overall organisation's success.

In their article (1994), the American Institute of Certified Public Accountants (AICPA) discuss integrated practice systems (IPS) designed to help member accountants serve their clients and maintain high-quality practices. Processes, documentation, technological solutions and training are put together to create this highly supportive ecosystem allowing accounting professionals to do their job better.

In related research (Rahman et al. 2015), authors are assessing how improvements in accounting management processes are positively impacting Malaysia's Corruption Perception Index (CPI). They describe how these changes are achieved by the introduction of a number of rewarding mechanisms and required key performance indicators (KPIs) to establish a governing framework, which (when implemented) brings the desired outcomes.

Increasingly organisations look closely at cultural aspects of people management improving staff morale and level of satisfaction with their jobs. The accounting sector is also experiencing this phenomenon. In their research Parker (2008) noted that ‘managers are increasingly being called upon to develop their employees’ expertise and creativity, communicating with them rather than dictating to them, being more emotionally aware of their needs’ (Parker 2008).

As can be seen, the analysed literature does not offer a clear and suitable path for MS to take and get their problems addressed, while retaining strong qualities of their operation. This means that we would need to propose and implement another method to achieve the desired project outcomes.

4.4 Methodology - Proposed Solution

A new approach to operational planning and scheduling was developed by the lead author and has recently been patented. The method, 'Operational Scheduling with Business Modelling and Genetic Algorithms' (Petukhov 2016), presents an improved approach to planning, scheduling and optimisation.

The recently patented approach adopts a three-phase process to operational management. Planning is the first component, and it prescribes what needs to be done, in what order and with what resources. Its main objective is to deliver valid operational plans. The second part is scheduling. It takes the earlier prepared plans and, using data about suitable and available resources, generates schedules. Lastly, this method makes use of very advanced search and optimisations techniques, usually applied in relatively mature environments, from a project management discipline point of view. As a whole, the method allows operational managers to have valid, current and optimised operational plans and schedules. The research team realised that some of the components described in the larger method could still be applied to industries and problem domains that do not normally use project management principles in their full capacity. The team have chosen to select only planning and scheduling parts of the larger earlier mentioned method in this case study. Together with some additional techniques, we will investigate if a given professional services organisation could achieve their ambitious plans to greatly improve process efficiencies by applying some of the techniques from this lager operational management method.

Accounting practices manage their compliance jobs in a continuous pipeline fashion, where every set of taxation reports is produced on a times and materials (T&M) basis and clients pay for the actual time that staff have spent on a given job. Sometimes a firm chooses to not charge clients for the full effort allocated to their work. This is how the 'write-offs' appear. Simply speaking, they are operational losses.

As can be seen in Table 4.5 Summary of the outcomes, the 'As Is' analysis conducted in the MS practice for the 2014 financial year had identified losses of 7.66% relative to the revenue. Additionally, analysis of job handling time identified significant delays in job completion. If

allowed to persist, these losses and delays would negatively impact financial performance and staff morale.

A method combining projectisation and productisation was proposed to tackle these two problems,

Projectisation entails bringing the main principles of project management into the way teams work. In this case, every client job would become a project with an appointed staff member assuming the role of a project manager. The project manager needs to ensure that a given job is completed on time and within the allocated budget, while actively managing risks and issues related to the job. The implementation of projectisation is discussed further in section 0.

All accountants responsible for the clients' jobs and acting as project managers agree to deliver financial reports within the prices and timeframes, outlined in the model. Exceptions are managed using a change management process. Information justifying a required change is presented, and outcomes are communicated to all parties, including the client.

Those organisations offering their services on the T&M basis do not quite know how much a fully delivered offering is going to cost them, and for that reason, they cannot provide a firm price to their customers when work starts.

This also applies vice versa when the seller is offering a well-defined and clearly priced packaged product; the customers have confidence that they will not have to spend more than what is listed in the product catalogue.

A sample product catalogue is shown in Table 4.1 Product Catalogue Sample, which was used as a case showing how a list of offerings could be made available to the consumer audience. In that table, sourced from one of the car distributors' web sites, we can see how a well-defined product is packaged, costed and priced to let customers know how much they will pay for a given offering.

Such an approach gives certainty to the clients and gives a competitive advantage to the products and service providers.

Table 4.1 Product Catalogue Sample

Catalogue #	Model	Price (from)
1	IMPREZA	$23,490
2	LIBERTY	$33,804
3	BRZ	$37,150
4	WRX	$42,993
5	WRX STI	$55,147
6	XV	$31,484
7	FORESTER	$32,974
8	OUTBACK	$39,996

Accounting services typically are provided by MS on a T&M basis where consulting services' hourly rates are published and the number of hours spent on a given job is applied to that rate; the final bill for the total amount chargeable is then sent to a client. This approach has a number of weaknesses. Firstly, clients do not have certainty of how much they will need to pay for these accounting services, as they only receive an estimate of how much effort MS will need to put in to get their returns prepared.

Secondly, publishing hourly rates applicable to various staff depending on their seniority and skill level can be disadvantageous. This is especially true in the current commercial environment where a number of accounting firms outsource work overseas and can publish much lower costs of their labour.

To productise is to package the offering into suitable well-defined bundles, which could be offered to the clients and create certainty about what MS is offering and for how much. To achieve that a product catalogue and a pricing model were developed.

Product catalogues and pricing models would allow the firm to walk away from the T&M approach and to create that certainty that all clients want. Productisation also helps to reduce write-offs. These would decrease significantly or could even be converted into profit items when the effort planned is higher than the actual effort allocated to a given job.

4.5 The Experiment - Case Study

It was agreed to analyse how the problems experienced by the study participants are addressed by known and tested methods in order to progress with the research project. If the study could identify those methods, which help to manage accounting practices effectively, while helping to reduce the write-offs and average job handling times, such approaches could be implemented within the research project and help MS to get where they want to be relative to their strategic objectives.

According to their web site, Matthews Steer are North West Melbourne's premier business consultants, currently employing more than 50 staff.. They provide accounting services to help their clients to be compliant with the Australian taxation laws

While they have a strong reputation for being a high quality and low-risk accounting practice, they face some challenges and risks which (if not addressed) might negatively impact this organisation in the near future.

The main challenges the organisation experienced included:

- Average job handling time was too long and in some instances, reached eight weeks.
- Level of write-off was very high.

This research had to propose improvements to the existing process and organisational strategy, which, when implemented, would allow for capitalising on the organisation's strengths and opportunities while addressing weaknesses and mitigating risks.

It was expected that if the organisation could address the identified problems and achieve its strategic objectives utilising only a local resource pool, then no off-shore outsourcing would be required to reduce operational costs, and MS would be able to maintain their established role in the Australian accounting and business advisory sector.

While implementing parts of the Operational Scheduling method, a set of clear objectives was established: to achieve a reduction of write-offs and a reduction in the average job handling time. Analysis of both the 'As Is' state and the 'To Be' state was conducted, and a mechanism of getting the desired changes implemented was agreed upon. Outcomes of the 'As Is' analysis can be seen in Table 4.5 Summary of the outcomes (column related to the 2014 financial year).

This research has resulted in practical changes to the way Matthews Steers' Compliance Unit works. We have witnessed substantial improvements to the firm's bottom line. Based on analysis and comparison of two years of data, we can conclude that as the result of the implemented improvements, write-offs for those jobs included into this experiment decreased by 9.4% of the relevant revenue amount. This number shows the difference between the 2014 and 2016 financial years. The average job handling time was reduced significantly.

4.5.1 Implementation Approach

The following implementation approach was proposed and approved.

- Create a detailed implementation schedule.
- Conduct research of the 'As Is' state and analyse it.
- Agree on the 'To Be' state.
- Agree on how to get there.
- Execute the change plan.
- Collect all the data describing the 'As Is' and the 'To Be' states.

Once problems to be tackled were confirmed, and the way forward was agreed upon, it was time to start implementing the improvements.

4.5.2 Execute the change plan

The teams needed to produce templates serving as job completion plans that were used for the delivery of clients' statements of accounts to implement the recommended changes. They also needed to adopt a number of planning and scheduling techniques as well as agree on roles and responsibilities within the Compliance group. According to this change plan, the main deliverables included clients' jobs completion plans, relevant roles and labour rates and time estimates related to various delivery tasks. The team also agreed to develop a product catalogue, showing a list of offerings and pricing as well as applicable terms and conditions.

Major milestones achieved

- August 2014 – Transformation commenced
- June 2015 – Pricing models were developed, and a sample of participants was defined
- February 2016 – First outcomes were measured
- June 2016 – Full financial year outcomes were measured

4.5.3 Projectisation

The Projectised MS Tax and Compliance Operation started to manage each client job as a separate project. Senior accountants, acting as the project manager, started to manage scope, time and resources in relation to each tax report. They addressed relevant risks and issues effectively and delivered outcomes of the highest quality possible.

The number of reviews, normally conducted as part of the delivery process, were reduced and the number of team members actively involved with a given client job was also decreased. Given that the more expensive senior staff were involved with such reviews before, this change alone helped to reduce delivery costs significantly.

The newly appointed project managers were driving every initiative and were responsible for successful completion (on time, within budget, to required quality). The same managers would escalate issues promptly and include all the parties that could help resolve the issues, into the relevant communications.

Records were kept to monitor each initiative scheduled and actual execution times and efforts.

Senior MS staff started to manage their operation by exception. They would help to solve issues when required.

The number of concurrently handled jobs was reduced because in-flight jobs were completed with fewer delays related to jobs being paused and resumed at a later stage when the required resources and inputs were not available.

It was also noticed that a more effective task-level management was applied (not just job level management). Finally, jobs closure would include feedback and analysis of lessons learned.

4.5.4 Productisation

It was agreed that MS would productise their offering. They took steps to develop a well-defined product catalogue, which included costs and pricing information.

The newly developed MS service catalogue had three facets:

- Sales Stream
- Delivery Stream
- Project Management Stream

Table 4.2 Product Catalogue Facets - Sales shows how when a price list is published to current and prospective clients, they can clearly see what they are getting and for how much. This helps with client certainty and keeps the internals of MS operations not exposed to the wide audience.

Table 4.2 Product Catalogue Facets - Sales

Sales Stream	• This is what the sales teams and customers see • A well-defined set of products and pricing is published • A place for optional price movement is reserved • Packaging and pricing have to be attractive and competitive • In the sample catalogue (see Table 4.1) we can see a list of vehicles and prices available to customers

Table 4.3 Product Catalogue Facets – Delivery shows how the delivery team applies their skills and knowledge when compiling the service catalogue, which allows MS to be profitable while offering services at competitive pricing.

Table 4.3 Product Catalogue Facets – Delivery

Delivery Stream	• Delivery Management analyses previous experience in product/service delivery and recommends packaging and pricing • This is where effort/cost/margin is planned for a given type of product/service • Delivery Management provides a complete analysis of the proposed packaging/pricing model for the stakeholders to review/approve • Delivery Management will be responsible for keeping the entire model up to date • Sample catalogue (see Table 4.1) was compiled by Subaru delivery management based on their previous delivery experience and should allow for the successful operation of this car manufacturer

Table 4.4 Product Catalogue Facets - Project Management shows how project managers responsible for doing the work for MS clients use the catalogue and the pricing model to complete jobs on time and within budgets.

Table 4.4 Product Catalogue Facets - Project Management

Project Management Stream (aka Governance)	• Project management stream will apply the approved model to day-to-day project planning and execution • Project management stream will be responsible for delivering customer projects on time and within the agreed budget • They will ensure that planned efforts/costs/margins kept in the execution phase • Project management stream will manage deviations from the 'standard' customer needs • Project management stream will constantly provide their feedback to the delivery management • Relative to the sample catalogue (see Table 4.1) car maker's project manager will need to deliver new cars within planned costs and margins.

The pricing model was compiled and approved for various service types. MS delivery teams and participating clients have been briefed about this new billing method.

Strict financial management control was adopted to ensure staff do not allocate time in excess of the planned effort. Communication with client representatives was also improved to ensure that input required for jobs (commencing and in progress) is provided in a timely manner and in full to avoid multiple information requests and response cycles.

Failures in the internal process would not result in the client paying more for the service; instead, such inefficiencies would be managed and financially covered internally by MS.

Once the transformation work commenced, the continuous improvement cycle was established, as shown in
Figure 4.1 Continuous Improvement.

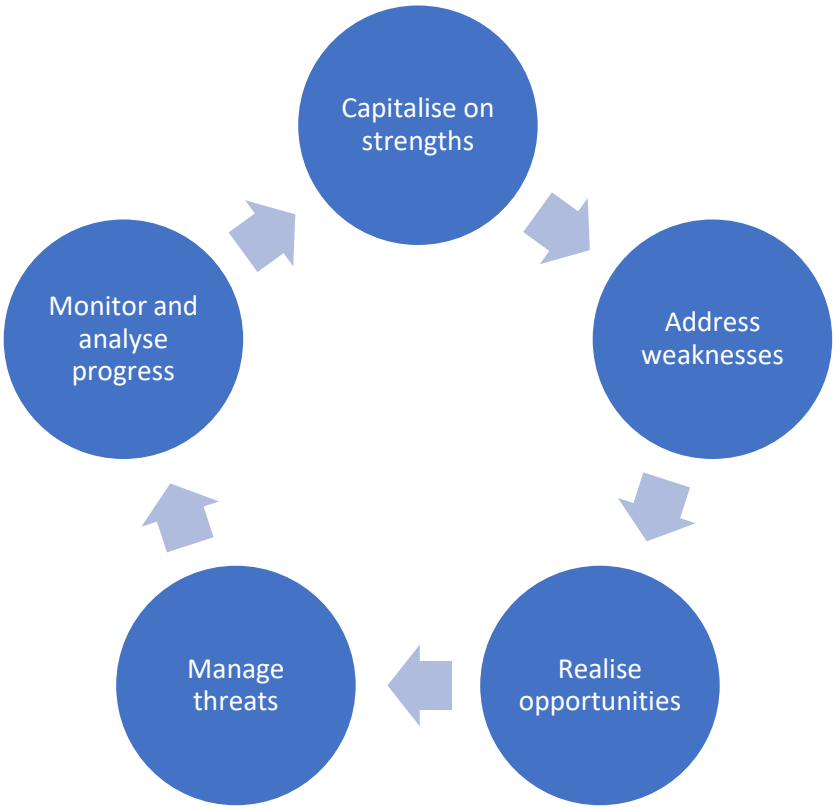

Figure 4.1 Continuous Improvement

A number of client jobs were taken into this new delivery model. We had a chance to collect a full set of data showing the performance of the MS team before and after the transformation. The outcomes achieved are described in the Conclusion section of this thesis.

4.6 Findings and Related Work

MS data for the Australian financial years (1 July to 30 June) 2014, 2015 and 2016 was made available for analysis. A number of MS client jobs from the financial year 2016 (FY2016) job pipeline were selected to participate in this case study. Consequently, the FY2016 results reflect the state of the organisation after the proposed changes were implemented relative to the selected sample of tax and compliance jobs.

Data analysis was focused on the following measures:

- Write-offs
- Job handling time

For the write-offs, the attributes of interest were:

- Financial year (FY2014, FY2015, FY2016)
- Participation in the experiment (Y/N) (in scope or not in scope)
- The absolute value in dollars
- Percentage of revenue

This data is shown in Figure 4.2 Average Write-offs (% of revenue).

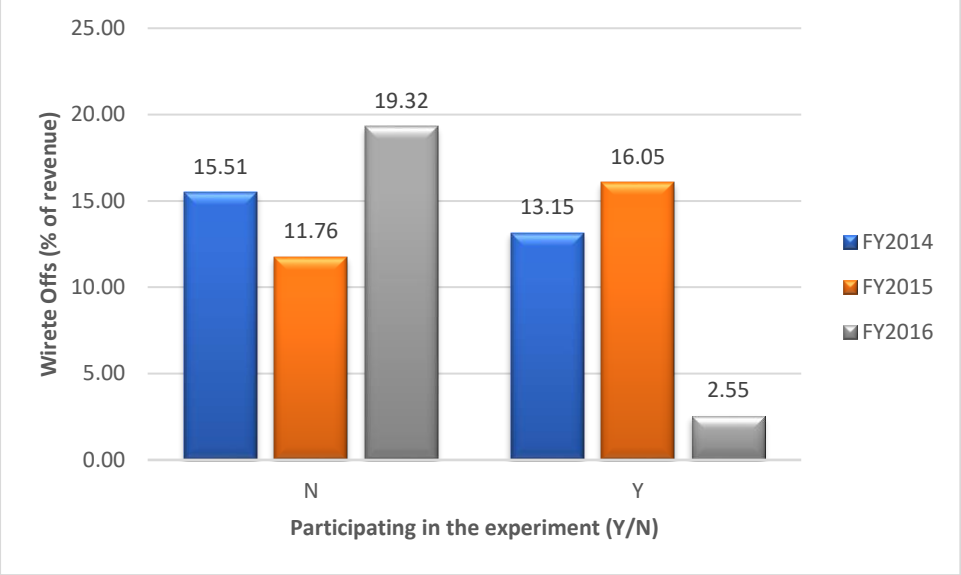

Figure 4.2 Average Write-offs (% of revenue)

We also wanted to see how the total write-offs related to total revenue for the clients participating in the experiment. This is demonstrated in Figure 4.3 Sum of Total Write-Off as Percentage of Total Revenue which displays how for the participating clients the percentage of total write-offs relative to the total revenue in the period of this experiment (FY2016) went down from 8.51% to -1.09%, meaning that the loss in FY2015 has become a profit in FY2016.

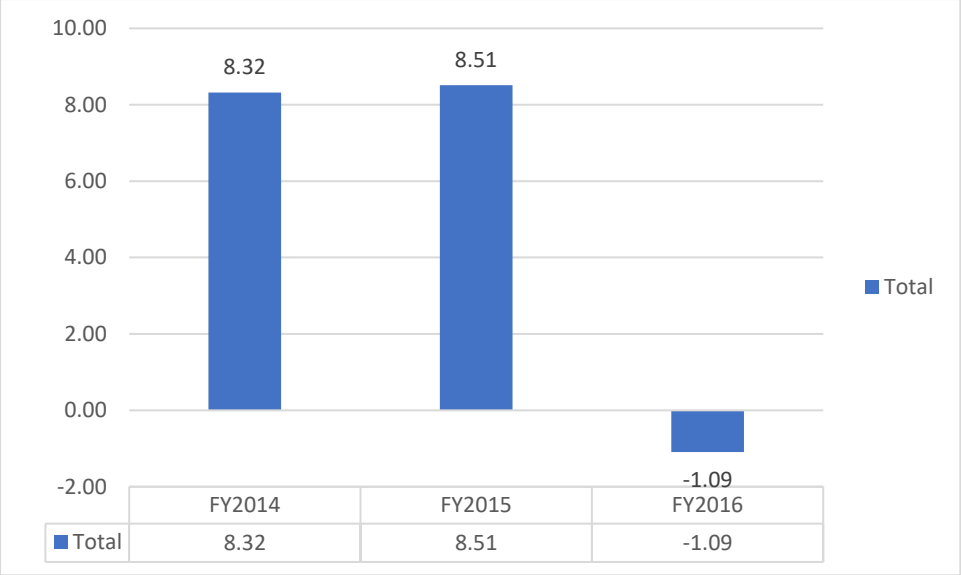

Figure 4.3 Sum of Total Write-Off as Percentage of Total Revenue

This is the most significant outcome of this study and the applied improvements.

For the job handling times, the attributes of interest were:

- Financial year (FY2014, FY2015, FY2016)
- Participation in the experiment (Y/N) (in scope or not in scope)
- Average job handling time in days

This data is shown in Figure 4.4 Average Job Handling Times. It can be observed that for the clients participating in the experiment, this attribute decreased by 28.18% when compared to FY2015 and FY2016. This is one of the most significant outcomes of this case study and related improvements. Noticeably, those client jobs not participating in the study also experienced a reduction in the average job handling time, but it was not significant and their write-offs increased. For that reason, it can be clearly concluded that only the participating client jobs show significant improvements across both qualities (i.e. the value of write-offs and duration of the average job handling time).

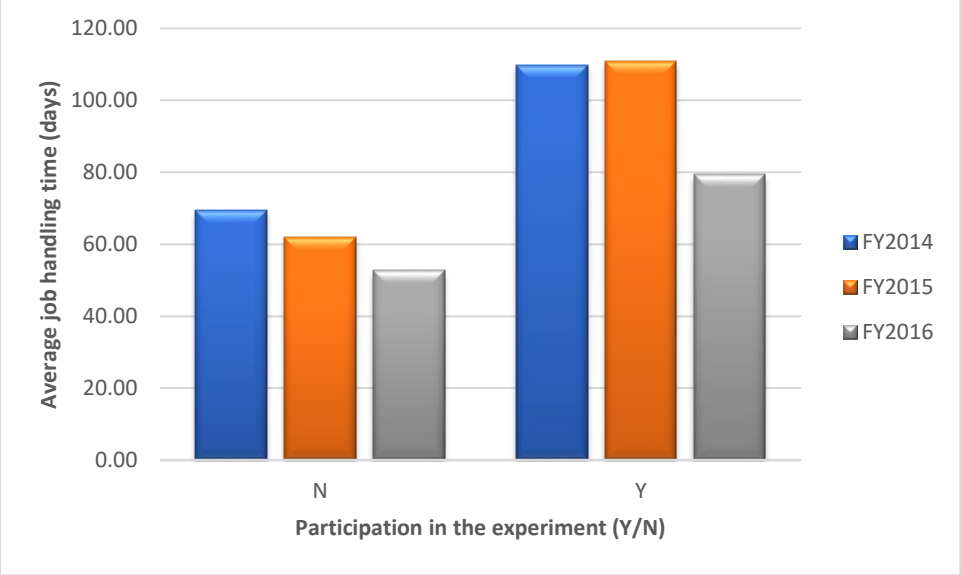

Figure 4.4 Average Job Handling Times

The projectisation component could be taken a step further to allow the operation managers to always have current and optimised schedules. This would require MS to adapt the technical component delivered within the larger Argo Project Management Portal (aka Argo PMP). The portal would be used to maintain operational plans and a pool of available and suitable resources. When plans are complete, the users can automatedly generate schedules to have a view of who does what at any given moment in time within the respective workgroup. The optimisation could also be employed to allow for even more streamlined operation.

The author has been inspired by this success and is looking forward to testing the proposed new method in other industry sectors. Future research effort could aim at improvements in the transport and logistics industry, as well as the building and construction industry.

Chapter 5 - IT Projects and Programs Scheduling with Operational Management Optimisation

5.1 Introduction

5.1.1 Motivation

The software development sector in Australia and overseas is a relatively mature industry. For several decades, it has experienced a significant growth mainly related to an almost exponential increase in demand for business processes streamlining and automation capabilities. According to the forecast by Gartner, available in 2018, 'spending on information technology (IT) products and services in Australia are forecast to reach almost A$93 billion in 2019, an increase of 3.5 per cent from 2018, slightly higher than the global average growth rate of 3.2 per cent'.

While the information technology (IT) sector grew in size, it was also subjected to a number of external and internal factors, which impact how it is shaped today and how it is going to look like in the near and far future. These include:

- The globalisation of the workforce
- The constant change of the tool set used to deliver IT solutions
- Increase in complexity of the offered IT solutions
- Need to provide new and modified solutions earlier to help clients maintain their competitive edge

All these dynamics make the solution delivery management a very complicated task. Project managers who run these initiatives have to keep up with the constant changes in the domain and need to deliver IT initiatives on time and within budget to the specified quality requirements.

Following the invention of a new operational optimisation method (Petukhov 2016) and its implementation in a laboratory environment, it seemed to be beneficial to try it in various industry settings and by doing so prove its suitability and benefit in the real-life problem domain. Specifically, in this experiment, the team wanted to apply it to the information technology project delivery optimisation space to see if this given industry sector can capitalise on the opportunity. As resource allocation optimisation is a common problem in the many

domains of that sector, the team have decided to select the IT program resource allocation domain as the target space of this experiment.

5.1.2 Approach and Methodology

Similar to other case studies that have performed to show the feasibility of the new development optimisation method, a suitable dataset was sourced to represent the problem domain. The literature review was conducted to investigate the context of the problem space and understand how existing knowledge addresses optimisation challenges. The study process has progressed into the actual solution proposal and implementation stage. A problem domain model was engineered and built on the top of the enterprise calibre technology stack. The input data set was imported into the model. Following that, the solution model was constructed in the same computing environment. Finally, scheduling automation and scheduling optimisation engines were developed. All the components have comprised an end-to-end operational scheduling and optimisation solution. This capability was used to run the experiment where required schedules were automatically generated and optimised.

5.1.3 Expected outcomes

We were expecting that the method is successfully applied as the technology required for its implementation is built within a reasonable timeframe. They also wanted to see how outcomes of the optimisation experiment show a population of suitable solutions that all meet the 'must-have' requirements (i.e. hard constraint). The proposed scheduling solutions would be varying across different qualities by how they address the 'nice to have' requirements (i.e. soft constraints). Within a given population of suitable schedules, the soft constraints characteristics would have to vary by a significant percentage (e.g. between 5 to 10%). If these outcomes are achieved, the team would be able to conclude that the cause study objectives have been met.

5.1.4 Chapter structure

This chapter describes the overall eco-system of information technology (IT) and its enablers. By conducting a literature review, the author represents various concepts and critical challenges. They follow with more literature review focused on possible ways to tackle optimisation challenges. Physically the chapter is structured as follows. Section 2 provides background information on the IT sector. It focuses on the latest delivery methods which revolutionise the whole IT sector in Australian and abroad. It shows a number of enabling technologies that contribute significantly to the success of IT. In this section, the majority of the literature review is presented to lay out the field where optimisation opportunities can be

applied. Section 3 shows how optimisation challenges are addressed in various areas of the IT environment. Here we continue presenting outcomes of the literature review with emphasis on solutions currently available to operators when they want to tackle optimisation problems. In section 4, the team propose their own solution to optimisation challenges and describe the case study, showing what was completed in preparation for the experiment and how the testing was performed and results obtained. Observations are presented in section 5. Section 6 summarises the results and proposes future work in the telecommunications space. Raw data representing experiment outcomes can be found in Table 5.2 IT Project Schedules.

5.2 Background and Key Concepts

Organisations around the world want to dramatically change the way economic activities are conducted to reflect on increased environmental awareness and a desire to enjoy quality of life while still contributing productively to economies and enjoying the reward for that contribution. In that context, the author can observe a number of ‘demands’ or ‘pressures’ applied to IT and how it is being defined and delivered. These demands include:

- Business Agility – the requirement to achieve things in an agile fashion with maximum useful values being delivered as soon as possible and a need to enhance the initially provisioned products using the continuous improvement approach
- Environment Sustainability – the need to conduct economic and recreational activities without depletion or degradation of natural resources and allow for long-term environmental quality
- Work and Life Balance – the intent to enable a workforce to interact with colleagues and do their work at anytime from anywhere, while still maintaining a high quality of life, good health, and ability to meet their family and other ‘non-work related’ commitments
- Market consumer and completion pressures are present and remain current
- Regulatory requirements enforced by relevant authorities

The author thinks that IT program managers have a number of enablers at their disposal. They will be better equipped and will be able to respond to the demand more successfully if they make good use of those helping methods and technologies. These include:

- Cloud computing allows organisations to abstract their computing environment’s hosting platform with the view of being able to manage those in the most effective way possible.
- Internet of things (IoT) approach makes use of the advanced wireless communication capabilities and allows multiple devices surrounding us in our day-to-day lives to become

smart computing unities fully integrated into the broader IT systems and enabling reach spatially aware data management in real-time.

- XaaS anything as a service (SaaS, IaaS, etc.) concept helps people and organisation to consume already available or operationally quickly established on-demand ready to go services, supporting their strategic capabilities.
- Effective human resources management allows the most expensive and the most widely used resource type to be planned and allocated in the most effective and optimised way possible.
- Supporting processes and tools help the managers to apply relevant concepts and principles while utilising a number of modern methods and technologies, allowing them to deal with the complexity and size of work they perform when managing programs. These will also support information sharing across different delivery stakeholders' groups.

5.2.1 Cloud Computing

The first enabler to discuss from this list is cloud computing (CC). In the opinion of the research team, it contributes to a number of demands that IT program management is facing. In particular, it helps with environment sustainability and with addressing the market pressures by reducing operational costs of program delivery.

As highlighted by Thomas (2008), the complexity of the IT delivery domain has significantly increased in recent years. Delivery teams are forced into a combination of multi-tiered hardware, complex object-oriented (OO) frameworks and middleware tools. Every so often, developers start working with new application frameworks and with new application programming interfaces (APIs). These factors make the IT delivery very challenging. On a positive side, it is observed that the application developers are getting a helping hand from the recently introduced concepts of cloud computing (CC) and software as a service (SaaS). Cloud computing offers infrastructure provisioning through a small set of services delivered globally over the Internet. SaaS is a streamlined way to provide and consume software applications, where end-users should not be concerned with a lot of internal complexities; instead, they are presented with an over the Internet access to the required functionality and only pay for the usage of those functions in question. Service providers are responsible for establishing and on-going management of these offerings. They apply their skills and knowledge to make the service providers' proposition meeting customer demand while making the end-to-end delivery process profitable and sustainable. CC makes computing infrastructure a relatively inexpensive commodity which is readily available for relatively easy setup and consumption. Cloud computing services may be invoiced using simple REST XML

requests, making them easy to integrate with any programming language used by the consuming group to manage the infrastructure they employ to deliver IT programs. It is worthwhile mentioning that while cloud service has started by only offering limited web and storage services, it has now evolved and includes databases and other technology components.

While discussing the same topic, Buyya et al. (2009) propose that cloud computing (CC) will one day become the 5th utility (after water, electricity, gas and telephony) and will support the required level of information technology services for the general community. In the context of CC delivery, resources are allocated using virtual machines (VMs). Not different to other resource allocation problems, infrastructure allocation in CC comes down to a balancing act between customer needs, which are defined by service level agreements (SLAs) and the service provider's ability to stand up required infrastructure which is drawn from a pool of suitable and available resources. There are a number of cloud management solutions currently available on the market. They help to address a multitude of various requirements related to cloud services. It is essential that these services are implemented in an energy-efficient way to decrease their power costs and carbon footprint.

As described by Buyya and others (2010) 'Cloud computing has been coined as an umbrella term to describe a category of sophisticated on-demand computing services initially offered by commercial providers, such as Amazon, Google, and Microsoft' (Buyya, Broberg & Goscinski 2010). It allows the abstraction of computing infrastructure implementation in the 'cloud'. This term reflects the level of abstraction when service consumers – businesses and individuals – are not concerned about implementation details of the supporting infrastructure hosted in the cloud. They simply access those services to fulfil their needs at anytime from anywhere.

The authors proposed the following classification of cloud services: (a) Infrastructure as a Service, (b) Platform as a Service, and (c) Software as a Service.

According to Sarathy and others (2010), another area for the cloud architecture to cover is dynamic allocation and management of 'resources in response to changing demand patterns in real-time', driven by the end-users being increasingly concerned about the latency of services consumed. Approaches enabling these needs are often sub-optimal, very expensive and cannot support high volume demand. Because of advances in hardware-virtualisation, and the separation of 'infrastructure and application management, it is now possible to provide

dynamic visibility and control of services management to meet the rapidly growing demand for cloud-based services' (Sarathy, Narayan & Mikkilineni 2010).

5.2.2 Internet of Things (IoT)

We agree that the Internet of things (IoT) is a significant technological advance that helps to address challenges related to IT solutions delivery in general and to IT project and program delivery specifically. It allows distributing computer power and overall system intelligence across many devices ('things'). The existing literature covers the concept and its main characteristics extensively.

One of the reviewed papers states that a new phenomenon is now being experienced known as the 'Internet of Things (IoT; also known as the Internet of Objects)' (Xia et al. 2012). It observes that IoT comprises of a multiple of interconnected devices, which are equipped with connectivity and self-management functionality. They think that IoT will drive the growth of Internet consumption by integrating many components via connected built-in devices. This will result in a distributed network of computing components interacting with humans and with other devices. As underlying technologies rapidly evolve, IoT is presenting opportunities for a large number of new tools. These can improve the quality of our lives.

According to Ning and Hu (2012), while 'the Internet of Things (IoT) is developing rapidly and becoming a hot topic around the world' (Ning & Hu 2012), two designs for IoT are considered. 'A dimension model is established to classify the complicated IoT technologies, and a layer model is built for Future IoT system architecture' (Ning & Hu 2012). They discussed the approaches for IoT development phases and bring attention to the fact that a wide variety of IoT-related technological concepts has been developed to support this paradigm.

The application of IoT is enormous; it 'can be applied for intelligent building, smart grid, smart home, intelligent hospital, environment monitoring, mine safety management, and ticket management, etc. In fact, almost all intelligent systems can be referred to as IoT applications' (Ning & Hu 2012). By doing so, it broadens the horizons of IT programs delivery. Functionality, which could only be considered in a Sci-Fi type context, is now possible to implement and be made available to the end-users.

Urban IoTs has been designed and implemented to support smart city vision (Zanella et al. 2014). Their solution takes advantage of current advances in communication technologies to help provide better outcomes for both city governments and residents. It is only possible

because the Internet of things (IoT) is an 'incorporate transparently and seamlessly a large number of different and heterogeneous end systems, while providing open access to selected subsets of data for the development of a plethora of digital services' (Zanella et al. 2014).

In their publication, Wortmann and Flüchter (2015) are also reporting on the growth of IoT. They observe a substantial increase in interest in the IoT. A number of forums were established to agree on frameworks and regulations for the IoT and organisations around the world introduced IoT-based commercial offerings. IoT-related acquisitions have been completed including the takeover of Nest by Google for $3.2 billion and the purchase of SmartThings by Samsung. Governments, industry and academia acknowledge the Internet of things as a significant economic development enabling opportunity. Available analysis indicates that the IoT could become a market worth $7.1 trillion. The authors think that the 'implementation of a connected product typically requires the combination of multiple software and hardware components in a multilayer stack of IoT technologies' (Wortmann & Flüchter 2015). An IoT technology stack typically includes three main tiers (i.e. the 'thing or device layer', the 'connectivity layer' and the 'IoT cloud layer').

Continuing the discussion on IoT Domingos and Martins (2017) highlight that traditionally, business processes use the Internet of things (IoT) to distribute information. At the same time, 'the increase of computational capabilities of IoT devices provides them with the means to also execute parts of the business logic' (Domingos & Martins 2017) in separate parts of a larger solution. This allows them to reduce the amount of data transfer and decrease the server-based computations. The Business Process Model and Notation (BPMN) methods already help modellers to define the overall processing logic. Still, 'they are not restricted to standard BPMN elements, and they generate an IoT device-specific low-level code' (Domingos & Martins 2017). The work they presented describes both core and IoT specific processing flow of business operations.

5.2.3 XaaS

This chapter's discussion around IT program delivery enablement by the latest advances in science and technology should also cover the topic of XaaS. According to some literature, Everything as a service, also known as XaaS, is an approach enabled by the computation performed in multiple cloud spaces with shared resources. More and more capabilities are being delivered in the 'as a service' fashion.

In their case study around a data analytics scenario, Dwivedi and Kulkarni (2008) show how information as a service is delivering data analytics. In a typical enterprise scenario, information management is strongly coupled with the enabling applications. The new approach offers a more abstract technique of data acquisition, loading, transformation, quality check, and reporting. Their paper demonstrates 'how shared services, business processes, rules, and semantics are used to provide quality and agility to the internal processes' (Dwivedi & Kulkarni 2008). The method was implemented by an industry organisation information services provider called Omega. They aimed to automate their data provisioning processes to establish a service-oriented architecture (SOA).

Historically, IoT services were 'delivered as physically isolated vertical solutions, in which all system components ranging from sensory devices to applications are customized and tightly coupled for the requirements of each specific project' (Li et al. 2013). The robustness and scalability of such solution architecture would be limited, causing significant issues for the IoT vendors. Recently novel PaaS frameworks were proposed (Li et al. 2013). They provide 'essential platform services for IoT solution providers to efficiently deliver and continuously extend their services' (Li et al. 2013). PaaS is a sub-type of XaaS paradigm, and it helps organisations to deliver IT solutions in a more effective manner and by doing so, be more agile and more competitive. IoT solutions can be delivered using this approach as virtual verticals by leveraging computing resources and middleware services on the cloud. Some of these solutions can support the multi-tenant architecture which 'helps to isolate the operation environments of different solutions, enabling virtual vertical service delivery that is more extensible and scalable compared to the mainstream physically isolated vertical solutions' (Li et al. 2013).

According to some research, large enterprises increasingly leverage modern delivery methods to increase quality and decrease costs. Smaller organisations could not follow that path because of significant initial investment related to such implementations. 'The Software as a Service (SaaS) model provides access to applications hosted in a cloud environment, allowing users to try services at low cost and scale as needed' (Bitterman et al. 2014). One of such service types is the Simulation as a service (SMaaS).

Polymer Portal was the first-generation SMaaS platform. It was established to combine and make available various modelling, simulation and training capabilities. A number of improvements can be implemented in the future.

> Integrated AAA for both VM and HPC services can be provided once a common Active Directory domain is established. In addition, the HPC simulation interface can be fully automated so that Polymer Portal users can seamlessly move simulations from the VM to HPC environments. Finally, the set of services provided by Polymer Portal can be packaged for hosting by other service providers, and also can be expanded to address other problems facing polymer manufacturers, including polymer composite properties, extrusion modeling and tensile strength. extrusion modeling and tensile strength (Bitterman et al. 2014).

Closer to home, Australian Public Sector (APS) agencies at all levels, including federal, state, and local have looked at the cloud technology and digital transformation (Gill et al. 2014).

The main objective of Information and communications technology (ICT) in Australian Government is to enable government functions, streamline and automate processes and make the user experience more enjoyable and satisfied with the services that APS offers to the individuals and organisations, including the ATO, Centrelink and others.

ICT solutions have to be delivered and supported in the most effective way possible to demonstrate the duty of care of taxpayers' investments and ensure the most favourable return on investment (RIO) is achieved. To enable this outcome, the responsible working groups strive to employ the most relevant and productive ways to complete these implementations while employing the latest advances in academic research and technology.

Adoption of cloud computing technologies across government ICT implementations should make the infrastructure project more efficient and productive. By definition, this paradigm goes hand in hand with business agility and a very dynamic balancing act between demand and supply in the ICT service provisioning domain. To manage these kinds of initiatives successfully, one needs to adopt a governance model that supports that required level of adaptability. The author has spent a great deal of effort assessing if an agile enterprise architecture framework could be suitable for the task. They tabled all the strong points about this approach and some disadvantages. One such potential issue was that it required all groups involved to work together in a collaborative and well-governed fashion, which in itself may present a number of significant challenges.

Still, the authors advocate for 'the use of an agile enterprise architecture framework to developing and implementing the adaptive cloud technology-enabled enterprise architecture in the Australian government context' (Gill et al. 2014)

When analysing advances of cloud computing in European manufacturing, in the context of the latest developments in cyber-physical systems (CPSs) Juan-Verdejo (2016) describes opportunities for the European manufacturing sector. They think that the IoT complemented by the Internet of services will lead to the next significant phase of industrial evolution. It transforms the manufacturing and logistics to employ digital technologies and advances the growth of processes with 'machine-to-machine' connectivity. CPSs communicate in real-time and enhance the business agility of engineering businesses. These approaches take advantage of effective data management and services while utilising cloud architecture provisioned by various services providers. That research team have considered a multi-cloud marketplace architecture leveraging varying cloud ecosystems at different abstraction. It can also be seen that organisations with highly complex systems requirements can benefit from the advantages offered by the cloud paradigm.

5.2.4 Effective governance and resources management

Effective governance and resources management is a crucial requirement to achieve any success when delivering IT projects and programs in organisations' portfolios. People are the main contributors to the late delivery of IT products and services. They are also relatively expensive. Because of that, it is absolutely crucial to establish and maintain a robust process and technologies that will allow for such efficient resource utilisation. For decades companies across the globe have progressed in that direction, and existing literature provides sufficient volume of relevant research and case studies. Some of it will be presented here to demonstrate proper resource management can support organisations to strive for better competence and sustainability.

According to Weill and Ross (2005), in the context of the broader ICT governance, industry participants establish one level of IT management or another. Their approaches vary in how they assign managerial responsibilities between various stakeholders and working groups. In the absence of a 'formal IT governance, individual managers are left to resolve isolated issues as they arise, and those individual actions can often be at odds with each other' (Weill & Ross 2005). The researchers studied around 300 companies. The outcomes suggested that IT governance is an area of uncertainty for the senior stakeholders at most organisations. 'On average, just one in three senior managers know how IT is governed by his company' (Weill & Ross 2005). When the leadership team take ownership of the IT governance processes, organisations can expect a better return on investment (RIO) of their IT initiatives across the enterprise. It can be seen that well-functioning IT governance is not something that can happen by accident. Successful organisations carefully design management. In those

organisations, executives apply pre-arranged governance policies and provide effective leadership of their IT operations at all times. Between 60 and 80% of managerial stakeholders in such an organisation have a good grasp of the IT governing policies. On the other hand, one of the critical indicators of IT governing policies effectiveness is the impact they have on the companies' operations overall.

In their research Bloch, Blumberg and Laartz (2012) describe how risky and sometimes unsuccessful IT delivery could be. According to their data, 'As IT systems become an important competitive element in many industries, technology projects are getting larger, touching more parts of the organization, and posing a risk to the company if something goes wrong' (Bloch, Blumberg & Laartz 2012). Unsuccessful delivery statistics are staggering.

> Half of all large IT projects—defined as those with initial price tags exceeding $15 million—massively blow their budget. On average, large IT projects run 45 percent over budget and 7 per cent over time while delivering 56 percent less value than predicted. Software projects run the highest risk of cost and schedule overruns. These findings—consistent across industries— emerged from research recently conducted on more than 5,400 IT projects by McKinsey and the BT Centre for Major Programme Management at the University of Oxford. After comparing budgets, schedules, and predicted performance benefits with the actual costs and results, we found that these IT projects, in total, had a cost overrun of $66 billion, more than the GDP of Luxembourg. We also found that the longer a project is scheduled to last, the more likely it is that it will run over time and budget, with every additional year spent on the project increasing cost overruns by 15 percent (Bloch, Blumberg & Laartz 2012).

Many organisations manage to absorb losses. Still, 17% of IT initiatives record such significant financial damage that they could potentially jeopardise the very existence of a given organisation. These failures are known as 'black swans'. They occur significantly more often than one can imagine. In some cases, the black swans record their budget overruns between 200 and 400%. Such overruns happen in some complex construction projects delivering major road infrastructures. They were also observed in retail when a given company commenced a $1.4 billion effort to uplift their information technology solutions, but because of the numerous challenges, the initiative was stopped. The organisation could not keep up with its competitors; it initiated another project to as much as $600 million. This project was to deliver a new supply chain management system. When that initiative failed, the retailer had to file for bankruptcy.

Some information on how IT governance works in the modern workplace is provided by Horlach and others (2016). They acknowledge that industry players struggle with the 'digitalisation'. Many enterprises want to create a new digital IT organisation to help the business to be more agile in adapting their IT strategies. They will be able to see their services and products delivered to the market in a timely fashion and meeting customer needs well. A phase in a company lifecycle when traditional IT coexists with digital IT has been labelled as 'bimodal IT' or 'two-speed IT'. The bimodal IT significantly impacts the business-IT alignment in organisations. They further described the characteristics of traditional IT and digital IT and summarised feasible method of establishing bimodal IT on the architectural, process and organisational levels. They raised some concerns related to this bimodal IT structure. It was acknowledged that bimodal IT is a transition status and should not be adopted as a long term answer. Companies adopt trimodal as well as other n-speed IT delivery structure in order to stay competitive and to manage a gap between business and IT. That very same team continues one year later (Horlach et al. 2017) to show how IT governance is achieved when the organisation has different methods for business-focused and IT delivery work in (aka bimodal IT). They present outcomes of a study dedicated to bimodal IT implementations in nine enterprises and present a few kinds of bimodal IT in these companies demonstrating that specific techniques are adopted to improve the IT positioning in the respective organisational environment. While assessing similarities and differences of the researched models, they identified opportunities for future research in this problem domain. In conclusion, the team confirmed that several implementations approaches, ranging from bimodal development to a transformation towards agility of the whole IT in the organisation exist in practice. They have also found that 'bimodal IT' still requires the change of the IT groups and does not extend to the larger organisational transformation; this fact continues to contribute to segregation between business and IT (Horlach et al. 2017).

Further exploring the challenges IT faces in the digitisation age, Haffke and others (2017) employed 'qualitative executive interview data' to explore the 'bimodal approach' companies take in their IT operation that delivers on digital transformations strategy. They conclude that 'for many organizations, a bimodal IT design, of which we found three distinct archetypes to exist, serves as a transitional stage in the pursuit of embedding a higher level of agility and a stronger exploration focus in the IT function, which ultimately operates unimodal' (Haffke, Kalgovas & Benlian 2017). It seems that this model of running IT in two different modes supports the staged digital transformation and allows management to reach the end goal of having the whole IT working in the new model with less disruption. This approach, of course, puts pressure on those groups involved due to the complex organisational structure required to enable such split and gradual transition to the future state.

More exploration of how traditional and agile governance approach works in the organisation was done by Jöhnk et al. (2017). In their opinion, the digital transformation demands organisations to re-evaluate the way they communicate with consumers, assess the value propositions, make use of data and effectively manage their operations. Increasingly, IT organisations around the world are stimulated to adopt a digital way of conducting business in an agile and programmatic manner. Existing literature covers the structure of a standard very well. Still, there is high ambiguity on how to run bimodal IT organisations. To increase knowledge in this area, a design variations taxonomy was proposed for the agile mode. That classification consists of seven different aspects of IT setups. That taxonomy contributes to a better understanding of the researched domain.

It is challenging to underestimate the importance of robust human resource management, and literature review shows the significant volume of related work. In one such study, the scientists focused on human resource governance in secondary and tertiary institutions. Haiyan (2019) obtained data extracts from relevant data repositories in the researched organisations. They conducted data cleansing and data mining activities to complete their analysis of the problem domain. Once the data was ready and initiation analysis was complete, they applied modern visualisation techniques to make outcomes of their study more appealing to various audiences and to highlight any trends and dependencies between various data qualities captured. In their opinion the ability to present results in an effective and easy to digest manner helped the stakeholders to make better decisions in the human resource management activities that they conduct on a day-to-day basis. Ultimately it helped colleges and universities to manage their human assets better and utilise these resources in the most effective and optimised way possible. It also has improved the talent development in the organisation as well as the overall level of staff satisfaction and work-life balance.

When researching the UK building and construction sector, Kusimo and others (2019) analysed problems related to resource governance. They have engaged 14 industry experts from the participant-organisations. The participants were split into two equal-size focus groups to provider their subject matter opinions on the topic of resource management in five sample projects.

> The analysis has identified seven key factors that affect resource 380 management, which are: (1) poor understanding of project complexity at the tender stage, (2) incomplete survey of the project site, (3) little visibility of resource profile at the tender stage, (4) changes to project schedule, (5) running multiple projects in parallel, (6) shortage of specialised resources, and (7) poor management of client-specific

> authorisations and certifications. A critical factor that contributes to these problems is the poor data management practice of keeping data in silos. As such, big data approaches must be adopted for resource management to allow the integration of huge and diverse data (Kusimo et al. 2019).

Further on the topic of human resource management Nasirian and others (2018) introduce other aspects of this field. In their opinion, using multiskilled human resources refers to the ability to dynamically reallocate labour between various workstations in response to bottlenecks in the delivery process. They investigate 'improvements in tangible performance measures which can be achieved by incorporating a multiskilled workforce in off-site construction' (Nasirian, Arashpour, & Abbasi 2018). In that context,

> Scheduling in off-site construction analysed in flowshop environment with multiskilled human resource in which operations processing time depends on the amount of human resource allocated to it. The objective of this optimisation problem is to minimise production makespan taking into account labour costs associated with different flexibility strategies. To this end, a mathematical framework incorporating flowshop principles developed, formulations coded in an open source programming interface and solved with a commercial solver providing free license to academic usage. Production data from a prefabrication factory based in Melbourne, Australia fed to the model providing a basis for comparison based on different indicators of productivity. The findings of this study are insightful for human resource development in off-site construction by providing cost and productivity corresponding to different multiskilling strategies (Nasirian, Arashpour, & Abbasi 2018).

Other industries where human resource performance and allocation directly impacts organisational productivity can benefit greatly from the findings of that research.

5.2.5 Management processes and tools

Understandably the crucial role in supporting IT success and its ability to deal with the multitude of uncertainties and challenges of today's delivery environment is the tools set of processes and technologies available to IT management practitioners and helping them to manage solution deliveries productively. In this section, the author lists a few representatives of that collection and briefly discuss what they offer to streamline projects' governance.

Widely used in the corporate world the SAP package of modules helps to implement end-to-end financial controls to all departments of an enterprise. Significantly high in cost of implementation and on-going support, this family of products is usually only available to larger

organisations with hefty IT budgets. As Zupsic (2003) puts it, ‘selection of SAP as the information collection tool for a company is based on a number of important criteria’ (Zupsic 2003). A lot of companies choose to integrate with SAP because of its outstanding information management qualities and its ability to help organisations to reduce their operational costs. When considering SAP implementations every company needs to decide which SAP modules they would want to adopt. The inclusion of the project systems (PS) module recognises management's understanding of the importance and value to be realised from the utilisation of this tool in managing project costs. To maximise the benefit, the PS module must be implemented in such a way as ‘to ensure timely and accurate information is available on the projects in a useful format that is accessible to the right audience’ (Zupsic 2003). Utilising the cost tracking functionality of the PS module by organisations other than strictly capital will increase the benefits derived from SAP implementations.

In their book, Franz (2007) talks more about project management with SAP Project Systems. They described its planning function as follows.

> Once you have properly mapped a project using the work breakdown structure (WBS) and the network structure, you can use various SAP Project System functions to plan the dates of the individual work packages, estimate the expected costs and revenues, and provide internal and external resources and materials on schedule before the project starts (Franz 2007).

Depending on the requirements, users can select various planning functionality to suit their specific needs. A sample of such selection could be a scenario when a project manager can compile initial estimated milestones and costs with minimal effort while still in the quotation or approval phase of a given project. They can add another level of details later. They can also do it using other planning functions or additional structures. In their analysis, the authors go into details of how various resource management functions are supported in that package (i.e. planning, budgeting, scheduling, execution and reporting).

One of the methods widely used to deliver initiatives in waterfall fashion is called ‘PRINCE2’ (Commerce 2009). The abbreviation stands for PRojects IN Controlled Environments (version 2). It helps project managers around the world to deliver their projects successfully. It is known that this method is prevalent in the UK, Australia and other Western countries. Governments and education are among those who prefer this approach as it fits well with their processes around communications and business case management. PRINCE2 can work for any kind of initiative in any ecosystem. It describes an end-to-end approach to running all the project

management procedures, considered to be a minimum for adequately performing project management function. Benefits of employing this project governance method are listed below:

- It offers robust governance to manage project initiation, execution and completion
- It offers a standardised governance method that can be applied by both expert and beginners in the project management discipline
- It motivates continuous improvement in a governance practice
- It helps with better communications and transparency in the entire organisation involved with the project delivery

This method offers a standard description of a project as ‘a temporary organization that is created for the purpose of delivering one or more business products according to an agreed Business Case‘ (Commerce 2009). The method prescribes a number of controls which help project management practitioners to deliver their projects in a predictable fashion. Still, the means of how PRINCE2 is executed in a given initiative varies significantly. Adjusting the approach to work in a particular scenario is critical to the overall project success. Project management practitioners should be mindful of the fact that each delivery environment might require custom technique event though the overall method is selected from the widely adopted offerings.

As described by (Vaníčková 2017), setting up a project within the PRINCE2 methodology is quite an involved undertaking. They specifically address project management needs in an enterprise in the service industry. In their study, they try to match the project objectives with the market of services providers and apply the principals of PRINCE2 to supplier selection and service delivery. They wanted to establish a point of reference so that in the future, the described principles and processes could be used by others in the field. This work was done in the context of a small project with a budget of less than CZK 200,000, which had only run for a short time (sometimes less than one month). The authors believed that the PRINCE2 project management methodology offered a practical approach to the service delivery with an emphasis on the industry context and given project management discipline best practices. They also agreed that the adoption of this methodology could lead to the increased success rate of service delivery. Such success criteria would account for the procedure, risk analysis and quality of the deliverables through the delivery life cycle.

Probably the second most well-known method of delivering projects in ‘traditional’ well-structured fashion is PMBOK (PMI 2008). The initial edition of the PMBOK Guide was published in 1996. Defined by PMI, it is adopted by hundreds of thousands of project

management professionals worldwide. This method is a result of the collaboration and knowledge accumulated by a community of project management professionals, describing the main principals of project management as applicable to a variety of projects. This standard is considered as the vital instrument used to support project management function and deliver organisational results in a predictable fashion. Relative to PRINCE2, this method offers a more detailed definition of some important project management concepts driving planning, scheduling and monitoring of the project success in a very controlled fashion. PMBOK includes ten knowledge areas:

1. Project Integration Management
2. Project Scope Management
3. Project Time Management
4. Project Cost Management
5. Project Quality Management
6. Project Human Resource Management
7. Project Communications Management
8. Project Risk Management
9. Project Procurement Management; (PMI 2008)

Some argue that while PMBOK is undoubtedly a good starting point, offering a good foundation for the longer-term project management function, more work specific to a given delivery ecosystem needs to be done in order to establish a well-structured governance model for successful project delivery.

A significant number of technological tools were created to make project managers' lives easier and help them to manage their initiatives in an effective manner. One of those tools is Microsoft Project software. Developed by the modern IT world heavyweight, this package provides a comfortable working environment for persons, teams, and enterprise groups to effectively manage all types of work. Simple tasks and complex projects and programs (Chatfield 2010) can be managed using this tool. It implements many principles of the project management frameworks and supports the waterfall approach in a very structured and precise fashion. It tightly supports planning, scheduling, resource allocation, budget management, workload analysis and progress monitoring processes of the broader project management processes. Its project plan files act as a repository for all project-related information, including tasks list, resources, calendars and costs data. Notably, Microsoft continues to develop the product actively, and new versions of this package are being released regularly, introducing new and enhanced feature set to make project managers more productive.

Stover, Biafore and Marinescu and others (2011) provide a detailed description of the Microsoft Project solution and show how project managers can go beyond the basics and apply some advance techniques to manage their projects more effectively. Their 'reference packs hundreds of timesaving solutions, troubleshooting tips, and workarounds' (Stover, Biafore & Marinescu 2011). They demonstrate how the experts in the field benefit Project 2010's value proposition and help their readers to reach new skill levels in their proficiency with the package. They show how to 'take charge of the project triangle—time, money, and scope, to balance your plan, enable collaboration among team members, sponsors, and other project stakeholders' (Stover, Biafore & Marinescu 2011). Various management processes automated by the software are described, including manual tasks scheduling, usage of the automated scheduling engine, tracking and controlling projects with earned value management (EVM). They also demonstrate how this package integrates well with other Microsoft software, including Excel® and Viisio® to allow for true collaboration in an enterprise project management environment.

Clarity PPM Fundamentals (Velpuri 2011) provides an overview of another well-known management automation tool - CA Technologies' flagship Clarity PPM (Project Portfolio Management). The authors offer industry best practices for utilising the Clarity product. They bring their extensive experience to give readers the best insights into making Clarity more powerful and useful. Aimed at different governance roles (head of PMO, executive, project manager) this package allows responsible managers to manage and track all their projects within one portfolio solution, publish dashboards to executives and stakeholders and provide insight into resourcing and budget issues on a project and portfolio level. It helps organisations to streamline the prioritisation process and improve customer satisfaction by fulfilling new requests faster. In addition to that, it helps with team collaboration and proactive issues management. Automated status updates allow management to take action promptly.

Clarity helps users perform quantitative analysis of the projects and programs they run across their organisation's portfolio. Project managers can measure various key performance indicators (KPIs). These include statistics on planned versus actual expenditure, return on investment (ROI), break-even modelling, and other relevant information. An 'advanced analytics' module and more in-depth assessment and reposting is available. In summary, this package delivers features that help management practitioners to align their business strategies and market requirements.

The author continues their review of various project management tools with a look at Oracle Primavera – a cloud-based, robust and easy-to-use solution (Williams 2012). In this demonstration of Oracle Primavera P6 Enterprise Project Portfolio Management, users can

manage their projects from just anywhere using simple e-mail and the P6 iPhone app. They can create a new plan using one of the three ERP systems: Oracle EBS, JD Edwards, and PeopleSoft. This package is an integrated project portfolio management (PPM) solution comprising role-specific functionality to satisfy each team member's needs, responsibilities and skills. Using this tool, project managers can organise projects, add activities and relationships, assign roles and resources and schedule projects. They can also manage a portfolio taking advantage of portfolio analysis, portfolio capacity planning, ROI, and tracking performance. This package is widely used around the world in many industries for planning large-scale projects. The current version of this software allows project managers to

- Optimise resource allocation and track project progress
- Monitor and visualise project performance versus plan
- Select and prioritise projects in line with strategy

As the twenty-first century rolled in, project delivery professionals were introduced to agile approaches. While initially starting in the software development area, they now play a significant role in the overall project management discipline. According to Mihalache (2017), these agile ‘methods designed to help teams to develop applications faster and safer’ (Mihalache 2017). The new delivery approach required new facilitating and governing techniques and technologies. Existing literature offers a rich set of reviews of available agile delivery management tools, which streamline and automate project management processes while enabling a high degree of communication, collaboration and productivities, as well as a self-organising approach, as advocated for in agile methods. Analysis and selection of suitable tools out of the overwhelming market offering is not a trivial task and the researchers’ attempt to present a way of classification and categorisation, allowing managers to select the most suitable technology to be adopted into their delivery streams. In their study Mihalache (2017) provide a comparison of the following packages:

- Jira
- VersionOne
- Rally
- Visual Studio Team Services

Their features are extensively analysed, and a complete picture is presented to the reader with a view to making their selection more straightforward. The above list is not complete by any means; it can be extended by other tools offering similar agile team management functionality including Asana, Trello and Monday. Each of the offerings has its specific strong

and weak points. It is the responsibility of the team management to make a call and integrate the most suitable solution for the benefits of all involved with the agile delivery.

5.3 Problem Statement and Known Solutions

5.3.1 Problems

As described earlier in this chapter, a fully functional IT implementation is complicated and vast. It is supported by a magnitude of human resources and various equipment which work together to deliver required outcomes and products of work. These include architects, designers, developers, testing analysts, computer devices (both client and servers), physical offices and meeting facilities.

All the resources involved with IT delivery need to be effectively managed, and if possible, allocation of these resource has to be optimised. For optimisation to be effective and comprehensive, it would need to cover the following solution qualities:

- Human resources utilisation
- Equipment utilisation
- Offices and meeting rooms utilisation
- Costs of delivery
- Delivery timing
- Ability to meet various stakeholders' priorities relative to different initiatives and outcomes
- Geographical awareness and optimal route planning of related transportations

5.3.2 Known Solutions

Cloud computing

Van den Bossche and others (2010) addressed the 'current lack of support tools to deal with the inherent complexity of cost-optimal resource allocation within such a hybrid setting' (Van den Bossche, Vanmechelen & Broeckhove 2010). They researched the structure of software parts in the overall cloud solution and have analysed algorithms driving the construction and launch of hybrid clouds. They have studied automated resource allocation and support. Within their Cloud Procurement Endpoint (CPE) they implement an optimisation engine, which forms the critical point of their optimisation capability to schedule the application workloads in a cost-minimising manner. They think that tackling issues like the calculation of network costs, thoroughly assessing the runtime costs, and applying other relevant considerations could be

addressed by developing custom heuristics or using other optimisation techniques (Van den Bossche, Vanmechelen & Broeckhove 2010).

In IT clouds, 'it is desirable to avoid wasting resources as a result of under-utilization and to avoid lengthy response times as a result of over-utilization' (Yazir et al. 2010). That research team proposed a new technique for dynamic resource allocation in clouds. The main value of their work was two-fold. First, they adopted 'a distributed architecture where resource management is decomposed into independent tasks, each of which is performed by Autonomous Node Agents that are tightly coupled with the physical machines in a data center' (Yazir et al. 2010). Second, 'the Autonomous Node Agents carry out configurations in parallel through Multiple Criteria Decision Analysis using the PROMETHEE method' (Yazir et al. 2010). Outcomes of the experiments have demonstrated that this approach has improved both scalability and flexibility.

Results of the simulations constructed during the experiments have shown that the proposed method was more beneficial in big data centres compared to centralised methods. Also, simulation results have shown that their method should trigger less service level agreement (SLA) violations by levelling distribution of the allocated resource and improving their utilisation using a slightly higher number of physical machines (PMs) in the data centre. The authors conclude: 'The flexibility of our approach comes from its ability to easily change the weights of criteria and adding/removing criteria in order to change configuration goals' (Yazir et al. 2010).

In another study on cloud computing (Wu, Garg & Buyya 2011), the researchers investigate the impact of this paradigm on the traditional software sales model. They think that cloud computing helps to address a number of application deployment and management complexities. Changing from traditional software to cloud helps service providers to establish reliable revenue streams. However, to offer managed services to clients, SaaS vendors have to maintain their own computing asset or lease it from other hosting organisations. In that situation SaaS providers would need to allow for additional costs. The service provider will aim to minimise the cost of resources while maintaining a satisfactory minimum service level for its customers. In their opinion, when the service provider aims to decrease infrastructure costs and reduce reported SLA violations, they should utilise resource allocation algorithms, which will allow exploring solutions that take into account various operational objectives. They offer three cost-driven algorithms. These calculations take into account several factors, including service requests arrival frequency, service provisioning time and penalty amount. These algorithms were implemented to help SaaS providers to address the dynamics of customers'

needs. The algorithms also deal with the 'heterogeneity of Virtual Machines'. We took into account the customers' quality of service (QoS) indicators, including latency of response and service provisioning period. While considering these factors, they have completed a comprehensive analysis to showcase how the algorithms optimise providers' costs and improve their performance relative to SLAs when implementing intelligent resource allocation for the cloud.

Continuing on how cloud computing is currently being managed in the most effective way possible, Beloglazov and others (2012) reiterate that cloud computing has introduced utility-oriented IT services to a wide users' audience. It enables a reliable hosting of applications for consumer, scientific and business domains. They also highlighted that data centres which host cloud applications consume a lot of electricity. This relates to high operational costs and carbon footprints. Based on that, they think that in a strive to reduce the impact on the environment, they discuss a concept of 'Green Cloud'. In their work, they need to discuss architectural principals and requirements for energy-efficient cloud solutions. Using that architecture, they suggest a way of introducing a number of algorithms, which can optimise resource acquisition and allocation in a cloud computing environment with energy efficiency in mind. The resulting solution would still satisfy the negotiated requirements of quality of service (QoS). They have validated the proposed technique by completing a performance evaluation testing with the 'CloudSim toolkit'. 'The results demonstrate that the Cloud computing model has immense potential as it offers significant cost savings and demonstrates high potential for the improvement of energy efficiency under dynamic workload scenarios' (Beloglazov, Abawajy & Buyya 2012). It is notable that their words advanced the cloud in two directions; a reduction in data-centre energy consumption costs and a reduction of greenhouse gas emissions. That team needed to develop a software platform that supports the energy-efficient governance of resources contributing to the cloud data-centre function. They leveraged readily available cloud technologies and offerings including virtualisation offerings, such as free of charge Xen and KVM, and paid offerings like VMware, Amazon's Elastic Compute Cloud (EC2), Simple Storage Service (S3) and Microsoft's Azure. They have utilised bespoke solutions such as Aneka, which is a .NET-based system for building cloud platforms. Additionally, they implemented a general-purpose resource manager and plug-in software adaptors to support integration with other cloud management portals, including Aneka and Amazon EC2.

Ergu et al. (2012) think that a cloud computing resource allocation is a complicated task because it has to take into account many alternative devices with varying capacities. They have aimed to develop a prototype for 'task-oriented resource allocation' in cloud computing.

Resource assignment tasks were graded by the ‘pairwise comparison matrix technique’ and the ‘Analytic Hierarchy Process’. The required computing devices were allocated in line with the task’s priorities. Additionally, an induced bias matrix was adopted to recognise the problematic elements. Two samples were tabled to confirm the proposed method. These two examples have shown that the scores change with various values of consistency ratio (CR). The outcomes indicated that it was beneficial to find the inconsistent elements and improve the consistency ratio when the weights of tasks are assigned to allocate the resources in a cloud computing environment.

According to Papagianni et al. (2013), cloud computing supports a more streamlined usage of computing devices, emphasising on solution scalability and ‘as needed’ service provisioning. Distributed cloud infrastructure extends over a dynamic resource allocation environment moving away from traditional data-centre oriented models. It offers better communication and computational services to satisfy quality of service (QoS) requirements in scope. When enabling the efficient realisation of such solutions, computing and networking components need to be managed effectively. In their paper the researchers formulated ‘the optimal networked cloud mapping problem as a mixed-integer programming (MIP) problem, indicating objectives related to cost-efficiency of the resource mapping procedure while abiding by user requests for QoS-aware virtual resources’ (Papagianni et al. 2013). They then proposed a method for the efficient mapping of resource requests onto a shared substrate interconnecting various islands of computing resources and adopted a heuristic methodology to address the problem. The efficiency of the approach was demonstrated in a simulation/emulation environment, that allowed for flexible, structured and comparative performance evaluation. The study was concluded by outlining a proof-of-concept realisation of the proposed schema, mounted over the European Future Internet test-bed FEDERICA, a resource virtualisation platform augmented with network and computing facilities. They identified a future opportunity to extend the demonstrated framework and to take into consideration new and more dynamic heterogeneous computing arrangements.

On the same topic, another research paper (Sarathy, Narayan & Mikkilineni 2010) proposed and described a model for a network-centric data-centre infrastructure management stack. That model applied vital concepts that have enabled dynamism, scalability, reliability and security in the telecommunications industry. It demonstrated how dynamic resource management could be implemented to allow for real-time service assurance for network-centric data-centre architecture.

Internet of things (IoT)

This section will show how resource management is done in IoT environments.

After analysing applicable problems on the industry and academia, Ning and Hu (2012) conclude that 'IoT is not a specific industry but a new stage of intelligentization and informatization development'. They reorganised the 'Unit IoT and Ubiquitous IoT (U2IoT)' architecture for 'Future IoT'. They describe how, with that architecture in mind, a dimension model is implemented to create a taxonomy of the complicated IoT techniques, and an entire model is constructed during system implementation.

Another study looks at the problem of tasks allocations (Colistra, Pilloni & Atzori 2014) in the context of the Internet of things (IoT). It re-iterates that implementation of the IoT paradigm relies on collections of cooperatively intelligent and connected devices. Deployment of applications in these environments needs to take into account the available resources, such as electrical energy, memory, processing, and object-capability, to perform a given task, which is often limited. In their paper Colistra, Pilloni and Atzori (2014) have defined the issue related to resource management for the distributed applications in the IoT, and they described the architecture and functionalities of a relevant middleware that represented a possible solution. They then proposed an acceptable technique for communication between network devices supporting the target application. They demonstrated that using this technique, they can converge a solution where resources are homogeneously allocated among the network's nodes. Performance evaluation of experiments in simulation mode and in real scenarios shows that the algorithm converges with a percentage error of about 5% with respect to the optimal allocation obtainable with a centralised approach. Real experiments validated the simulation results. Node dynamics proved to converge, and the percentage error was lower than 20% when each node has transmitted five packets on average and lower than 5% after 20 packets.

One research team (Alsaffar et al. 2016) when discussing service delegation and resource allocation based on collaboration between fog and cloud computing, provided a new algorithm for managing and delegating user request in order to balance workload. It uses 'decision rules' of linearised 'decision tree' using the following conditions: 'services size, completion time, and VMs capacity' (Alsaffar et al. 2016). They stated that despite the extensive adoption

> of cloud computing (e.g., services, applications, and resources), some of the services, applications, and smart devices are not able to fully benefit from this attractive cloud computing paradigm due to the following issues: (1) smart devices might be lacking in

> their capacity (e.g., processing, memory, storage, battery, and resource allocation), (2) they might be lacking in their network resources, and (3) the high network latency to a centralized server in the cloud might not be efficient for delay-sensitive application, services, and resource allocations requests. Fog computing is a promising paradigm that can extend cloud resources to the edge of the network, solving the abovementioned issue. As a result, in this work, we propose an architecture of IoT service delegation and resource allocation based on collaboration between fog and cloud computing. We provide a new algorithm that is decision rules of linearized decision tree based on three conditions (services size, completion time, and VMs capacity) for managing and delegating user request in order to balance workload. Moreover, we propose an algorithm to allocate resources to meet service level agreement (SLA) and quality of services (QoS) as well as optimizing big data distribution in fog and cloud computing (Alsaffar et al. 2016).

Based on the result of experiments, they have concluded that the proposed approach could efficiently balance workload, improve resource allocation efficiently, optimise data distribution, and show better performance than other methods.

Cloud IoT are subject to latency issues due to distributed nature of its computing environment. To avoid the kind of problems, management of the collected data starts on the IoT edge. Still, the limited processing capacity does not allow for complete data processing. This means that we need to offload some part of that processing to the gateway or servers. This approach would present challenges and needs to analyse the overall network bandwidth and compacity of the centralised computing layers. On the other hand, as technology evolves more capacity that can fit into smaller and less expensive devices comprising the edge notes of the IoT solutions, it has become apparent that more computation can be handed over to the embedded devices and other network components. Samie et al. (2016) studied the allocation of computing capacity and network bandwidth in local networks of IoT edge tiers. They have presented a new technique that optimises resource utilisation as much as possible. That technique involved extending of the on-board processing model and application of mathematical optimisation algorithms. Outcomes of a health monitoring proof of concept showed up to 40% improvement in utilisation of network bandwidth. That team achieved about a 1.5-hour saving in the battery life of IoT components.

In their study focused on the business process management in the IoT environment, Domingos and Martins (2017) have observed that in the last years, organisations have been using more and more business processes to capture, manage and optimise their activities.

They remind us that ‘a business process is a collection of inter-related events, activities, and decision points that involve actors and resources; and that collectively lead to an outcome that is of value for an organization or a customer’ (Domingos & Martins 2017). In business domains like supply chain management, intelligent transport systems, domotics, or remote healthcare, business processes can deliver a competitive edge by using the information and functionalities provided by the Internet of things (IoT) devices. The researchers consider IoT as a global infrastructure that interconnects things (physical and virtual). IoT devices connect things with communication networks. These devices can also have features like sensing, actuation, data capture, data storage and data processing.

Business processes can use IoT information to incorporate real-world data, to make informed decisions, optimise their execution, and adapt themselves to changes. The recently enabled opportunity to increase the computing capacity of IoT hardware allowed these devices to execute a significant part of the overall business logic. For example, IoT devices can process data and drive execution logic locally. They propose to use Business Process Modeling Notation (BPMN) to make sure the process flow is documented well and to utilise the constructed model to allocated workloads between different system components in a way allowing for the most optimised resource optimisation.

In their paper, Tsiropoulou and others (2017) are looking at the resource allocation in smart IoT applications. They address the problems around coalition formation among machine-to-machine (M2M) communication type devices and resource management. Every M2M component is assessed by its availability and its readiness to exchange information with other parts of the Internet of things (IoT) ecosystem.

> Physical ties among devices also exist based on their physical distance proximity and communication channel quality. Those three factors: energy availability, interest and physical ties, are considered into the coalition formation process and the coalition-head selection. Each M2M device is associated with a holistic utility function, which appropriately represents its degree of satisfaction with respect to Quality of Service (QoS) prerequisites fulfilment. Given the created coalitions among the M2M devices, a distributed power control framework is proposed towards determining each M2M device’s optimal transmission power in order to fulfil its QoS prerequisites (Tsiropoulou, Paruchuri & Baras 2017).

They checked the effectiveness of this approach via modelling and prototyping. They also compared the superiority of that approach relative to other methods.

It can be seen in this case, the authors, not much deferent from other researchers in the optimisation space, propose improving resource optimisation while respecting the QoS requirements.

Another approach to resource allocation optimisation in cloud computing for IoT is discussed by Choi and Lim (2016). They explore a 'combinatorial auction' as a simplified technique for resource assignment in that domain. The satisfaction of the quality of service (QoS) requirements is recognised as one of the challenges in resource allocation tasks. Maximisation of the provider profit is probably another critical objective. It makes sense to reduce operational costs when aiming to increase the profitability of a given business operation. Following this logic, the researchers thought that it would be useful to reduce the costs of penalties the service providers needed to pay when related service level agreements (SLA) were violated. As such, reduction of the penalty costs becomes an objective function of their optimisation process. This process considers various factors in play to assess possible solutions and produces (known as 'combinatorial auction system') what it thinks is the most efficient one. They make a reduction of the penalty payment their objective. They have analysed the job's urgency based on the 'deadline constraint' when winners are identified in the 'combinatorial auction'. Following that, they calculated the likelihood of a failure to meet the deadline customer request. Then, the researchers calculated the anticipated operational profitability when a given job is nominated as a favourite out of a bidding round. To analyse the performance of the proposed method, they compared outcomes of their testing including provider's profit and success rate of job completion with similar results achieved using the conventional resource allocation mechanism obtained from the real resource allocation information.

The study outcomes have proved that the proposed mechanism offered better profitability and improved job completion indicators compared with the traditional arrangement.

XaaS

The best practices in the SaaS and integration domain are discussed by Hai and Sakoda (2009). In their opinion, the 'rising adoption of software-as-a-service (SaaS) applications by enterprise organizations has been driven by a deep dissatisfaction with on-premise applications' (Hai & Sakoda 2009). That traditional approach required organisations to procure and install expensive infrastructure and incur high costs of resources required to complete customisations, upgrades and support. The significant initial expanse and a difficult to estimate return on investment have pushed organisations to explore better ways of acquiring the

required services. Many industry players have found that SaaS applications could be onboarded easily at a predictable cost. This new requirement has motivated rapid innovation and adoption of SaaS and supporting technologies. Organisations still need to integrate these applications with their internally managed systems. Without such full integration, the benefits of SaaS applications will diminish.

They conclude:

> Although SaaS has dramatically transformed the application lifecycle, it has not significantly reduced the complexities of integration with SaaS applications. Organizations are still faced with vendor-specific APIs and varying levels of integration capabilities from different SaaS solution providers. Since most enterprise organizations require integrations to the back office, many of the same traditional integration challenges are encountered. Integration-as-a-service solutions are beginning to simplify integrations, especially in the Cloud-to-Cloud space, but they do not yet offer the same level of capabilities as their on-premise counterparts. SaaS solution providers are starting to focus more on pre-built integrations, which will help reduce the cost and complexity of integration (Hai & Sakoda 2009).

As can be seen, the authors propose a wider adoption of the integration-as-a-service solution to achieve more effective utilisation of the resources involved with a given implementation.
A study focused on QoS-driven service selection was conducted by He et al. (2012). They acknowledge that ‘Cloud-based software applications (Software as a Service - SaaS) for multi-tenant provisioning have become a major development paradigm in Web engineering’ (He et al. 2012). They achieved research results as follows.

> We have proposed MSSOptimiser, a QoSdriven approach which supports the service selection for multi-tenant cloud-based software applications (Software as a Service - SaaS). Using optimisation techniques, particularly Integer Programming, it helps SaaS developers determine the optimal services for a multi-tenant SaaS that meet different stakeholders’ QoS requirements, including the optimisation goal of the SaaS provider and the different levels of QoS constraints of different end-users. In largescale scenarios where the SaaS optimisation problem is computationally expensive, MSSOptimiser provides a greedy algorithm to find a near-optimal solution efficiently. We have evaluated MSSOptimiser using an example SaaS synthetically generated based on a large real-world Web services dataset, and compared the effectiveness and performance of the proposed approach to existing approaches. (He et al. 2012).

In the current very competitive business ecosystem organisations' profitability is one of the highest priorities. Dib (2014) looks at how to maximise the platform as a service (PaaS) returns while respecting the applicable service level agreement constraints. In their opinion 'cloud computing' (CC) is an emerging technology revolutionising the acquisition and promotion of IT infrastructure. The impact of CC and especially PaaS offerings is crucial because the number of PaaS consumers and providers is rising, and because of the footprint of this approach in the overall IT services, provisioning space has significantly increased. PaaS vendors plan to generate more profit from the services they offer. In doing so, they face numerous challenges, including effective management of the required resources and meeting their commitments under the SLAs with their customers.

Their research has addressed these difficulties and focused on optimising the PaaS vendor profit. Their work has considered applicable penalties if the QoS levels are violated. To increase the service provider revenue, this work looked at a cloud-bursting PaaS and proposed a return optimisation approach to find the most cost-effective resources allocations to cover the needs of the application. After a request is available, the optimisation engine estimated the cost of hosting utilising the private and the public infrastructure and selects an optimal variance. When private resources are not available, the rule applies to one of the following options. The first one takes resources from already running services. It will take into account additional costs if their QoS is negatively impacted and penalties apply. The second option evaluates the possible penalty related to the new application due to the delay of its set up while waiting for a private resource to be released. This option was applied together with application-specific heuristics.

To demonstrate the suitability of their profit optimisation approach to a given group of applications, the research team looked at 'rigid and elastic computational capabilities' (Dib 2014). They developed a deadline-based income function and demonstrated two heuristics to work with the profit optimisation policy for maximising the profit. They defined three scenarios of resource allocation by the computational applications. The heuristic selects an approach with a minimum penalty.

The researchers have defined and built a PaaS architecture called Meryn that was able to implement the income optimisation policy. The Meryn technology relied on virtualised private infrastructure utilising an IaaS manager. To support scalability, 'Meryn made use of independent virtual clusters, and it supported each virtual cluster by means of existing technology (e.g., OGE, Hadoop)' (Dib 2014). Each technology was dedicated to a given application kind (e.g. batch, MapReduce). Private infrastructure is dynamically allocated in line

with rules and objectives. A service-specific configuration component was run on each virtual cluster to support SLAs. To check their work, the team built a sample application that supported difference functional modes and utilised workload models. They have performed runs on the Grid's 5000 testbeds. The outcomes have shown that the developed profit optimisation model allowed the vendor to show up to 11.59% more profit compared to a basic approach. The completion time of workloads using optimisation model was slightly higher compared to the basic approach. Also, QoS levels of some customers were impacted. As we can see, the above approach proposed to consider a compromise between better resource optimisation and some of the penalties, which service providers would have to pay to the customer. The researchers believed that this is a feasible solution as long the balance between optimisation gains and penalty losses is leading to better financial outcomes overall.

Another way to introduce an optimised and cost-effective SaaS resources placement on cloud is presented by Bhardwaj and Sahoo (2015). They bring attention to the fact that cloud computing is a very beneficial infrastructure delivery model for both consumers and service providers. Cloud computing is used by many SaaS providers as their main application hosting platform. It allows them to meet the growing demand for SaaS delivery and consequent increase in the required infrastructure. This model helps to improve the robustness of the end-user solutions and brings about better profitability for the service providers. In their paper, the researchers presented a mathematical model for SaaS Placement Problem (SPP). It is designed to minimise the total cost of acquisition and on-going management of that CC infrastructure that supports SaaS. The team have showcased a novel framework for obtaining an optimal solution to SPP using particle swarm optimization (PSO). They tested this new approach using the in-house simulator to check the performance of this approach while employing the 'Greedy heuristic'. The research conducted an extensive quantitative analysis of the costs associated with resource placement to support SaaS offerings hosted in the cloud. The outcomes of simulation experiments have shown in favour of the SaaS resource allocation using particle swarm optimization approach (SPPSOA).

Van den Bossche and others (2015) have explored how to optimise infrastructure as a service (IaaS) with reserved contract procurement with load prediction. In their opinion, the increased popularity of cloud solutions 'has increased the relevance of automating the complex and time-consuming tasks of selecting, procuring and managing cloud resources' (Van den Bossche, Vanmechelen & Broeckhove 2015). In their work, the team have presented a technique to streamline procurement management in the context of service vendors. These arrangements give the customer a significant discount relative to pay-per-hour options, at the price of an upfront expense. They developed a program which uses load prediction to perform cost-

effective procurement and checked if the utilisation of automated time series estimating is beneficial in this problem domain.

5.4 Case Study

We have applied method and techniques developed in the more extensive study to the optimisation of IT projects scheduling. It includes identifying project activities and resource allocation.

As can be seen in Figure 5.1 Argo AI - E2E Scheduling Process, implementation of the automation and optimisation engines are at the core of the new method.

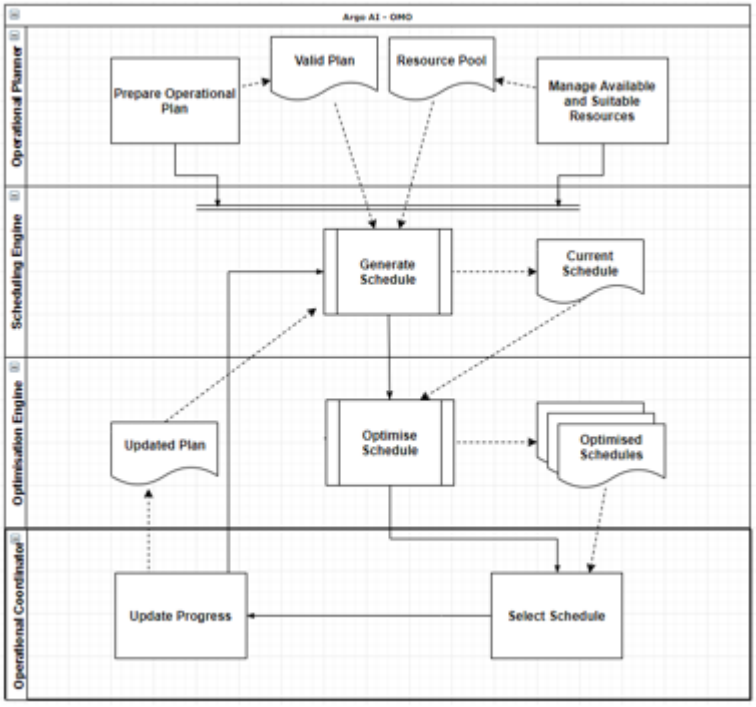

Figure 5.1 Argo AI - E2E Scheduling Process

Within the experiment, we have completed the following work components.

The author has collected and analysed the input dataset describing IT project delivery and required qualities of different resources that are available to fulfil the delivery needs.

The team have built a domain problem model representing the scenario, that captures relationships between deferent domain entities and hard constraints. Figure 5.2 Scheduling Problem represents a snapshot of that model.

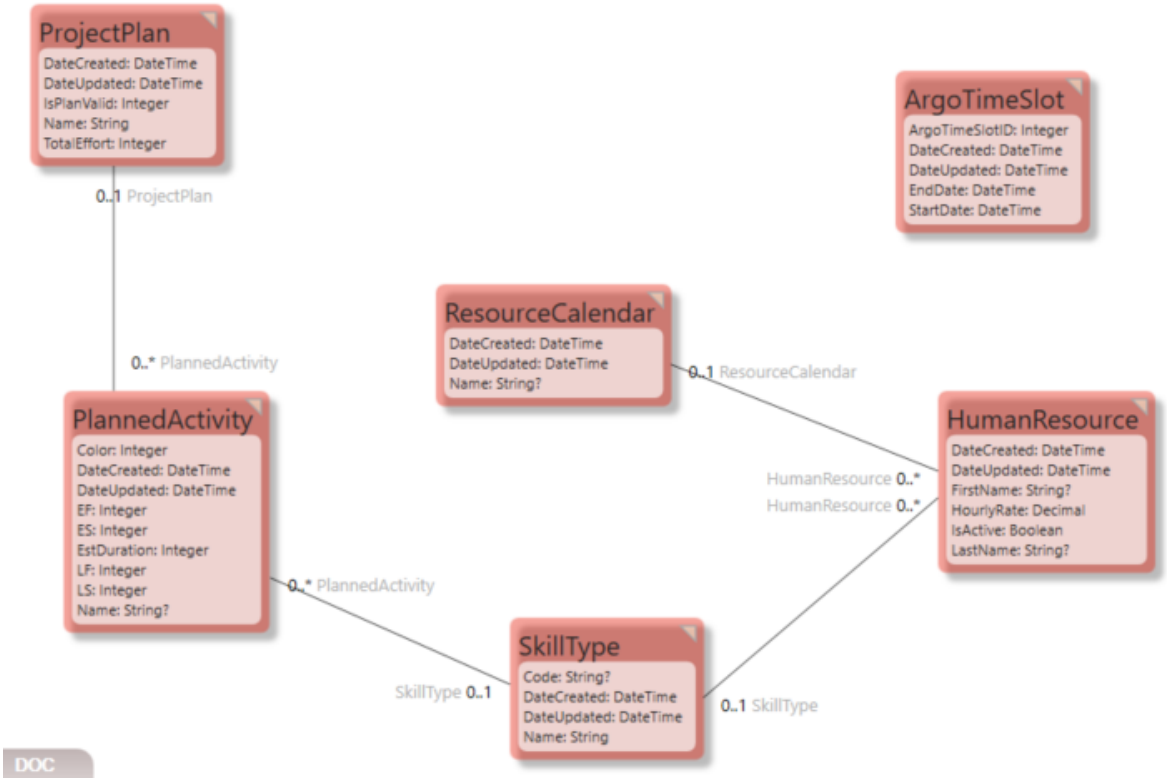

Figure 5.2 Scheduling Problem

The team have built a model representing the solution domain and structured to house all the information related to generated schedules and reflect relevant relationships. Figure 5.3 Scheduling Solution provides a snapshot of that model.

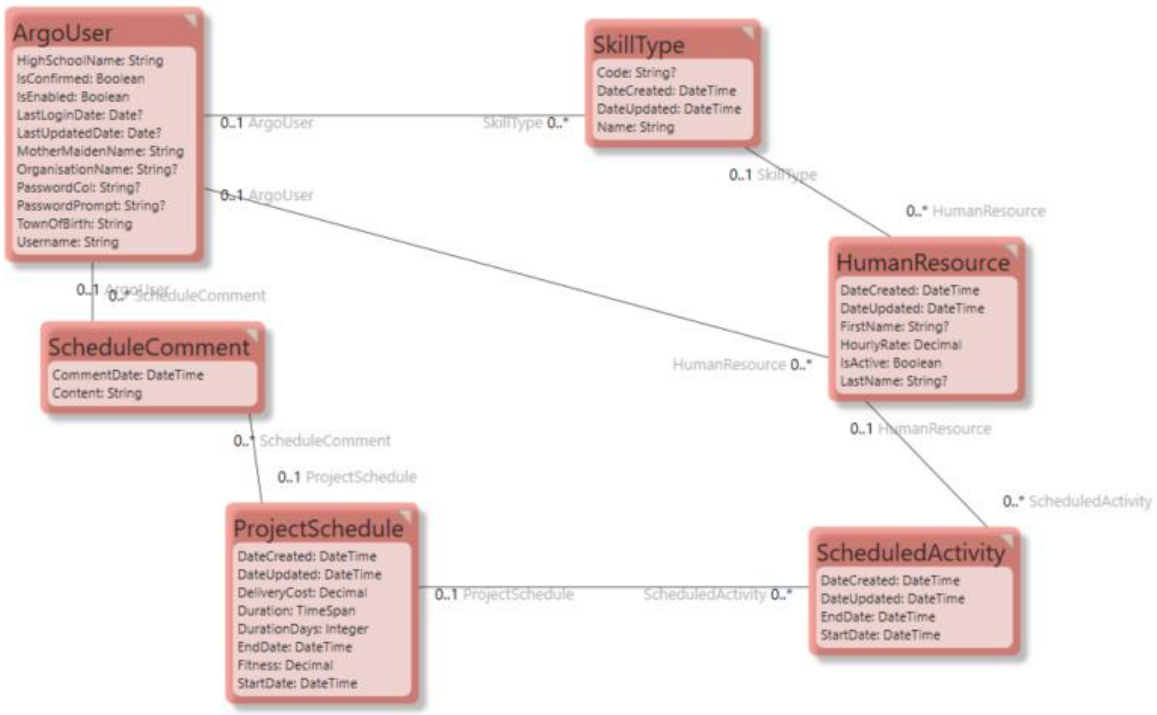

Figure 5.3 Scheduling Solution

They have developed a schedule generation engine, which allows creating valid and current operational solutions based on the earlier compiled solution design (aka solution plan) and the resource pool of available and suitable team members.

The work progressed to see how the outcomes of the scheduling engine could be optimised. Using the genetic algorithm approach, the author developed the optimisation engine, which generates optimised schedules out of the earlier produced samples.

Figure 5.4 GA - Cross Over provides a view of how the cross-over phase of the genetic operation selects a fitter sample to be included in the progressive search for an optimal solution.

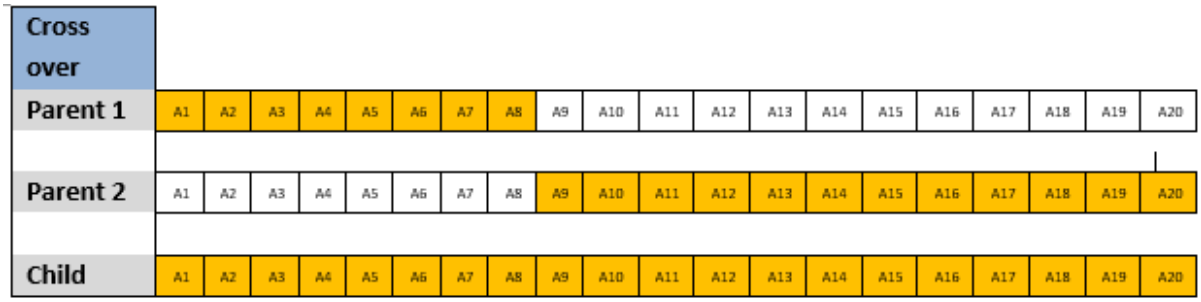

Figure 5.4 GA - Cross Over

Figure 5.5 GA – Mutation is included to show how the mutation step of the genetic operations modifies a given component of a sample to introduce randomness into the heuristic search.

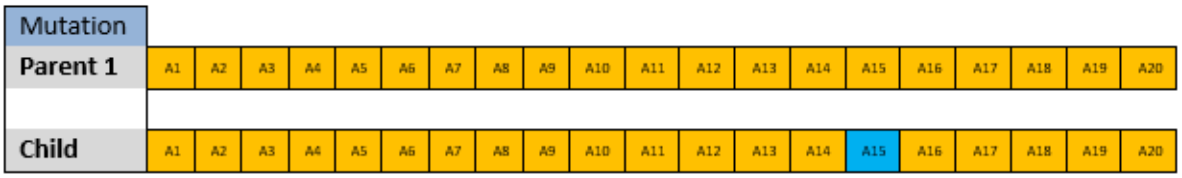

Figure 5.5 GA – Mutation

Out of the optimisation phase, a population of the suitable solution was generated. The end-user is presented with a view of that dataset and is able to select one variant to be taken into the program execution.

This is where the experiment concludes.

5.5 Findings and Related Work

In the business of IT solution delivery, the competition is fearless. Companies struggle to survive under market pressures. Shareholders and company boards demand profits and sustainable financial position. The following formula shows how the total operating profit would be calculated, based on the revenue generated via all the services sold to the end consumer and known operational costs.

$P = \sum_{j=1}^{N} Rj - \sum C;$

where:

P – Total operational profit

N – Total number of customer services provisioned

R – Revenue generated out of each customer services provisioned

C – Total costs of service operation

The amount of revenue companies can generate is usually limited by the competition and other market forces. They have very little ability to increase that value.

Costs of operations, however, is an entirely internally controlled factor and organisations embark on significant endeavours to reduce those to increase their profits. The tabled optimisation method allows taking these cost-saving exercises further by applying modern

artificial intelligence (AI) techniques and finding operational solutions which can offer additional costs savings.

Information presented in Table 5.2 IT Project Schedules shows how using the method a population of suitable solutions was generated. Each of those solutions meets the 'must-have' requirements (aka hard constraints). However, they meet the 'nice to have' requirements (aka soft constants) with various success rates. In particular, it can be seen how delivery costs and delivery time-related efficiency were achieved by the generated allocation schedules. The better a given solution meets a given soft constraint, the higher is the score for that quality. Table 5.3 IT Project Optimisation shows that the maximum and minimum values for delivery costs and duration used to measure how optimisation fluctuate significantly. This factor alone justifies costs of initiatives which organisations would run to implement efficiencies. For example, delivery duration parameter varied between minimum value in the population and its maximum counterpart by 19.52%. With a level of certainty, it can be assumed that if the optimisation phase was not applied to the end-to-end scheduling, a single generated solution, available to the end-users, would not be the most optimal. This means that only applying the optimisation techniques would allow the operators to find better quality schedules, which would allow achieving significant cost savings. This point is extremely important as in the current financial climate governing bodies, and sponsoring groups would like to see strong business cases when approving their capital expenditure.

Future work can extend this research in two distinctive directions.

1. Domain complexity
2. Optimisation complexity

When considering the first direction, we'd implement the method with a problem model much more complex and reflecting architectural reaches of multiple components comprising a modern IT delivery framework. A number of such components like dynamic organisational structures, data management, XaaS, cloud computing and IoT were already discussed earlier and will not be too difficult to continue their exploration in the technology implementation phases of the coming research.

Significantly spatial dimension can be added to the method to acknowledge the increased importance of geographical qualities of the scheduled solution. This will be especially beneficial when working with mobile workforce implementations.

The second one – optimisation complexity – can be covered by making the optimisation objectives much more extensive than explored and implemented here. In this experiment, the team have only worked with their fitness functions (i.e. delivery costs, delivery duration). Going forward, the author can look at including the following objectives:

- Human resources utilisation
- Equipment utilisation
- Offices and meeting rooms utilisation
- Ability to meet various stakeholders' priorities relative to different initiatives and outcomes
- Geographical awareness and optimal route planning of related transportations

The researcher anticipated that there would be much more opportunities to investigate the optimisation space even beyond the directions anticipated above.

The supporting technology can be improved to allow for larger populations of suitable solutions to be generated and made available for potentially better optimisation. Also, technology could be tuned to run the analysis and provide recommendations in near real-time for more intensive operational management function (i.e. running a truck company, running a fleet of hire vehicles, etc.)

Chapter 6 - Telecommunications Network Resource Allocation with Operational Management Optimisation

6.1 Introduction

6.1.1 Why was this work conducted?

Following the invention of a new operational optimisation method (Petukhov 2016) and its implementation in a laboratory environment, it seemed to be beneficial to try it in various industry settings and by doing so prove its suitability and benefit in the real-life problem domain. Specifically, in this experiment, the team wanted to apply it to the telecommunications resource allocation optimisation space to see if this given industry sector can capitalise on the opportunity. As resource allocation optimisation is a common problem in the private and public sector, we have decided to select the network resource allocation domain as the target space of this experiment.

6.1.2 How was it done? What were the approach and methodology?

Similar to other case studies that have performed to show the feasibility of the new development optimisation method, a suitable dataset was sourced to represent the problem domain. The literature review was conducted to investigate the context of the problem space and understand how existing knowledge addresses optimisation challenges. The study process has progressed into the actual solution proposal and implementation stage. Problem domain model was engineered and built on the top of the enterprise calibre technology stack. The input data set was imported into the model. The solution model was constructed in the same computing environment. Finally, scheduling automation and scheduling optimisation engines were developed. All the components have comprised an end-to-end operational scheduling and optimisation solution. This capability was used to run the experiment where required schedules were automatically generated and optimised.

6.1.3 What were the expected outcomes?

The research team was expecting that the method is successfully applied; the technology required for its implementation is built within a reasonable timeframe. They also wanted to see how outcomes of the optimisation experiment show a population of suitable solutions, which all meet the ‘must-have’ requirements (aka hard constraint). Member scheduling solutions

would be varying across different qualities by how they address the 'nice to have' requirements (aka soft constraints). Within a given population of suitable schedules, the soft constraints qualities would have to vary by a significant percentage (e.g. between 5 to 10%). If these outcomes are achieved, the team would be able to conclude that the cause study objectives have been achieved.

6.1.4 How is the chapter structured?

This chapter describes the overall eco-system of 5G technology and its enablers. By conducting a literature review, the author describes various concepts and critical challenges. They follow with more literature review focused on available ways to tackle optimisation challenges. Physically the chapter is structured as follows. Section 2 provides background information on the telecommunications sector. It focuses on the latest 5G technology that revolutionises the whole wireless communication space in Australian and abroad. It shows a number of enabling technologies which contribute significantly to the success of 5G. In this section, the majority of the literature review is presented to layout the field where optimisation opportunities can be applied. Section 3 shows how optimisation challenges are addressed in various areas of the telecommunications environment. Here we continue presenting outcomes of their literature review with emphasis on solutions currently available to operators wanting to tackle optimisation problems. In section 4, the team propose their own solution to optimisation challenges and describe the case study, showing what was completed in preparation for the experiment and how the testing was performed and results obtained. Outcomes of the case study are presented in section 5. Section 6 summarises the case study outcomes and proposes future work in the telecommunications space. Raw data representing experiment outcomes can be found in APPENDIX A.

6.2 Background and Key Concepts

6.2.1 5G

New standards and delivery methods, allowing for a multiple of speeds, bandwidth and reliability are gaining momentum in the current telecommunications world. In Australia, fifth-generation (5G) enabled mobile solutions are being rolled out across the country by multiple service providers. As stated by Zikria et al. (2018), the 'Fifth generation (5G) network is projected to support large amount of data traffic and massive number of wireless connections' (Zikria et al. 2018). Various telecommunications services have specific requirements in relation to the quality of service (QoS). The 5G mobile network addresses the limits of previous

mobile telecommunications protocols (i.e., 2G/3G/4G). It is considered to be a key enabler for the future Internet of things (IoT).

This technology will offer the consumer unprecedented levels of service, allowing for large data transfers in the wireless space in virtually real-time mode. According to Zhang et al. (2018), the currently considered requirements include 'peak data rates of 20 Gb/s, user experienced data rates of 100 Mb/s, a spectrum efficiency improvement of 3*, support for up to 500 km/h mobility, 1 ms latency, a connection density of 106 devices/km2, a network energy efficiency improvement of 100*, and an area traffic capacity of 10 Mb/s/m2' (Zhang et al. 2018). According to Khanna (2019), in the near future, 50 billion computing devices will be connected to the global IP network. 5G technology is developing at an extraordinary rate. It will allow organisations and individuals to communicate ever more reliably and efficiently. 5G will offer a very low latency (decreased to 1 ms). This will allow telecommunications services to support data and speed demanding activities such as 'virtual reality, driverless cars, factory robots, the emerging technology of Internet of Things (IoT), machine to machine communication, online gaming etc.' (Khanna 2019).

When being implemented, 5G mobile network will dynamically be allocated resources according to the immediate demand. Sheer volume of consumer devices and network components providing telecommunications services presents an enormous challenge of effective allocation of available resources to cover the demand. When solving this allocation problem, every small efficiency introduced to this allocation process will result in significant benefits being realised by the telecommunications companies.

6.2.2 SDN

Modern telecommunications networks are supported by complex and large technical architectures. Increasingly network solutions delivered using a software-defined network (SDN) approach. One way to do it would be provisioning a network function virtualisation (NFV) topology defined by the European Telecommunications Standards Institute (ETSI).

In their conference paper, Martin et al. (2019) discuss details of the successful launch of the 'Madrid Quantum Network'. 'This network is novel because it has been the first installed in production sites of a telecommunications operator and moreover it is managed through a software-defined networking (SDN) structure that integrates classical and quantum channels' (Martin et al. 2019). Among other topics, it focuses on one of its main architectural components, the quantum SDN node. Integration approach and interface implementation for

this solution were constructed in line with the specifications established by ETSI (European Telecommunications Standards Institute).

According to Khalili et al. (2019), 'network softwarization seems like a proper candidate to answer the systems interoperability and multi-tenancy challenges' relevant to today's telecommunications networks implementation. 'It represents an overall transformation trend for designing, implementing, deploying, managing and maintaining network equipment and components via software programming' (Khalili et al. 2019). Costs and energy consumption can be reduced when implementing modern approaches such as 'softwarisation technologies', 'network function virtualization (NFV)' and 'software-defined networking (SDN)'.

In their paper, Kim et al. (2018) present a solution based on SDN and 5G.

> We present a reconfigurable base-station of which its configuration can be determined by the software describing various network services required for the 5G mobile communications. In order for the software to be efficiently ported on the target platform, this paper suggests the concept of the RVM as an enabler for restructuring of logical nodes and/or radio characteristics of the base-station system. The base-station platform adopting the RVM enables the base-station system to cope with the evolution of various network services through a simple software download without any hardware changes (Kim et al. 2018).

Over the years, a number of patents were registered indicating the interest in this topic. One of them authored by Lokman and others (2018) helps those concerned with SDN roll out to implement systems and methods for convergence of software-defined network (SDN) and network function virtualization (NFV). This invention offers an innovative working solution to manage a number of components comprising the SDN effectively.

Interestingly enough, the idea of adopting the concept of SDN is being looked at in domains other than telecommunications. In their survey, Rehmani et al. (2019) are exploring its application to the energy distribution business. They show how the smart grid (SG) implementations can be taken to another level of programmability and compatibility and reliability by building the network components on the top of the SDN layer. SG includes a set of devices including 'phasor measurements units (PMUs), smart meters, supervisory control and data acquisition system to complex power generating and dispatching units' (Rehmani et al. 2019). SDN helps to form the foundation of effective SG control. They confirmed that when

SDN principals are applied in SG environments, opportunities arise to improve efficiency and resiliency of the end-users' solutions.

Another example of successful SDN application is tabled by Sanvito et al. (2018) They think that 'one of the key advantages of Software-Defined Networks (SDN) is the opportunity to integrate traffic engineering modules able to optimize network configuration according to traffic' (Sanvito et al. 2018). The network could be reconfigured as network conditions change, so as to achieve better efficiencies in resources utilisation in comparison to traditional static approaches. In their paper, the authors present a way of utilising SDN architecture to implement adaptive and robust routing approaches.

In their US patent Sela et al. (2019) propose a 'system, method, and computer program product for providing security in Network Function Virtualization (NFV) based communication networks and Software Defined Networks (SDNs)' (Sela et al. 2019). When implemented, the SDN-based solution can be easily re-configured to respond to security threats or suspicious activities. While the registration paper goes into the details of the invited method, we can clearly observe how beneficial the SDN concepts are in the context of network implementation for communication services and other domains where virtualisation of information technology (IT) functions is taking place.

6.2.3 Network Slicing

One way to support the 5G implementations and build-in required dynamics was to introduce network slicing, when a larger physical telecommunications network is separated into numerous logical layers, each functioning as a distinct network and providing services of its own, by using network virtualisation technologies, while considering their quality of service (QoS) requirements. This approach is subjected to numerous challenges related to the ability to deal with often conflicting priorities of the demand and service providers' capacity to allocated resources in an optimal fashion. Dighriri et al. (2018) have conducted an analysis of how such allocation can be done. They have offered a heuristic-based prioritised resource allocation scheme that takes into consideration both the intra-slice priorities and executes the resource allocation accordingly in order to meet the quality of service (QoS) requirements dictated by the service slice.

In their conference paper, Costanzo et al. (2018) also agree that 'network slicing is considered a key technology for the upcoming 5G system, enabling operators to efficiently support multiple services with heterogeneous requirements, over a common shared infrastructure'

(Costanzo et al. 2018). They demonstrated a solution for configuring ‘network slices’ in the ‘cloud radio access network’ (C-RAN). This architecture is considered the reference network architecture for 5G. They considered that the adoption of this approach should lead to a reduction of ‘capital expenditure (CAPEX)’ and ‘operational expenditure (OPEX)’. Their experiment showed how the introduction of network slicing allows for the respect of separate networks’ performances and for better re-use of the underlying physical infrastructure to achieve the anticipated efficiencies.

In their paper, Hoang et al. (2018) developed a technique for orchestrated network slicing. The research team proposes the optimal strategy that accomplishes ‘cross-slice admission configuration’ and resource assignment in 5G systems. To achieve their objectives, the team have employed the ‘Markov decision process’ and used the ‘value iteration algorithm’ to find the relevant optimisation approach. That prototype addresses a set of slicing challenges and tries to show how bandwidth resources can be efficiently shared across separate network slices at the same time while considering their unique requirements.

Costa-Perez et al. (2017) propose an innovative architectural design for a ‘5G transport solution (labelled 5G -Crosshaul) targeting the integration of existing and new front haul and backhaul technologies and interfaces’ (Costa-Perez et al. 2017). The concept of the Crosshaul comes from the infrastructure split related to the earlier days of mobile networks implementations. Based on the outcomes of existing research and standardisation forums leading the development of 5G, such as ‘5GPPP, NGMN, 3GPP, IEEE, ITU, IETF and ETSI’, the telecommunications community seem to agree that ‘front haul’ and ‘backhaul’ will merge into what some in research and standards groups refer to as ‘cross haul’ or ‘Xhaul’. The proposed design implements the idea of ‘network slicing’ used by the industry for realising a ‘flexible, sharable, and cost-effective 5G system’. It utilises a number of telecommunications techniques to lower costs and enable economies of scale and deliver carrier-grade QoS including ‘multi-tenancy/network slicing’ support.

As presented at the 2018 European Conference on Networks and Communications by Costa-Requena et al. (2018), it is extremely challenging to meet the required 5G network’s speed and throughput. ‘3GPP has defined a new architecture based on virtualization and Software-Defined Networks (SDN) supporting network slices that can fulfil those requirements’ (Costa-Requena et al. 2018). They presented the first realisation of the new 5G ‘user plane function (UPF)’ component that supported SDN and provided an optimised transport for improved speed as required in 5G networks. Their paper showed the results of implementing the ‘fully

distributed UPF/SDN network slicing', which is a building block for 'Ultra-Reliable Low Latency Communications (URRLC)' and the 'Mobile Edge Computing'. They conclude their work with the following statement:

> The modular SDN based user plane allows dynamic allocation of UPF in any part of the network as well as optimal management and orchestration of user plane resources. The system can scale up horizontally with additional UPF modules when traffic demand increases or vertically with additional instances of the 5G EPC (Costa-Requena et al. 2018).

As we can see, the dynamic and intelligent network resources allocation is very beneficial in the context of that study.

Another research paper by Ordonez-Lucena et al. (2017) looks at the realisation of network slicing as a suitable solution to simultaneously accommodate the wide range of services over a common network infrastructure; that vertical-specific use cases will be in demand in the context of 5G implementation in line with the SDN architecture proposed by Open Networking Foundation (ONF). They claim that 'although such architecture paves the way for network slicing implementation, it lacks some essential capabilities that can be supplied by NFV' (Ordonez-Lucena et al. 2017). To address that shortfall, the team analysed a proposal from the ETSI to incorporate the capabilities of SDN into the NFV architecture. They remind their readers that 'the concept of separated virtual networks deployed over a single network is indeed not new (e.g. VPN), although there are some specificities that make network slices a novel concept' (Ordonez-Lucena et al. 2017). Network slices are complete logical networks implemented on the top of a hosting network, either physical or virtual. The authors demonstrate an implementation case study of how NFV functional blocks, SDN controllers, and their interactions can work with network slicing. The same study shows how relevant resource split into two categories:

- Network Functions (NFs), which are functional blocks that provide specific network capabilities. NFs can be physical or virtualised.
- Infrastructure Resources represented by hardware and software for supporting NFs.

The ability to effectively allocate these resources and manage them through the operational cycle to ensure the balance between supply and demand is optimal and presents both the major challenge and a very attractive opportunity to those responsible for network administration.

Zhang et al. (2017) also state that when implementing 5G networks, the 'efficient resource allocation schemes should be exploited to improve the flexibility of network resource allocation and capacity of 5G networks based on network slicing' (Zhang et al. 2017). They also highlight the need for novel mobility management models required to support smooth handover in 5G solutions. The researchers introduced a resource assignment solution which allows satisfaction of technical requirements in the most effective way possible.

6.2.4 Edge Computing

Mobile Edge Computing (MEC), also known as Multi-access Edge Computing, is a concept which helps to manage mobile network components in a more efficient way while helping to achieve main communication objectives like lower latencies and better service reliability by pushing some of the devices closer to the network consumers (the edge). This protocol plays an important role in 5G implementations. It is especially relevant in the context of significantly larger volumes of data being communicated throughout the network and higher expectations of the delivery speeds. MEC works closely with SDN and cloud computing (CC). In their ETSI White Paper, Hu et al. (2015) describe a few MEC application scenarios. These include:

- Augmented Reality
- Intelligent Video Acceleration
- Connected Cars
- Internet of Things Gateway

Shi et al. (2016) have researched the following applications of MEC:

- Cloud Offloading
- Video Analytics
- Smart Home
- Smart City
- Collaborative Edge

In their paper, Xiong et al. (2018) describe how MEC architecture fits into the blockchain technology, which has recently become 'a promising decentralized data management framework'. That research team proposes multiple access to mobile edge computing to manage blockchain applications in the mobile Internet of things (IoT) environments. When complete, that solution will solve the proof-of-work challenges for mobile users. For efficient edge resource management in mobile blockchain, they have used a 'Stackelberg game model'.

It is known that the application of the MEC goes well beyond the examples tabled here. A very well-known standard body – European Telecommunications Standards Institute (ETSI) – is running the Industry Specification Group (ISG)' on MEC. That group is delivering 'normative Group Specifications that will enable the hosting of third-party applications in a multi-vendor environment' (Hu et al. 2015). They also think that 'MEC complements NFV and is fully aligned with the emerging distributed cloud approach. It is recognised as a key technology of the future 5G era, satisfying the demanding requirements for ultra-low latency and stimulating innovation' (Hu et al. 2015).

Looking closer into the 'Internet of Things (IoT)' scenario, Premsankar and others (2018) recognised that IoT 'devices (including sensors, smartphones, and wearables) are characterized by limited computational and energy resources. Such limitations are currently addressed by offloading processing and storage from resource-constrained devices to the cloud' (Premsankar, Di Francesco & Taleb 2018). As a result, network performance (i.e. bandwidth and communication latency) may become bottlenecks. They show how applying MEC to this case may help with this risk mitigation. Results of their experiments show that MEC does allow to meet the latency requirements of applications implementing one of the IoT cases – virtual and augmented reality. They have observed that pushing the deployment of some computing resources at the network edge helps improve the overall solution quality of the end-user satisfaction with the offering.

Roman and others (2018) talk about security concerns applicable to MEC. In their study, they have holistically analysed the security threats, challenges, and mechanisms inherent in the edge computing paradigms. The following security threats need to be accounted for:

- Denial of Service (DoS)
- Man in the middle
- Rogue gateway
- Physical damage
- Privacy leakage
- Privilege escalation
- Service manipulation
- Rogue data centre
- VM manipulation
- Injection of information
- Service manipulation

The above lists are clearly not full, but rather indicative of what should be considered when assessing security risks related to edge implementations.

Not only MEC promises to deliver highly responsive cloud services for mobile computing but also helps to mask transient cloud outages (Satyanarayanan 2017). This happens when 'cloud service becomes unavailable due to network failure, cloud failure, or a denial-of-service attack, a fallback service on a nearby cloudlet can temporarily mask the failure' (Satyanarayanan 2017). A cloudlet could act as a proxy for the larger cloud and perform its functions. When the failure is rectified, those communications committed to the cloudlet will have to be propagated to the restored cloud.

Existing literature on MEC identified the following challenges and opportunities (Shi et al. 2016):

- Programmability
- Naming
- Data Abstraction
- Service Management
- Privacy and Security
- Optimisation Metrics

Programmability. Normally, the software is written in a given programming language and is then compiled for a certain executing environment. Differently, in edge computing, computation is distributed across all the tiers comprising the solution, and the edge nodes would be running on heterogeneous platforms. Thus, the executing domain of these nodes differ from one another, and the programmer is faced with a challenge to compile a software that has to be suitable for the edge computing platform.

Naming. When MEC is implemented the number of items incorporated into the network's solution is incredibly large. The naming convention in edge computing is very important for programming, addressing, things identification, and data communication. This presents a rather unusual challenge to the implementation of working groups.

Data Abstraction. Again, a sheer volume of communication between that already large volume of network devices generates a lot of data. Its effective management becomes a challenge on its own.

Service Management. The researchers argue that the following four fundamental features should be supported to guarantee a reliable system. These are: differentiation, extensibility, isolation and reliability.

Privacy and Security. At the edge of the network, user privacy and data security protection are the most important services that should be provided.

Optimisation Metrics. As the entire solution employing the MEC is much more complex, the optimisation will also be much more challenging.

6.2.5 Heterogeneous Cloud

Cloud computing is known to be a model for enabling convenient on-demand network access to a shared pool of configurable virtualised computing resources that can be rapidly provisioned when required and released at the end of their lifecycle with minimal management effort from the service providers.

While traditionally cloud computing infrastructure assumes a homogeneous cloud when all the solution components are deployed on a single vendor platform, heterogeneous cloud comes into picture when various network parts are deployed to infrastructure hosted by more than one service provider and therefore helps to avoid vendor lock-in.
Academic literature and industry specifications describe implementations of heterogeneous cloud in multiple publications.

In the context of storage management implementation, Borlick et al. (2019) have proposed ‘a method, a system, and a computer program product in which a computational device stores a first part of data in a first cloud storage maintained by a first entity’ (Borlick et al. 2019). The rest ‘of the data is stored in second cloud storage maintained by a second entity’ (Borlick et al. 2019).

Presenting at the 2018 USENIX Annual Technical Conference, Klimovic, Litz, and Kozyrakis (2018) proposed a technology that recommends ‘optimal configurations of compute and storage resources based on sparse training data collected across applications and candidate configurations’ (Klimovic, Litz, & Kozyrakis 2018). Known as Selecta, that tool utilises ‘latent factor collaborative filtering’ to forecast how a given system will perform across various parameters. This prediction is calculated based on information collected by categorising system workloads. The proposal is successfully addressing challenges related to the

implementation of storage for data analytics solutions, which utilise ‘data-intensive workloads’ in ‘public cloud’ environments. These include ‘selecting the right capacity, bandwidth, and latency’ for these applications, given the populations of the suitable solutions are large and the relationships between system qualities are complex. Additionally, they acknowledged that finding the supply and demand balance, defined by the different intensity data transfer and different types of available storage devices, is also very challenging.

Lee et al. (2018) have been exploring ‘multitenant cellular network slicing under the heterogeneous cloud radio access network (H-CRAN) architecture’. The scheme responsible for that slicing is considering the following factors: ‘tenants’ priority, baseband resources, front haul and backhaul capacities, quality of service (QoS) and interference’. They conclude that with the ‘dynamic allocation’ of all computing devices, their method could maintain a great resource utilisation level in scenarios with tenants provided ‘homogeneous’ and ‘heterogeneous’ capabilities.

Peng et al. (2015) stipulated that ‘a heterogeneous cloud radio access network (H-CRAN) is presented as the advanced wireless access network model’. It helps telecommunications companies to achieve objectives of their 5G roll-outs. They acknowledge that ‘software-defined H-CRAN’ system architecture is compatible with ‘software-defined networks (SDN)’. The major challenges observed in the researched domain include resource allocation optimisation and energy consumption that may impact the adoption of H-CRANs.

Zhang et al. (2015) have discussed various aspects of heterogeneous cloud small cell networks. ‘Heterogeneous small cell network has attracted much attention due to the explosive demand of users’ data requirement’ (Zhang et al. 2015). In this technology, small cells (i.e. femtocell, relay, picocell) ‘together with macrocells, can improve the coverage and capacity of cell-edge users and hotspot by exploiting the spatial reuse of spectrum’ (Quek et al. 2013, in Zhang et al. 2015). These small cells can absorb the increase in data usage. For instance, ‘in an indoor environment, WiFi and femtocells can offload most of the data traffic from macrocells’ (Peng et al. 2015, cited in Zhang et al. 2015). Adoption of small cells could decrease capital expenditure (CAPEX) as well as the operating expenditure (OPEX) due to the self-installing and self-operating features of femtocells base stations. Outcomes of their research allow operators to improve the volume of HCSNet and retain the expected end-users’ QoS.

6.2.6 Hybrid Multiple Cloud

As described in a patent titled ‘Location-aware virtual service provisioning in a hybrid cloud environment‘, when an enterprise data centre runs ‘out of capacity, the enterprise cloud operator may opt to buy more hardware, which permanently increases hardware and operational costs’ (Chang et al. 2018). An alternative approach would be to get the required resources from a public cloud repository, and temporarily increase data-centre costs during the times of high demand. According to a paper by Chang et al. (2018) ‘When the enterprise data center leases capacity from a public or cloud data center, the combination of the enterprise cloud and public cloud is referred to as a hybrid cloud’ (Chang et al. 2018).

As Leavitt (2013) puts it, we know two main hybrid cloud provisioning models. The first one is known as a cloud-bursting model. It prescribes organisations utilise ‘in-house cloud’ capacity to run applications under normal conditions and ‘public cloud’ services to manage situations when applications’ activity is unexpectedly increasing and for other ad hoc needs. In the second approach, organisations run applications for sensitive and confidential information on privately hosted computing environments and employ outsourced capacities for less critical applications. As indicated by Kantarcioglu,

> Users get higher overall throughput because they increase public cloud resource usage as demand increases. Keeping private data locally under control in a secure private cloud enhances the security. And using public-cloud resources as needed might be cheaper than investing significant resources in building a large private cloud infrastructure (Kantarcioglu in Leavitt 2013).

In their US patent paper, Chang et al. (2018) describe how a location awareness is achieved within a ‘service provisioning scheme to reduce latency observed in conducting policy evaluations across a network in a hybrid cloud environment network, e.g., the Internet, in a hybrid cloud environment’ (Chang et al. 2018). The location attributes of cloud resources could be used for provisioning several virtual capabilities such as Virtual Security Gateways (VSGs), Virtual Wide Area Application Services (vWAAS), and Adaptive Security Appliances (ASAs).

In another US patent, Chang, Patra and Bagepalli. (2018) propose a system and method for scaling multi-clouds in a hybrid cloud architecture: hybrid cloud architecture and Intercloud Fabric (ICF), which is available commercially from Cisco Systems, Inc., of San Jose, California. This is an enterprise-centric hybrid cloud solution which extends enterprise infrastructures of customers to public clouds in order to fulfil hybrid cloud use cases such as workload migration, cloud bursting and disaster recovery. ICF allows a given enterprise to effectively recreate its data centre within a public cloud. Multi-cloud adds additional public

clouds to architectures that use hybrid clouds. That is, multi-clouds add more clouds to the mix than a conventional hybrid cloud, which normally joins a private cloud and a public cloud. A multi-cloud approach could be implemented by two or more public cloud services providers. The ability to scale multi-clouds in hybrid cloud architecture is critical to allow for the efficient implementation of multi-clouds. The multi-cloud strategy opens an opportunity to allow an enterprise to migrate workloads from an enterprise data centre to one or more public clouds or service provider clouds, and to use the cloud-native services offered by one or more cloud providers. Their method provides a routing interface in an ICS for connecting cloud services. It allows services of multiple clouds and, hence, cloud providers, to be utilised in a more efficient manner.

Another multi-cloud related development (Chang et al. 2018) proposes a distributed hybrid cloud orchestration model. They observed that when an enterprise data centre shares or leases computing resources from another data centre (e.g., a public cloud data centre), the resultant combination of computing resources is referred to as a 'hybrid' cloud. Its infrastructure generally includes two or more clouds that inter-operate network communication, such as a network overlay. Because of that hybrid cloud can represent an interaction between multiple clouds (private and public). The private cloud might join a public cloud and consume its resources in a secure and scalable way. Hybrid cloud environments offer numerous advantages. Still, the expansion of cloud services, and/or migration of workloads between cloud environments is often onerous and complex. The researchers proposed an infrastructure orchestration module, which is used to provide low-level abstractions of infrastructure orchestrations, to address these complexities. Such abstractions include cloud resources discovery, cloud resource lifecycle management, image format transformation, image transportation and/or template creation. The VMM/cloud platform infrastructure adapter module is used to provide a cloud adapter layer, for example, for translating infrastructural orchestration functions into VMM/cloud-specific APIs (e.g., vCenter, API, AWS API, OpenStack API) and submitting API requests to target VMM/cloud API endpoints.

Another US patent registration (Doctor & Probst 2018) addresses challenges related to hybrid cloud network monitoring systems for tenant use. They acknowledge that public cloud services providers publish tenant application programming interfaces (API). These interfaces support features concerned with managing the IaaS components programmatically. Still, the use of such public cloud services is normally kept separate from the use of existing computing resources in data centres managed by an enterprise. To deal with this issue, they have proposed a virtualisation manager, which includes a hybrid cloud management module

configured to manage and integrate virtualised computing resources provided by cloud computing systems with virtualised computing resources to form a unified ‘hybrid’ computing platform.

Maes et al. (2018) continue research in the hybrid cloud space by proposing a novel method to orchestrate hybrid cloud services. It shows how orchestration of the cloud services can be improved to cover hybrid cloud services. Ultimately the solution in question implements the end-to-end coverage of all the resources included in a given hybrid cloud solution.

According to Petcu (2014), deployment of network resources to multiple clouds is natural evolution from ‘in-silo clouds’. Companies go through such a transition to achieve higher service availability and decrease operational costs. Some technology, helping to manage such consumption is already available. Their paper provides a discussion on multiple clouds and offers a taxonomy. It defines and classifies the suitable software and services. Also, their research describes consumers’ and providers’ business needs and functional requirements relevant to this space. They state that

> There are two basic delivery models in place for multiple Clouds: Federations and Multi-Clouds. In the first case the Cloud providers are in agreement with each others to provide the Federation aiming to enhance the service offer to their service consumers, while in the second case, a third party is building unique entry point for multiple Clouds, without a prior agreement with and between the Cloud providers (Petcu 2014).

They point out that a ‘hybrid cloud’ is a type of ‘multi-cloud’ that connects two or more clouds that vary in their deployment models (Public, Private, Community).

Reed et al. (2018) registered a US Patent that introduces a resource managing broker to complement a hybrid cloud management system. The proposed solution includes a management interface, components which implement the broking functionality. The demonstrated management interface facilitates user-selection of services including service models and deployment models for an internal cloud and an external cloud. The cloud broker is coupled with the management interface and it automates service components configuration. The resource broker is coupled with the cloud broker to manage a resource inventory of the internal cloud. In some examples, the resource broker could manage pools of resources in other clouds, but in some cases, other cloud includes its own inventory and resource management functionality and is coupled to the cloud broker through cloud connector. Typically, the resource broker does not manage external clouds because clouds of third-party

service providers may include dissimilar resource management functions and responsibilities. External clouds are then also coupled to the cloud broker through cloud connectors.

As stated by Sotomayor et al. (2009) 'cloud' is 'an infrastructure-as-a-service (IaaS) system, in which IT infrastructure is deployed in a provider's data center as virtual machines' (Sotomayor et al. 2009). With their adoption rate growing, IaaS clouds, tools and technologies appear that can help companies to migrate their physical hardware to a private or hybrid cloud infrastructure provisioning model. The research provides an analysis of available virtual infrastructure (VI) management tools, which would cover various flavours of cloud implementations, including multiple hybrid clouds and will support a full life cycle of the VMs in question.

> OpenNebula is an open source, virtual infrastructure manager that deploys virtualized services on both a local pool of resources and external IaaS clouds. Haizea, a resource lease manager, can act as a scheduling back end for OpenNebula, providing features not found in other cloud software or virtualization-based data center management software (Sotomayor et al. 2009).

These two open-source projects, 'OpenNebula' (www. opennebula.org/) and 'Haizea1' (http://haizea.cs.uchicago.edu/), support one another. They are utilised to host 'virtual infrastructures (VIs)' in private or hybrid clouds. OpenNebula is a 'VI manager'. It is designed to establish and support virtual machines (VMs). This management can manage VMs one at a time or in groups, whether deployed to private or external public clouds. Haizea can be described as a resource provisioning orchestrator. It performs as a scheduling engine for OpenNebula. It can offer leasing functionality which is not available in other cloud management systems.

As stated by Van den Bossche and others (2010):

> With the recent emergence of public cloud offerings, surge computing – outsourcing tasks from an internal data center to a cloud provider in times of heavy load– has become more accessible to a wide range of consumers. Deciding which workloads to outsource to what cloud provider in such a setting, however, is far from trivial (Van den Bossche, Vanmechelen & Broeckhove 2010).

The objective of their paper is to demonstrate how to increase the utilisation of the enterprise data centre and how to minimise the cost of running the tasks hosted externally while fulfilling the consumers' quality of service (QoS) constraints. They have examined possible solutions

of this optimisation problem in 'a multi-provider hybrid cloud setting with deadline-constrained and preemptible but non-provider-migratable workloads that are characterized by memory, CPU and data transmission requirements' (Van den Bossche, Vanmechelen & Broeckhove 2010). They have proposed a binary integer formula to solve the scheduling problem and evaluated the processing costs of this approach. They have found out that the proposed approach results in a controllable resolution of the scheduling challenge in the 'public cloud'. They acknowledged that this method would be less effective in a 'hybrid cloud' environment because of significant differences in timing factors.

As can be seen here, SDN, network slicing, Mobile Edge Computing, heterogeneous and hybrid clouds are all enabled of 5G technology. Existing literature describes architectures, protocols and applications relevant to all these concepts. It also tables all the opportunities and challenges related to those. This study's literature review clearly shows that the optimisation problem is a very common topic discussed and addressed in almost all related research.

6.3 Problem Statement and Known Solutions

6.3.1 Problems

As described earlier in this chapter, a fully functional 5G implementation is complex and large. It is supported by a magnitude of the physical and virtual devices which work together in line with a number of protocols and specifications. Some of these include SDN, network slicing, Mobile Edge Computing, heterogeneous cloud and hybrid cloud.

All the components of the new network architecture need to be effectively managed, and if possible, the allocation of related resources has to be optimised. For optimisation to be effective and comprehensive, it would need to cover the following solution qualities:

- CPU utilisation
- Storage utilisation
- Memory utilisation
- Costs of resource allocations in multiple hybrid clouds
- Resource sharing among network slices
- Service delivery speeds and responsiveness in the context of MEC (Mobile Edge Computing)
- Reliability of relevant network components (self-healing)

6.3.2 Known Solutions

Existing literature has a magnitude of discussions on how the optimisation problem is currently addressed by both academia and industry. Presented below is a subset of those discussions, indicating the known approach to tackling efficiencies and search for optimal system performance and resource allocation in balance with the costs of implementation and users' expectations.

SDN

In a traditional telecommunications network constructed out of physical purpose-built devices, resource management and optimisation is challenging as the cost of replacing devices in their installation locations is high. This means that to deal with potential increases in demand initially installed network components often have performance quality much higher than initially required, meaning that utilisation levels are quite low. As solutions are utilised, and demand for service increases, the earlier provisioned infrastructure becomes better utilised. Unfortunately, sometimes such increase in consumer needs never eventuates. This results in lower levels of utilisation persisting over the full solution life cycle.

By its definition (out of the ETSI SDN/NFV specification) of making the network components implemented as software packages, the SDN open numerous opportunities for resource allocation automation and optimisation. This is largely possible because it is relatively easy and inexpensive to deploy software-defined network components to meet the current requirements and when they later change, redeploy upgraded network component configured and to meet the latest needs. This way, it is not necessary to allow for redundancy to cover a possible increase in demand and, as a result, maintain high levels of resource utilisation.

Software-defined satellite networks help to avoid over-allocation of satellite bandwidth and maximise efficiency (Khalili et al. 2019).

> In some cases, content might be pushed to the edge in order to offload the network and improve the end users' QoE. Some Network Function (NF) can also be migrated to the edge, leading to the transport of different 5G interfaces as defined in through the satellite. In the backhaul example, no NF is migrated, thus the satellite would carry 5G N1, N2 and N3 interfaces (Khalili et al. 2019).

A paper on 'Quantum aware SDN nodes' in the 'Madrid quantum network' discusses the SDN controller, which 'gathers information from each SDN-QKD node and set the optical connections appropriate to serve the application requests in the different nodes' (Martin et al. 2019). This approach allows a QKD device to publish its capabilities and for the SDN controller

to know what resources could be assigned to workloads and be aware of the overall network status. This logic can optimise the combined utilisation of both ‘quantum’ and ‘classical’ sections of the entire network solution.

According to Rehmani et al. (2019), SDN can bring many benefits related to the smart grid (SG) traffic optimisation.

> For instance, SDN’s controller can help to build different data trees depending upon specific SG application and its QoS requirements. These data trees can work in publish/subscribe fashion. The utility needs data from PMU and meters residing in consumer’s premises. With the help of SDN, two different data trees with varying depth and QoS requirements can be easily managed. The PMU’s data collection tree can be of real-time QoS requirement with smaller depth, while consumer’s meter data collection tree can be of smaller width in order to tackle with limited memory constraint of flow tables in the OpenFlow switches (Rehmani et al. 2019).

Advantages of SDN-based SGC include: 1) packet forwarding performance, 2) fairness among smart meters, 3) scheduling and flow aggregation, 4) bandwidth allocation, and 5) WAN traffic communication applications.

‘Traffic Engineering (TE) plays a crucial role for service providers since it permits to optimize network performance, reduce operational costs, and load balance the utilization of network resources’ (Sanvito et al. 2018). To improve the routing optimisation process, the authors propose a multi-TM robust optimisation method.

Network slicing

Discussing orchestration as a key process for network slicing Ordonez-Lucena et al. (2017) remind us that ‘orchestration can be defined as the art of both bringing together and coordinating disparate things into a coherent whole’ (Ordonez-Lucena et al. 2017). Implementation of the optimisation policies is also the responsibility of the employed orchestration part of the larger architecture.

Zhang et al. (2017) ‘introduced a logical architecture for network slicing based 5G systems, and present a scheme for managing mobility between different access networks’ (Zhang et al. 2017). They have employed a genetic algorithm to optimise resource

allocation. They also show how the available resource allocation scheme, which considers interference management, can guarantee mixed QoS.

In a new approach for implementing existing and new 'front haul' and 'backhaul networks' into a modern smart grid (SG) transport solution was presented by Costa-Perez et al. (2017). They address challenges around the 'flexibility, data plane interoperability, and system-wide management and optimization of heterogeneous technologies of the integrated SG transport network referred to as SG-Crosshaul' (Costa-Perez et al. 2017). Resource Management Application (RMA) was a critical part of the proposed solution.

> The RMA is the decision entity in charge of making optimized decisions on the control and management of the underlying network, computing, and storage resources. The RMA collects different types of information from the underlying network infrastructure via the NBI, and runs optimization algorithms for context-aware system-wide resource allocation. Such decisions, for example, routing and re-routing, coordinated transmission power control, and algorithms to configure local scheduling (Costa-Perez et al. 2017).

To manage physical resources, the RMA can run optimisation in interaction with a controller.

At the 2018 European Conference on Networks and Communications Costa-Requena et al. (2018) presented a realisation of the innovative 5G 'user plane function (UPF)' that works with SDN and provides an optimised mechanism to reduce network latency. That UPF enables the usage of efficient transport technologies (e.g. virtual LANs [VLANs], Multiprotocol Label Switching [MPLS], generic routing encapsulations [GREs]) in the 'mobile backhaul' right after the Evolved Node B (eNB).

As presented by Dighriri et al. (2018), effective resource allocation in the network slicing situation can be implemented. In their research they have offered a 'heuristic-based prioritized resource allocation scheme'. It takes into consideration the 'intra-slice' priorities and runs the resource allocation process to meet the 'Quality of Service (QoS)' requirements specified by the 'service slice'. That resource allocation method was described in their paper. The method can be used to deal with the additions of new slices or consumers. It implements a global optimisation of the resources related to all 'service slices'.

According to Hoang et al. (2018), it is difficult to implement resource orchestration of the network slicing solution. They show how the optimisation process would run to find the most efficient balance between the demand for services and the availability of suitable resources.

When using network slicing telecommunications 'service providers can reduce overall costs by shifting more components to a common physical infrastructure while optimizing its use, allowing them to respond more dynamically to changing market demands by deploying new applications and services as needed' (Lokman et al. 2018).

In their prototype, implementing a system to manage network slices in the 'Cloud Radio Access Network (C-RAN)', Costanzo et al. (2018) showed how operators could deal with the spectrum slicing problems. They aim to achieve efficient sharing of the bandwidth capacity among various slices and take into account the unique service performance needs. Their prototype utilised the 'Open Air Interface (OAI)' technology and a specific software-defined network (SDN) controller, known as FlexRAN. It implements a 'software-defined network (SDN)' architecture and efficiently shares spectrum between different network slices.

Edge computing

Implementations of mobile edge computing (MEC) help to 'optimize network operations and resource utilization' (Hu et al. 2015), while allowing for the growth of mobile traffic. In that context 'knowledge of real-time radio network conditions and context information can be used to optimize the network and service operation (responding and adapting to changing network conditions)' (Hu et al. 2015). This technology enables innovative 'service scenarios that can ensure enhanced personal experience and optimized network operation' (Hu et al. 2015). A few examples available in the literature demonstrate how the geographical closeness of users and objects and network and context information could play their role in optimisation network resources allocation.

Implementations of the IoT solutions are particularly sensitive to the geographical factors impacting communication. This makes MEC even more useful when managing network resources. Its ability to push processing to the edge nodes has become an enabler for the successful deployment of next-generation IoT applications (Premsankar et al. 2018). NFV and SDN also help to support this optimised resource management approach.

As established by Roman and others (2018) the 'benefit of deploying cloud services at the edge of mobile networks like 5G include low latency, high bandwidth and access to radio network information and location awareness' (Roman, Lopez & Mambo 2018). It is largely that location awareness that helps to optimise management of the existing mobile infrastructure. Optimised VM lifecycle would be made possible as the result of the ability to dynamically allocate components of the service infrastructure in a highly distributed environment. In those

conditions, data centres located on the edge of a given network might be owned by different infrastructure providers and can communicate regardless of their physical location. The same optimisation of VMs management can be achieved across their lifecycle in the 'fog computing' ecosystems where the goal is to optimise the allocation of VMs over a set of local clusters. A number of algorithms have been made available to deal with scenarios where VMs need to be replicated, migrated, and merged. For these optimisation algorithms to work, the decentralised infrastructure should be able to access local information. As long as this is possible, the method can be modified to work with any edge paradigm.

According to Shi et al. (2016) 'edge computing' deals with many geographically separate tiers with various processing power. In such a complex system architecture workloads allocation is very important. The network operator needs to determine which tier should handle a given workload. Multiple allocation strategies are available to deal with this. For example:

> Evenly distribute the workload on each layer or complete as much as possible on each layer. The extreme cases are fully operated on endpoint or fully operated on cloud. To choose an optimal allocation strategy, we discuss several optimization metrics in this section, including latency, bandwidth, energy and cost (Shi et al. 2016).

Xiong et al. (2018) show how in the context of established MEC and related services pricing models offered by providers, services consumers need to manage their requests for edge computing services to maximise the return on investment (RIO). Introducing pricing models, which encourage consumers to consider a better return on their investment, has become a common approach to achieve resource allocation optimisation and better utilisation of available infrastructure.

How is an optimisation applied in the possible outage context?

Heterogeneous cloud

In their research related to 'heterogeneous cloud radio access network (H-CRAN)' as the modern telecommunications network paradigm Peng et al. (2015), demonstrated system components that allow intelligent and self-organising network management. Such a method would be applicable to a scenario where the network layer had to implement 'self-configuration', 'self-optimisation', and 'self-healing'. Such a scenario would allow for 'ultra-dense communication' when a large number of nodes are being launched. That study shows

how powerful optimisation strategies are employed to enable traffic optimisation and optimal system performance.

In ‘cooperative interference mitigation and handover management in HCSNet, where cloud radio access network is combined with small cells’ (Zhang et al. 2015) energy-efficient resource optimisation, optimised system performance, optimised handover scheme and self-optimising power control are topics of interest. These are being addressed by the introduced optimisation algorithms.

In the context of storage management implementation, Borlick et al. (2019) have proposed a method to store information on multiple cloud entities. One of the objectives of any implementation in this space, recognised by the researcher and achieved in the proposed solution is the effective management and optimisation of scare network resources.

Presented at the 2018 USENIX Annual Technical Conference by Klimovic, Litz, and Kozyrakis (2018) a new tool, known as Selecta, introduces ‘near-optimal configurations of compute and storage resources based on sparse training data collected across applications and candidate configurations’ (Klimovic, Litz, & Kozyrakis 2018). It helps with the overall storage optimisations in relation to all functions and components of the underlining solution.

When they implement multitenant cellular network slicing under the ‘heterogeneous cloud radio access network (H-CRAN)’ architecture (Lee et al. 2018), the network throughput optimisation was introduced via optimal resource allocation.

Hybrid multiple cloud

Like many other researchers, Van den Bossche et al. (2010) are motivated by opportunities to contribute to the goal of cost-optimal resource allocation. They apply their resource to a hybrid cloud setting. They investigate ‘the design of software components and algorithms for building and deploying hybrid clouds efficiently, and for automated resource provisioning and management at the level of an entire organization’ (Van den Bossche, Vanmechelen & Broeckhove 2010). Within their Cloud Procurement Endpoint (CPE), they implement an optimisation engine, which is responsible for scheduling the application function in a cost-minimising fashion. They think that tackling issues like network costs, relations between runtime and network traffic costs, other ad hoc considerations could be done by designed bespoke heuristics or using other optimisation instruments. In their opinion, this could be investigated further in future research.

When applying one of the two known hybrid cloud deployment models (Leavitt 2013), opportunities for cost reduction via the optimal use of public cloud infrastructure are identified and explored. They consider applying the cloud-bursting model when organisations use in-house cloud environments to run their enterprise applications and public cloud capacity to manage applications' activity increases. Also, they could utilise the cloud-bursting model when organisations execute applications that manage sensitive data on private clouds and push other applications to public cloud vendors. Depending on the use case, slightly different optimisations and efficiencies come into play around data transfer and synchronisation in the context of effective exchange of information between the public and private clouds.

Looking at the multiple clouds from the consumer requirements point of view, Petcu (2014) focus on cost optimisation balanced with the improvement of service quality. In their discussion, a way to find the right balance between the two by applying effective resource management techniques is presented. A broker component is able to make proposals for service provisioning contributes to a multi-criteria optimisation system.

In a new hybrid cloud services orchestration method Maes et al. (2018) improve resource allocation by introducing application programming interfaces (APIs), which allow resource management function to be performed across at least two of the cloud resources. This efficiency can be applied to various types of cloud services, including clouds formed from traditional networks, public clouds, private clouds, next-generation data centres, managed clouds and virtual private clouds.

A method where users can reconfigure the hybrid clouds with different infrastructures, platforms and software to optimise workload management on appropriate resource pools is proposed by Reed et al. (2018) in their US patent.

6.4 Case Study

We have applied the method and techniques developed in the larger study to the optimisation of telecommunications network allocation resources, which is a highly complex domain. It includes network design, planning and resource provisioning.

As can be seen in Figure 6.1 Argo AI - E2E Scheduling Process, implementation of the automation and optimisation engines are at the core of the new method.

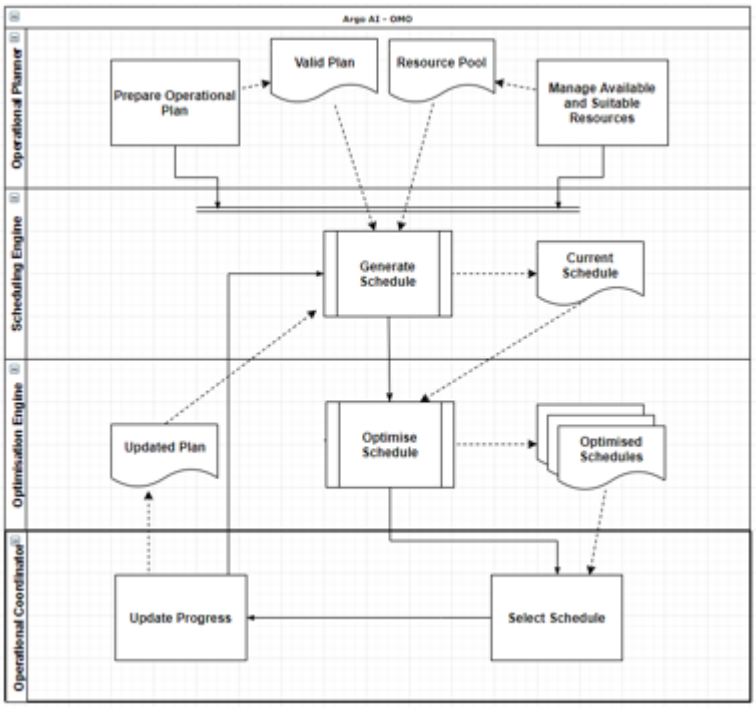

Figure 6.1 Argo AI - E2E Scheduling Process

Within the experiment, we have completed the following work components.

The author has collected and analysed the input dataset describing network designs, required qualities of different network components, and network devices that are available to fulfil the needs.

The team have built a domain problem model representing the scenario that captures relationships between deferent domain entities and hard constraints. Figure 6.2 Network Problem represents a snapshot of that model.

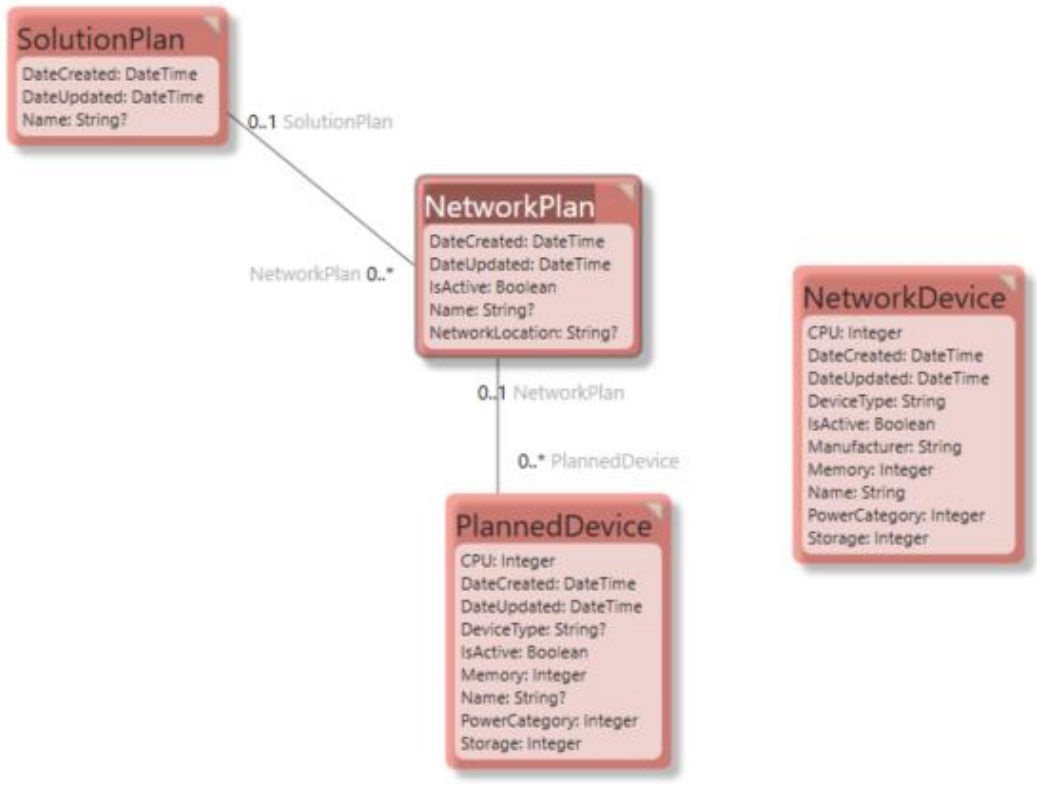

Figure 6.2 Network Problem

The team have built a model representing the solution domain and structured to house all the information related to generate schedules and reflect relevant relationships. Figure 6.3 Network Solution provides a snapshot of that model.

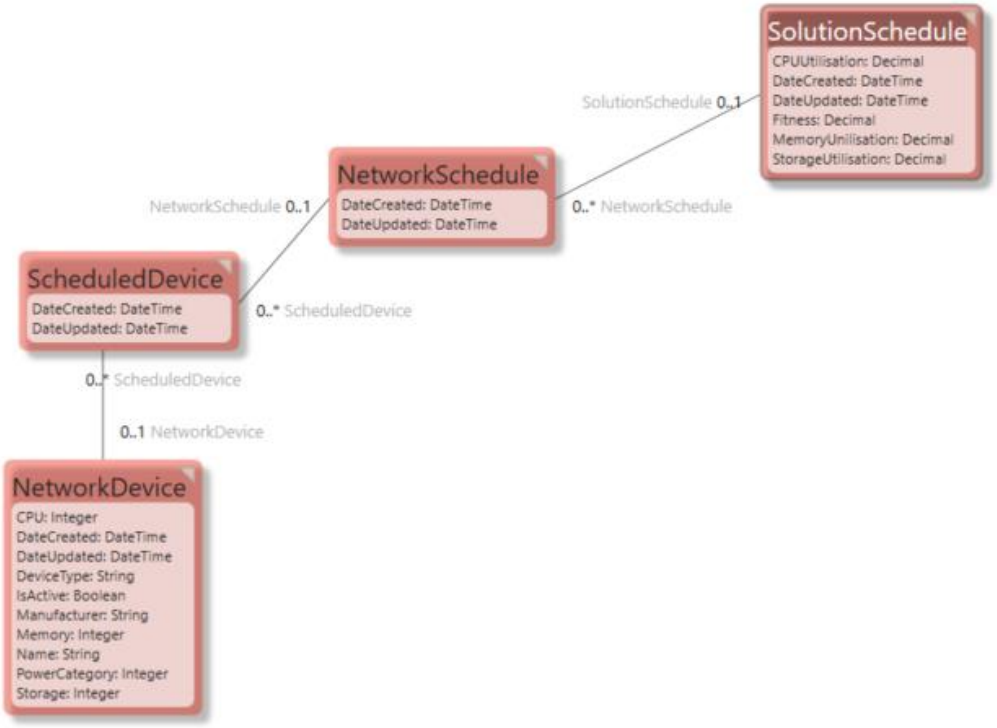

Figure 6.3 Network Solution

The author has developed a schedule generation engine, which allows creating valid and current operational solutions based on the earlier compiled solution design (solution plan) and the resource pool of available and suitable network devices.

The work progressed to see how the outcomes of the scheduling engine could be optimised. Using the genetic algorithm approach, the author developed the optimisation engine, which generates optimised schedules out of the earlier generated samples.

Figure 6.4 GA - Cross Over provides a view of how the cross-over phase of the genetic operation selects a fitter sample to be included in the progressive search for an optimal solution.

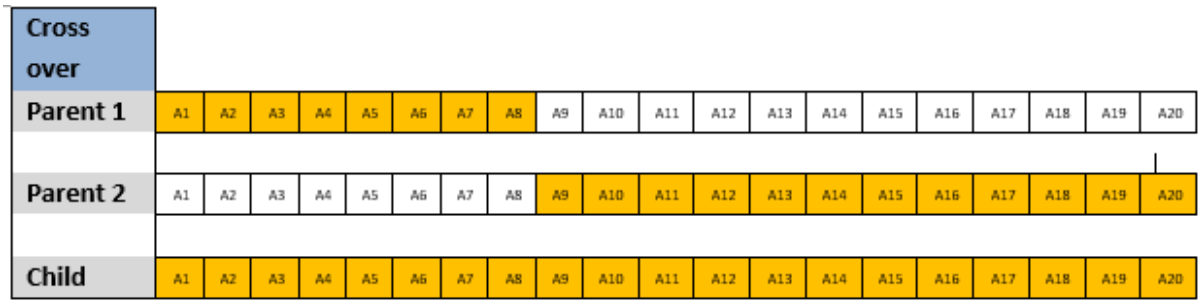

Figure 6.4 GA - Cross Over

Figure 6.5 GA – Mutation is included to show how the mutation step of the genetic operations modifies a given component of a sample to introduce randomness into the heuristic search.

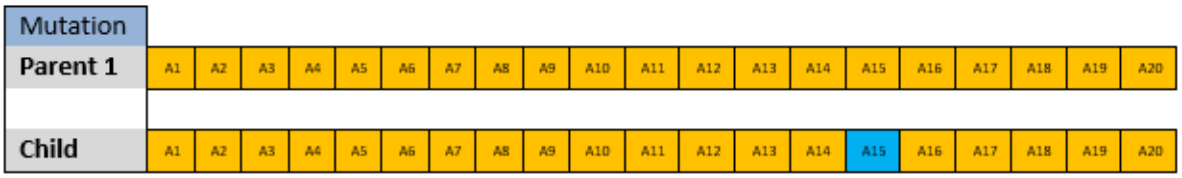

Figure 6.5 GA – Mutation

Out of the optimisation phase, a population of the suitable solution was generated as represented in Table 6.2 Sample Dataset. The end-user is presented with a view of that dataset and is able to select one variant to be taken into the operational management.

This is where the experiment concludes.

6.5 Findings and Related Work

In the telecommunications business, the competition is fearless. Companies struggle to survive under market pressures. Shareholders and company boards demand profits and sustainable financial position. The following formula shows how the total operating profit would be calculated, based on the revenue generated via all the services sold to the end consumer and known operational costs.

$P = \sum_{j=1}^{N} Rj - \sum C;$

where:

P – Total operational profit

N – Total number of customer services provisioned

R – Revenue generated out of each customer services provisioned

C – Total costs of service operation

The amount of revenue companies can generate out of each service is normally limited by the competition and other market forces. They have very little ability to increase that value.

Costs of operations, however, is an entirely internally controlled factor and organisations embark on significant endeavours to reduce those and increase their profits.

The tabled optimisation method allows taking these cost-saving exercise further by applying modern artificial intelligence (AI) techniques and finding operational solutions that can offer even finer costs savings.

Information presented in Table 6.2 Sample Dataset shows how using the method a population of suitable solutions was generated. Each of those solutions meets the 'must-have' requirements (hard constraints). However, they meet the 'nice to have' requirements (soft constants) with various success rates. In particular, it can be seen how CPU usage, memory utilisation and storage efficiency were achieved by the generated allocation schedules. The better a given solution meets a given soft constraint, the higher is the score for that quality. As can be seen from the data analysis in Table 6.1 Summary of the Outcomes, the maximum and minimum values for all three dimensions used to measure optimisation fluctuate significantly. This factor alone justifies costs of initiatives that organisations would run to implement efficiencies. For example, CPU utilisation parameter varied between minimum value in the population and its maximum counterpart by 12.96%. With a level of certainty, it can be assumed that if optimisation phase was not applied to the end-to-end scheduling, a single generated solution, available to the end-users, would not be the most optimal. This means that only applying the optimisation techniques would allow the operators to find better schedules and to achieve significant cost savings. The point is extremely important as in the current financial climate governing bodies and sponsoring groups want to see strong business cases when approving more or less sizeable capital expenditure.

Future work can extend this research in two distinctive directions:

1. Domain complexity
2. Optimisation complexity

When considering the first one, we implement the method with a problem model much more complex and reflecting architectural reaches of multiple components comprising a modern telecommunications network. A number of such components such as network slicing, MEC and multiple clouds were already discussed in the paper earlier and will not be too difficult to continue their exploration in the technology implementation phases of the coming research.

Significantly spatial dimension can be added to the method to acknowledge the increased importance of geographical qualities of the network solution. This will be especially beneficial when working with MEC implementations.

The second one can be covered by making the optimisation objectives much more extensive than explored and implemented here. In this experiment, the author has only worked with their fitness functions (i.e. CPU utilisation, storage utilisation, memory optimisation). Going forward, the author can look at including the following objectives:

- Costs of resource allocations in multiple hybrid clouds
- Resource sharing among network slices
- Service delivery speeds and responsiveness in the context of MEC (mobile edge computing)
- Reliability of relevant network components (network self-healing)

The researcher anticipated that there would be many more opportunities to investigate the optimisation space even beyond the direction anticipated above.

The supporting technology can be improved to allow for larger populations of suitable solutions to be generated and made available for a potentially finer optimisation. Also, technology could be improved to run the analysis and provide recommendations in near real-time for more intensive network management function (e.g. applying self-healing techniques, rectifying know issues).

Chapter 7 - Climate Change and Operational Management Optimisation

7.1 Introduction

7.1.1 Why was this study work conducted?

This study was done to establish the possible relation between how the climate change agenda and advances in artificial intelligence (AI) are recognised. The author specifically looked at AI-enabled optimisation of operational management with a view to identifying a clear and pragmatic path to addressing some of the client change issues. The team would like to propose a set of actions, which in combination with other initiatives, become the Climate Change Plan.

7.1.2 How was it done? What were the approach and methodology?

To complete this study, we had to:

- Analyse the climate change challenge
- Review its impact on human life
- Assess actions that can be taken to tackle the problem
- Evaluate the feasibility of applying AI optimisation techniques to achieve some outcomes

7.1.3 What were the expected results?

We believe that a newly developed operational scheduling method (Petukhov 2016) can be employed to reduce resource consumption across enterprises around the world in various industry sectors. Doing so will drive the delivery on the client change Sustainable Development Goals (SDGs).

7.1.4 How is the chapter structured?

This chapter describes the climate change issue being faced today and explores the opportunity to apply some optimisation methods and technology to address some of the related issues. By conducting a literature review, the author describes various concepts and critical challenges. They follow with an analysis of what could be done using the earlier defined and implemented operational optimisation method. Physically the chapter is structured as

follows. Section 2 provides background information on the topic of climate change. It focuses on how it impacts us and on what can be done to tackle it. It confirms that human activity is a significant contributor to the increase of greenhouse gases in the atmosphere. Section 3 shows how the challenges are addressed, focusing on the UN 2030 strategy and its sustainable development goals. Here the author continues presenting outcomes of the literature review with emphasis on opportunities AI presents in the context of the climate change dilemma. In section 4, the team propose their own solution and describe the proposed method. Outcomes observed during one of the related case studies are presented in section 5. Section 6 summarises this work and considers future research in this area. Raw data representing experiment outcomes can be found in APPENDIX A.

7.2 Background and Key Concepts

7.2.1 Climate change is real

American climate science expert James Hansen claimed in 1988 that global warming had started. The wider society started to recognise this problem. ‘Even though climate science has now firmly established that global warming is occurring, that human activities contribute to this warming, a significant portion of the American public remains ambivalent or unconcerned’ (Dunlap 2013). Many politicians (particularly in the US) deny the need to reduce carbon footprint (Brownstein 2010, quoted by Dunlap 2013).

According to Dunlap and Jacques (2013), the traditional political views have a major impact in ignoring the reality of ‘anthropogenic global warming (AGW)’, especially when they question the credibility of climate change research. They have found that ‘with the help of American CTTs climate change denial has spread to several other nations and that an increasing portion of denial books are produced by individuals with no scientific training’ (Dunlap & Jacques 2013).

In the study that analysed data collected from all the continents Bain et al. (2016) observe that opinions on climate change issues among the sample of the participants varied significantly.

Recently the international community consolidated their effort, and an undisputed scientifically collected and analysed information supports the concepts strongly.

Climate change is real, and it impacts our lives today. Natural disasters are more frequent and more catastrophic. Our health suffers because of reduced air quality and hot weather. Our agriculture struggles because of droughts; our wildlife hammered by the bush fires.

7.2.2 It impacts our lives and lives of future generations

The impact of change is observed every day around us. The summer of 2020 in Australia has become a record-breaking and devastating fire session.

The 2019–20 fire season in Eastern Australia was unprecedented in the size and number of fires in temperate Australian forests. ‘These fires are an indication that changes to the fire regime predicted under climate change, including more frequent and more severe fires, may now be occurring’ (Nolan et al. 2020).

7.2.3 Human economic activities are a factor in this change

It is known that human economic activities contribute to this change significantly. Plenty of academic research exists that makes this conclusion and based on this extensive research it could be said there is no reason not to believe this is the case.

The study by Vinuesa et al. (2020) emphasises that cryptocurrency technologies including Bitcoin are consuming the same amount of electric power as some countries. In their opinion, this enormous footprint together with other significant electricity consumption economic sectors make delivery on particular climate change targets very difficult. These include the Sustainable Development Goal (SDG) 7 and Sustainable Development Goal (SDG) 13. The detailed analysis demonstrates that the ICT sector would consume around 20% of the global electricity production by 2030. It accounts for approximately 1% today. Change for the greener practices ICT is therefore critical.

According to Chen et al. (2020), ‘increasing energy demands pose huge environmental challenges globally’. The approaches are being researched to exercise the opportunity of meeting the ‘1.5-degree global warming target’ established by the Paris Agreement. Organisations are developing the capacity to reach the United Nations Sustainable Developmental Goals. In that study, they have provided a summary of some crucial approaches that could address energy sustainability.

‘Governments around the world are acknowledging the importance of zero-emission vehicles in achieving their climate, air quality and energy security goals’ (Li et al. 2020). Many countries

are looking at the implementation of alternative and environmentally friendly transportation means, including electric vehicles (EVs). They consider many policies which will promote and enable the expansion of 'new energy vehicles' (NEVs) and the financial incentive for the market participants to adopt this new approach to cover their transportation needs.

7.2.4 We need to act to reduce this negative impact on our planet

It is vital to understand the dynamics of society to support the action to address the anthropogenic climate change (ACC) issues. It seems the picture is not black and white. The existing literature looks at how supporting the climate change movement and its denial is spread across various community groups (McCright et al. 2016). Stokes and Warshaw (2017) concluded that

> A majority of the public across every state supports renewable energy policies if public health benefits and job creation are emphasized. Republican leadership is also essential, particularly in Republican-dominated state legislatures. If, however, costs are imposed on residential ratepayers through rapid bill increases tied to renewable energy policies, this will very likely undermine support. In fact, emphasizing cost increases of $10 a month would likely decrease public support more than emphasizing air quality, job creation or partisan primes would increase it (Stokes & Warshaw 2017).

As can be seen, the public would support actions if they improve their economic prospect, and they would probably deny those actions if a possibility of financial loses is being tabled.

7.3 Problem Statement and Known Solutions

7.3.1 Problems

According to some research, the changes to the climate now being observed and predictable development of this problem may lead to the planet not being able to support life as we know it in a relatively short time. Some argue that by the end of this century the temperatures might rise by 3 to 5 degrees Celsius. They think that such a dramatic change may cause a number of natural catastrophic events leading to humanity looking to lose half of its population.

If we do not act and address this problem now, tomorrow might be too late.

7.3.2 Known Solutions

The problem is identified, but how do we solve it? As the classic Russian writer has put it in 1863 (Чернышевский 2015), what should we do?

According to Vinuesa and others (2020), a lot could be done to reduce ICT usage of electricity and consequently manage the overall growth of electricity demand sustainably. They suggest improving cooling systems in the data centres, implementing efficiency for already established consuming capacities and adopting more sources of renewable energy.

SDGs

The so-called '2030 agenda for sustainable development', accepted by the United Nations in 2015, has introduced 17 Sustainable Development Goals (SDGs) 'to end poverty, protect the planet and ensure that all people enjoy peace and prosperity, now and in the future' (Morton, Pencheon & Squires 2017). Table 7.1 GSGs provides a list of these goals.

Table 7.1 GSGs

1	End poverty in all its forms everywhere on this planet
2	End hunger, and achieve food security and improved nutrition, and promote sustainable agriculture practises
3	Warrant healthy living and advocate for well-being
4	Ensure inclusive and acceptable quality education, and advocate for lifelong learning opportunities for all
5	Reach gender parity, empower all women and girls in every aspect of their lives
6	Warrant availability and sustainable management of water and hygiene for all
7	Warrant access to affordable, reliable, sustainable and modern energy for all
8	Advocate for sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Establish resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduce inequality within and among countries
11	Warrant that cities and human settlements are inclusive, safe, resilient and sustainable
12	Ensure sustainable consumption and production patterns
13	Undertake immediate action to combat climate change and its impacts

14	Establish conserve and maintainable use the oceans, seas and marine resources for sustainable development
15	Protect, restore and promote sustainable use of land-based ecosystems, protect our planet vegetation, 'combat desertification', and halt and slow down 'land degradation' and pause 'biodiversity loss'
16	Advocate for peaceful and inclusive societies supporting sustainable development; provide access to justice for all; build responsible and inclusive institutions at all levels of our society
17	Reinforce the means of implementation and revitalise the Global Partnership for Sustainable Development

A breakdown of Goal 9 can be seen in Table 7.2 Goal 9 Structure below (Resolution 2015). This would be of particular interest to those workgroups involved with information technology and research and delivery.

Table 7.2 Goal 9 Structure

9.1	Develop good quality, reliable, sustainable, and resilient infrastructure, including local and transborder infrastructure, to support economic development and human well being, with an aim to establish inexpensive and equitable access for all
9.2	Promote inclusive and maintainable industrialisation and, by 2030, significantly raise the industry's portion of engagement and gross domestic product, in line with national conditions, and double its share in the least developed countries
9.3	Increase the access of small scale industrial and other enterprises, specifically in developing countries, to financial services, such as affordable credit, and integration into the supply and demand marketplaces
9.4	By 2030, upgrade infrastructure and industries to make them more maintainable, with increased resource allocation efficiency and greater acceptance of clean and environmentally friendly technologies and industrial processes, with all countries taking action in line with their respective potential
9.5	Enhance scientific research, upgrade the technical competences of industrial sectors in all societies, especially in developing countries; including, encouraging innovation and significantly increasing the number of research and development workers (R&D) per 1 million people, and increase R&D expenditure
9.a	Facilitate sustainable and resilient infrastructure development in the third world countries through improved monetary, and technical help the disadvantaged and developing countries

9.b	Support local technology development, R&D in developing countries
9.c	Raise the level of access to information and communications technology, and endeavour to provide public availability of the Internet in the least developed countries by 2020

According to Liu (2019), China is implementing goal 9 of the 2030 agenda for sustainable development in various domains. In their opinion, China's industry started a new era of driving cooperative international development and supporting sustainable growth across multiple industry sectors around the world. They support international cooperation by implementing the 'Belt and Road Initiative (BRI)'. This project will deliver on a global development strategy accepted by the Chinese administration in 2013. It includes infrastructure delivery and investments in 70 countries and across Asia Europe, and Africa. The BRI helped to implement inclusive and sustainable industrial development.

> In the Second Belt and Road Forum for International Cooperation convened in Beijing in April 2019, the heads of 40 participating countries or international organizations spoke highly of the efforts made through the BRI to facilitate connectivity, promote economic growth and prosperity, eliminate global poverty, mitigate unbalanced development, and help realizing the United Nations' sustainable development goals, and held in-depth discussions and reached important consensus on promoting green and sustainable development to implement the UN 2030 Agenda and other issues (Liu 2019).

As stated by Long (2019), 'The goals set forth by the United Nations in their 2030 Agenda for Sustainable Development are steep and ambitious, to say the least. It is no small feat to be tasked with curing world poverty and hunger or ensuring that there is quality education for all' (Long 2019). They firmly believe that if any significant progress is experienced on this journey of achieving these goals, it (this success) would not be accomplished because of the efforts of a person or a group of people. Instead, this would be achieved by a collaborative action of companies, states and countries.

Fukuda-Parr and Muchhala (2020) have conducted a study to show how the Sustainable Development Goals (SDGs) are considered in both developed and developing countries. They say that to tackle the SDGs successfully society needs to change the way it thinks about economic development. The approach to economic development projects needs to be redefined to reflect on transformation of post-colonial to a global context. As the former president of Ireland Mary Robinson remarked, 'The universal nature of the new sustainable

development agenda was hard-won and transformative. No longer are we talking about development with a donor-recipient mind-set. No country has achieved sustainable development. Every country is challenged, in different ways, to achieve the seventeen goals. Only through action at home and cooperation internationally can transformation be achieved' (Robinson 2017, cited in Fukuda-Parr & Muchhala 2020).

In their study, Di Foggia (2020) discuss how advances in electricity provisioning projects contribute to sustainable development goals. They observe that because SDG 7 aims to ensure access to affordable, reliable, durable, and modern energy for all it is important to indicate how smart meter projects can benefit from the latest achievements in science and technology. In their opinion, energy utilities play a crucial role in achieving a more sustainable urban environment through improved performance in the management and delivery of energy services. It is no wonder that today energy utilities manage and provide many smart services, and more and more systems based on smart meters, advanced energy management solutions, and applications that favour an active role for customers are being developed. In this respect, energy utilities must be able to create well-designed revenue management systems to capture the value they create, being in a regulated environment. For this to happen, policymakers should ensure regulatory stability and the fair distribution of costs between operators and users in the energy sector. Long term investment in technology enabling power grids will benefit energy utilities, users and society.

AI can help to address the SDGs

As stated by Vinuesa et al. (2020), artificial intelligence (AI) should bring a positive impact on all the 'Sustainable Development Goals (SDGs)'. They go on and describe how 'Sustainable Development Goal 1' relates to poverty issues, 'Sustainable Development Goal 4' focuses on good schooling, 'Sustainable Development Goal 6' covers clean water and sanitation, 'Sustainable Development Goal 7' discusses accessible and renewable energy, and 'Sustainable Development Goal 11' looks at 'sustainable cities'. As AI can bring significant improvements into how organisations run their operations and how they plan and consume various types of resources, including human, computing and transportation, it can bring significant optimisation to the provisioning of food, health, water, and energy services to the planet population. It should also help to reduce carbon emissions by contributing to efficiencies introduced by 'circular economies' and 'smart cities' to the resource management space.

The optimisation can reduce resource consumption across many industry sectors

Various industry sectors will have different resource types available to complete related activities. Table 7.3 Industry Sectors presents considered industry sectors and those types of resources that they would typically have at their disposal.

Table 7.3 Industry Sectors

#	Industry Sector	Types of Resources Consumed
1	Telecommunications	Humans, computing infrastructure, electric power
2	Health	Humans, building infrastructure, medical equipment, electric power
3	Retail / Transport / Logistics	Humans, vehicles, fuel, building infrastructure, electric power
4	Building / Construction	Humans, building machinery and vehicles, fuel, electric power
5	Professional Services	Humans, electric power
6	Postal Services / Utilities	Humans, electric power, vehicles, fuel
7	Education	Humans, building infrastructure, electric power
8	Banking / Finance / Wealth Management	Human, building infrastructure, electric power
9	Manufacturing	Humans, building infrastructure, manufacturing machinery, electric power
10	Agriculture	Humans, agricultural machinery and vehicles, fuel, electric power

When attempting to optimise a given operation, steps need to be implemented to reduce resource consumption of a given type while still maintaining the service level agreements and the quality of service.

In their work, de Castro Vivas et al. (2020) have presented a comprehensive method comprised of both analytical and mathematical models. They designed this method to assess and optimise sustainable supply chains. In their case study, they implemented optimisation using the mathematical model that allowed to allocate resources according to the critical environmental objectives, which would all to achieve ecological sustainability. These objectives include efforts related to the establishment of efficient operations, including restoration of services impacted by reduced performance.

Another case study was conducted in an attempt to demonstrate an impact on the ‘6th goal of the 17 sustainable development goals’ (Awe et al. 2020), it modelled and optimised the water distribution systems (WDS). This research was completed in Nigeria and related to Kurudu

post-service housing estate. The research team have estimated 'the water demand, model flow, velocity and head loss for the case study using EPANET software and finally optimizing the system using LINGO software' (Awe et al. 2020). The optimisation technique they have developed allowed to improve system running cost parameters while still delivering on the main service objectives effectively. Some results showed a 38% decrease in the total costs of the system acquisition and on-going support.

When addressing a problem of how to calculate the percentage targets for new energy vehicle (NEV) Li et al. (2020) have developed 'a multi-period credit market dynamic equilibrium model' (Li et al. 2020). They have proposed four scenarios, including 'a baseline scenario (scenario BS), a decelerated growth scenario (scenario DG), a constant growth scenario (scenario CG) and an accelerated growth scenario (the scenario AG)' (Li et al. 2020). They showed that:

> (1) more stringent NEV credit targets will slow down the growth of ICEV production and promote the substantial growth of NEVs. Compared with the baseline scenario, the cumulative NEV production increase in scenario DG is the highest (113%), followed by that in scenario CG (87%) and scenario AG (62%); (2) with the NEV credit targets increasing, the demand for CAFC credits will decrease accordingly. Meanwhile, automakers can purchase NEV credits to offset CAFC credit deficits at a low price. Thus, due to the NEV credits accounting benefits, increasingly more stringent NEV credit targets will even make a negative contribution to energy saving goals of CAFC credit management; (3) with the maturity of battery technology and the realization of scale advantages, NEVs produced by automakers A, B and C could all achieve cost-effective breakeven points. (4) from the perspective of NEV promotion cost, the lowest cost can be achieved in scenario accelerated growth scenario. (Li et al. 2020).

7.4 The Solution

7.4.1 Argo AI – OMO can implement the optimisation

The method

Whether one is applying a Project Management Body of Knowledge (PMBOK), Projects in Controlled Environment (PRINCE2) or agile project delivery approach to their project/program/portfolio management, initial development and following maintenance of effective operational schedules is paramount to the overall success of any initiative. Scheduling in complex and large problem domains is resource consuming and challenging. It becomes especially difficult when project conditions often change within relatively short time

periods. Failure to respond to this change in a timely manner will result in all sorts of problems occurring in a given management space.

Argo AI – OMO (Petukhov 2016), also known as Operational Management Optimisation, helps operational managers to always have valid, current and optimised schedules of the activities their workgroups perform. It helps to manage resources of various types (humans, infrastructure, vehicle, electricity, fuel) more effectively by implementing optimisation processes via artificial intelligence (AI) techniques.

Recognition

This method is now recognised and protected by Australian law in the form of a certified Australian Standard Patent and described in a number of studies conducted within this larger PhD Project.

Maturity

Argo Computing Services - listed in eServices Register - offers the Argo AI (artificial intelligence) solution to Australian and overseas clients. This offering of Operational Management Optimisation (OMO), helps operational managers to always have valid, current and optimised schedules of the activities their workgroups perform. This offering is based on the intellectual property that the author has developed over the last few years.

It is supported by the our extensive experience delivering concurrent complex solutions across multiple industry sectors, including:

- Business and IT Consulting
- Postal Services and Utilities
- Stockbroking and Wealth Management
- Education – Higher Education/Colleges/Schools
- Finance – Banking/Accounting/Insurance
- Automotive Engineering
- Retail and Logistics
- Telecommunications
- Health, Social and Community Services
- Security and Intelligence

A number of case studies were completed to check if the method can be applied successfully in real-life industry settings. Table 7.4 Completed Case Studies shows which industry domains were covered by those experiments.

Table 7.4 Completed Case Studies

#	Industry Sector	Problem Domain	Most Significant Outcome
1	Telecommunications	IT environment management	Implemented automated allocation to testing needs
2	Professional Services	Delivery of the Tax and Compliance Function	Write-offs for a given financial year reduced by 9.60%
3	IT Consulting	Implement web application	Project cost can be optimised by 11.87%
4	Building and Construction	Running a building project	Delivery time can be optimised by 7.60%
5	Telecommunications	Network resource allocation optimisation	CPU utilisations can be optimised by 12.96%

Potential

While significant work was done to complete case studies and show how this method is working in industry domains, we will continue to run experiments and apply this method in more real-life scenarios.

Table 7.5 Future Case Studies

#	Industry Sector	Problem Domain – Subject to Optimisation
1	Transport and Logistics	Vehicle fleet allocation
2	Utilities	Electric power utilisation
3	Building and Construction	Building machinery allocation
4	Telecommunications	Computing environments optimisation
5	Banking and Finance	Human resource allocation optimisation

7.5 Findings and Related Work

Information presented in Table 6.2 Sample Dataset shows how using the method a population of suitable solutions was generated. Each of those solutions meets the 'must-have' requirements (hard constraints). However, they meet the 'nice to have' requirements (soft constants) with various success rate. In particular, it can be seen how CPU usage, memory utilisation and storage efficiency were achieved by the generated allocation schedules. The better a given solution meets a given soft constraint, the higher is the score for that quality. As can be seen from the data analysis in Table 6.1 Summary of the Outcomes, the maximum and minimum values for all three dimensions used to measure optimisation fluctuate significantly. This factor alone justifies costs of initiatives that organisations would run to implement efficiencies. For example, the CPU utilisation parameter varied between minimum value in the population and its maximum counterpart by 12.96%. With a level of certainty, we can assume that if optimisation phase was not applied to the end-to-end scheduling, a single generated solution, available to the end-users, would not be the most optimal. This means that only applying the optimisation techniques would allow the operators to find better schedules, and to achieve significant cost savings. The point is extremely important as in the current financial client governing bodies and sponsoring groups want to see strong business cases when approving more or less sizeable capital expenditure.

Future work can extend this research in two distinctive directions.

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2. Optimisation complexity

When considering the first direction, we would implement the method with a problem model much more complex and reflecting architectural reaches of multiple components comprising a modern telecommunications network. A number of such components such as network slicing, MEC and multiple clouds were already discussed earlier and will not be too difficult to continue their exploration in the technology implementation phases of the coming research.

Significantly spatial dimension can be added to the method to acknowledge the increased importance of geographical qualities of the network solution. This will be especially beneficial when working with mobile edge computing implementations.

The second point can be covered by making the optimisation objectives much more extensive than explored and implemented here. In this experiment, the author has only worked with their fitness functions (i.e. CPU utilisation, storage utilisation, memory optimisation). Going forward, the author can look at including the following objectives:

- Costs of resource allocations in multiple hybrid clouds
- Resource sharing among network slices
- Service delivery speeds and responsiveness in the context of MEC (Mobile Edge Computing)
- Reliability of relevant network components (network self-healing)

The researcher anticipated that there would be much more opportunities to investigate the optimisation space even beyond the direction anticipated above.

The supporting technology can be improved to allow for larger populations of suitable solutions to be generated and made available for a potentially finer optimisation. Also, technology could be improved to run the analysis and provide recommendations in near real-time for more intensive network management function (i.e. applying self-healing techniques, rectifying know issues, etc.).

Chapter 8 - Thesis Conclusions

In this research, the author has proved that a combination of business modelling and genetic algorithms allows splitting the solution delivery into logically complete components where different techniques could be used to deal with varies types of challenges and complexities. Variances in operational structure and business rules associated with different problem domains are dealt with by the modelling component. It ensures the solution is not locked on a given problem space and can be extended to other problem areas. Genetic algorithms are employed to search the solution domains in a very productive and programmatic fashion to deliver a well-optimised solution to scheduling problems.

As described in Chapter 2, in the completed research, the newly proposed optimisation approach has addressed all the tabled problems applicable to the operational management space.

The author proved that GA operations can be implemented without employing the encoding/decoding technique.

The author has shown how SQL can be used as an implementation language.

The author has proved that native database tables could be used to store all the information which subsequently is processed by scheduling and optimisation modules of the proposed system.

The proposed implementation of genetic algorithms helps to search the solution domains in a very productive and programmatic fashion to deliver a well-optimised solution to the scheduling problems.

Out of Chapter 3, it can be concluded that the case study, which proposed a set of techniques to projectise and productise an accounting operation, was completed successfully. Study participants can now observe a full one-year data set showing outcomes of this implementation.

It can be acknowledged with confidence that it is possible to apply projectisation principles described in earlier defined project planning and scheduling methods (Petukhov 2016) to an

accounting practice operation. Such a change has led to a much more streamlined delivery model.

Productisation of an accounting services function was also implemented within the same case study, which was implemented as a transformation initiative in a given practice.
When completed, these transformational changes allowed the firm to achieve significant results across both measurable and non-measurable performance indicators.

The following outcomes were achieved:

- Raw data collected over a period of two years (FY2015, FY2016) shows a reduction of the write-offs by 9.61%
- Job handling time has been reduced by 28.18%
- Those jobs where clients were not taken into this study did not show a reduction in the write-offs

In order to become more competitive, a number of accounting practices have started to send their work off-shore. Matthews Steer wanted to decrease operating costs without having to follow this trend, as they are keen to maintain a pool of local talent to support natural long-term growth while maintaining the high quality of work performed for the clients. This engagement with Victoria University researchers allowed them to do just that.

This tested approach can now be taken into other professional services organisations in Australia and overseas to help them in achieving their long and medium-term strategic objectives.

Chapter 4, which discussed the application of the team's optimisation method in IT projects and programs scheduling and optimisation space, concludes that the outcomes of the experiment are complete and precise. The case study demonstrated it is possible to generate multiple valid solutions (population) for IT projects and programs schedules, providing an opportunity to choose an optimal solution. The generated dataset demonstrates a distribution of total project costs with 2.33% variance and distribution of the total delivery duration variance of 19.52%.

The earlier developed Operational Scheduling with Business Modelling and Genetic Algorithms method can be used to achieve optimisation objectives when scheduling IT projects and programs.

Chapter 5 summarised a case study which discussed the application of our optimisation method in a telecommunications network's resource allocation space. The outcomes of the experiment are complete and clear. The case study demonstrated it is possible to generate multiple valid solutions (population) for network device allocation, providing an opportunity to choose an optimal solution. The generated dataset demonstrates a distribution of CPU utilisations with 12.96% variance, storage with 7.5%, and finally memory with 20.42%. If interested parties need to assess the monetary impact of the achieved efficiencies, they can extend the calculations by applying the costs of the related services and volumes of network resources they manage.

Out of Chapter 6, it can be concluded that climate change is real, and it impacts our lives today. The research concludes that climate changes impact the frequency and severity of natural disasters. It impacts human health as the air quality decreases and temperatures rise. The research claims that droughts become frequent, and because of that, agriculture struggles to maintain consistent levels of productivity and profitability. Fires triggered by the weather conditions devastate wildlife. The research also resonates with other views expressed by both academic and industry experts, that human economic activities contribute to this climate change significantly.

The 2030 agenda for sustainable development has established 17 Sustainable Development Goals (SDGs) to end poverty, protect our planet, and ensure that all of us enjoy peace and prosperity. While humanity exercises many options and ways to address the issue and reduce the amount of the greenhouse gases in our atmosphere, there is strong evidence that applying AI to improve economic activities in various domains can reliably bring about the benefits and help us to achieve SDGs in a predictable fashion. Argo AI – OMO helps organisations to optimise their resource usage by applying AI techniques. When this method is adopted, there is a better chance to deliver on the Climate Change Plan.

This research now concludes that all the objectives and research questions tabled in the Introduction section of this document have been addressed in full.

Further research in this field would benefit from focusing on running more case studies in the new business domain to confirm the universality of the method further. These additional studies could cover more complicated problem domains. The size of scheduling artefacts can also be increased to show how very large operations can benefit when applying this method.

With the recent development of machine learning techniques, this research could extend and include predictive analysis into schedules to see what resources will be more likely to complete activities on time and apply some preference rules based on that intelligence.

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APPENDIX A

Table 4.5 Summary of the outcomes

Matthews Steer Accountants and Advisors - Project Engage (aka BPI Project) 2014 – 2016										
#	Description	2014	2015	2016	Movement 2014-2015, %	Movement 2015-2016, %	Movement 2014-2016, %	Movement 2014-2015	Movement 2015-2016	Movement 2014-2016
1	The planned reduction of white offs, % of revenue (as per the project brief)	7%	3%		-57.14%			-4.00%		
2	All compliance clients. Average job handling time (days)				-9.72%	-16.92%	-25.00%			
3	Compliance clients, participating in project Engage. Average job handling time (days)				0.92%	**-28.18%**	-27.52%			
4	All compliance clients. Revenue. ($$$)				3.55%	4.72%	8.44%			
5	All compliance clients. Write-offs. ($$$)				8.43%	-42.27%	-37.41%			
6	All compliance clients. Write offs. % of revenue	7.66%	8.02%	4.42%	4.71%	-44.88%	-42.28%	0.36%	-3.60%	-3.24%

7	Compliance clients, participating in project Engage. Revenue. ($$$)				15.95%	-4.41%	10.83%			
8	Compliance clients, participating in project Engage. Write-offs. ($$$)				18.66%	-112.29%	-114.58%			
9	Compliance clients, participating in project Engage. Write offs. % of revenue	8.32%	8.51%	-1.09%	2.34%	-**112.86%**	-113.16%	0.19%	**-9.61%**	-9.41%
10	Compliance clients, not participating in project Engage. Revenue. ($$$)				-1.80%	9.38%	7.40%			
11	Compliance clients, not participating in project Engage. Write-offs. ($$$)				3.44%	-3.17%	0.17%			
12	Compliance clients, not participating in project Engage. Write offs. % of revenue	7.37%	7.76%	6.87%	5.34%	-11.47%	-6.74%	0.39%	-0.89%	**-0.50%**
13	Compliance clients, not participating in project Engage. Average job handling time (days)	69	61	52	-11.59%	-14.75%	-24.64%	-8	-9	-17

Table 4.6 In Scope clients

Total Number of Client Jobs	In Scope	Out of Scope
264	50	214
100%	19%	81%

Table 5.1 IT Project Plans

Project Plan ID	Name	Planned Activities	Schedules
112	Argo IT Solution	49	98
163	Digital Banking	50	102
157	Second Digital Super Fund	572	101
156	First Digital Super Fund	714	101
159	Third Digital Super Fund	1,103	101

Table 5.2 IT Project Schedules

Project Plan ID	Name	Project Schedule ID	Start Date	End Date	Duration	Delivery Cost	Fitness
112	Argo IT Solution	6255	6 September 2017	1 October 2017	26	$8,955.00	2,832

		6257	6 September 2017	1 October 2017	26	$8,955.00	3,033
		6258	6 September 2017	1 October 2017	26	$8,955.00	2,832
		6259	28 September 2017	1 October 2017	4	$8,955.00	9,707
		6260	28 September 2017	1 October 2017	4	$8,955.00	9,707
		6261	28 September 2017	1 October 2017	4	$8,955.00	9,707
		6262	28 September 2017	1 October 2017	4	$8,875.00	9,712
		6263	28 September 2017	1 October 2017	4	$8,635.00	9,813
		6264	28 September 2017	1 October 2017	4	$8,875.00	9,712
		6265	28 September 2017	1 October 2017	4	$8,635.00	9,813
		6266	28 September 2017	1 October 2017	4	$8,635.00	9,813
		6267	28 September 2017	1 October 2017	4	$8,635.00	9,813
		6268	28 September 2017	1 October 2017	4	$8,635.00	9,813
		6269	28 September 2017	1 October 2017	4	$8,595.00	9,316

		6270	28 September 2017	1 October 2017	4	$8,595.00	9,316
		6271	28 September 2017	1 October 2017	4	$8,515.00	9,821
		6272	28 September 2017	1 October 2017	4	$8,555.00	9,819
		6273	28 September 2017	1 October 2017	4	$8,515.00	9,821
		6274	28 September 2017	1 October 2017	4	$8,555.00	9,819
		6275	28 September 2017	1 October 2017	4	$8,515.00	9,821
		6276	28 September 2017	1 October 2017	4	$8,515.00	9,821
		6277	28 September 2017	1 October 2017	4	$8,475.00	9,657
		6278	28 September 2017	1 October 2017	4	$8,515.00	9,821
		6279	28 September 2017	1 October 2017	4	$8,515.00	9,821
		6280	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6281	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6282	28 September 2017	1 October 2017	4	$8,445.00	9,827

		6283	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6284	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6285	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6286	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6287	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6288	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6289	28 September 2017	1 October 2017	4	$8,445.00	9,827
		6290	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6291	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6292	28 September 2017	1 October 2017	4	$8,405.00	9,163
		6293	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6294	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6295	28 September 2017	1 October 2017	4	$8,365.00	9,833

		6296	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6297	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6298	28 September 2017	1 October 2017	4	$8,365.00	9,833
		6299	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6300	28 September 2017	1 October 2017	4	$8,165.00	9,597
		6301	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6302	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6303	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6304	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6305	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6306	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6307	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6308	28 September 2017	1 October 2017	4	$8,325.00	9,836

		6309	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6310	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6311	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6312	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6313	28 September 2017	1 October 2017	4	$8,325.00	9,336
		6314	28 September 2017	1 October 2017	4	$8,285.00	9,239
		6315	28 September 2017	1 October 2017	4	$8,405.00	9,830
		6316	28 September 2017	1 October 2017	4	$8,285.00	9,239
		6317	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6318	28 September 2017	1 October 2017	4	$8,325.00	9,836
		6319	28 September 2017	1 October 2017	4	$8,325.00	9,711
		6320	28 September 2017	1 October 2017	4	$8,405.00	9,830
		6321	28 September 2017	1 October 2017	4	$8,405.00	9,830

		6322	28 September 2017	1 October 2017	4	$8,405.00	9,705
		6323	28 September 2017	1 October 2017	4	$8,225.00	9,644
		6324	28 September 2017	1 October 2017	4	$8,445.00	10,077
		6325	28 September 2017	1 October 2017	4	$8,265.00	9,640
		6326	28 September 2017	1 October 2017	4	$8,225.00	9,644
		6327	28 September 2017	1 October 2017	4	$8,445.00	10,077
		6328	28 September 2017	1 October 2017	4	$8,265.00	9,640
		6329	28 September 2017	1 October 2017	4	$8,445.00	10,077
		6330	28 September 2017	1 October 2017	4	$8,445.00	10,077
		6331	28 September 2017	1 October 2017	4	$8,445.00	9,160
		6332	28 September 2017	1 October 2017	4	$8,525.00	9,154
		6333	28 September 2017	1 October 2017	4	$8,445.00	9,160
		6334	28 September 2017	1 October 2017	4	$8,525.00	9,154

		6335	28 September 2017	1 October 2017	4	$8,455.00	9,159
		6336	28 September 2017	1 October 2017	4	$8,455.00	9,159
		6337	28 September 2017	1 October 2017	4	$8,085.00	9,188
		6338	28 September 2017	1 October 2017	4	$8,085.00	9,188
		6339	28 September 2017	1 October 2017	4	$8,445.00	9,160
		6340	28 September 2017	1 October 2017	4	$8,085.00	9,188
		6341	28 September 2017	1 October 2017	4	$8,485.00	9,824
		6342	28 September 2017	1 October 2017	4	$8,485.00	9,824
		6343	28 September 2017	1 October 2017	4	$8,085.00	9,188
		6344	28 September 2017	1 October 2017	4	$8,485.00	9,824
		6345	28 September 2017	1 October 2017	4	$8,485.00	9,824
		6346	28 September 2017	1 October 2017	4	$8,165.00	9,181
		6347	28 September 2017	1 October 2017	4	$8,145.00	9,225

		6348	28 September 2017	1 October 2017	4	$8,425.00	9,828
		6349	28 September 2017	1 October 2017	4	$8,125.00	9,185
		6350	28 September 2017	1 October 2017	4	$8,125.00	9,185
		6351	28 September 2017	1 October 2017	4	$8,385.00	9,831
		6352	28 September 2017	1 October 2017	4	$8,085.00	9,188
		6353	28 September 2017	1 October 2017	4	$8,385.00	9,831
		6354	28 September 2017	1 October 2017	4	$8,385.00	9,831
		6355	28 September 2017	1 October 2017	4	$8,005.00	9,244
163	Digital Banking	6457	2 October 2017	19 October 2017	18	$18,700.00	3,435
		6458	6 September 2017	22 September 2017	17	$18,700.00	3,549
		6459	6 September 2017	22 September 2017	17	$18,580.00	3,266
		6460	6 September 2017	22 September 2017	17	$18,620.00	3,510
		6461	6 September 2017	22 September 2017	17	$18,700.00	3,549

		6462	6 September 2017	22 September 2017	17	$18,580.00	3,266
		6463	6 September 2017	22 September 2017	17	$18,700.00	3,549
		6464	6 September 2017	22 September 2017	17	$18,700.00	3,549
		6465	6 September 2017	22 September 2017	17	$18,660.00	3,550
		6466	6 September 2017	22 September 2017	17	$18,660.00	3,550
		6467	6 September 2017	22 September 2017	17	$18,660.00	3,550
		6468	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6469	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6470	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6471	6 September 2017	22 September 2017	17	$18,660.00	3,359
		6472	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6473	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6474	6 September 2017	22 September 2017	17	$18,540.00	3,554

		6475	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6476	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6477	6 September 2017	22 September 2017	17	$18,540.00	3,554
		6478	6 September 2017	22 September 2017	17	$18,140.00	3,568
		6479	6 September 2017	22 September 2017	17	$18,180.00	3,566
		6480	6 September 2017	22 September 2017	17	$18,500.00	3,556
		6481	6 September 2017	22 September 2017	17	$18,180.00	3,566
		6482	6 September 2017	22 September 2017	17	$18,180.00	3,566
		6483	6 September 2017	22 September 2017	17	$18,140.00	3,568
		6484	6 September 2017	22 September 2017	17	$18,140.00	3,568
		6485	6 September 2017	22 September 2017	17	$18,140.00	3,568
		6486	6 September 2017	22 September 2017	17	$18,140.00	3,568
		6487	6 September 2017	22 September 2017	17	$17,900.00	3,476

		6488	6 September 2017	22 September 2017	17	$17,900.00	3,476
		6489	6 September 2017	22 September 2017	17	$18,140.00	3,558
		6490	6 September 2017	22 September 2017	17	$17,740.00	3,481
		6491	6 September 2017	22 September 2017	17	$17,740.00	3,481
		6492	6 September 2017	22 September 2017	17	$17,900.00	3,576
		6493	6 September 2017	22 September 2017	17	$17,900.00	3,576
		6494	6 September 2017	22 September 2017	17	$17,900.00	3,576
		6495	6 September 2017	22 September 2017	17	$17,900.00	3,576
		6496	6 September 2017	22 September 2017	17	$16,460.00	3,630
		6497	6 September 2017	22 September 2017	17	$17,900.00	3,576
		6498	6 September 2017	22 September 2017	17	$16,460.00	3,630
		6499	6 September 2017	22 September 2017	17	$16,460.00	3,630
		6500	6 September 2017	22 September 2017	17	$16,460.00	3,630

		6501	6 September 2017	22 September 2017	17	$16,460.00	3,630
		6502	6 September 2017	22 September 2017	17	$16,460.00	3,630
		6503	6 September 2017	22 September 2017	17	$16,420.00	3,632
		6504	6 September 2017	22 September 2017	17	$16,540.00	3,850
		6505	6 September 2017	22 September 2017	17	$16,500.00	3,619
		6506	6 September 2017	22 September 2017	17	$16,540.00	3,850
		6507	6 September 2017	22 September 2017	17	$16,420.00	3,632
		6508	6 September 2017	22 September 2017	17	$16,540.00	3,850
		6509	6 September 2017	22 September 2017	17	$16,540.00	3,850
		6510	6 September 2017	22 September 2017	17	$16,500.00	3,629
		6511	6 September 2017	22 September 2017	17	$16,540.00	3,850
		6512	6 September 2017	22 September 2017	17	$16,500.00	3,619
		6513	6 September 2017	22 September 2017	17	$16,540.00	3,850

		6514	6 September 2017	22 September 2017	17	$16,540.00	3,617
		6515	6 September 2017	22 September 2017	17	$16,540.00	3,617
		6516	6 September 2017	22 September 2017	17	$14,940.00	3,889
		6517	6 September 2017	22 September 2017	17	$14,940.00	3,889
		6518	6 September 2017	22 September 2017	17	$14,940.00	3,889
		6519	6 September 2017	22 September 2017	17	$14,760.00	3,898
		6520	6 September 2017	22 September 2017	17	$14,700.00	3,901
		6521	6 September 2017	22 September 2017	17	$14,760.00	3,898
		6522	6 September 2017	22 September 2017	17	$14,880.00	3,892
		6523	6 September 2017	22 September 2017	17	$14,700.00	3,901
		6524	6 September 2017	22 September 2017	17	$14,700.00	3,901
		6525	6 September 2017	22 September 2017	17	$14,740.00	3,899
		6526	6 September 2017	22 September 2017	17	$14,700.00	3,901

		6527	6 September 2017	22 September 2017	17	$14,700.00	3,901
		6528	6 September 2017	22 September 2017	17	$14,700.00	3,701
		6529	6 September 2017	22 September 2017	17	$14,620.00	3,715
		6530	6 September 2017	22 September 2017	17	$14,700.00	3,901
		6531	6 September 2017	22 September 2017	17	$14,620.00	3,715
		6532	6 September 2017	22 September 2017	17	$14,260.00	3,544
		6533	6 September 2017	22 September 2017	17	$14,340.00	3,710
		6534	6 September 2017	22 September 2017	17	$14,660.00	3,713
		6535	6 September 2017	22 September 2017	17	$14,340.00	3,801
		6536	6 September 2017	22 September 2017	17	$14,340.00	3,801
		6537	6 September 2017	22 September 2017	17	$14,620.00	3,524
		6538	6 September 2017	22 September 2017	17	$14,260.00	3,816
		6539	6 September 2017	22 September 2017	17	$14,380.00	3,799

		6540	6 September 2017	22 September 2017	17	$14,620.00	3,715
		6541	6 September 2017	22 September 2017	17	$14,460.00	4,014
		6542	6 September 2017	22 September 2017	17	$14,460.00	4,014
		6543	6 September 2017	22 September 2017	17	$14,540.00	3,529
		6544	6 September 2017	22 September 2017	17	$14,460.00	4,014
		6545	6 September 2017	22 September 2017	17	$14,460.00	4,014
		6546	6 September 2017	22 September 2017	17	$14,460.00	4,014
		6547	6 September 2017	22 September 2017	17	$14,060.00	3,827
		6548	6 September 2017	22 September 2017	17	$14,060.00	3,827
		6549	6 September 2017	22 September 2017	17	$14,480.00	4,013
		6550	6 September 2017	22 September 2017	17	$14,060.00	3,736
		6551	6 September 2017	22 September 2017	17	$14,060.00	3,736
		6552	6 September 2017	22 September 2017	17	$14,520.00	4,011

		6553	6 September 2017	22 September 2017	17	$13,940.00	3,653
		6554	6 September 2017	22 September 2017	17	$13,940.00	3,653
		6555	6 September 2017	22 September 2017	17	$14,520.00	3,921
		6556	6 September 2017	22 September 2017	17	$14,120.00	3,823
		6557	6 September 2017	22 September 2017	17	$13,940.00	3,653
		6558	6 September 2017	22 September 2017	17	$14,520.00	3,921
157	Second Digital Super Fund	5326	1 June 2017	6 January 2019	8	$4,811,740.00	3,398
		5327	7 February 2017	6 January 2019	29	$4,773,884.00	2,666
		5328	1 June 2017	6 January 2019	8	$4,813,020.00	3,396
		5329	1 June 2017	6 January 2019	8	$4,811,740.00	3,398
		5330	7 February 2017	6 January 2019	29	$4,773,884.00	2,666
		5331	1 June 2017	6 January 2019	8	$4,810,140.00	3,398
		5332	1 June 2017	6 January 2019	8	$4,811,740.00	3,398
		5333	1 June 2017	6 January 2019	8	$4,810,140.00	3,398
		5334	1 June 2017	6 January 2019	8	$4,808,260.00	3,399
		5335	1 June 2017	6 January 2019	8	$4,809,740.00	3,397
		5336	1 June 2017	6 January 2019	8	$4,808,260.00	3,399
		5337	1 June 2017	6 January 2019	8	$4,808,260.00	3,399
		5338	1 June 2017	6 January 2019	8	$4,808,260.00	3,399
		5339	1 June 2017	6 January 2019	8	$4,808,260.00	3,399

		5340	1 June 2017	6 January 2019	8	$4,802,060.00	3,399
		5341	1 June 2017	6 January 2019	8	$4,806,860.00	3,399
		5342	1 June 2017	6 January 2019	8	$4,803,460.00	3,399
		5343	1 June 2017	6 January 2019	8	$4,805,260.00	3,399
		5344	1 June 2017	6 January 2019	8	$4,805,260.00	3,399
		5345	1 June 2017	6 January 2019	8	$4,803,460.00	3,399
		5346	1 June 2017	6 January 2019	8	$4,796,860.00	3,394
		5347	1 June 2017	6 January 2019	8	$4,802,140.00	3,395
		5348	1 June 2017	6 January 2019	8	$4,802,980.00	3,399
		5349	1 June 2017	6 January 2019	8	$4,802,140.00	3,358
		5350	1 June 2017	6 January 2019	8	$4,802,140.00	3,358
		5351	1 June 2017	6 January 2019	8	$4,800,980.00	3,398
		5352	1 June 2017	6 January 2019	8	$4,799,060.00	3,398
		5353	1 June 2017	6 January 2019	8	$4,771,740.00	3,344
		5354	1 June 2017	6 January 2019	8	$4,799,060.00	3,398
		5355	1 June 2017	6 January 2019	8	$4,767,900.00	3,343
		5356	1 June 2017	6 January 2019	8	$4,769,820.00	3,344
		5357	1 June 2017	6 January 2019	8	$4,799,020.00	3,398
		5358	1 June 2017	6 January 2019	8	$4,795,500.00	3,397
		5359	1 June 2017	6 January 2019	8	$4,771,700.00	3,343
		5360	1 June 2017	6 January 2019	8	$4,799,020.00	3,398
		5361	1 June 2017	6 January 2019	8	$4,760,140.00	3,342
		5362	1 June 2017	6 January 2019	8	$4,766,900.00	3,346
		5363	1 June 2017	6 January 2019	8	$4,795,020.00	3,397
		5364	1 June 2017	6 January 2019	8	$4,764,980.00	3,344
		5365	1 June 2017	6 January 2019	8	$4,765,300.00	3,346

		5366	1 June 2017	6 January 2019	8	$4,789,900.00	3,395
		5367	1 June 2017	6 January 2019	8	$4,761,180.00	3,345
		5368	1 June 2017	6 January 2019	8	$4,761,500.00	3,346
		5369	1 June 2017	6 January 2019	8	$4,789,340.00	3,394
		5370	1 June 2017	6 January 2019	8	$4,756,340.00	3,343
		5371	1 June 2017	6 January 2019	8	$4,761,500.00	3,346
		5372	1 June 2017	6 January 2019	8	$4,787,340.00	3,393
		5373	1 June 2017	6 January 2019	8	$4,757,980.00	3,339
		5374	1 June 2017	6 January 2019	8	$4,759,900.00	3,341
		5375	1 June 2017	6 January 2019	8	$4,779,060.00	3,392
		5376	1 June 2017	6 January 2019	8	$4,751,260.00	3,337
		5377	1 June 2017	6 January 2019	8	$4,751,620.00	3,337
		5378	1 June 2017	6 January 2019	8	$4,779,060.00	3,355
		5379	1 June 2017	6 January 2019	8	$4,751,300.00	3,336
		5380	1 June 2017	6 January 2019	8	$4,751,620.00	3,337
		5381	1 June 2017	6 January 2019	8	$4,778,660.00	3,355
		5382	1 June 2017	6 January 2019	8	$4,751,300.00	3,336
		5383	1 June 2017	6 January 2019	8	$4,750,820.00	3,338
		5384	1 June 2017	6 January 2019	8	$4,778,660.00	3,356
		5385	1 June 2017	6 January 2019	8	$4,750,500.00	3,336
		5386	1 June 2017	6 January 2019	8	$4,739,620.00	3,333
		5387	1 June 2017	6 January 2019	8	$4,779,060.00	3,357
		5388	1 June 2017	6 January 2019	8	$4,776,660.00	3,357
		5389	1 June 2017	6 January 2019	8	$4,738,020.00	3,332
		5390	1 June 2017	6 January 2019	8	$4,776,660.00	3,357
		5391	1 June 2017	6 January 2019	8	$4,741,820.00	3,335

		5392	1 June 2017	6 January 2019	8	$4,737,980.00	3,332
		5393	1 June 2017	6 January 2019	8	$4,776,740.00	3,357
		5394	1 June 2017	6 January 2019	8	$4,740,380.00	3,338
		5395	1 June 2017	6 January 2019	8	$4,737,980.00	3,332
		5396	1 June 2017	6 January 2019	8	$4,767,460.00	3,357
		5397	1 June 2017	6 January 2019	8	$4,730,660.00	3,336
		5398	1 June 2017	6 January 2019	8	$4,736,060.00	3,333
		5399	1 June 2017	6 January 2019	8	$4,765,300.00	3,355
		5400	1 June 2017	6 January 2019	8	$4,733,660.00	3,331
		5401	1 June 2017	6 January 2019	8	$4,735,580.00	3,333
		5402	1 June 2017	6 January 2019	8	$4,765,300.00	3,355
		5403	1 June 2017	6 January 2019	8	$4,734,540.00	3,333
		5404	1 June 2017	6 January 2019	8	$4,732,380.00	3,330
		5405	1 June 2017	6 January 2019	8	$4,765,300.00	3,354
		5406	1 June 2017	6 January 2019	8	$4,729,420.00	3,330
		5407	1 June 2017	6 January 2019	8	$4,727,260.00	3,326
		5408	1 June 2017	6 January 2019	8	$4,749,300.00	3,356
		5409	1 June 2017	6 January 2019	8	$4,729,420.00	3,330
		5410	1 June 2017	6 January 2019	8	$4,726,860.00	3,326
		5411	1 June 2017	6 January 2019	8	$4,749,300.00	3,356
		5412	1 June 2017	6 January 2019	8	$4,726,980.00	3,331
		5413	1 June 2017	6 January 2019	8	$4,722,260.00	3,325
		5414	1 June 2017	6 January 2019	8	$4,749,300.00	3,356
		5415	1 June 2017	6 January 2019	8	$4,726,540.00	3,328
		5416	1 June 2017	6 January 2019	8	$4,722,220.00	3,324
		5417	1 June 2017	6 January 2019	8	$4,740,900.00	3,352

		5418	1 June 2017	6 January 2019	8	$4,712,780.00	3,317
		5419	1 June 2017	6 January 2019	8	$4,712,020.00	3,314
		5420	1 June 2017	6 January 2019	8	$4,738,900.00	3,351
		5421	1 June 2017	6 January 2019	8	$4,705,580.00	3,308
		5422	1 June 2017	6 January 2019	8	$4,705,580.00	3,308
		5423	1 June 2017	6 January 2019	8	$4,737,700.00	3,351
		5424	1 June 2017	6 January 2019	8	$4,713,180.00	3,318
		5425	1 June 2017	6 January 2019	8	$4,703,580.00	3,307
		5426	1 June 2017	6 January 2019	8	$4,737,540.00	3,351
156	First Digital Super Fund	5225	1 June 2017	17 July 2019	16	$6,281,096.00	3,069
		5226	3 July 2017	17 July 2019	14	$6,285,648.00	3,086
		5227	1 June 2017	17 July 2019	16	$6,282,288.00	2,964
		5228	1 June 2017	17 July 2019	16	$6,281,096.00	3,069
		5229	3 July 2017	17 July 2019	14	$6,285,648.00	3,086
		5230	3 July 2017	17 July 2019	14	$6,285,568.00	3,086
		5231	3 July 2017	17 July 2019	14	$6,285,648.00	3,086
		5232	3 July 2017	17 July 2019	14	$6,285,568.00	3,086
		5233	3 July 2017	17 July 2019	14	$6,283,568.00	3,087
		5234	3 July 2017	17 July 2019	14	$6,281,168.00	3,086
		5235	3 July 2017	17 July 2019	14	$6,283,568.00	3,087
		5236	3 July 2017	17 July 2019	14	$6,283,568.00	3,087
		5237	3 July 2017	17 July 2019	14	$6,283,568.00	3,087
		5238	3 July 2017	17 July 2019	14	$6,283,568.00	3,087
		5239	3 July 2017	17 July 2019	14	$6,283,968.00	3,086
		5240	3 July 2017	17 July 2019	14	$6,283,968.00	3,086
		5241	3 July 2017	17 July 2019	14	$6,281,968.00	3,087

		5242	3 July 2017	17 July 2019	14	$6,284,608.00	3,087
		5243	3 July 2017	17 July 2019	14	$6,284,608.00	3,087
		5244	3 July 2017	17 July 2019	14	$6,274,288.00	3,088
		5245	3 July 2017	17 July 2019	14	$6,269,488.00	3,088
		5246	3 July 2017	17 July 2019	14	$6,274,288.00	3,088
		5247	3 July 2017	17 July 2019	14	$6,269,488.00	3,088
		5248	3 July 2017	17 July 2019	14	$6,269,488.00	3,088
		5249	3 July 2017	17 July 2019	14	$6,269,488.00	3,088
		5250	3 July 2017	17 July 2019	14	$6,274,048.00	3,088
		5251	3 July 2017	17 July 2019	14	$6,264,928.00	3,086
		5252	3 July 2017	17 July 2019	14	$6,264,928.00	3,086
		5253	3 July 2017	17 July 2019	14	$6,274,448.00	3,088
		5254	3 July 2017	17 July 2019	14	$6,258,328.00	3,090
		5255	3 July 2017	17 July 2019	14	$6,258,328.00	3,090
		5256	3 July 2017	17 July 2019	14	$6,273,808.00	3,088
		5257	3 July 2017	17 July 2019	14	$6,258,328.00	3,090
		5258	3 July 2017	17 July 2019	14	$6,258,328.00	3,090
		5259	3 July 2017	17 July 2019	14	$6,258,328.00	3,090
		5260	3 July 2017	17 July 2019	14	$6,258,568.00	3,090
		5261	3 July 2017	17 July 2019	14	$6,257,848.00	3,090
		5262	3 July 2017	17 July 2019	14	$6,258,568.00	3,090
		5263	3 July 2017	17 July 2019	14	$6,251,368.00	3,091
		5264	3 July 2017	17 July 2019	14	$6,257,848.00	3,090
		5265	3 July 2017	17 July 2019	14	$6,251,368.00	3,091
		5266	3 July 2017	17 July 2019	14	$6,251,368.00	3,091
		5267	3 July 2017	17 July 2019	14	$6,251,368.00	3,091

		5268	3 July 2017	17 July 2019	14	$6,251,368.00	3,091
		5269	3 July 2017	17 July 2019	14	$6,248,208.00	3,086
		5270	3 July 2017	17 July 2019	14	$6,248,528.00	3,086
		5271	3 July 2017	17 July 2019	14	$6,251,048.00	3,091
		5272	3 July 2017	17 July 2019	14	$6,248,608.00	3,086
		5273	3 July 2017	17 July 2019	14	$6,246,528.00	3,086
		5274	3 July 2017	17 July 2019	14	$6,251,448.00	3,092
		5275	3 July 2017	17 July 2019	14	$6,251,448.00	3,092
		5276	3 July 2017	17 July 2019	14	$6,251,448.00	3,092
		5277	3 July 2017	17 July 2019	14	$6,251,448.00	3,053
		5278	3 July 2017	17 July 2019	14	$6,251,448.00	3,092
		5279	3 July 2017	17 July 2019	14	$6,251,448.00	3,092
		5280	3 July 2017	17 July 2019	14	$6,201,448.00	3,083
		5281	3 July 2017	17 July 2019	14	$6,247,048.00	3,091
		5282	3 July 2017	17 July 2019	14	$6,247,448.00	3,091
		5283	3 July 2017	17 July 2019	14	$6,201,048.00	3,083
		5284	3 July 2017	17 July 2019	14	$6,247,448.00	3,091
		5285	3 July 2017	17 July 2019	14	$6,246,008.00	3,090
		5286	3 July 2017	17 July 2019	14	$6,199,608.00	3,080
		5287	3 July 2017	17 July 2019	14	$6,246,648.00	3,091
		5288	3 July 2017	17 July 2019	14	$6,246,648.00	3,091
		5289	3 July 2017	17 July 2019	14	$6,193,608.00	3,079
		5290	3 July 2017	17 July 2019	14	$6,245,688.00	3,091
		5291	3 July 2017	17 July 2019	14	$6,244,248.00	3,091
		5292	3 July 2017	17 July 2019	14	$6,187,208.00	3,078
		5293	3 July 2017	17 July 2019	14	$6,226,328.00	3,082

		5294	3 July 2017	17 July 2019	14	$6,243,848.00	3,091
		5295	3 July 2017	17 July 2019	14	$6,177,128.00	3,076
		5296	3 July 2017	17 July 2019	14	$6,242,408.00	3,092
		5297	3 July 2017	17 July 2019	14	$6,242,408.00	3,092
		5298	3 July 2017	17 July 2019	14	$6,177,128.00	3,075
		5299	3 July 2017	17 July 2019	14	$6,242,408.00	3,092
		5300	3 July 2017	17 July 2019	14	$6,242,408.00	3,092
		5301	3 July 2017	17 July 2019	14	$6,175,688.00	3,074
		5302	3 July 2017	17 July 2019	14	$6,227,368.00	3,085
		5303	3 July 2017	17 July 2019	14	$6,240,808.00	3,091
		5304	3 July 2017	17 July 2019	14	$6,175,368.00	3,074
		5305	3 July 2017	17 July 2019	14	$6,224,968.00	3,084
		5306	3 July 2017	17 July 2019	14	$6,240,808.00	3,091
		5307	3 July 2017	17 July 2019	14	$6,175,368.00	3,075
		5308	3 July 2017	17 July 2019	14	$6,237,088.00	3,090
		5309	3 July 2017	17 July 2019	14	$6,237,808.00	3,091
		5310	3 July 2017	17 July 2019	14	$6,174,648.00	3,072
		5311	3 July 2017	17 July 2019	14	$6,226,608.00	3,088
		5312	3 July 2017	17 July 2019	14	$6,237,408.00	3,091
		5313	3 July 2017	17 July 2019	14	$6,159,288.00	3,070
		5314	3 July 2017	17 July 2019	14	$6,208,088.00	3,080
		5315	3 July 2017	17 July 2019	14	$6,234,208.00	3,090
		5316	3 July 2017	17 July 2019	14	$6,156,488.00	3,068
		5317	3 July 2017	17 July 2019	14	$6,210,208.00	3,088
		5318	3 July 2017	17 July 2019	14	$6,210,208.00	3,088
		5319	3 July 2017	17 July 2019	14	$6,153,848.00	3,068

		5320	3 July 2017	17 July 2019	14	$6,186,968.00	3,083
		5321	3 July 2017	17 July 2019	14	$6,210,208.00	3,088
		5322	3 July 2017	17 July 2019	14	$6,153,448.00	3,067
		5323	3 July 2017	17 July 2019	14	$6,207,688.00	3,079
		5324	3 July 2017	17 July 2019	14	$6,200,128.00	3,125
		5325	3 July 2017	17 July 2019	14	$6,153,928.00	3,069
159	Third Digital Super Fund	5427	1 June 2017	14 September 2019	16	$8,813,134.00	3,109
		5428	17 August 2016	14 September 2019	28	$8,824,020.00	2,464
		5429	1 June 2017	14 September 2019	16	$8,809,886.00	3,141
		5430	1 June 2017	14 September 2019	16	$8,813,134.00	3,109
		5431	17 August 2016	14 September 2019	28	$8,824,020.00	2,464
		5432	1 June 2017	14 September 2019	16	$8,809,134.00	3,103
		5433	1 June 2017	14 September 2019	16	$8,809,886.00	3,141
		5434	1 June 2017	14 September 2019	16	$8,809,134.00	3,109
		5435	1 June 2017	14 September 2019	16	$8,810,686.00	3,141
		5436	1 June 2017	14 September 2019	16	$8,809,886.00	3,141

		5437	1 June 2017	14 September 2019	16	$8,810,686.00	3,141
		5438	1 June 2017	14 September 2019	16	$8,809,726.00	3,140
		5439	1 June 2017	14 September 2019	16	$8,809,726.00	3,140
		5440	1 June 2017	14 September 2019	16	$8,805,886.00	3,142
		5441	1 June 2017	14 September 2019	16	$8,805,886.00	3,142
		5442	1 June 2017	14 September 2019	16	$8,805,886.00	3,142
		5443	1 June 2017	14 September 2019	16	$8,801,886.00	3,143
		5444	1 June 2017	14 September 2019	16	$8,801,886.00	3,143
		5445	1 June 2017	14 September 2019	16	$8,801,886.00	3,143
		5446	1 June 2017	14 September 2019	16	$8,806,286.00	3,142
		5447	1 June 2017	14 September 2019	16	$8,801,726.00	3,143
		5448	1 June 2017	14 September 2019	16	$8,801,886.00	3,143
		5449	1 June 2017	14 September 2019	16	$8,801,726.00	3,143

		5450	1 June 2017	14 September 2019	16	$8,801,726.00	3,143
		5451	1 June 2017	14 September 2019	16	$8,801,646.00	3,143
		5452	1 June 2017	14 September 2019	16	$8,799,206.00	3,142
		5453	1 June 2017	14 September 2019	16	$8,801,726.00	3,142
		5454	1 June 2017	14 September 2019	16	$8,801,646.00	3,143
		5455	1 June 2017	14 September 2019	16	$8,799,206.00	3,142
		5456	1 June 2017	14 September 2019	16	$8,801,886.00	3,143
		5457	1 June 2017	14 September 2019	16	$8,796,846.00	3,144
		5459	1 June 2017	14 September 2019	16	$8,789,606.00	3,146
		5460	1 June 2017	14 September 2019	16	$8,789,606.00	3,146
		5461	1 June 2017	14 September 2019	16	$8,796,846.00	3,144
		5462	1 June 2017	14 September 2019	16	$8,789,606.00	3,146
		5463	1 June 2017	14 September 2019	16	$8,789,606.00	3,146

		5464	1 June 2017	14 September 2019	16	$8,782,106.00	3,148
		5465	1 June 2017	14 September 2019	16	$8,780,506.00	3,148
		5466	1 June 2017	14 September 2019	16	$8,782,106.00	3,148
		5467	1 June 2017	14 September 2019	16	$8,780,506.00	3,148
		5468	1 June 2017	14 September 2019	16	$8,782,106.00	3,148
		5469	1 June 2017	14 September 2019	16	$8,780,506.00	3,148
		5470	1 June 2017	14 September 2019	16	$8,779,026.00	3,147
		5471	1 June 2017	14 September 2019	16	$8,774,066.00	3,144
		5472	1 June 2017	14 September 2019	16	$8,772,466.00	3,145
		5473	1 June 2017	14 September 2019	16	$8,777,426.00	3,147
		5474	1 June 2017	14 September 2019	16	$8,780,506.00	3,146
		5475	1 June 2017	14 September 2019	16	$8,749,786.00	3,141
		5476	1 June 2017	14 September 2019	16	$8,775,826.00	3,146

		5477	1 June 2017	14 September 2019	16	$8,780,106.00	3,146
		5478	1 June 2017	14 September 2019	16	$8,749,786.00	3,140
		5479	1 June 2017	14 September 2019	16	$8,775,426.00	3,146
		5480	1 June 2017	14 September 2019	16	$8,776,586.00	3,147
		5481	1 June 2017	14 September 2019	16	$8,746,586.00	3,142
		5458	1 June 2017	14 September 2019	16	$8,789,606.00	3,146
		5482	1 June 2017	14 September 2019	16	$8,773,506.00	3,146
		5483	1 June 2017	14 September 2019	16	$8,777,026.00	3,146
		5484	1 June 2017	14 September 2019	16	$8,745,586.00	3,141
		5485	1 June 2017	14 September 2019	16	$8,773,346.00	3,146
		5486	1 June 2017	14 September 2019	16	$8,774,626.00	3,146
		5487	1 June 2017	14 September 2019	16	$8,745,586.00	3,141
		5488	1 June 2017	14 September 2019	16	$8,772,546.00	3,147

		5489	1 June 2017	14 September 2019	16	$8,767,466.00	3,144
		5490	1 June 2017	14 September 2019	16	$8,743,346.00	3,141
		5491	1 June 2017	14 September 2019	16	$8,771,026.00	3,145
		5492	1 June 2017	14 September 2019	16	$8,775,266.00	3,145
		5493	1 June 2017	14 September 2019	16	$8,742,946.00	3,140
		5494	1 June 2017	14 September 2019	16	$8,771,026.00	3,145
		5495	1 June 2017	14 September 2019	16	$8,768,466.00	3,145
		5496	1 June 2017	14 September 2019	16	$8,742,946.00	3,140
		5497	1 June 2017	14 September 2019	16	$8,765,026.00	3,143
		5498	1 June 2017	14 September 2019	16	$8,743,386.00	3,139
		5499	1 June 2017	14 September 2019	16	$8,741,946.00	3,139
		5500	1 June 2017	14 September 2019	16	$8,756,066.00	3,145
		5501	1 June 2017	14 September 2019	16	$8,743,386.00	3,105

		5502	1 June 2017	14 September 2019	16	$8,741,946.00	3,105
		5503	1 June 2017	14 September 2019	16	$8,753,666.00	3,145
		5504	1 June 2017	14 September 2019	16	$8,772,186.00	3,113
		5505	1 June 2017	14 September 2019	16	$8,739,546.00	3,104
		5506	1 June 2017	14 September 2019	16	$8,752,866.00	3,144
		5507	1 June 2017	14 September 2019	16	$8,753,066.00	3,108
		5508	1 June 2017	14 September 2019	16	$8,738,746.00	3,104
		5509	1 June 2017	14 September 2019	16	$8,744,466.00	3,144
		5510	1 June 2017	14 September 2019	16	$8,745,266.00	3,111
		5511	1 June 2017	14 September 2019	16	$8,736,506.00	3,105
		5512	1 June 2017	14 September 2019	16	$8,743,186.00	3,144
		5513	1 June 2017	14 September 2019	16	$8,742,066.00	3,110
		5514	1 June 2017	14 September 2019	16	$8,734,466.00	3,102

		5515	1 June 2017	14 September 2019	16	$8,739,986.00	3,144
		5516	1 June 2017	14 September 2019	16	$8,728,346.00	3,101
		5517	1 June 2017	14 September 2019	16	$8,699,586.00	3,098
		5518	1 June 2017	14 September 2019	16	$8,731,706.00	3,140
		5519	1 June 2017	14 September 2019	16	$8,731,466.00	3,106
		5520	1 June 2017	14 September 2019	16	$8,668,626.00	3,085
		5521	1 June 2017	14 September 2019	16	$8,731,466.00	3,140
		5522	1 June 2017	14 September 2019	16	$8,748,386.00	3,108
		5523	1 June 2017	14 September 2019	16	$8,667,026.00	3,085
		5524	1 June 2017	14 September 2019	16	$8,713,866.00	3,138
		5525	1 June 2017	14 September 2019	16	$8,724,706.00	3,103
		5526	1 June 2017	14 September 2019	16	$8,663,826.00	3,084
		5527	1 June 2017	14 September 2019	16	$8,713,066.00	3,139

Table 5.3 IT Project Optimisation

Project Plan ID	Name	Min Cost	Max Cost	Delta Costs	Min Duration	Max Duration	Delta Duration %
112	Argo IT Solution	8,005	8,955	11.867582761	3	3	0.00
156	First Digital Super Fund	6,153,448	6,285,648	2.148389001	744	776	4.30
157	Second Digital Super Fund	4,703,580	4,813,020	2.326738357	584	698	19.52
159	Third Digital Super Fund	8,663,826	8,824,020	1.848998352	835	1,123	34.49
163	Digital Banking	13,940	18,700	34.146341463	16	17	6.25

Table 6.1 Summary of the Outcomes

Parameter	Max Score	Min Score	Abs Δ	% Δ
CPU	762.35	674.88	87.47	12.96
Memory	659.45	547.61	111.84	20.42
Storage	864.38	805.95	58.43	7.25

Table 6.2 Sample Dataset

Solution Schedule ID	Date Created	Solution Plan Name	CPU Utilisation	Memory Utilisation	Storage Utilisation	Number Of Devices Allocated
1358	01/05/2019	Network Solution	674.88	547.61	805.95	16260
1361	01/05/2019	Network Solution	681.20	554.07	811.03	16260
1359	01/05/2019	Network Solution	681.67	556.61	809.70	16260
1357	01/05/2019	Network Solution	681.67	556.61	809.70	16260
1364	01/05/2019	Network Solution	730.23	616.01	841.34	16260
1379	01/05/2019	Network Solution	737.99	629.60	843.59	16260
1373	01/05/2019	Network Solution	741.89	635.30	845.56	16260
1376	01/05/2019	Network Solution	742.68	636.46	845.97	16260
1382	01/05/2019	Network Solution	743.25	637.27	846.28	16260
1391	01/05/2019	Network Solution	745.91	634.33	852.36	16260
1385	01/05/2019	Network Solution	746.28	641.73	847.81	16260
1397	01/05/2019	Network Solution	755.51	642.29	861.36	16260
1362	01/05/2019	Network Solution	757.91	659.14	853.56	16260
1360	01/05/2019	Network Solution	757.91	659.14	853.56	16260
1366	01/05/2019	Network Solution	757.91	659.14	853.56	16260
1356	01/05/2019	Network Solution	757.91	659.14	853.56	16260
1370	01/05/2019	Network Solution	757.94	659.19	853.58	16260

1363	01/05/2019	Network Solution	757.97	659.21	853.62	16260
1368	01/05/2019	Network Solution	757.97	659.21	853.62	16260
1365	01/05/2019	Network Solution	757.97	659.21	853.62	16260
1367	01/05/2019	Network Solution	758.00	659.25	853.64	16260
1372	01/05/2019	Network Solution	758.00	659.25	853.64	16260
1374	01/05/2019	Network Solution	758.03	659.27	853.68	16260
1378	01/05/2019	Network Solution	758.03	659.27	853.68	16260
1369	01/05/2019	Network Solution	758.03	659.27	853.68	16260
1371	01/05/2019	Network Solution	758.03	659.27	853.68	16260
1375	01/05/2019	Network Solution	758.09	659.33	853.74	16260
1377	01/05/2019	Network Solution	758.09	659.33	853.74	16260
1384	01/05/2019	Network Solution	758.09	659.33	853.74	16260
1380	01/05/2019	Network Solution	758.09	659.33	853.74	16260
1381	01/05/2019	Network Solution	758.15	659.39	853.80	16260
1383	01/05/2019	Network Solution	758.15	659.39	853.80	16260
1386	01/05/2019	Network Solution	758.15	659.39	853.80	16260
1390	01/05/2019	Network Solution	758.15	659.39	853.80	16260
1392	01/05/2019	Network Solution	758.21	659.45	853.86	16260
1387	01/05/2019	Network Solution	758.21	659.45	853.86	16260
1389	01/05/2019	Network Solution	758.21	659.45	853.86	16260

1436	02/05/2019	Network Solution	760.90	650.50	863.81	16260
1394	01/05/2019	Network Solution	761.66	652.22	863.78	16260
1400	01/05/2019	Network Solution	761.71	652.28	863.81	16260
1388	01/05/2019	Network Solution	761.72	652.29	863.83	16260
1399	01/05/2019	Network Solution	761.72	652.29	863.83	16260
1393	01/05/2019	Network Solution	761.72	652.29	863.83	16260
1395	01/05/2019	Network Solution	761.72	652.29	863.83	16260
1406	01/05/2019	Network Solution	761.74	652.29	863.86	16260
1412	01/05/2019	Network Solution	761.75	652.33	863.84	16260
1401	01/05/2019	Network Solution	761.79	652.35	863.89	16260
1396	01/05/2019	Network Solution	761.79	652.35	863.89	16260
1398	01/05/2019	Network Solution	761.79	652.35	863.89	16260
1405	01/05/2019	Network Solution	761.79	652.35	863.89	16260
1402	01/05/2019	Network Solution	761.82	652.36	863.93	16260
1404	01/05/2019	Network Solution	761.82	652.36	863.93	16260
1407	01/05/2019	Network Solution	761.82	652.36	863.93	16260
1454	02/05/2019	Network Solution	761.83	652.38	863.95	16260
1418	01/05/2019	Network Solution	761.89	652.50	863.93	16260
1415	01/05/2019	Network Solution	761.94	652.55	863.98	16260
1409	01/05/2019	Network Solution	761.95	652.59	863.96	16260

1410	01/05/2019	Network Solution	761.98	652.64	863.98	16260
1403	01/05/2019	Network Solution	761.98	652.64	863.98	16260
1408	01/05/2019	Network Solution	761.98	652.64	863.98	16260
1414	01/05/2019	Network Solution	761.98	652.64	863.98	16260
1430	02/05/2019	Network Solution	761.98	652.54	864.09	16260
1424	02/05/2019	Network Solution	762.03	652.66	864.04	16260
1442	02/05/2019	Network Solution	762.03	652.57	864.15	16260
1413	01/05/2019	Network Solution	762.05	652.70	864.04	16260
1411	01/05/2019	Network Solution	762.05	652.70	864.04	16260
1420	01/05/2019	Network Solution	762.05	652.70	864.04	16260
1416	01/05/2019	Network Solution	762.05	652.70	864.04	16260
1439	02/05/2019	Network Solution	762.05	652.73	864.01	16260
1433	02/05/2019	Network Solution	762.08	652.70	864.10	16260
1417	01/05/2019	Network Solution	762.11	652.76	864.10	16260
1419	01/05/2019	Network Solution	762.11	652.76	864.10	16260
1422	02/05/2019	Network Solution	762.11	652.76	864.10	16260
1427	02/05/2019	Network Solution	762.14	652.79	864.12	16260
1426	02/05/2019	Network Solution	762.14	652.84	864.07	16260
1421	01/05/2019	Network Solution	762.14	652.84	864.07	16260
1425	02/05/2019	Network Solution	762.14	652.77	864.15	16260

1428	02/05/2019	Network Solution	762.14	652.77	864.15	16260
1423	02/05/2019	Network Solution	762.14	652.77	864.15	16260
1432	02/05/2019	Network Solution	762.14	652.77	864.15	16260
1431	02/05/2019	Network Solution	762.15	652.78	864.18	16260
1438	02/05/2019	Network Solution	762.15	652.78	864.18	16260
1434	02/05/2019	Network Solution	762.15	652.78	864.18	16260
1429	02/05/2019	Network Solution	762.15	652.78	864.18	16260
1448	02/05/2019	Network Solution	762.18	652.78	864.24	16260
1444	02/05/2019	Network Solution	762.21	652.84	864.24	16260
1435	02/05/2019	Network Solution	762.21	652.84	864.24	16260
1437	02/05/2019	Network Solution	762.21	652.84	864.24	16260
1440	02/05/2019	Network Solution	762.21	652.84	864.24	16260
1443	02/05/2019	Network Solution	762.27	652.90	864.30	16260
1441	02/05/2019	Network Solution	762.27	652.90	864.30	16260
1446	02/05/2019	Network Solution	762.27	652.90	864.30	16260
1451	02/05/2019	Network Solution	762.27	652.93	864.27	16260
1449	02/05/2019	Network Solution	762.29	652.90	864.33	16260
1447	02/05/2019	Network Solution	762.29	652.90	864.33	16260
1456	02/05/2019	Network Solution	762.32	652.95	864.33	16260
1445	02/05/2019	Network Solution	762.32	652.95	864.33	16260

1450	02/05/2019	Network Solution	762.32	652.95	864.33	16260
1452	02/05/2019	Network Solution	762.32	652.95	864.33	16260
1453	02/05/2019	Network Solution	762.35	652.97	864.38	16260
1455	02/05/2019	Network Solution	762.35	652.97	864.38	16260