Resource allocation and scheduling within the context of fibre network deployment

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Dissertation submitted in fulfilment of the requirements for the degree *Master of Engineering in Computer and Electronic Engineering* at the North-West University

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Graduation ceremony: May 2019

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November 2018

Declaration

I, Quinton van Riet hereby declare that the dissertation entitled *Resource allocation and scheduling within the context of fibre network deployment* is my own original work and has not already been submitted to any other university or institution for examination.

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Signed on the 20th day of November 2018 at Potchefstroom.

Acknowledgements

I wish to express my sincere gratitude to my supervisors Prof Fanie Terblanche and Prof Leenta Grobler for providing your invaluable guidance, comments, and suggestions throughout this study.

To my fiancée, Elizabeth, thank you for all your love and support. Thank you for always believing in me and my capabilities.

I am forever grateful for the opportunities and abilities God has given me to be able to do what I love.

Abstract

The Resource-constrained Project Scheduling Problem (RCPSP), where a schedule must obey the resource constraints and precedence constraints of various activities over time, is one of the most studied scheduling problems. During the scheduling process, each activity requires a quantity of some resource for each period. The total resource consumption for each of the time periods must be less than or equal to the availability of resources. A precedence graph determines the order in which the activities may be scheduled.

Existing project management tools such as MS Project do not take complex objective functions into account and are unable to cater for telecommunication-specific side constraints. A fibre network deployment scheduling model is proposed to assist with the resource allocation and scheduling of project activities. The proposed model will take the time value of money into account and will perform resource allocation and scheduling with the objective of maximising Net Present Value (NPV).

In this dissertation, two Mixed-integer Programming (MIP) formulations of the RCPSP are presented, the time-indexed and resource flow formulation. An experimental comparison of instances involving varying activity duration sizes is performed. The impact of these problem characteristics on the performance of the models is evaluated when considering the minimisation of makespan as the scheduling objective. The results from the minimisation of makespan models are used to solve the scheduling of fibre deployment activities with the objective of maximising NPV.

Computational results of the formulations presented in this dissertation are compared using datasets from the literature as well as generated datasets. Conclusions of each model are drawn according to the instance characteristics. Based on the results it is found that the resource flow formulation performed better than the time-indexed formulation when the duration of project activities increased. The hybrid approach improves the MIP models by using Constraint Programming (CP) as a primal heuristic to determine initial feasible solutions for the MIP models to increase NPV.

Keywords: *Constraint Programming, FTTH Deployment, Mixed-integer Programming, Optimisation, Passive Optical Network, Resource Allocation, Resource-constrained Project Scheduling Problem, RCPSP.*

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List of Acronyms

3DTV 3-Dimensional Television

AI Artificial Intelligence

AON Active Optical Network

CAPEX Capital Expenditure

CO Central Office

CP Constraint Programming

FTTB Fibre-to-the-Building

FTTC Fibre-to-the-Cabinet

FTTD Fibre-to-the-Desktop

FTTH Fibre-to-the-Home

FTTN Fibre-to-the-Node

FTTP Fibre-to-the-Premises

FTTx Fibre-to-the-x

FTTZ Fibre-to-the-Zone

GA Genetic Algorithm

GDP Gross Domestic Product

HDTV High-definition Television

IRR Internal Rate of Return

ISPs Internet Service Providers

ITU International Telecommunication Union

LP Linear Programming

MIP Mixed-integer Programming

MILP Mixed-integer Linear Programming

NPV Net Present Value

ONUs Optical Network Units

OPEX Operating Expenditure

P2P Point-to-Point

PON Passive Optical Network

PSPLIB Project Scheduling Problem Library

RCPSP Resource-constrained Project Scheduling Problem

TVOD Transactional Video on Demand

Chapter 1

Introduction

The first chapter serves as an introduction to this dissertation. In this chapter background information on fibre networks is discussed. The motivation for this research together with the research objectives and methodology are presented. Chapter 1 concludes with an overview of this dissertation.

1.1 Background

The demand for higher bandwidth and data throughput by end users have Internet Service Providers (ISPs) pursuing to deliver the latest internet connectivity solution. Optical networks have been adopted due to several advantages they offer over copper networks. Some advantages of optical fibre are [1]:

- Higher bandwidth throughput;
- Lower total cost of ownership;
- Future proof;

- Improved network reliability;
- Less weight;
- Occupies less space;
- Immune to electromagnetic interference and crosstalk.

These advantages led to the global deployment of fibre optic networks. A Passive Optical Network (PON) is the most suitable architecture for Fibre-to-the-Home (FTTH) networks since it has several advantages over a Point-to-Point (P2P) and an Active Optical Network (AON). A P2P network requires a significant amount of fibre since all fibre cables are deployed from the central office directly to the end user. An AON architecture has an active node which requires power to function as well as backup power in the event of a power failure. In addition, it requires cooling and space. A PON has no active devices and only uses fibre and passive components which can be concealed underground. PONs are the most attractive fibre network solution due to their simplicity and lower costs compared to P2P and AON. Figure 1.1 illustrates a PON architecture where a fibre cable connects the Central Office (CO) to a splitter, and the splitter then splits the signal to multiple Optical Network Units (ONUs). Fibre duct sharing is a technique that is used when fibre cables share the same route, instead of placing each fibre cable in a separate trench.

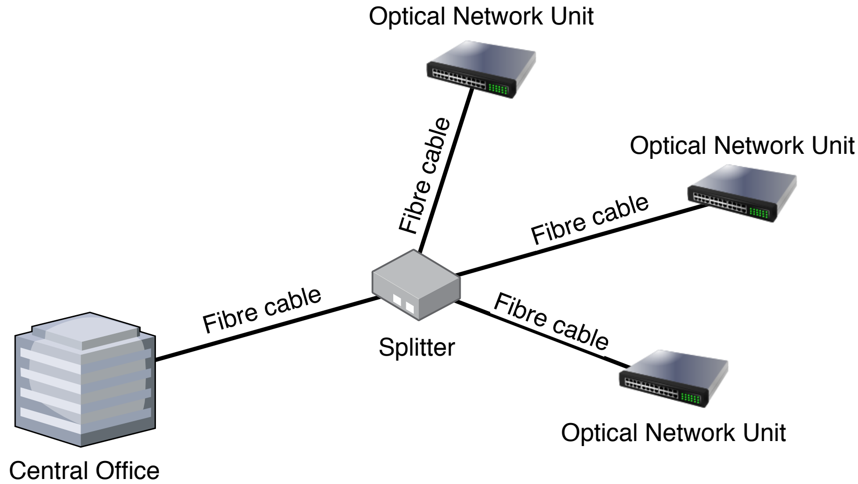


Figure 1.1: Passive Optical Network (PON) example

The increasing demand for higher bandwidth is due to the constant deployment of new global services that tend to gradually require more bandwidth. According to the authors in [2], it is expected that within 5 years, users will require 1Gbps links. This is to accommodate services such as High-definition Television (HDTV), Transactional Video on Demand (TVOD), 3-Dimensional Television (3DTV), online gaming, cloud platforms, file sharing and the overall increase of services demanding more internet usage from devices. In [3], it is reported that Korea's ultra-broadband networking vision of upgrading current 100Mbps fibre to 1Gbps has started in 2014. Although the first commercial gigabit internet service launched in October 2014, nationwide home internet upgrades is actively in progress.

Fibre-to-the-x (FTTx) is a way of bringing fibre closer to the end user. The type of architecture used for fibre optic networks is indicated by substituting the variable x. Fibre can be delivered to the end user's home, premises, building, cabinet, node, zone or desktop. These architectures are shown as FTTH, Fibre-to-the-Premises (FTTP), Fibre-to-the-Building (FTTB), Fibre-to-the-Cabinet (FTTC), Fibre-to-the-Node (FTTN), Fibre-to-the-Zone (FTTZ) and Fibre-to-the-Desktop (FTTD). In this dissertation, the main focus is on FTTH where fibre runs from the CO and reaches the boundary of the living space, delivering high bandwidth to the end user.

Fibre optic deployment typically involves two separate activities - the first step involves the design of the fibre network, followed by the physical deployment. Considerable work has been done in the last decade to provide the telecommunications industry with automated fibre network design tools [4, 5]. A typical objective of fibre network design models is to provide the least cost network design, based on demand projections and topology information. With an "optimal" network design at hand, the next step is to put a project management plan in place for the physical deployment.

Fibre uptake by businesses as well as home users is rapidly increasing, making further infrastructure development viable. The problem associated with high costs and low uptake is that the payback period for the operator's FTTH investments is too long. The critical issue for operators to address is to cut deployment costs to shorten the payback period. If fibre deployment companies can improve their deployment schedules by managing a deployment project to increase its Net Present Value (NPV), it would lead to financial benefits for both the fibre company as well as its end users. The NPV of deployment projects is an essential measurement in considering the viability of rolling out fibre infrastructure in new areas. The rollout of fibre infrastructure in a new area is viable when the capital expenditure is low, and the uptake is good.

In a publication by R. Ding [6], it is mentioned that according to research by the International Telecommunication Union (ITU), when broadband penetration increases by 10 percentage points, Gross Domestic Product (GDP) rises 1.3 percent, employment rises by 2 to 3 percent, productivity increases 5 to 10 percent, and innovation rockets 15-fold. At the same time, greenhouse gas emissions fall by 5 percent.

1.2 Research motivation

Optical fibre networks are currently considered the most suitable network solution capable of providing the demand for high bandwidths over long distances. Despite the decrease in optical fibre costs, deploying fibre networks is still considered expensive. The critical issue for operators to address is to cut deployment costs by extending broadband coverage to areas that contain high-value customers first. When residents who have the desire to spend money on fibre is supplied at the early stage of deployment, the uptake will be high - impacting deployment costs. When revenue is generated during deployment, it impacts the deployment cost by taking the time-value of money into account. This can be achieved by applying a project management plan to fibre deployment in new areas.

Existing project management tools such as MS Project do not take complex objective functions into account and are unable to cater for telecommunication-specific side constraints. A fibre network deployment scheduling model is proposed to assist with the resource allocation and scheduling of project activities. The proposed model will take the time value of money into account and will perform resource allocation and scheduling with the objective of maximising NPV.

The development of a Resource-constrained Project Scheduling Problem (RCPSP) formulation is considered for determining the schedule of a fibre network deployment project in order to maximise NPV, subject to fibre network specific constraints.

1.3 Research objectives

The research objectives for this dissertation:

- Develop a fibre network deployment scheduling model to assist with the resource allocation and scheduling of project activities by maximising NPV.
- Evaluate the computational efficiency of the time-indexed and resource flow RCPSP formulations.
- Examine the feasibility of Constraint Programming (CP) as a modelling technique.
- Improve the performance of the Mixed-integer Programming (MIP) models by integrating MIP and CP to form a hybrid model.

1.4 Research methodology

A literature review on fibre network planning and fibre network deployment is conducted to obtain some insights into the research area of fibre deployment, before seeking a solution to the problem. In an attempt to solve the research problem, a literature study is performed on recent work in RCPSP. The work on RCPSP is examined to promote the development of a RCPSP model that solves a fibre network deployment schedule. First, a small-scale implementation of the RCPSP is developed which is formulated to minimise the total project completion time. The results of the minimisation model are verified and validated before scaling the model. A small-scale maximisation of net present value implementation of the RCPSP is developed. For this case, the results of the maximisation model is verified and validated before scaling the model to larger problems. Mathematical modelling techniques such as MIP and CP are applied to both aforementioned models to improve the performance of the RCPSP. An outline of the research methodology, as applied in this study, is shown in Figure 1.2. The right-hand side of the flow diagram indicates the chapter numbers where evidence of the specific phase or component can be found.

1.5 Validation and verification

The Project Scheduling Problem Library (PSPLIB) [7] contains a repository of RCPSP problem instances. The RCPSP instances are used to benchmark newly developed models and algorithms. The repository contains solutions to three sets of data: j30, j60 and j90. There are 480 problem instances in each dataset. All problem instances of the j30 dataset have optimal solutions. Although the majority of the j60 and j90 sets have optimal solutions, some only contain feasible solutions. These PSPLIB solutions are used to verify the MIP and CP solutions of the minimisation of makespan mathematical models in Chapter 4.

The solutions of the mathematical models for scheduling fibre deployment activities with the objective of maximising NPV are verified by first developing a small-scale fibre deployment example, where it is possible to find a solution through manual calculations. The same fibre deployment example is also solved through the automated RCPSP model. The NPV determined by the automated RCPSP model is then verified with the manual calculated NPV before scaling the model to bigger problem instances.

The RCPSP models are also verified by extracting the start times of the activities from the solution, together with the duration of each activity. A Gantt chart is then used to plot the extracted information. The graphical nature of a Gantt chart aids in validating the solution in terms of feasibility. By examining the Gantt chart, it is possible to verify that the precedence relations are obeyed and that all resource capacities are satisfied.

The validity of the RCPSP models is considered through the construction of potential real-world networks to determine whether the models can perform resource allocation and scheduling within the context of fibre network deployment.

1.6 Dissertation overview

This dissertation consists of six chapters. Chapter 1, serves as an introduction to the research by providing background information on fibre networks and net present value in project management. This chapter also includes the motivation for this research, the research problem, objectives and the research methodology as applied in this study.

Chapter 2, reviews the work in the network planning literature and related work in network deployment. A general definition of the RCPSP is given and illustrated in Figure 2.1. Various mathematical modelling techniques are explored and are later implemented in Chapter 4.

Chapter 3, addresses the research problem by first discussing the technical aspects of fibre network deployment followed by a hypothetical example of RCPSP applied to fibre network deployment scheduling.

In Chapter 4, the mathematical models for the resource allocation and scheduling of fibre network deployment are formulated. The minimisation of makespan and maximisation of NPV models are defined as both time-indexed and resource flow RCPSPs.

The solutions of all the models defined in Chapter 4, are recorded in Chapter 5. The results of the different mathematical modelling techniques such as MIP, CP and a hybrid of the two techniques are compared, verified and discussed. The RCPSP model is validated in Section 5.3.

In the final chapter, Chapter 6, the research is concluded by summarising the research problem, concluding the findings and presenting recommendations for possible future research.

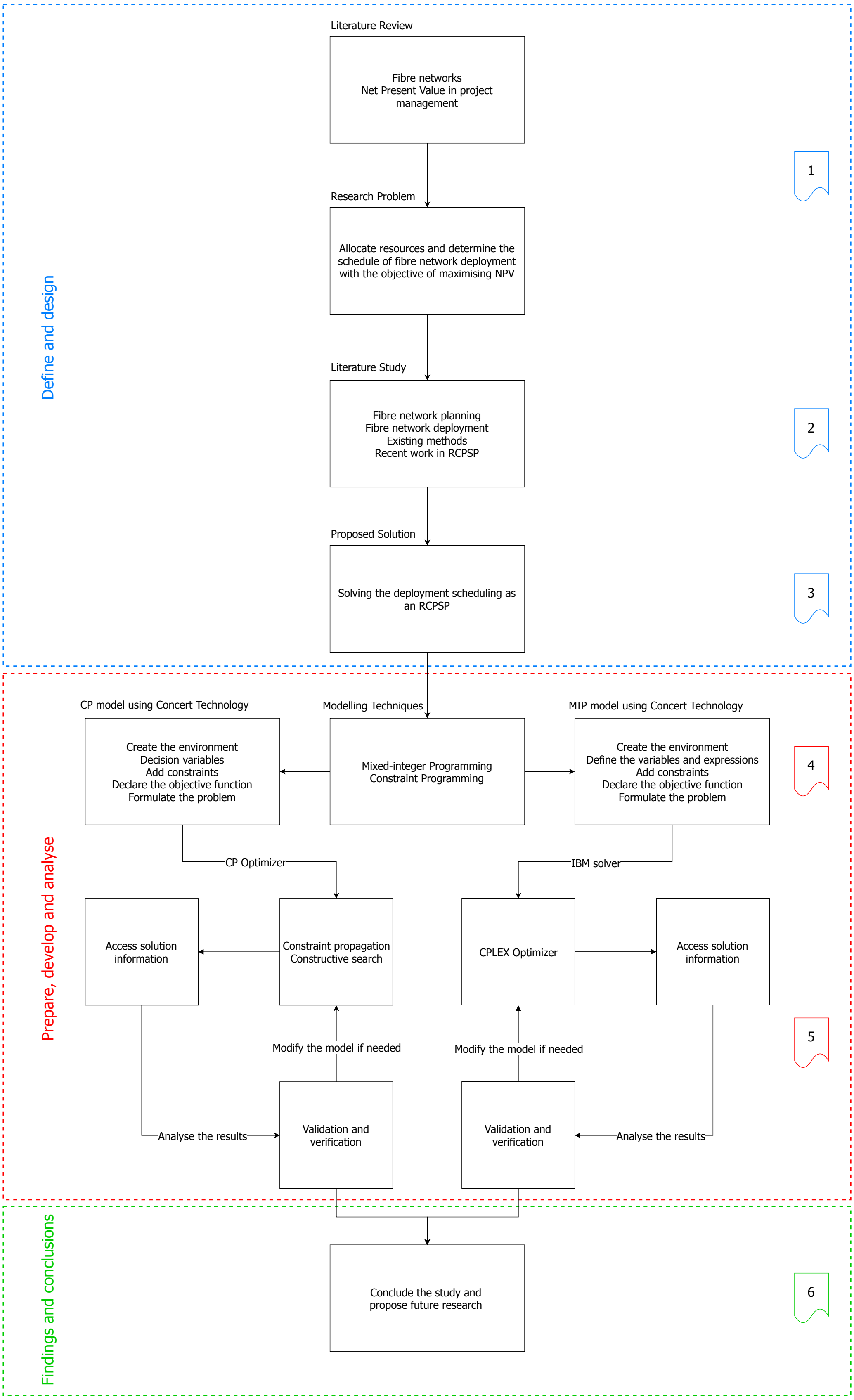


Figure 1.2: Research methodology as applied in this study

Chapter 2

Literature Study

In this chapter, work in network planning literature, as well as related work in network deployment, is briefly reviewed. A general definition of the RCPSP with some of its implementations is presented. Various mathematical modelling techniques are explored and are later used in Chapter 4.

2.1 Fibre network planning

A substantial amount of work has been done in the last decade to provide the telecommunication industry with automated fibre network design tools. These models consider accuracy, scalability and minimising network costs.

In the work performed by van Loggerenberg [5], the focus was on improving the accuracy of PON planning models as well as enhancing scalability to a point where large-scale problems can be solved feasibly. The model implements fibre duct sharing, network constraints, multiple splitter types and scalable economies. The improved accuracy and lower estimated deployment costs of the model caused the computational effort to increase considerably. The model was then refined through heuristic techniques which decreased the solution time while keeping deployment costs comparably low.

Laureles [4] studied the shortcomings associated with single-period network planning by conducting case studies on incremental FTTH planning. One of the benefits that incremental planning has over single-period planning is by eliminating network modifications post-deployment. The results from the Mixed-integer Linear Programming (MILP) model for the incremental FTTH planning problem showed a decrease in the number of splitters required by the network. Fewer splitters meant savings in trenching and fibre costs. The model also proved to be scalable through one of the case studies.

In general, automated planning models solve multilayer core network problems in a top-down manner. Capacities are solved for the top-most layer, and the solution is then used to solve the next lower layer. These planning models are considered suboptimal, bearing high costs. Jacholke [8] developed a MILP multilayer network model that integrates multiple layers into a single model by solving each layer as a multicommodity flow problem. The model determines the optimal network topology for which the capital expenditure is minimal. The increased computational effort of the multilayer network model has been addressed by decomposing the problem through Bender's decomposition [9] and applying column generation [10, 11].

2.2 Fibre network deployment

In the literature we find several works where the evaluation of the viability of FTTx investments are made through techno-economic models. Telecommunications companies construct deployment plans by comparing predefined deployment plan areas that are considered profitable, and then apply techno-economic analysis. Techno-economic analysis evaluates the technical requirements of the project (e.g., amount of fibre, splitters, optimal network design), as well as the economic requirements (e.g., cost, profit).

Azodolmolky and Tomkos [12] developed a techno-economic model to assist network planners and service providers in selecting a deployment strategy and network design. Their model provides high-level insight into Ethernet FTTB deployment through Capital Expenditure (CAPEX) and Operating Expenditure (OPEX). The results are based on a case study for an Ethernet FTTB deployment in Athens, Greece.

Jerman-Blazic [13] compared and evaluated suitable methods for delivering broadband services at the municipal and backbone level. The model is based on network value analysis that also involves CAPEX and OPEX calculations. The financial assessment for technology deployment is reflected through techno-economic evaluations such as NPV and Internal Rate of Return (IRR). The results are based on a case study for the Telekom Slovenia company and deals with upgrading the current network backbone while considering future development and trends of broadband services in the country.

Further work by Kampouridis *et al.* [14] developed a framework that wraps around the existing techno-economic models by using a Genetic Algorithm (GA) as a decision support tool when it comes to deciding which areas fibre networks should be deployed to first. For instance, given 100 areas, the GA determines that Areas 10-30 should be deployed in Year 1, then Areas 50-60 in Year 2, and so on. Where existing works usually construct deployment plans by manually comparing predefined deployment plan areas that are considered profitable, and then apply techno-economic analysis. The model by Kampouridis *et al.* [14] attempts to remove the need for human interference in the decision-making process. Although this model searches for deployment areas that returns the highest profit, it does not attempt to further increase profit by scheduling the order in which activities need to be executed when examining a specific deployment area.

2.3 The Resource-constrained project scheduling problem (RCPSP)

In general, the resource-constrained project scheduling problem (RCPSP) can be defined in the following way. A project consists of a number of activities indexed by the set $\mathcal{N} = \{1, 2, ..., N\}$. The project is completed when all activities have been processed. Each activity $i \in \mathcal{N}$ has an expected processing time d_i. There is a set $\mathcal{R}$ of renewable resources that may be used during an activity. The resources are called renewable because their full capacity is available in every period. While being processed, activity $i \in \mathcal{N}$ requires some quantity of resource $r \in \mathcal{R}$. Resource r has a limited instantaneous capacity of U_r during the processing of activities. A so-called precedence constraint determines the order in which activities may be processed. The precedence constraint forces activity $j \in \mathcal{N}$ to be preceded by activity $i \in \mathcal{N}$. The objective of RCPSP is to find a schedule where the duration is minimal, by assigning a start time to each activity while adhering to the precedence relations and resource availabilities. Figure 2.1 demonstrates a typical RCPSP schedule.

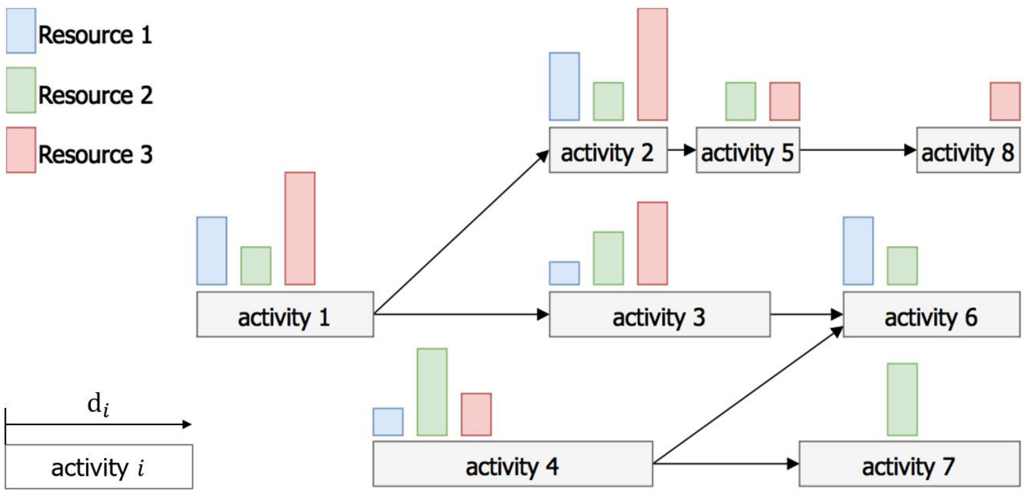


Figure 2.1: The resource-constrained project scheduling problem (RCPSP)

The RCPSP is widely known and has been studied and applied in many industries [15–18]. Resource scheduling is typically used in civil engineering where construction projects are large, and contractors are under pressure to complete these projects as quickly as possible. In [18], variants and extensions of the RCPSP are introduced. The use of the branch-and-bound algorithm, as defined in Section 2.5.4, to maximise NPV is well suited for RCPSP with discounted cash flow formulations. This algorithm is based on a scheduling generation scheme which resolves resource conflicts by adding new precedence constraints between activities in conflict [17].

2.4 Net present value in project management

Money in the present time is worth more than the same amount in the future; this is because money can be used to make more money and the affects that inflation has on the future value of money. This is known as the time value of money [19]. NPV is used to compare the value of money now with the value of money in the future.

In an article by W. Wetenkamp [20], the author presents how NPV can be used as a proper tool to ensure effective project management. He further proves that an investment project's appraisal methods, such as NPV, can and should be used as an ongoing monitor of project health. NPV is regarded the tool of choice among financial analysts due to its time value of money consideration and because it provides a concrete number that managers can use to easily compare an initial outlay of cash against the present value of the return.

NPV can be defined in short, as the difference between the present value of positive cash flow (income) and the present value of negative cash flow (expense) over time. NPV is therefore used to determine the profitability of an investment or project.

The formula for calculating NPV is given by:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \tag{2.1}$$

where,

C_t = the expected net cash flow at period t

r = discount rate

t = number of time periods

When the NPV calculation results in a positive value, it indicates that the predicted earnings of the project exceed the expected costs. A general rule applies when using NPV as a metric for making investment decisions. The rule entails that a positive NPV indicates a profitable investment while a negative NPV will result in a net loss. The larger the NPV, the greater the benefit to the company. This concept is the basis for the NPV Rule, which dictates that the only investments that should be made are those with positive NPV values.

2.5 Mathematical modelling techniques

Mathematical modelling is used to translate a description of a problem into a mathematical language for a computer to perform numerical calculations. The accuracy of any model depends on both the state of knowledge about the problem and how well the modelling is performed. Optimisation in mathematical modelling is a technique used to find the best possible solution, or *optimal solution*, by either minimising or maximising an objective function.

2.5.1 Linear programming

George B. Dantzig formally introduced Linear Programming (LP) in 1947. Linear programming is a mathematical modelling technique in which a problem described by a linear objective function is either maximised or minimised subject to a set of linear inequality constraints. LP enables one to determine the existence of optimal solutions.

A linear program written in standard form:

$$\text{maximise} \quad c^T \vec{x} \tag{2.2}$$

$$\text{subject to} \quad Ax \leq \vec{b} \tag{2.3}$$

$$\vec{x} \geq 0 \tag{2.4}$$

where $c \in \mathbb{R}^n, b \in \mathbb{R}^n, A \in \mathbb{R}^{m \times n}$ and $x \in \mathbb{R}^n$.

A two-variable linear program can be solved using the *graphical method*. This method involves formulating a set of linear inequalities subject to the constraints. The inequalities are plotted on an X-Y plane. By plotting all the inequalities on a graph, the feasible region is found through the intersecting region. The feasible region represents all values the model can take and also provides the optimal solution. Figure 2.2 represents an illustration of the graphical method displaying the intersecting region.

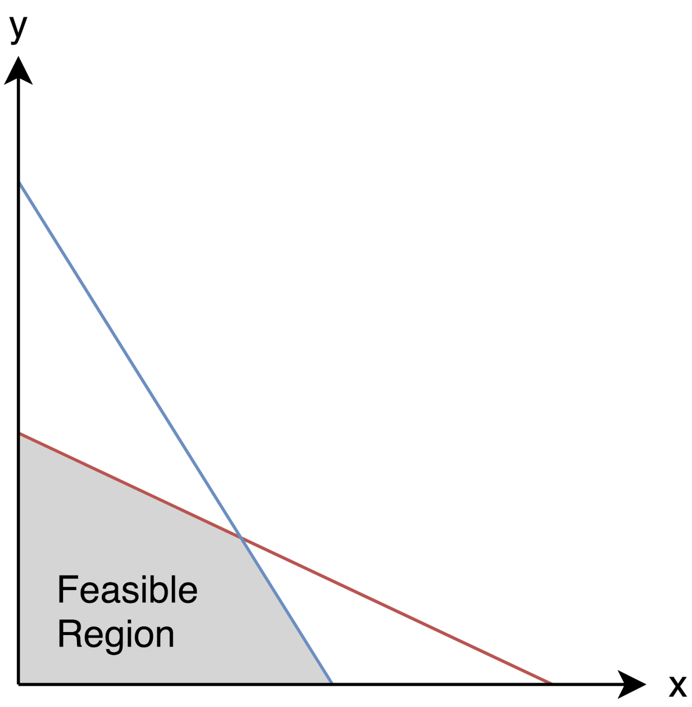


Figure 2.2: Linear programming graphical method

2.5.2 Simplex method

Most real-world linear programming problems are too complex to be solved using the graphical method since they usually have more than two variables. The *Simplex method* was invented by George B. Dantzig in 1947 and is often used to find the optimal solution to multivariable problems [21]. The simplex method is a set of instructions used to examine corner points in a methodical fashion until the best solution is found. The following steps are used to solve a linear programming problem using the simplex method:

- Transform to standard form
- Introduce slack variables
- Create the tableau
- Pivot variables
- Create a new tableau
- Check for optimality
- Identify optimal values

A detailed discussion for each of these steps can be found in [22]. Klee and Minty [23] showed that the worst-case behaviour of the simplex method grows exponentially fast. However, the average running time of the simplex algorithm is a polynomial-time method and therefore it is known to be efficient in practice [22].

2.5.3 Mixed-integer programming

Integer programming is essentially similar to linear programming; the only difference is that integer programming requires the decision variable only to be integer values. *Mixed-integer Programming* (MIP) is where at least one of the variables are forced to be integer values and allows other variables to be continuous as well. Mixed-integer programming models an application as a system of linear constraints on real and integer variables [24]. Linear programs are polynomial-time where mixed-integer programs are complex and NP-complete. A particular case of MIP is where the decision variable (e.g., x_i) can only be 0 or 1 at the solution. These variables are called binary integer variables and are used to model yes/ no decisions. One of the techniques used to solve MIP models is through *Branch-and-Bound*. With the branch-and-bound method, the integrality constraints are removed from the MIP model and solved as a linear program. This relaxation gives an optimistic bound where all constraints are viewed globally.

2.5.4 Branch-and-Bound

The *Branch-and-Bound* algorithm is an example of a systematic enumeration over the search space of all candidate solutions. Solutions are found by sub-dividing the search space into branches in a tree-like structure and then recursively searching each subspace for a better solution [25]. Before identifying new candidate solutions, the branch is checked against the upper and lower bounds of the optimal solution, if the branch fails to produce a better solution than the best solution so far, the branch gets discarded.

Figure 2.3 illustrates the branch-and-bound tree implemented on the following binary integer programming problem.

$$\text{maximise} \quad 10x_1 + 20x_2 + 30x_3 \tag{2.5}$$

$$\text{subject to} \quad 5x_1 + 8x_2 + 3x_3 \leq 10 \tag{2.6}$$

$$x_i \in \{0, 1\} \quad (i \in 1..3) \tag{2.7}$$

The optimal solution when maximising the objective function in (2.5) is 40. The binary integer variables x_1, x_2, x_3 are set to $1, 0, 1$ respectively.

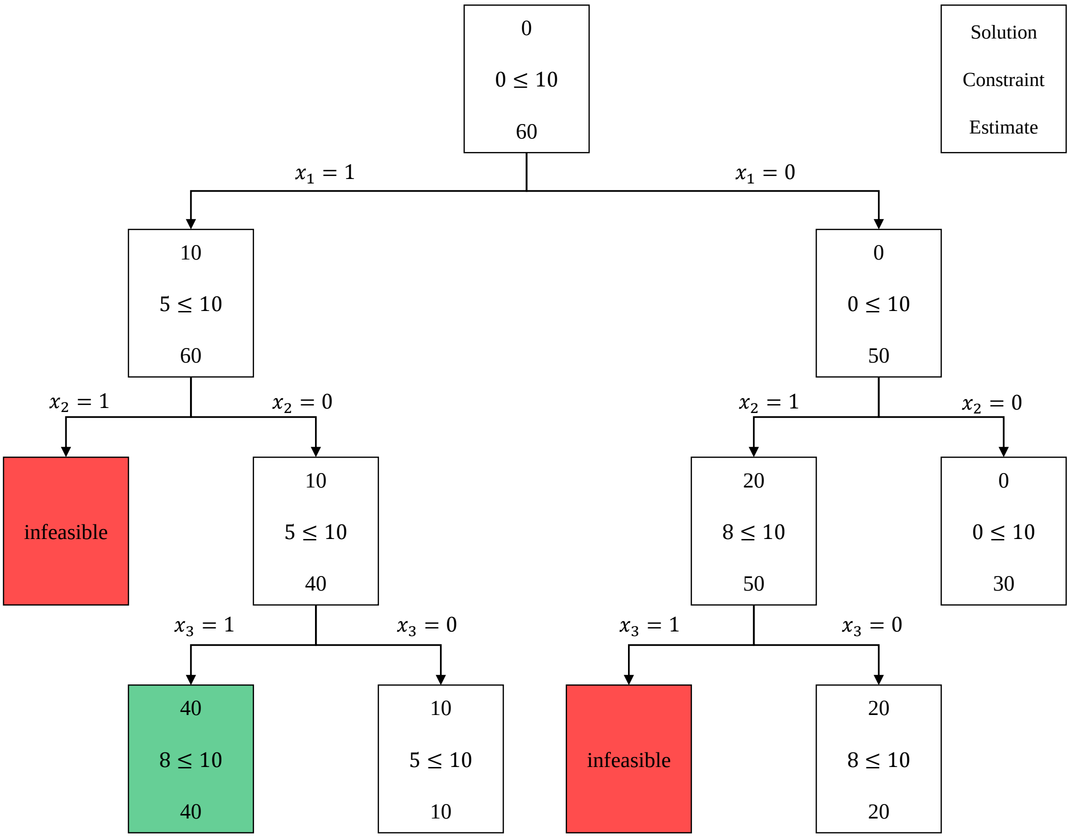


Figure 2.3: Binary branch-and-bound example

2.5.5 Constraint programming

Constraint Programming (CP) has become very popular in solving hard real-world problems in recent years [26]. Although historically CP can be traced back to when Artificial Intelligence (AI) was being researched in the sixties and seventies [24]. CP is used to solve problems by stating constraints about the problem area and, consequently, finding a solution satisfying all the constraints [26]. A constraint can intuitively be described as a restriction on a space of possibilities [24]. In CP, constraints are used to reduce the set of values that each variable can take, by removing values that cannot appear in any solution. Therefore, a constraint on a sequence of variables is a relation on their domains.

2.5.6 Constraint propagation

Constraint propagation is the process of reducing the domains of the decision variables, until no more variable domains can be reduced, or when a domain becomes empty and a failure occurs. An example of such a propagation process is when the decision variable i has an initial domain [0..10], j has an initial domain [0..10] and k has an initial domain [0..1] where the constraints over the variables are given as:

$$i + 10j \leq 5, \tag{2.8}$$

$$k \; != \; j, \tag{2.9}$$

$$k \; != \; i \tag{2.10}$$

The first constraint (2.8) reduces the domain of i to [0..5] and j to [0] through domain reduction. Constraint propagation then attempts to reduce the domain of every constraint involving j. Domain reduction on constraint (2.8) is then repeated after assuming the new domain of decision variable j, but finds that the domains of i and j cannot be reduced further by this specific constraint. The next constraint involving j is constraint (2.9) which reduces the domain of k to [1], since the domain of j has been fixed to [0]. An attempt to reduce the domain of every constraint involving k is then implemented by constraint propagation. The next constraint involving k is constraint (2.10) which removes the value 1 from the domain of i through domain reduction. Finally, constraint propagation then attempts to reduce the domain of every constraint involving i, but finds that the domain of i cannot be reduced further.

The values of the final domains are:

$$\begin{aligned} i &= [0\ 2..5], \\ j &= [0], \\ k &= [1] \end{aligned}$$

2.6 Summary

In this chapter, previous work on fibre network planning and deployment were studied. The general RCPSP approach was introduced, where the objective was to minimise makespan. The research goal of formulating the RCPSP, to solve fibre deployment scheduling, with the objective of maximising NPV is defined in Section 3.2. Mathematical modelling techniques such as MIP and CP, presented in this chapter, is implemented in Chapter 5.

Chapter 3

The Fibre Network Deployment Problem

This chapter addresses the research problem. First, the technical aspects of fibre network deployment are defined. Subsequently, the research goal of solving the fibre network deployment scheduling as a RCPSP is then addressed.

3.1 Technical aspects of fibre network deployment scheduling

Fibre network deployment is very expensive, and in order to maintain profitability, optimal use of resources is crucial. This may be achieved through the optimal scheduling of deployment activities that are expected to maximise NPV. The NPV of deployment projects is an essential measurement in considering the viability of rolling out fibre infrastructure in new areas. The rollout of fibre infrastructure in a new area is viable when the capital expenditure is low, and the uptake is good.

The type of fibre network to be considered in this dissertation, as introduced earlier in Section 1.1, is a Passive Optical Network (PON) that delivers Fibre-to-the-Home (FTTH). A passive optical fibre network consists of a CO, trenches, conduits, fibre, splitters and ONUs as represented in Figure 3.1. In FTTH deployment, high-speed optical fibres are connected from the CO to the ONUs with passive components in-between. These optical fibres are concealed underground and are preserved by placing them inside conduits.

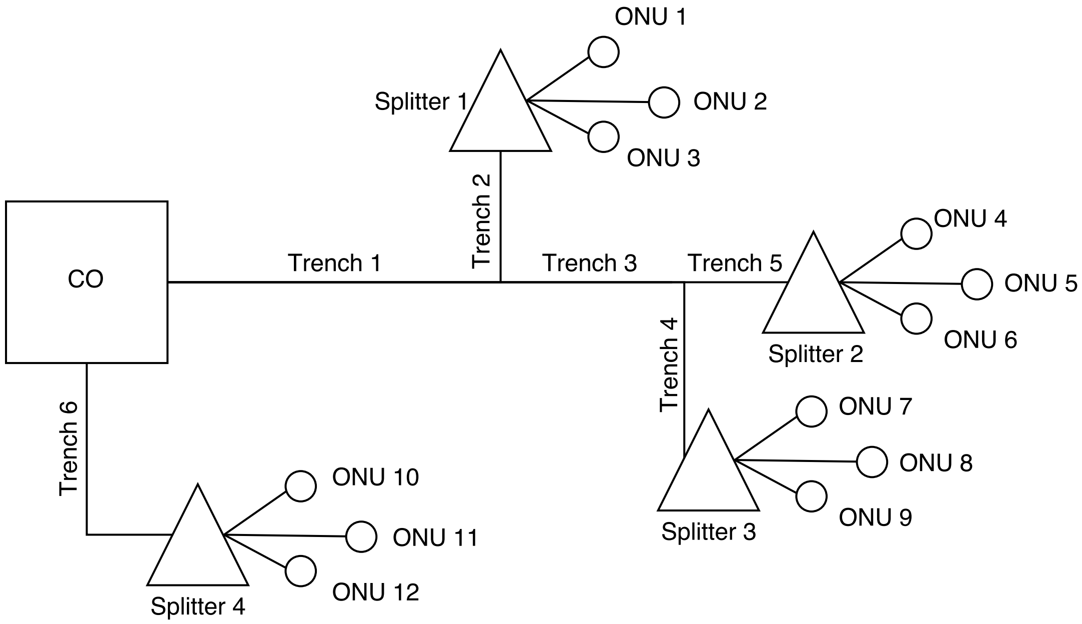


Figure 3.1: Elements of a simple fibre network

3.2 Solving the fibre network deployment scheduling as an RCPSP

In Section 2.3, a general RCPSP model was introduced where it was stated that a project consists of a number of activities together with a set of renewable resources. In fibre network deployment scheduling, the *project activities* entail the construction of a central office; the excavation of trenches; the installation of conduits, fibre, splitters, and ONUs. Other time-consuming activities include the splicing and testing of fibre cables.

The *renewable resources* are the number of excavation tools; man-hours of the workforce; and the availability of fibre, splitters, and ONUs.

Typically, the objective in solving RCPSP problems is to minimise the makespan, *i.e.*, complete the project in the shortest possible time. However, by maximising NPV the financial aspects of the project are better captured.

The cash flow associated with each activity may be an expense (negative cash flow) or an income (positive cash flow). The formula for NPV (2.1) considers this difference between negative cash flow and positive cash flow over time. Positive cash flow is the revenue that ONUs produce once a single path from the CO through to one of the ONUs has been completed. When areas that contain high-value customers who have the desire to spend money on fibre, is supplied first, the uptake will be high, and service providers can start producing revenue at the early stage of deployment. Negative cash flow is the costs associated with installing/ constructing the:

- CO;
- trenches and conduits;
- fibre;
- splitters;
- and ONUs.

A so-called precedence graph determines the sequencing of the activities. The precedence graph starts at the source node and ends at the sink node. The precedence relation states the order in which activities may be executed. For instance, the scheduling of the conduit and fibre activities cannot be placed ahead of the corresponding trenching activity. The trenches need to be excavated before the conduits and fibre cables are placed underground. Consider a set of activities $N = \{1, 2, 3, 4, 5\}$. The precedence graph corresponding to the set N is presented in Figure 3.2. The precedence constraint forces activity 2 to be preceded by activity 1 and 4.

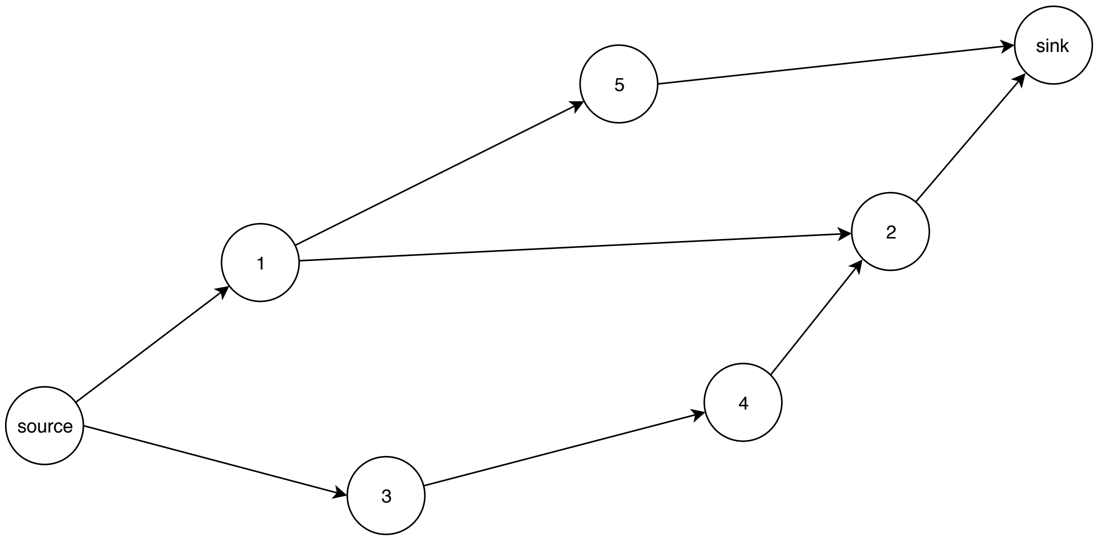


Figure 3.2: Precedence graph of set $N = \{1, 2, 3, 4, 5\}$

The process of solving the fibre network deployment scheduling as a RCPSP is clearly demonstrated through the consideration of a simple example, using the fibre network shown in Figure 3.1. This fibre network layout consists of 51 activities and the objective is to find a schedule that maximises this deployment's NPV. In this example, the only resource to be considered is the resource associated with the trenching activities. One resource is examined to simplify the demonstration of resource allocation and activity scheduling. The precedence graph of the simple fibre network is displayed in Figure 3.3.

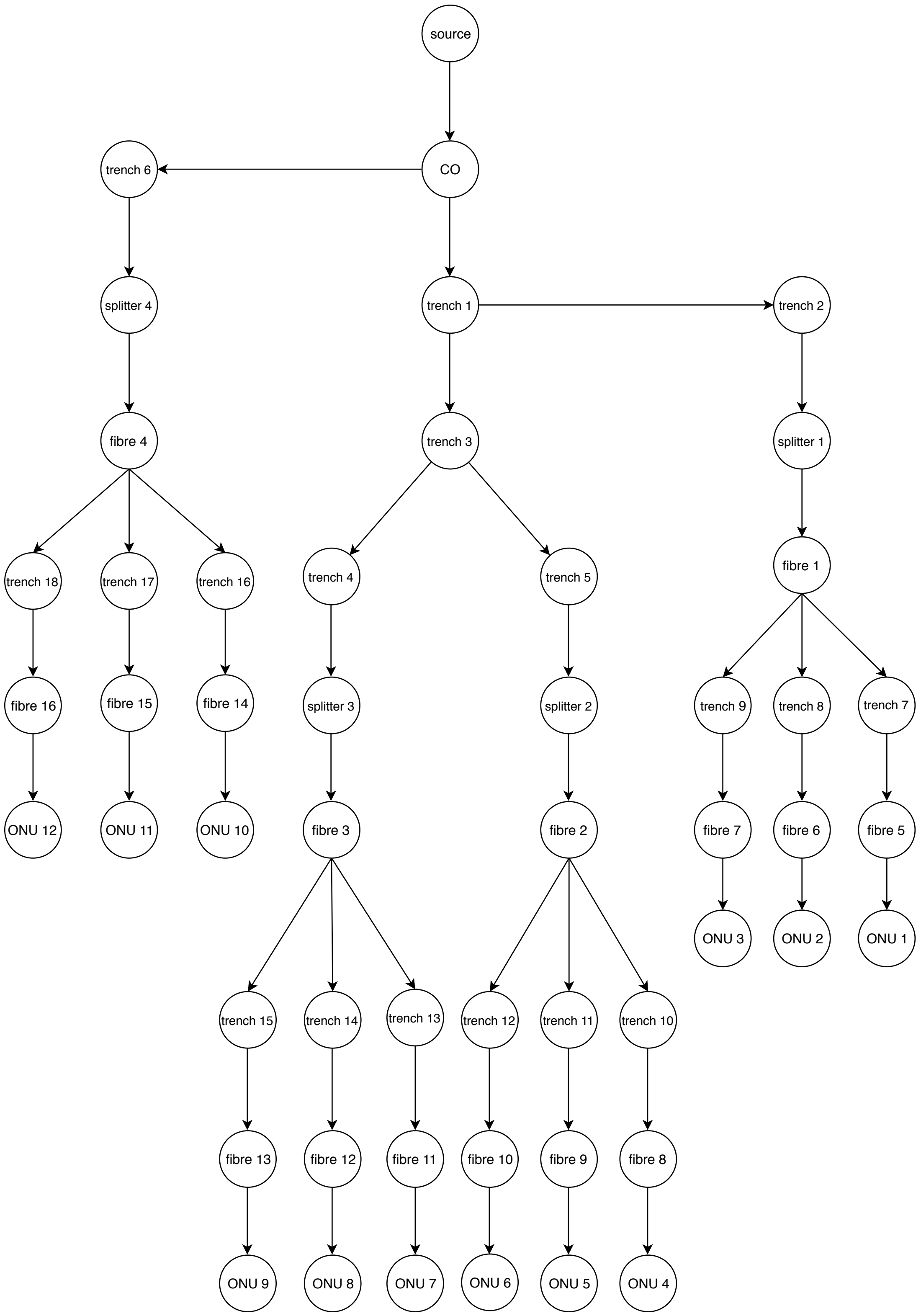


Figure 3.3: Precedence relations of the simple fibre network illustrated in Figure 3.1

When considering the sequencing of all *trenching* activities, there are certain tools (resources) required to excavate trenches. Figure 3.4 illustrates the resource usage and trenching durations for the case where the model excludes any resource usage limit. The RCPSP model structures the trenching activities in such a way that all activities will attempt to execute simultaneously, subject to their precedence constraints. The available slots between activity start times 0 - 7 and 13 - 15 are reserved for other activities according to the precedence graph in Figure 3.3.

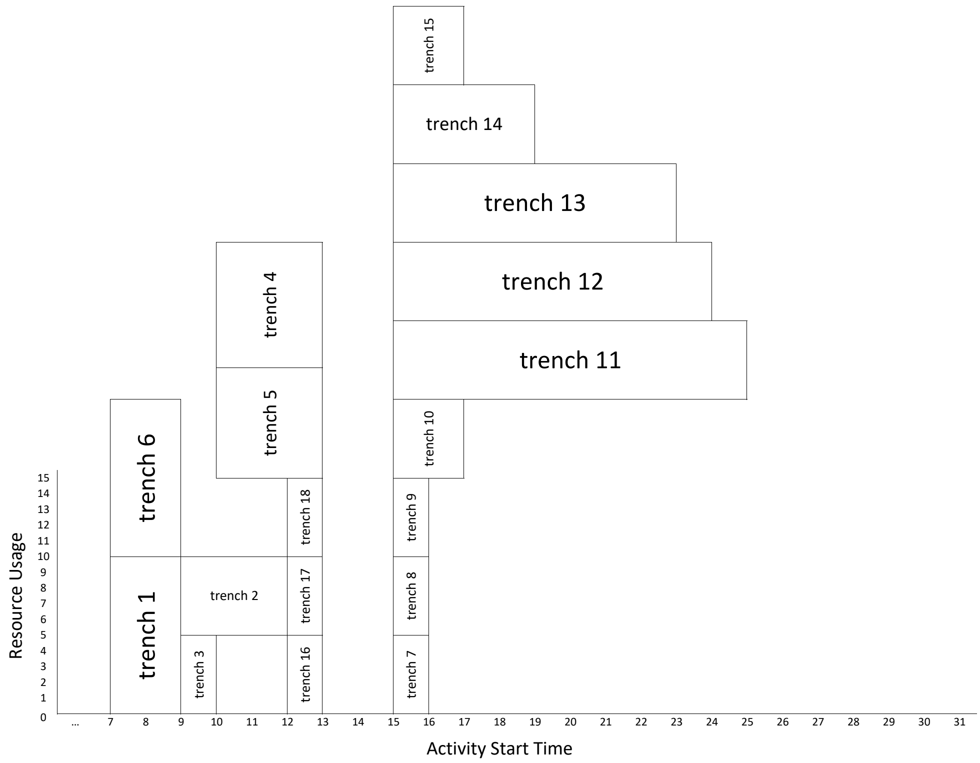


Figure 3.4: Resource usage over time (no resource constraint)

In FTTH deployment there are limited instantaneous capacities for the resources consumed by each deployment activity since there is a fixed amount of tools available for excavating trenches. For this reason, the trenching activities that may execute simultaneously are limited. When adding a resource usage limit of 15 to the model, the trenching activities are restructured and arranged in such a way that the resource usage capacities are never exceeded. Figure 3.5 illustrates the resource usage and trenching durations for the case where the RCPSP model includes a resource usage constraint. As a result of adding the constraint, the projected duration for completing all trenching activities changes from 25 to 31 days. The available slots between activity start times 0 - 7 and 11 - 12 are reserved for other activities according to the precedence graph in Figure 3.3.

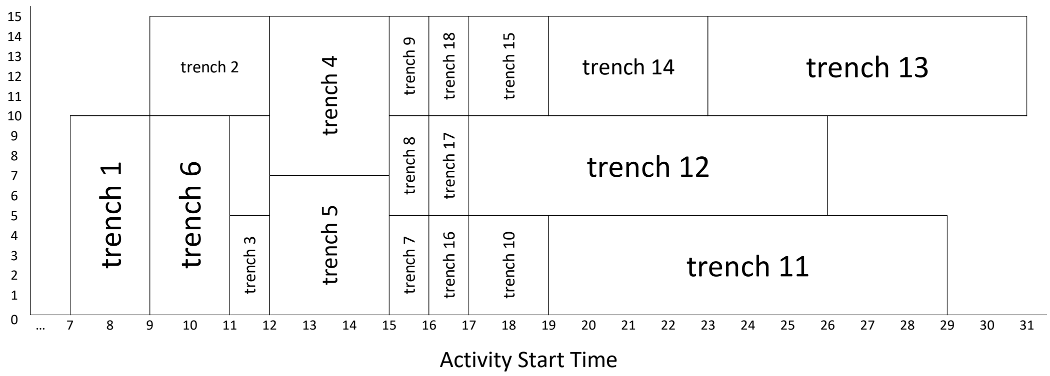


Figure 3.5: Resource usage over time (with resource constraint)

When the objective of the scheduling is to maximise the deployment project's NPV, the RCPSP model attempts to arrange all negative cash flow activities to be performed as late as possible while scheduling all positive cash flow activities early. The trenching activities with the lowest negative cash flow, which also forms part of a branch that would generate the most revenue at the ONUs, are scheduled first.

The start times of the activities are extracted from the solution, together with the duration of each activity and are then plotted on a Gantt chart, as illustrated in Figure 3.6. Although financial analysts may favour the NPV value of the solution, the graphical nature of a Gantt chart is also required to validate the solution concerning feasibility. For this example, Figure 3.6 shows that the precedence relations are obeyed, and all parallel trenching activities can be checked against the resource usage shown in Figure 3.5.

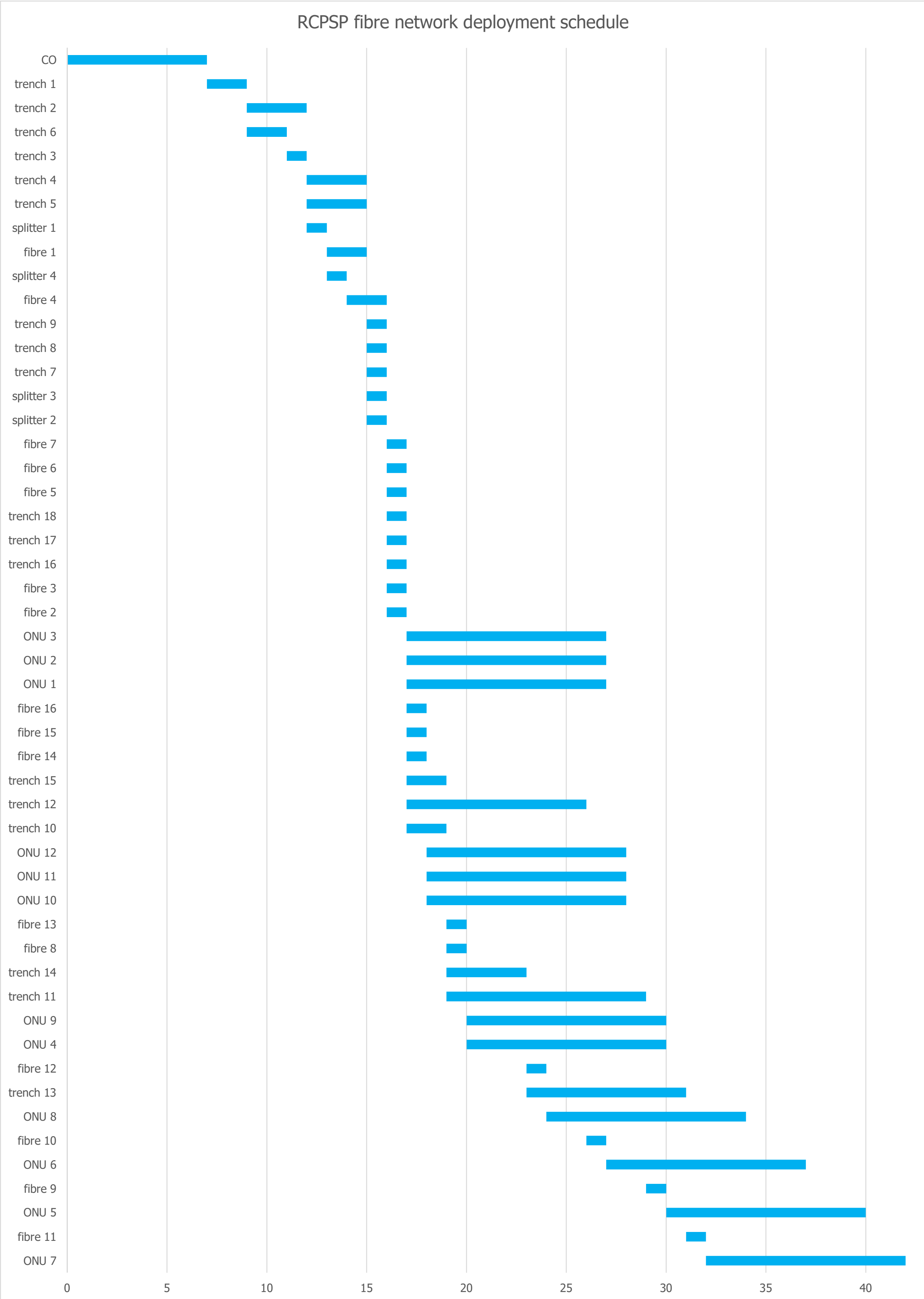


Figure 3.6: Gantt chart for the simple RCPSP example

3.3 Summary

The profitability of fibre network deployment relies on proper planning and effective resource utilisation. This may be achieved through the optimal scheduling of deployment activities by maximising NPV. In this chapter, a brief overview of the technical aspects of fibre network deployment scheduling was provided. A comprehensive discussion of all aspects concerning fibre deployment is beyond the scope of this dissertation. Therefore, some elements related to typical fibre network deployment were described.

A small-scale example was used to illustrate how fibre network deployment scheduling may be solved within the RCPSP framework. In the chapters to follow, the explicit formulation of the RCPSP model is presented.

Chapter 4

Mathematical Models

In this chapter, the mathematical models for the resource allocation and scheduling of fibre network deployment are presented. The two formulations of the RCPSP is the time-indexed and resource flow formulations for both the minimisation of makespan as well as the maximisation of NPV.

4.1 General notation

Let the set $\mathcal{N}$ represent the index set of all activities. Where an activity $i \in \mathcal{N}$ may, for example, represent the construction of a central office, or the excavation of trenches for installing fibre. Each activity $i \in \mathcal{N}$ has a duration d_i. There is a set $\mathcal{R}$ of renewable resources that may be used during an activity. A resource $r \in \mathcal{R}$ may, for example, represent the digging tools required to excavate trenches, the man-hours necessary to complete an activity, or the availability of fibre cables. Let v_{ir} denote the amount of resource $r \in \mathcal{R}$ being consumed by an activity $i \in \mathcal{N}$, per day. U_r represents the upper limit (or capacity) of resource $r \in \mathcal{R}$ for activity $i \in \mathcal{N}$.

The precedence graph $\mathcal{H}(\mathcal{N}, \mathcal{Z})$ provides the precedence terms of the RCPSP. Let $\mathcal{Z}$ represent the arc set of the precedence graph. Each arc $(i, j) \in \mathcal{Z}$ denotes the precedence relation that states activity $j \in \mathcal{N}$ should be preceded by activity $i \in \mathcal{N}$.

The formulation of the various RCPSP models in this chapter is facilitated by introducing a source and sink activity. If $\mathcal{N} = \{0, 1, ..., N\}$ represents the index set of all activities, the index 0 is used to indicate the source activity, and the index N is used to indicate the sink activity.

4.2 The time-indexed RCPSP

The first section presents the time-indexed formulation for the minimisation of makespan, followed by the time-indexed maximisation of NPV formulation.

4.2.1 Minimisation of makespan

The model formulation presented below was first introduced by Pritsker *et al.* [27]. Let $\mathcal{T} = \{1, 2, ..., |\mathcal{T}|\}$ signify the time indices. The decision variable, $x_{it} \in \{0, 1\}$, indicates the start time of an activity. When $x_{it} = 1$, activity $i \in \mathcal{N}$ is scheduled to start at the beginning of time period $t \in \mathcal{T}$. Let $\mathcal{T}(i) \subseteq \mathcal{T}$ denote the set of available start time periods for an activity $i \in \mathcal{N}$ based on the earliest, $E_i^{\mathcal{N}}$ and latest, $L_i^{\mathcal{N}}$ start times. $\mathcal{N}(t) \subseteq \mathcal{N}$ represents the set of activities available to start at time period $t \in \mathcal{T}$ based on the earliest and latest start times, *i.e.* $E_i^{\mathcal{N}} \leq t \leq L_i^{\mathcal{N}}$, for all $i \in \mathcal{N}(t)$.

The time-indexed formulation generally yields good LP relaxation [28]. However, it involves a pseudo-polynomial number of variables.

The objective of the *time-indexed RCPSP* when *minimising makespan* is to

$$\text{minimise} \sum_{t \in \mathcal{T}} t x_{Nt}, \tag{4.1}$$

subject to the constraints

$$\sum_{t \in T(i)} x_{it} = 1, \qquad i \in \mathcal{N}, \tag{4.2}$$

$$\sum_{t \in T(j)} t x_{jt} - \sum_{t \in T(i)} t x_{it} \geq d_i, \qquad (i,j) \in \mathcal{Z}, \tag{4.3}$$

$$\sum_{i \in \mathcal{N}(t)} \sum_{\substack{k \in T \\ k \leqslant t}} v_{ir} x_{ik} \leq U_r, \qquad r \in \mathcal{R},\ t \in \mathcal{T}. \tag{4.4}$$

The objective function (4.1) minimises the start time of the sink activity N. The constraint in (4.2) forces each activity to be scheduled to one of the time periods $t \in \mathcal{T}$. Constraint (4.3) structures the precedence relations according to the precedence graph $\mathcal{H}(\mathcal{N}, \mathcal{Z})$. The constraint in (4.4) applies an upper limit to the resource consumption of $r \in \mathcal{R}$.

4.2.2 Maximisation of NPV

The objective of the *time-indexed* RCPSP when *maximising NPV* is to

$$\text{maximise} \sum_{i \in \mathcal{N}} \sum_{k \in \mathcal{T}} \left(\sum_{t=k}^{t<k+d_i} \frac{c_i}{(1+\alpha)^t} \right) x_{ik}, \tag{4.5}$$

subject to the constraints

$$\sum_{t \in T(i)} x_{it} = 1, \qquad i \in \mathcal{N}, \tag{4.6}$$

$$\sum_{t \in T(j)} t x_{jt} - \sum_{t \in T(i)} t x_{it} \geq d_i, \qquad (i,j) \in \mathcal{Z}, \tag{4.7}$$

$$\sum_{i \in \mathcal{N}(t)} \sum_{\substack{k \in T \\ k \leqslant t}} v_{ir} x_{ik} \leq U_r, \qquad r \in \mathcal{R},\ t \in \mathcal{T} \tag{4.8}$$

The objective function (4.5) maximises NPV for all cash flows, c_i at a discount rate α. The constraint in (4.6) forces each activity to be scheduled to one of the time periods $t \in \mathcal{T}$. Constraint (4.7) structures the precedence relations according to the precedence graph. The constraint in (4.8) applies an upper limit on the resource consumption of $r \in \mathcal{R}$.

4.3 The resource flow RCPSP

The first section presents the resource flow formulation for the minimisation of makespan, followed by the resource flow maximisation of NPV formulation.

4.3.1 Minimisation of makespan

The model formulation presented below was first introduced by Artigues *et al.* [29]. The graph $\mathcal{G}(\mathcal{N}, \mathcal{A})$ provides the flow of resources of the RCPSP. Let $\mathcal{A}$ represent the arc set of the flow of resources among the nodes in $\mathcal{N}$. Each arc $(i, j) \in \mathcal{A}(i)$ denotes an arc for which node i is the source and the notation $(i, j) \in \mathcal{A}(j)$ denotes an arc for which node j is the target. The flow of resources from the sink and source activities are set equal to the availability of the resources, *i.e.*, $v_{0r} = v_{Nr} = U_r$, for all $r \in \mathcal{R}$.

The resource flow variables, $f_{ijr} \geq 0$, are introduced to indicate the flow of a resource $r \in \mathcal{R}$ from activity i to j. The decision variables $z_{ij} \in \{0,1\}$, also known as the *linear ordering variables*, manages the order of activities based on the flow of resources. When $z_{ij} = 1$, activity j is scheduled to start following the completion of activity i, this allows resources to be transferred from activity $i \in \mathcal{N}$ to $j \in \mathcal{N}$. The resource flow formulation is compact, in the sense that it involves a polynomial number of variables and constraints. However, it yields poor LP relaxation [28].

The objective of the *resource flow RCPSP* when *minimising makespan* is to

$$\text{minimise} \;\; s_N, \tag{4.9}$$

subject to the constraints

$$z_{ij} = 1, \qquad (i,j) \in \mathcal{Z}, \tag{4.10}$$

$$s_j - s_i - (d_i + M)z_{ij} \geq -M, \qquad (i,j) \in \mathcal{A}, \tag{4.11}$$

$$\sum_{(i,j)\in\mathcal{A}(i)} f_{ijr} = v_{ir}, \qquad i \in \mathcal{N},\ r \in \mathcal{R}, \tag{4.12}$$

$$\sum_{(i,j)\in\mathcal{A}(j)} f_{ijr} = v_{jr}, \qquad j \in \mathcal{N},\ r \in \mathcal{R}, \tag{4.13}$$

$$f_{ijr} - min\{v_{ir}, v_{jr}\}z_{ij} \leq 0, \qquad (i,j) \in \mathcal{A}, r \in \mathcal{R}. \tag{4.14}$$

The objective function (4.9) minimises the start time of the sink activity N. The constraint in (4.10) ensures feasibility concerning activity precedence. The constraint in (4.11) determines the linear ordering variables z_{ij} based on the start time s_j of activity j and the completion time of its predecessor i, given by $s_i + d_i$. The horizon, M, is the longest possible time required to complete the schedule, *i.e.* $\sum_{i=0}^{\mathcal{N}} d_i$. Constraint sets (4.12) and (4.13) imposes the resource flow requirements, declaring that all the flow of resources out of an activity (4.12) and all the flow of resources into an activity (4.13) should match the daily resource consumption v_{ir} by an activity i or v_{jr} by an activity j, respectively. The constraint in (4.14) allows resources to be transferred from activity i to j, when $z_{ij} = 1$, *i.e.* when activity j is scheduled to start after activity i.

4.3.2 Maximisation of NPV

The model formulation presented below was first introduced by Terblanche [30]. The resource flow formulation requires the optimisation of a non-linear function in order to maximise NPV, as opposed to the time-indexed formulation where the objective function is linear.

According to the approaches by Dantzig [31] and Markowitz and Manne [32], a piece-wise approximation of the objective function deals with each non-linear function $f_i(s_i)$.

$$\text{maximise} \sum_{i \in \mathcal{N}} f_i(s_i), \tag{4.15}$$

where

$$f_i(s_i) \;=\; c_i \; e^{-\alpha s_i}, \tag{4.16}$$

Let the points (s_{iv}, f_{iv}), $v \in \mathcal{V} = \{0, 1, \ldots, V-1\}$ be the vertices for the piece-wise linear approximation of the function $f_i(s_i)$. The decision variable, $y_i \in \mathbb{R}$, is used to approximate the value of $f_i(s_i)$ according to the piece-wise linear approximation. The variable, $\ell_{iv} \in \{0, 1\}$, is introduced to select the most fitting line segment for local approximation concerning the objective function. The variable, $\lambda_{iv} \geq 0$, $v \in \mathcal{V}$ expresses the decision variables s_i and y_i as convex combinations of the knots $(s_{iv}, y_{iv}), v \in \mathcal{V}$.

The objective of the *resource flow RCPSP* when *maximising NPV* is to

$$\text{maximise} \sum_{i \in \mathcal{N}} y_i, \tag{4.17}$$

subject to the constraints

$$z_{ij} = 1, \qquad (i,j) \in \mathcal{Z}, \tag{4.18}$$

$$s_j - s_i - (d_i + M)z_{ij} \geq -M, \qquad (i,j) \in \mathcal{A}, \tag{4.19}$$

$$\sum_{(i,j)\in\mathcal{A}(i)} f_{ijr} = v_{ir}, \qquad i \in \mathcal{N},\ r \in \mathcal{R}, \tag{4.20}$$

$$\sum_{(i,j)\in\mathcal{A}(j)} f_{ijr} = v_{jr}, \qquad j \in \mathcal{N},\ r \in \mathcal{R}, \tag{4.21}$$

$$f_{ijr} - min\{v_{ir}, v_{jr}\}z_{ij} \leq 0, \qquad (i,j) \in \mathcal{A}, r \in \mathcal{R}, \tag{4.22}$$

$$s_i - \sum_{v\in\mathcal{V}} \lambda_{iv} s_{iv} = 0, \qquad i \in \mathcal{N}, \tag{4.23}$$

$$y_i - \sum_{v\in\mathcal{V}} \lambda_{iv} y_{iv} = 0, \qquad i \in \mathcal{N}, \tag{4.24}$$

$$\sum_{v\in\mathcal{V}} \lambda_{iv} = 1, \qquad i \in \mathcal{N}, \tag{4.25}$$

$$\lambda_{i0} - \ell_{i1} \leq 0, \qquad i \in \mathcal{N}, \tag{4.26}$$

$$\lambda_{iv} - \ell_{iv} - \ell_{i(v+1)} \leq 0, \qquad i \in \mathcal{N}, v \in \mathcal{V} \setminus \{0, V-1\}, \tag{4.27}$$

$$\lambda_{i(V-1)} - \ell_{i(V-1)} \leq 0, \qquad i \in \mathcal{N}, \tag{4.28}$$

$$\sum_{v\in\mathcal{V}} \ell_{iv} = 1, \qquad i \in \mathcal{N}, v \in \mathcal{V} \setminus \{0\}. \tag{4.29}$$

The objective function (4.17) maximises NPV by adding all the linear piece-wise approximations $y_i \approx f_i(s_i)$ together, for all activities $i \in \mathcal{N}$. The constraint sets (4.18) - (4.22) correspond precisely to the constraint sets (4.10) - (4.14) which were described for the resource flow formulation for the minimisation of makespan. The constraints in (4.23) and (4.24) express s_i and y_i as convex combinations of the piece-wise linearisation knots of $f_i(s_i)$, for all activities $i \in \mathcal{N}$. Constraint (4.25) maintains the convexity conditions. The convexity variable, λ_{iv}, takes on an appropriate value based on the selection of a specific line segment, ℓ_{iv}, through the constraint sets (4.26), (4.27) and (4.28). The constraint in (4.29) selects the most fitting line segment for local approximation concerning the objective function.

4.4 Summary

The fibre network deployment scheduling problem involves determining the start times of fibre deployment activities in order to maximise NPV while taking specific constraints into account. In this chapter, two mathematical formulations of the RCPSP were presented for both the minimisation of makespan and the maximisation of NPV. Even though both, the time-indexed and resource flow formulations are different concerning their decision variables and constraints, both formulations provide the same optimal solutions when solved to optimality.

The computational results of the RCPSP formulations, presented in this chapter, are investigated in the next chapter.

Chapter 5

Computation

The results of the two mathematical formulations of the RCPSP presented in the previous chapter are solved for both the minimisation of makespan and the maximisation of NPV within this chapter. The computational properties of the time-indexed and resource flow formulations when using a MIP off-the-shelf solver are studied and discussed.

5.1 Test instance data

The *project scheduling problem library* (PSPLIB) [7] contains a repository of RCPSP benchmark instances to be used for the evaluation of the mathematical models in Chapter 4. The repository contains three sets of data: j30, j60 and j90. These sets contain RCPSP instances each comprising 30, 60 and 90 activities, respectively. There are 480 instances in each set which all differ in complexity. Each RCPSP instance includes a set of four resources. The properties of the PSPLIB test instance datasets are presented in Table 5.1.

Table 5.1: Test instance datasets from the literature

Dataset	Number of activities	Instances	Avg. activity duration	Number of resources
j30	30	480	5.5	4
j60	60	480	5.5	4
j90	90	480	5.5	4

5.2 Computational results

The solution methodology adopted in this dissertation for solving fibre deployment scheduling as a RCPSP is problem instances are either solved to optimality or a feasible solution is achieved if the time limit terminates the solution process.

All computational tests in this dissertation were performed on an Intel Core i5-3470 processor with four cores operating at 3.2 GHz and 8GB RAM. Linux Mint 18.1 was used as the operating system together with IBM ILOG CPLEX 12.7.1 as the solver.

The time limit implemented on each computational run was determined by considering the number of activities of the problem instance being solved. This meant that a total of 10 seconds computing time was allocated to each activity in the problem instance. For example, the j30 dataset where each of the 480 problem instances included 30 activities, the computing time for each instance was limited to 300 seconds.

When solving problems using MIP, the number of MIP variables depend on the time indices, *e.g.*, for a horizon M, and $\mathcal{N}$ activities, there are $M \times \mathcal{N}$ binary variables x_{ij}. As opposed to solving problems using CP, the number of CP variables is equal to the number of activities.

5.2.1 Minimisation of makespan

The PSPLIB solutions, mentioned in Section 5.1, are used to verify the MIP and CP solutions of the minimisation of makespan models in terms of instances solved to optimality.

The primary purpose of presenting the results of the minimisation of makespan models is to evaluate the computational efficiency of the various model formulations presented in Chapter 4 when using a MIP solver, as well as, evaluating the effect that CP has on computing times. First, the results of the two MIP formulations are compared independently of the CP approach in Table 5.2.

Table 5.2: The minimisation of makespan on the datasets from the literature: time-indexed vs. resource flow formulation

			Instances solved to optimality (%)		Avg. solution time (s)	
Dataset	**Number of activities**	**Avg. activity duration**	**Time-indexed**	**Resource flow**	**Time-indexed**	**Resource flow**
j30	30	5.5	88.75	84.79	10.78	49.88
j60	60	5.5	77.71	70.21	24.85	79.75
j90	90	5.5	77.08	60.42	102.20	241.17

The results in Table 5.2 reports that for all the datasets, the time-indexed formulation outperformed the resource flow formulation in terms of instances solved to optimality as well as the average solution time.

It should be noted, however, that the average activity durations for the datasets listed in Table 5.2 are all relatively short. In fibre network deployment the durations of activities are usually longer than the durations represented by the j30, j60 and j90 datasets. By increasing the duration of the activities, the computational efficiency of the time-indexed and resource flow formulations within the context of fibre network deployment scheduling may be evaluated. When the activity durations are longer, the number of variables grow exponentially. The duration d_i of all activities were adjusted by a factor of 10, *i.e.*, $d_i = 10d_i$. The adjusted datasets are called j30(10x), j60(10x) and j90(10x). Table 5.3 compares the minimisation of makespan results of the time-indexed and resource flow formulations for the extended activity duration datasets.

From the results in Table 5.3, it is evident that the use of the time-indexed formulation proves to be inefficient when considering problem instances where activities have longer durations. The time-indexed formulation did not manage to find an optimal solution for any of the j90(10x) instances. In contrast with the results displayed in Ta-

Table 5.3: The minimisation of makespan on the extended activity duration datasets: time-indexed vs. resource flow formulation

Dataset	Number of activities	Avg. activity duration	Instances solved to optimality (%)		Avg. solution time (s)	
			Time-indexed	Resource flow	Time-indexed	Resource flow
j30(10x)	30	55	49.17	83.96	103.46	48.59
j60(10x)	60	55	10.42	70.63	334.54	79.87
j90(10x)	90	55	0	61.46	-	265.07

ble 5.2, the resource flow formulation now outperforms the time-indexed formulation when activity durations are extended.

The resource flow formulation presents the advantage of involving fewer variables than the formulation indexed by time. Since the variables of the resource flow formulation is not a function of the time horizon, it has a better capability to deal with instances that have a large scheduling horizon.

In Table 5.4, the results of the resource flow MIP formulation is compared with the results of the CP solver since the resource flow formulation proved to respond better to the extended activity durations associated with fibre network deployment. The results of the CP approach is impressive. For both instances solved to optimality and the average solution time, the CP solver performed better than MIP. CP works well with performing scheduling. CP's constraint propagation process through domain reduction, together with the advantage of having fewer variables results in finding a solution faster.

Table 5.4: The minimisation of makespan on the extended activity duration datasets: MIP vs. CP

Dataset	Number of activities	Avg. activity duration	Instances solved to optimality (%)		Avg. solution time (s)	
			MIP	CP	MIP	CP
j30(10x)	30	55	83.96	100	48.59	3.51
j60(10x)	60	55	70.63	93.75	79.87	43.16
j90(10x)	90	55	61.46	85.21	265.07	42.91

5.2.2 Maximisation of NPV

The solutions of the mathematical models for scheduling fibre deployment activities with the objective of maximising NPV are verified by first developing a small-scale fibre deployment example, where it is possible to find a solution through manual calculations. The same fibre deployment example is also solved through the automated RCPSP model. The NPV determined by the automated RCPSP model is then verified with the manual calculated NPV before scaling the model to bigger problem instances.

In this section, the time-indexed and resource flow formulations are applied to the extended activity duration PSPLIB datasets to evaluate the NPV of fibre network deployment scheduling. The RCPSP instances are also solved using a CP approach to evaluate the effect that CP has on computing times. To improve the results of the time-indexed and resource flow formulations the integration of MIP and CP is proposed in the form of a hybrid technique.

The cash flow dataset used to solve the maximisation of NPV models was generated and consisted of negative and positive cash flow values. The same cash flow dataset was used for all the models in order to perform a direct comparison between the NPVs obtained from the various formulations. The modelling technique that returns the highest NPV value is an indication of the technique's ability to perform resource scheduling.

Table 5.5 and 5.6 display the maximisation of NPV solutions for the time-indexed and resource flow formulations when MIP, CP, and hybrid techniques are used.

When considering individual instances of the datasets in Table 5.5 and 5.6, it is clear that the MIP formulations determine optimal solutions where CP only achieves feasible solutions. The reason for the NPV of MIP being lower than the NPV of CP when considering the time-indexed formulation in Table 5.5 is as a result of the solution time limits assigned to the datasets. The time-indexed MIP requires more computation time to find feasible solutions that are near-optimal compared to CP.

Table 5.5: The maximisation of NPV on the extended activity duration datasets: time-indexed formulation

Dataset	Number of activities	Approach	Avg. NPV	Avg. solution time (s)	Feasible solution instances (%)
j30(10x)	30	MIP	495.33	218.12	99.17
		CP	535.07	0.12	100
		Hybrid	535.08	214.46	100
j60(10x)	60	MIP	424.47	570.95	87.50
		CP	546.01	0.62	100
		Hybrid	546.01	555.83	100
j90(10x)	90	MIP	380.73	900	38.96
		CP	556.39	1.42	100
		Hybrid	556.23	902.56	100

Table 5.6: The maximisation of NPV on the extended activity duration datasets: resource flow formulation

Dataset	Number of activities	Approach	Avg. NPV	Avg. solution time (s)	Feasible solution instances (%)
j30(10x)	30	MIP	540.93	43.24	100
		CP	535.07	0.12	100
		Hybrid	541.01	19.87	100
j60(10x)	60	MIP	573.18	258.26	95
		CP	546.01	0.62	100
		Hybrid	580.75	183.45	100
j90(10x)	90	MIP	497.88	600.89	51.46
		CP	556.39	1.42	100
		Hybrid	593.11	890.22	100

The results in Table 5.5 for the time-indexed formulation and Table 5.6 for the resource flow formulation show that the resource flow formulation obtains a higher NPV than the formulation indexed by time, within the assigned computation time limit. To further improve the solutions of the time-indexed and resource flow formulations, a hybrid approach is introduced. As mentioned earlier, although the MIP models are capable of producing optimal solutions, in most large RCPSP instances this has been shown to take an extremely long time. The CP model, on the contrary, finds a near-optimal solution rather quickly through domain reduction but lacks the optimality of MIP. The hybrid model uses the fast processing time of CP together with the accuracy of MIP.

In the first part of the hybrid model, CP is used as a primal heuristic by applying a solution time limit to the section. The heuristic finds a near-optimal solution within the assigned computation time limit. The final part of the hybrid model uses the initial feasible solution generated by the CP model as the starting solution for the MIP model to obtain an improved final solution value.

In Table 5.5 and 5.6, the results of the hybrid models improved the NPV and solution time of the MIP formulations by increasing NPV and reducing the solution time. The initial feasible solutions of CP assist MIP to improve the number of feasible solutions within the same computation time limits.

The reason for the low percentage feasible solution instances of the j90(10x) dataset in Table 5.6 is due to a large number of vertices chosen for the piece-wise linear approximation. By decreasing the number of vertices for the piece-wise linear approximation, the number of feasible solutions increases and the accuracy of the approximation decreases. Limiting the number of vertices to ten points, the percentage feasible solution instances increases from 51.46% to 98.13%, however, the NPV changes from 497.88 to $2,956.7$ which is hugely optimistic. The accuracy of the piece-wise linear approximation, therefore, depends on the number of vertices chosen.

5.3 Model validation

The validation of the RCPSP models is considered by solving a potential real-world network to determine whether the models can perform resource allocation and scheduling within the context of fibre network deployment. The objective is to find a deployment schedule for the PON planning problem by maximising NPV. Information of the specific PON network is listed in Table 5.7.

The specific PON planning problem, displayed in Figure 5.1, consists of 621 activities together with a set of four renewable resources. The renewable resources, displayed in Table 5.8, are the man-hours of the workforce (8 hours a day $\times$ 5 men); and the avail-

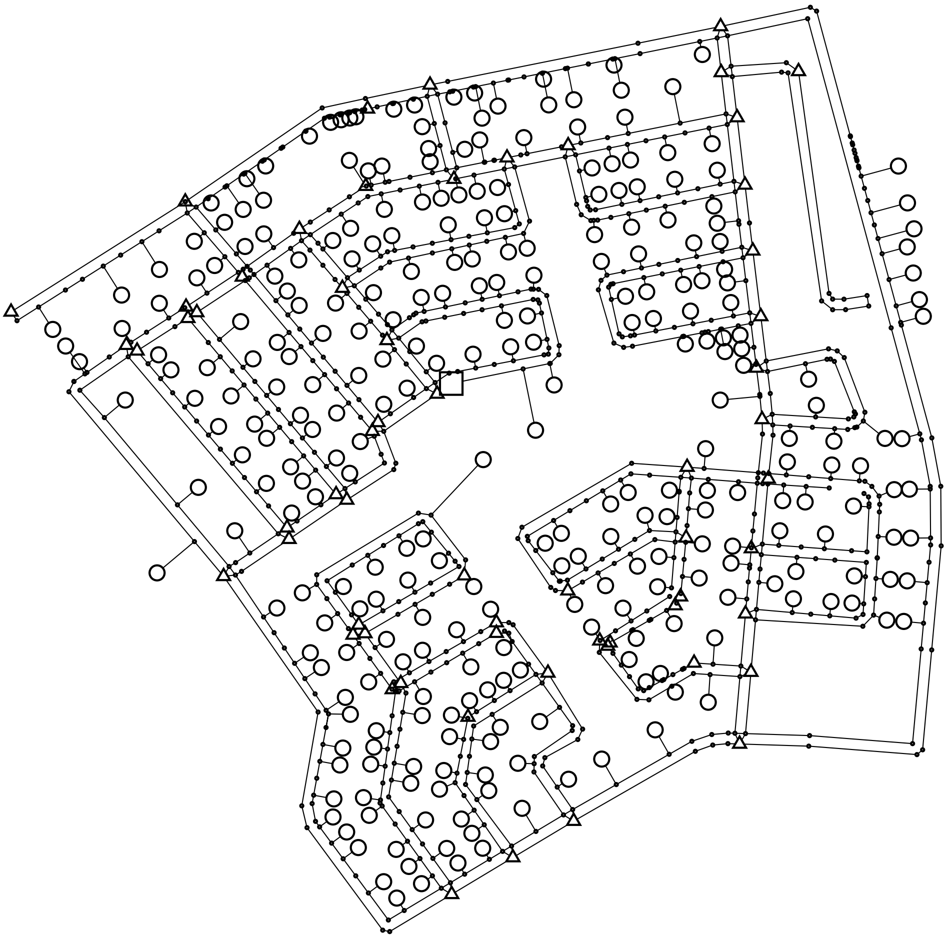


Figure 5.1: Validation PON Dassierand

Table 5.7: Real-world PON network

Area	Dassierand, Potchefstroom
Splitters	10
ONUs	300
Activities	621
Horizon	751 days

ability of fibre, splitters, and ONUs. The project activities with a negative cash flow entail the construction of a central office; the excavation of trenches; the installation of conduits, fibre, splitters, and ONUs. Positive cash flow is the revenue that ONUs produce once a single path from the CO through to one of the ONUs has been completed. Hereafter the ONUs generate revenue on a monthly basis. The financial input parameters for the RCPSP model is shown in Table 5.9.

Table 5.8: Resources for the validation model

Resource type	r	**Capacity (U_r)**
Man-hours	1	40
Fibre	2	40
Splitters	3	5
ONUs	4	20

Table 5.9: Input parameters for the validation model

Parameter	**Symbol**	**Value**
CO setup cost	C_c	(R 10 000)
Fibre cost per meter	C_f	(R 100)
Trenching cost per meter	C_t	(R 300)
Splitter installation cost	C_s	(R 3 000)
ONU revenue	C_u	R 1 000
NPV discount rate	NPV_r	10%

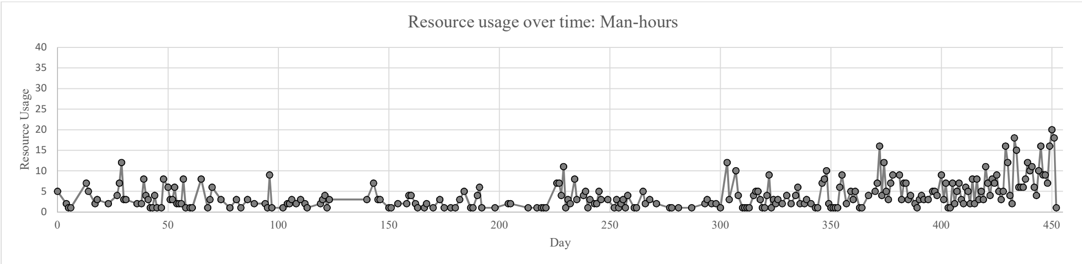
For the solutions of the RCPSP models to be valid, the solutions have to be feasible for the defined problem. A feasible solution reflects that all precedence relations of the activities are obeyed and that all parallel activities do not exceed the resource usage capacities. A total of 60 seconds computing time was allocated to each activity in the problem instance. This meant that 37 260 seconds (10 hours 21 minutes) computing time was allocated to solve the real-world PON network.

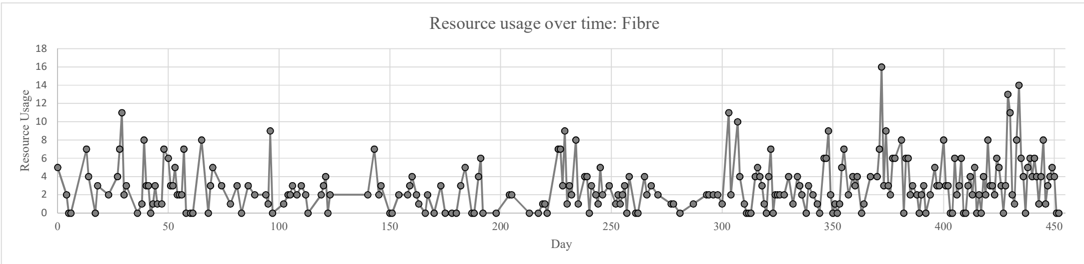
Figure 5.2 validates the solution of the MIP model by indicating that the resources used throughout the fibre deployment schedule never exceeds the capacities of the resources shown in Table 5.8. The validation output of the MIP model is shown in Table B.1 of Appendix B.

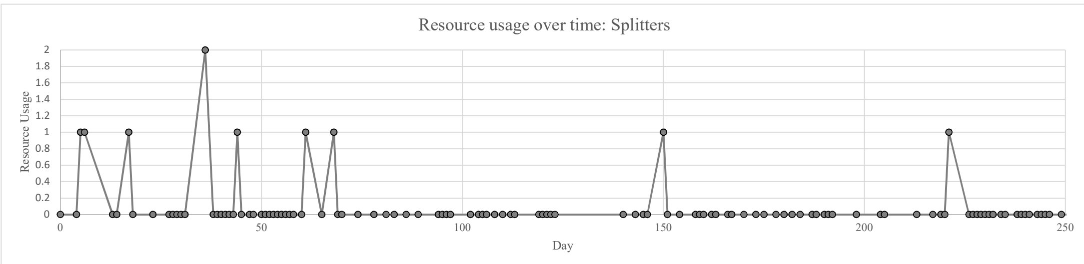
The solution of the CP approach is validated in Figure 5.3, indicating that the solution meets all resource capacity constraints. The output data of the CP approach is displayed in Table C.1 of Appendix C.

The solution of the MIP model was feasible with a NPV of -R17 948.04 and projected project duration of 452 days. The CP approach also found a feasible solution with a NPV of -R7 169.78 and a project duration of 117 days. In both cases, the NPV resulted in a negative value and therefore reports that the expected costs of the fibre deployment project exceeded the predicted earnings on project completion. This, however, is to be expected of a new fibre network deployment. As a result of the ONUs generating revenue during deployment, the NPV will be higher and the payback period would be shorter compared to a deployment that only starts to generate revenue after project completion.

The reason for the NPV of MIP being lower than the NPV of CP is as a result of the solution time limit that was allocated to solve the real-world PON. The CP approach finds a schedule that would complete the project in 117 days compared to the MIP model's 452 days. MIP requires more computation time to find optimal solutions compared to CP.







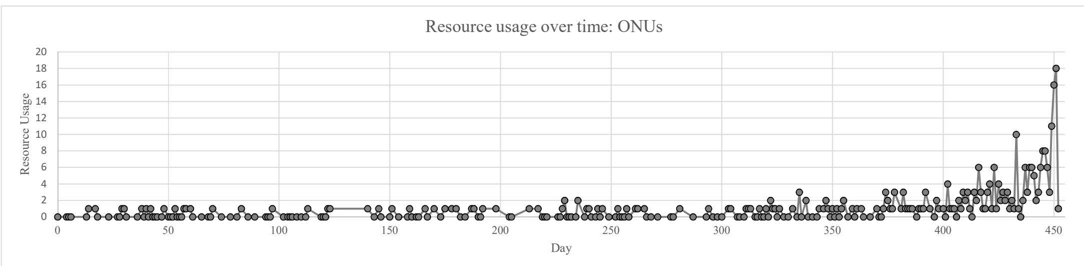
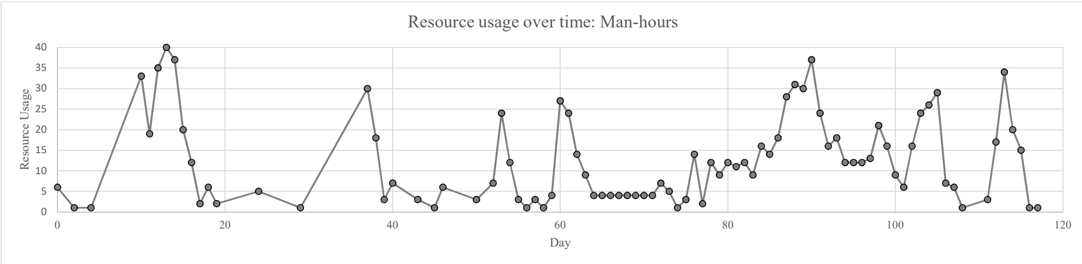
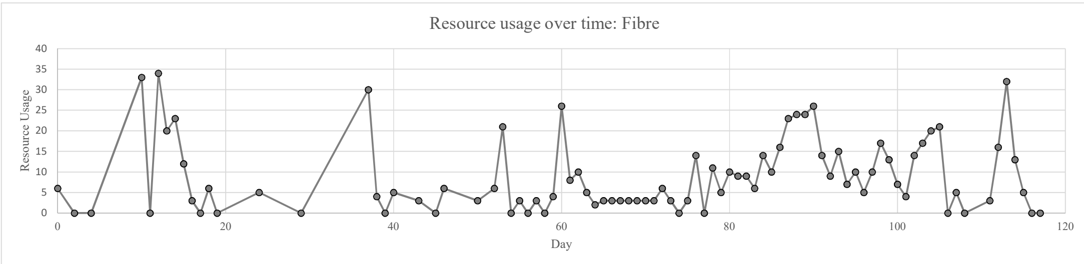
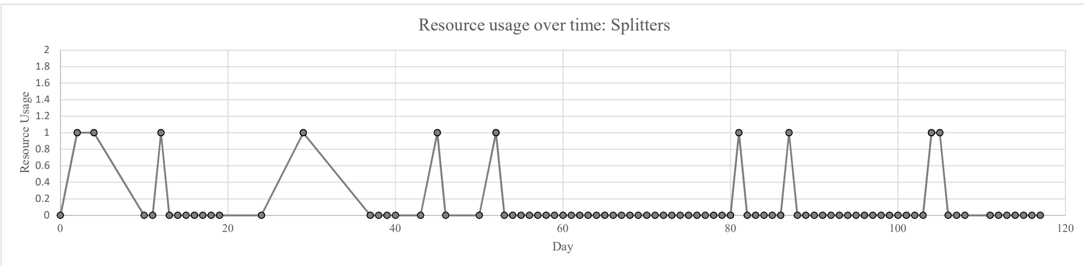


Figure 5.2: MIP model validation: Resource usage







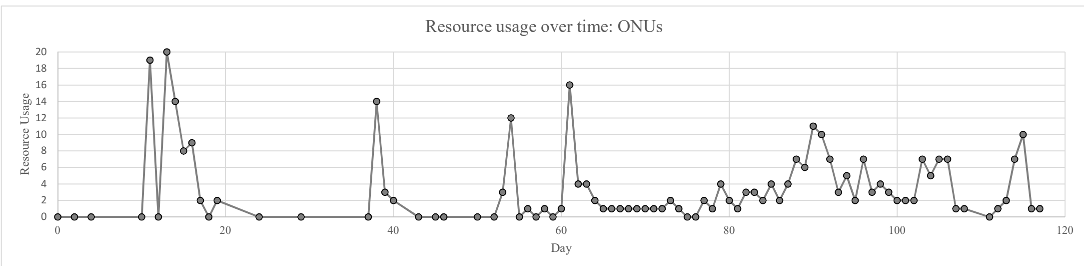


Figure 5.3: CP approach validation: Resource usage

5.4 Summary

The results of the two mathematical formulations of the RCPSP presented in Chapter 4 were solved for both the minimisation of makespan and the maximisation of NPV. The computational properties of the time-indexed and resource flow formulations when using a MIP off-the-shelf solver were studied and discussed.

Computational results of the two formulations were verified by using datasets from the literature as well as generated datasets. Based on the results it was found that the resource flow formulation performed better than the time-indexed formulation when the duration of project activities increased. The hybrid approach improved the MIP models by using CP as a primal heuristic to determine initial feasible solutions for the MIP models to increase NPV.

The validation of the RCPSP models was performed by solving a potential real-world network to determine whether the models could perform resource allocation and scheduling within the context of fibre network deployment. The objective was to find a deployment schedule for the PON planning problem by maximising NPV. The results of the resource flow MIP model and CP approach were feasible, and the precedence relations and resource consumptions were visually inspected to validate the solution.

Chapter 6

Conclusions and Recommendations

The findings on the essence of resource allocation and scheduling within the context of fibre network deployment are presented in this final chapter. The research problem, objectives and results are summarised. Conclusions and recommendations are formulated based on the research presented in this dissertation.

6.1 Summary

Fibre network deployment is very expensive, and in order to maintain profitability, optimal use of resources is crucial. This may be achieved through the optimal scheduling of deployment activities that are expected to maximise NPV.

The objectives of this dissertation were to:

1. Develop a fibre network deployment scheduling model to assist with the resource allocation and scheduling of project activities by maximising NPV.
2. Evaluate the computational efficiency of the time-indexed and resource flow RCPSP

formulations.

3. Examine the feasibility of CP as a modelling technique.
4. Improve the performance of the MIP models by integrating MIP and CP to form a hybrid model.

The conclusions of this research are presented in the following section of this chapter.

6.2 Conclusions

In this dissertation, the time-indexed and resource flow MIP formulations of the RCPSP were presented. The experimental comparison of the benchmark instances and the extended activity duration instances showed that the results of the time-indexed model outperformed the resource flow model concerning instances with small scheduling horizons. In fibre network deployment, where activities have longer durations, the resource flow model performed better than the time-indexed model. The reason for the resource flow model's capability to better deal with instances that have larger scheduling horizons is due to the number of variables not being a function of the time horizon.

The scheduling models proved to be scalable when solving benchmark instances where the number of project activities increased together with an increase in the duration of project activities.

The results of the two MIP minimisation of makespan formulations were compared independently of the CP approach. The resource flow formulation performed better than the time-indexed formulation when activity durations were extended. CP was used to minimise the makespan of the RCPSP instances with extended durations. The results of CP proved to be better than MIP regarding instances solved to optimality and faster average solution time.

The results of the two MIP maximisation of NPV formulations reported that the resource flow formulation performed better than the time-indexed formulation in terms of NPV and solution time. When individual instances of the datasets were considered, it confirmed that the MIP formulations determine optimal solutions while CP achieves near-optimal solutions.

The NPV determined by CP was higher than the two MIP formulations, within the assigned computation time limits of the RCPSP datasets. The hybrid approach improved the MIP models by using CP as a primal heuristic to determine initial feasible solutions for the MIP models to increase NPV.

6.3 Recommendations

CP should be used when finding a feasible solution is more important than finding an optimal solution. When it is essential to find an optimal solution, the resource flow formulation would be preferred when activity durations causes the time horizon to increase to a point where the time-indexed formulation becomes inefficient. MIP should be used when finding an optimal solution is critical; the objective is naturally modelled as a linear expression; and when computation time is not an issue. The integration of MIP and CP should be used when both linear optimisation and scheduling are present.

The maximisation of NPV models can be improved by developing a platform that automatically collects data from mobile services, governments, industry consultants, and other sources that identify residential areas containing high-value customers that would generate higher positive cash flow. This information can be used to improve the RCPSP model for fibre deployment scheduling, by reducing deployment costs and therefore decreasing the payback period of new deployments.

An improved hybrid model could be developed by performing a trade-off between MIP and CP solution times to determine the optimal point that would increase the computational efficiency of the model.

6.4 Final words

From the research conducted, it is demonstrated that various mathematical modelling techniques may be used to solve resource allocation and scheduling within the context of fibre network deployment. The use of these different modelling techniques involves high monetary stakes. For this reason, a trade-off between computational performance and overall deployment cost is required.

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Appendix A

Conference Article

Some of the work presented in this dissertation featured in the annual Southern Africa Telecommunication Networks and Applications Conference (SATNAC) under the title, "Resource allocation and scheduling of fibre network deployment."

Resource Allocation and Scheduling of Fibre Network Deployment

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***Abstract*—The resource-constrained project scheduling problem (RCPSP) is widely known and has been studied and applied in many industries. There is, however, a need to apply it specifically to the fibre deployment planning problem. In this paper, an RCPSP formulation is considered for determining the schedule of a fibre network deployment project plan in order to maximise net present value, subject to fibre network specific resources. Model validation is performed by comparing the RCPSP's results with the results of two heuristic approaches. The results show that the implementation of the RCPSP is very advantageous and leads to a significant increase in net present value.**

***Index Terms*—fibre-to-the-home deployment, resource allocation, resource-constrained project scheduling problem**

I. Introduction

Fibre optic deployment typically involves two separate activities - the first step involves the design of the fibre network, followed by the physical deployment. Considerable work has been done in the last decade to provide the telecommunications industry with automated fibre network design tools [1], [2]. A typical objective of fibre network design models is to provide the least cost network design based on demand projections and topology information. With an "optimal" network design at hand, the next step is to put a project management plan in place for the physical deployment.

It is necessary for FTTH (fibre-to-the-home) deployment to have a project management plan for the resource allocation and scheduling since each deployment activity has an expected processing time and cash flow. The cash flow associated with each activity may be an expense (negative cash flow) or an income (positive cash flow). In addition, the resources consumed by each deployment activity have limited instantaneous capacities, for example, the number of workforce available for the excavation of a trench. The sequencing of the activities are determined by a so-called precedence graph. It is, therefore, vital for certain activities to be moved ahead of other activities and for some activities to be performed simultaneously in order to find an optimal solution that maximises the project's net present value (NPV).

Negative cash flows specific to fibre network deployment activities are the costs of installing/ constructing the:

- central office (CO);
- trenches and conduits;
- fibre;
- splitters;
- and optical network units (ONUs).

Once a single path from the CO through to one of the ONUs has been completed (without the need for the entire project to be completed) the ONU can start to produce a positive cash flow which generates revenue for the fibre company.

In the literature, telecommunications companies construct deployment plans by comparing predefined deployment plan areas that are considered profitable, and then apply techno-economic analysis [3]. Techno-economic analysis evaluates the technical requirements of the project (eg., amount of fibre, splitters, optimal network design), as well as the economic requirements (eg., cost, profit). Further work by Kampouridis *et al.* [4] developed a framework that wraps around the existing techno-economic models by using a Genetic Algorithm (GA) as a decision support tool when it comes to deciding for which areas fibre networks should be deployed first. For instance, given 100 areas, the GA determines that Areas 10-30 should be deployed in Year 1, then Areas 50-60 in Year 2, and so on. Although this model determines deployment areas that returns the highest profit, it does not attempt to further increase profit by scheduling the order in which activities need to be executed in the specific deployment area.

The objective of this paper is to develop an RCPSP formulation that is specific to the fibre deployment planning problem. This RCPSP formulation determines the schedule of a fibre network deployment project plan in order to maximise net present value, subject to fibre network specific constraints. To the best of our knowledge, this is a first attempt to formulate the fibre deployment problem as an RCPSP.

In section II the RCPSP model is introduced, followed by the model formulation in section II-A. Section II-B provides an example to illustrate the concept of resource allocation specific to fibre network deployment. In section II-C the results of three solution approaches is shown to emphasise the benefits of the proposed RCPSP model.

II. Mathematical Models

The resource-constrained project scheduling problem (RCPSP) is widely known and has been studied and applied in many industries [5]–[8]. Resource scheduling is typically used in civil engineering where construction projects are large, and contractors are under pressure to complete these projects as quickly as possible. In [8], variants and extensions of RCPSP are introduced. The use of the branch-and-bound algorithm to maximise NPV is well suited for RCPSP with discounted cash flow formulations. This algorithm is based on a scheduling generation scheme which resolves resource conflicts by adding new precedence constraints between activities in conflict.

The project scheduling problem library (PSPLIB) [9] contains a repository of RCPSP benchmark instances to be used for the evaluation of the mathematical models developed for solving the FTTH deployment schedule. The repository contains three sets of data: j30, j60 and j90. These sets contain RCPSP instances each comprising 30, 60 and 90 activities, respectively. These sets contain 480 instances each which all differ in complexity. Each RCPSP instance includes a small set of only four resources. Initially, the small set of resources appear sufficient for developing a model for the RCPSP approach to solving the fibre network scheduling problem.

In order to represent the time-indexed formulation within the context of fibre deployment scheduling, a small-scale example is provided.

A. Time-Indexed Formulation of the RCPSP

The model formulation presented below was first introduced by Pritsker *et al.* [10]. Let $\mathcal{N}$ represent the index set of all activities. Where an activity $i \in \mathcal{N}$ may, for example, represent the construction of a central office, or the excavation of trenches for installing fibre. The duration of an activity $i \in \mathcal{N}$ is given by d_i. During the execution of an activity, one or more resources are consumed, the index set of all resources is defined by $\mathcal{R}$. A resource $r \in \mathcal{R}$ may, for example, represent the digging tools required to excavate trenches, the man hours necessary to complete an activity, or the availability of fibre cables. Let v_{ir} denote the amount of resource $r \in \mathcal{R}$ being consumed by an activity $i \in \mathcal{N}$, per day. U_r represents the upper limit (or capacity) of resource $r \in \mathcal{R}$ for activity $i \in \mathcal{N}$.

Let $\mathcal{Z}$ represent the arc set of the precedence graph. Each arc $(i, j) \in \mathcal{Z}$ denotes the precedence relation that states activity $j \in \mathcal{N}$ should be preceded by activity $i \in \mathcal{N}$.

Let $\mathcal{T} = \{1, 2, ..., |\mathcal{T}|\}$ denote the time period indices. The decision variable $x_{it} \in \{0, 1\}$ is used to indicate the start time of an activity. When $x_{it} = 1$, activity $i \in \mathcal{N}$ is scheduled to start at the beginning of time period $t \in \mathcal{T}$.

The objective of the time-indexed RCPSP when maximising NPV is to maximise

$$\sum_{i \in \mathcal{N}} \sum_{k \in \mathcal{T}} \left(\sum_{t=k}^{t<k+d_i} \frac{c_i}{(1+\alpha)^t} \right) x_{ik}, \tag{1}$$

subject to the constraints

$$\sum_{t \in T(i)} x_{it} = 1, \quad i \in \mathcal{N}, \tag{2}$$

$$\sum_{t \in T(j)} t x_{jt} - \sum_{t \in T(i)} t x_{it} \geq d_i, \quad (i, j) \in \mathcal{Z}, \tag{3}$$

$$\sum_{i \in \mathcal{N}(t)} \sum_{\substack{k \in T \\ k \leqslant t}} v_{ir} x_{ik} \leq U_r, \quad r \in \mathcal{R},\ t \in \mathcal{T} \tag{4}$$

The objective function (1) maximises NPV for all cash flows, c_i at a discount rate α. The constraint in (2) forces each activity to be scheduled to one of the time periods $t \in \mathcal{T}$. Equation (3) structures the precedence relations according to the precedence graph. The constraint in (4) applies an upper limit on the resource consumption of $r \in \mathcal{R}$.

B. Resource Allocation Example

Consider a fibre network deployment application where activities involve the construction of a central office, excavation of trenches, installation of fibre, splitters and ONUs. An illustration of such a network in its simplest form can be seen in Fig. 1.

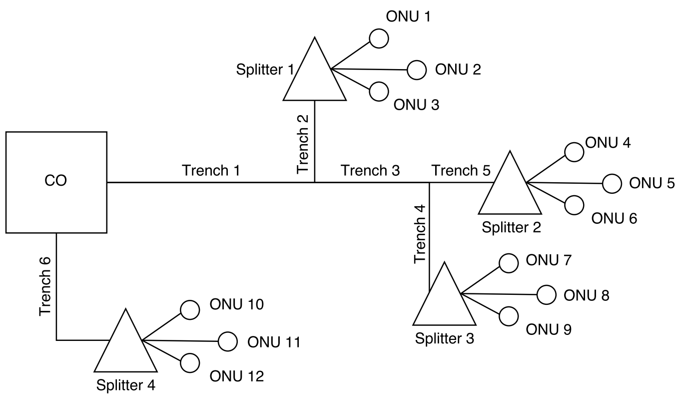

Fig. 1. Simple fibre network layout

The precedence graph for the simple fibre network under consideration is displayed in Fig. 2. The precedence graph starts at the source node and typically ends at the sink node, but for clarity, the sink node has been omitted in Fig. 2. The precedence relation states the order in which activities may be executed.

When considering the sequencing of all trenching activities for the project, there are certain tools (resources) required to excavate trenches. After solving the RCPSP model, Fig. 3 illustrates the resource usage and trenching durations for the case where the model excludes any resource usage limit. The solution of the model structures the trenching activities in such

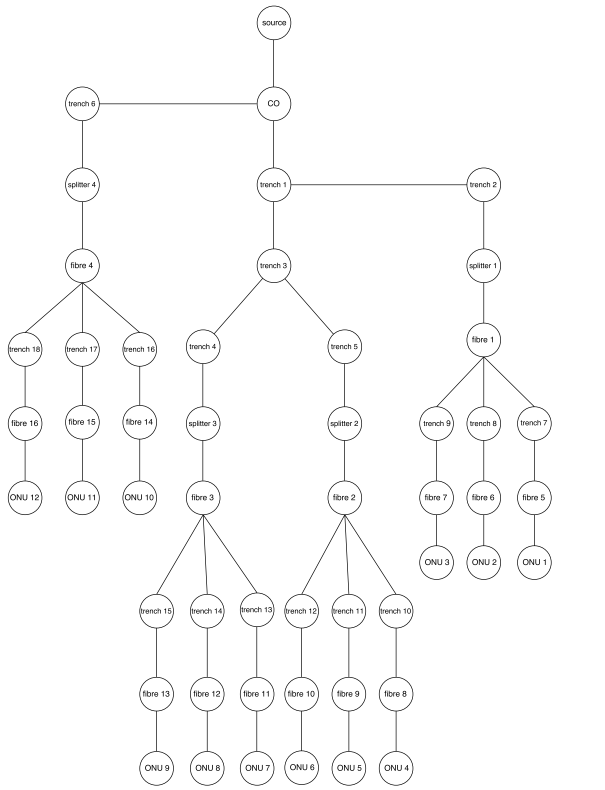

Fig. 2. Precedence relations of the simple fibre network illustrated in Fig. 1

a way that all activities will attempt to execute simultaneously, subject to their precedence constraints.

In Fig. 3 the estimated project completion for this simple fibre deployment plan is 25 days.

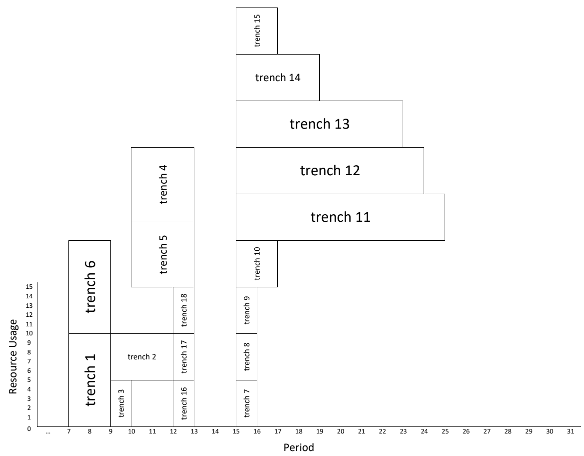

Fig. 3. Resource usage over time (no resource constraint)

With FTTH deployment there are limited instantaneous capacities for the resources consumed by each deployment activity since there is a fixed amount of tools available for excavating trenches. For this reason, the trenching activities that may be executed simultaneously are limited. When adding a resource usage limit, the trenching activities are restructured and arranged in such a way that the resource usage capacities are never exceeded. Fig. 4 illustrates the resource usage and trenching durations for the case where the RCPSP model includes a resource usage constraint.

In Fig. 4 the projected duration for completing all trenching activities changes from 25 to 31 days and the NPV reduces with 15.7 %.

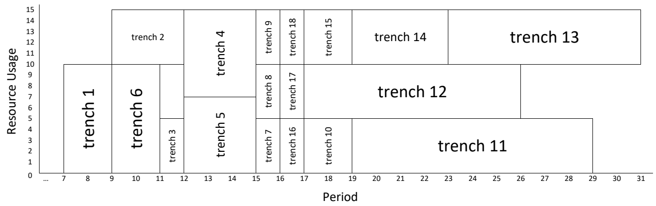

Fig. 4. Resource usage over time (with resource constraint)

For the case where the scheduling objective is to maximise the project's NPV the model attempts to arrange all negative cash flow activities to be performed as late as possible while scheduling all positive cash flow activities as early as possible. The trenching activities with the lowest negative cash flows that also forms part of a branch that would generate the most revenue at its ONU get scheduled first, while still adhering to the precedence constraint in (3).

C. Solution Approaches

Model validation is performed by considering three approaches to illustrate the benefits of the proposed scheduling model for the fibre network deployment project. In the approaches, two heuristic evaluations of fibre network deployment scheduling will be compared to the proposed RCPSP model solution.

1) Approach 1: In the first approach, a fibre network deployment schedule is determined by applying a depth-first search to the precedence graph in Fig. 2. For this approach, the order in which activities will be executed is shown in Table I.

The project's NPV and project completion time is calculated by use of a spreadsheet. For approach 1, the projected duration for completing all fibre deployment activities is 204 days. In comparing different solution approaches we are interested in the percentage difference in NPV from approach 1 to approach 2 and from approach 2 to 3.

2) Approach 2: The order of the fibre network deployment schedule is determined by use of an algorithm with a high priority on completing ONUs which promises the highest positive cash flow. All activities leading to the ONUs that would generate the most revenue get scheduled first. For this

TABLE I
APPROACH 1 DEPLOYMENT PLAN

Activity	Successors
CO	
trench 6	splitter 4, fibre 4, trench 16, fibre 14, ONU 10, trench 17, fibre 15, ONU 11, trench 18, fibre 16, ONU 12.
trench 1	trench 2, splitter 1, fibre 1, trench 7, fibre 5, ONU 1, trench 8, fibre 6, ONU 2, trench 9, fibre 7, ONU 3.
trench 3	trench 5, splitter 2, fibre 2, trench 10, fibre 8, ONU 4, trench 11, fibre 9, ONU 5, trench 12, fibre 10, ONU 6.
trench 4	splitter 3, fibre 3, trench 13, fibre 11, ONU 7, trench 14, fibre 12, ONU 8, trench 15, fibre 13, ONU 9.

approach, the order in which activities will be executed is shown in Table II.

TABLE II
APPROACH 2 DEPLOYMENT PLAN

Activity	Successors
CO	
trench 1	trench 3, trench 5, splitter 2, fibre 2, trench 10, fibre 8, ONU 4.
trench 2	splitter 1, fibre 1, trench 8, fibre 6, ONU 2, trench 7, fibre 5, ONU 1, trench 9, fibre 7, ONU 3.
trench 11	fibre 9, ONU 5, trench 12, fibre 10, ONU 6.
trench 4	splitter 3, fibre 3, trench 13, fibre 11, ONU 7, trench 14, fibre 12, ONU 8, trench 15, fibre 13, ONU 9.
trench 6	splitter 4, fibre 4, trench 16, fibre 14, ONU 10, trench 17, fibre 15, ONU 11, trench 18, fibre 16, ONU 12.

The algorithm of approach 2 is described by making use of the example in Fig. 5 accompanied by the following steps (1-6).

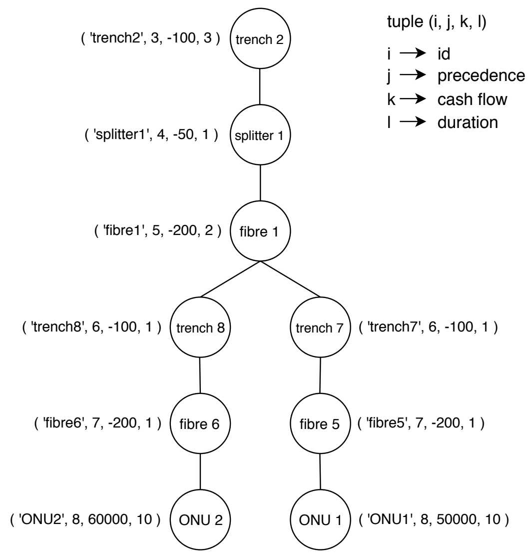

Fig. 5. Approach 2: Algorithm example

Step 1: Sort list of all ONU tuples according to the cash flow key (*k*) in descending order (highest positive cash flow first).

Step 2: Build and sort a list of activity tuples according to the precedence key (*j*) leading to the sorted list of ONU tuples in Step 1.

Step 3: Remove all duplicate activity tuples from the list of tuples resulting from Step 2.

Step 4: Determine the start time of each activity (s_{i+1}) by starting at $s_i = 0$ and adding the duration key (*l*) of activity *i* to s_i.

Step 5: Determine the NPV for each activity according to their start times in Step 4.

Step 6: Sum the NPVs of all activities determined in Step 5.

The projected duration of approach 2 for completing all fibre deployment activities is 204 days, which is the same as approach 1. However, the NPV from approach 1 to approach 2 increases with 297.5 $\%$.

3) Approach 3: For the third approach, an RCPSP formulation is considered for determining the schedule of a fibre network deployment project plan to maximise NPV, subject to fibre network specific resources. The solution for the simple fibre layout in Fig. 1 is determined by the RCPSP model. For this approach, the order in which activities will be executed is shown in Fig. 6.

The projected duration of approach 3 for completing all fibre deployment activities is 42 days compared to 204 days of approach 1 and 2. The NPV from approach 2 to approach 3 increases with 350.9 $\%$ and from approach 1 to 3 increases with 1,043.8 $\%$.

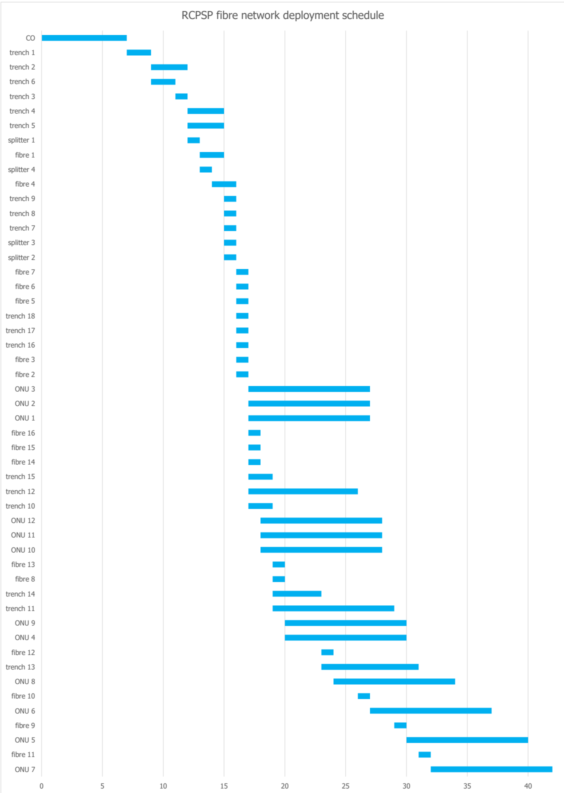

Fig. 6. Approach 3: RCPSP fibre network deployment schedule

D. Summary and Conclusion

The objective of this paper was to develop an RCPSP formulation that is specific to fibre deployment planning. The presented formulation is used to determine the schedule of a fibre network deployment project with the objective of maximising net present value. Three solution approaches were considered where approach 1 typically represents how fibre deployment scheduling is being done in practice. The results of approach 2 indicate an improvement over approach 1, however, the results of the automated RCPSP formulation in approach 3 displays a significant increase in NPV compared to the first two approaches. For this reason, we can conclude that the RCPSP approach presented in this paper looks promising and warrants practical implementation for verification purposes and possible future improvements.

ACKNOWLEDGEMENT

The authors appreciate the constructive feedback from the reviewers of this article and acknowledge the financial contribution made towards this research from MCorp Communications.

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Appendix B

MIP Validation Output

Table B.1: MIP model validation output

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
1	0	0	-10000	-10000	0	0	0	0
6	0	5	-1778.88	-1778.88	5	5	0	0
10	4	2	-593.093	-405.0904993	2	2	0	0
15	5	8	-3000	-1862.763969	1	0	1	0
19	6	8	-3000	-1693.42179	1	0	1	0
3	13	4	-1559.49	-451.7287036	4	4	0	0
32	13	1	-627.844	-181.8640428	2	2	0	0
87	13	1	-183.274	-53.08794953	1	1	0	0
320	14	1	-1305.98	-343.9053515	4	4	0	0
386	14	1	1000	263.3312543	1	0	0	1
12	17	8	-3000	-593.5340067	1	0	1	0
619	17	1	1000	197.8446689	1	0	0	1
2	18	3	-1095.78	-197.0856648	3	3	0	0
215	23	1	-496.77	-55.47835845	2	2	0	0
91	27	1	-621.017	-47.36973876	2	2	0	0
180	27	1	-433.962	-33.1016165	2	2	0	0
167	28	1	-1450.25	-100.5651926	4	4	0	0
304	28	1	-842.233	-58.40325727	3	3	0	0
4	29	6	-2042.96	-128.7869903	6	6	0	0
7	29	5	-1852.82	-116.8006771	5	5	0	0
479	29	1	1000	63.03940863	1	0	0	1
114	30	1	-517.451	-29.65436821	2	2	0	0
466	30	1	1000	57.3085533	1	0	0	1
36	31	1	-1104.89	-57.56331587	3	3	0	0
13	36	8	-3000	-97.04755292	1	0	1	0
21	36	1	-3000	-97.04755292	1	0	1	0
216	38	1	-180.138	-4.815964763	1	1	0	0
331	38	1	1000	26.73486306	1	0	0	1
5	39	5	-1722.11	-41.85488639	5	5	0	0
177	39	1	-848.644	-20.62580103	3	3	0	0
72	40	1	-857.695	-18.9507094	3	3	0	0
335	40	1	1000	22.09492815	1	0	0	1
166	41	1	-1003.05	-20.14756153	3	3	0	0
603	42	1	1000	18.2602712	1	0	0	1
219	43	1	-117.357	-1.948155134	1	1	0	0
14	44	8	-3000	-45.27339967	1	0	1	0
259	44	1	-1093.75	-16.50592696	3	3	0	0
recurring	44	1	1000	15.09113322				
262	45	1	-160.934	-2.207887667	1	1	0	0
112	47	1	-314.042	-3.560668415	1	1	0	0
recurring	47	1	1000	11.33819175				
73	48	1	-847.339	-8.733901874	3	3	0	0
143	48	4	-1304.33	-13.44431241	4	4	0	0
476	48	1	1000	10.30744705	1	0	0	1
8	50	6	-2298.04	-19.57597158	6	6	0	0
57	51	1	-852.025	-6.598198776	3	3	0	0
265	52	1	-276.076	-1.943609556	1	1	0	0
273	52	1	-581.915	-4.096754354	2	2	0	0
86	53	1	-342.72	-2.193446953	1	1	0	0
240	53	1	-645.47	-4.131081363	2	2	0	0
246	53	1	-539.935	-3.455645368	2	2	0	0
564	53	1	1000	6.400113659	1	0	0	1
261	54	1	-765.999	-4.456800602	2	2	0	0
274	55	1	-671.468	-3.551629354	2	2	0	0
269	56	1	-508.179	-2.443578782	2	2	0	0
198	57	1	-1292.09	-5.648195381	4	4	0	0
239	57	3	-944.905	-4.130523459	3	3	0	0
568	57	1	1000	4.371363745	1	0	0	1
497	58	1	1000	3.973967041	1	0	0	1
recurring	59	1	1000	3.61269731				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
573	60	1	1000	3.284270281	1	0	0	1
recurring	60	1	1000	3.284270281				
17	61	8	-3000	-8.957100768	1	0	1	0
174	65	1	-952.972	-1.943370497	3	3	0	0
248	65	1	-666.721	-1.359626433	2	2	0	0
257	65	1	-1116.74	-2.277338231	3	3	0	0
16	68	8	-3000	-4.596408975	1	0	1	0
recurring	68	1	1000	1.532136325				
147	69	3	-819.889	-1.141983381	3	3	0	0
70	70	1	-1634.33	-2.069435008	5	5	0	0
473	70	1	1000	1.266228368	1	0	0	1
recurring	70	1	1000	1.266228368				
recurring	72	1	1000	1.046469725				
254	74	1	-824.291	-0.712888906	3	3	0	0
recurring	74	1	1000	0.864851013				
recurring	77	1	1000	0.649775366				
237	78	1	-115.588	-0.068278396	1	1	0	0
recurring	78	1	1000	0.590704879				
141	81	3	-937.859	-0.416226812	3	3	0	0
536	83	1	1000	0.366781255	1	0	0	1
recurring	83	1	1000	0.366781255				
233	86	1	-884.661	-0.243784426	3	3	0	0
recurring	87	1	1000	0.250516532				
recurring	88	1	1000	0.227742302				
115	89	1	-620.457	-0.128458459	2	2	0	0
recurring	89	1	1000	0.207038456				
recurring	90	1	1000	0.188216778				
recurring	90	1	1000	0.188216778				
294	94	1	-709.776	-0.091244964	2	2	0	0
224	95	1	-213.25	-0.024922061	1	1	0	0
101	96	1	-671.835	-0.071378078	2	2	0	0
175	96	1	-911.101	-0.096798527	3	3	0	0
307	96	1	-1253.46	-0.133171933	4	4	0	0
474	97	1	1000	0.096584968	1	0	0	1
recurring	98	1	1000	0.087804516				
recurring	100	1	1000	0.072565716				
recurring	100	1	1000	0.072565716				
62	102	1	-187.141	-0.011223158	1	1	0	0
recurring	102	1	1000	0.059971666				
179	104	1	-600.332	-0.029754471	2	2	0	0
recurring	104	1	1000	0.04956336				
245	105	1	-573.998	-0.025862972	2	2	0	0
54	106	1	-914.433	-0.037456506	3	3	0	0
recurring	107	1	1000	0.037237686				
97	108	2	-683.903	-0.023151787	2	2	0	0
recurring	108	1	1000	0.033852442				
142	110	3	-1156.51	-0.03235594	3	3	0	0
188	112	1	-665.039	-0.015376815	2	2	0	0
544	113	1	1000	0.021019703	1	0	0	1
recurring	113	1	1000	0.021019703				
recurring	113	1	1000	0.021019703				
recurring	117	1	1000	0.01435674				
recurring	118	1	1000	0.013051582				
83	119	2	-546.592	-0.006485355	2	2	0	0
recurring	119	1	1000	0.011865074				
163	120	1	-217.808	-0.002349371	1	1	0	0
272	120	1	-637.2	-0.006873114	2	2	0	0
recurring	120	1	1000	0.010786431				
recurring	120	1	1000	0.010786431				
34	121	1	-1293.65	-0.012685333	4	4	0	0
571	122	1	1000	0.008914406	1	0	0	1

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
178	123	1	-688.229	-0.005577412	2	2	0	0
333	123	1	1000	0.008104005	1	0	0	1
recurring	127	1	1000	0.005535145				
recurring	128	1	1000	0.00503195				
recurring	130	1	1000	0.004158636				
recurring	130	1	1000	0.004158636				
recurring	132	1	1000	0.003436889				
recurring	134	1	1000	0.002840404				
recurring	137	1	1000	0.002134038				
recurring	138	1	1000	0.001940034				
185	140	1	-652.364	-0.001045958	2	2	0	0
558	140	1	1000	0.001603334	1	0	0	1
9	143	7	-2774.82	-0.003342573	7	7	0	0
recurring	143	1	1000	0.001204609				
recurring	143	1	1000	0.001204609				
recurring	143	1	1000	0.001204609				
234	145	1	-712.046	-0.000708873	2	2	0	0
484	145	1	1000	0.000995544	1	0	0	1
199	146	1	-894.359	-0.000809431	3	3	0	0
recurring	147	1	1000	0.000822764				
recurring	148	1	1000	0.000747967				
recurring	149	1	1000	0.00067997				
18	150	8	-3000	-0.001854464	1	0	1	0
recurring	150	1	1000	0.000618155				
recurring	150	1	1000	0.000618155				
533	151	1	1000	0.000561959	1	0	0	1
recurring	152	1	1000	0.000510872				
recurring	153	1	1000	0.000464429				
136	154	1	-450.105	-0.000190038	2	2	0	0
recurring	157	1	1000	0.000317211				
45	158	1	-443.558	-0.00012791	2	2	0	0
recurring	158	1	1000	0.000288374				
162	159	1	-1139.3	-0.000298677	3	3	0	0
344	159	1	1000	0.000262158	1	0	0	1
50	160	1	-950.54	-0.000226538	3	3	0	0
64	160	1	-168.756	-4.02188E-05	1	1	0	0
recurring	160	1	1000	0.000238325				
recurring	160	1	1000	0.000238325				
252	162	1	-509.41	-0.000100335	2	2	0	0
recurring	162	1	1000	0.000196963				
134	163	1	-349.996	-6.26694E-05	1	1	0	0
recurring	164	1	1000	0.000162779				
461	166	1	1000	0.000134528	1	0	0	1
51	167	1	-766.79	-9.37774E-05	2	2	0	0
recurring	167	1	1000	0.000122299				
recurring	168	1	1000	0.000111181				
350	170	1	1000	9.18848E-05	1	0	0	1
recurring	170	1	1000	9.18848E-05				
228	173	3	-941.051	-6.49649E-05	3	3	0	0
recurring	173	1	1000	6.90344E-05				
recurring	173	1	1000	6.90344E-05				
recurring	173	1	1000	6.90344E-05				
433	175	1	1000	5.70532E-05	1	0	0	1
recurring	175	1	1000	5.70532E-05				
recurring	177	1	1000	4.71514E-05				
527	178	1	1000	4.28649E-05	1	0	0	1
recurring	178	1	1000	4.28649E-05				
recurring	179	1	1000	3.89681E-05				
551	180	1	1000	3.54256E-05	1	0	0	1
recurring	180	1	1000	3.54256E-05				
recurring	180	1	1000	3.54256E-05				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	181	1	1000	3.22051E-05				
208	182	1	-896.609	-2.62503E-05	3	3	0	0
recurring	182	1	1000	2.92773E-05				
recurring	183	1	1000	2.66157E-05				
92	184	1	-845.149	-2.04493E-05	3	3	0	0
168	184	1	-445.478	-1.07788E-05	2	2	0	0
391	187	1	1000	1.81789E-05	1	0	0	1
recurring	187	1	1000	1.81789E-05				
507	188	1	1000	1.65263E-05	1	0	0	1
recurring	188	1	1000	1.65263E-05				
recurring	189	1	1000	1.50239E-05				
226	190	1	-241.875	-3.30355E-06	1	1	0	0
255	190	1	-1073.05	-1.46558E-05	3	3	0	0
recurring	190	1	1000	1.36581E-05				
recurring	190	1	1000	1.36581E-05				
11	191	6	-2059.25	-2.55686E-05	6	6	0	0
554	192	1	1000	1.12877E-05	1	0	0	1
recurring	192	1	1000	1.12877E-05				
recurring	194	1	1000	9.32866E-06				
recurring	196	1	1000	7.70963E-06				
recurring	197	1	1000	7.00876E-06				
525	198	1	1000	6.3716E-06	1	0	0	1
recurring	198	1	1000	6.3716E-06				
recurring	200	1	1000	5.26578E-06				
recurring	200	1	1000	5.26578E-06				
recurring	203	1	1000	3.95626E-06				
recurring	203	1	1000	3.95626E-06				
recurring	203	1	1000	3.95626E-06				
238	204	1	-783.78	-2.81894E-06	2	2	0	0
165	205	1	-565.055	-1.84752E-06	2	2	0	0
recurring	205	1	1000	3.26964E-06				
recurring	205	1	1000	3.26964E-06				
recurring	207	1	1000	2.70218E-06				
recurring	208	1	1000	2.45653E-06				
recurring	208	1	1000	2.45653E-06				
recurring	209	1	1000	2.23321E-06				
recurring	210	1	1000	2.03019E-06				
recurring	210	1	1000	2.03019E-06				
recurring	210	1	1000	2.03019E-06				
recurring	211	1	1000	1.84562E-06				
recurring	212	1	1000	1.67784E-06				
464	213	1	1000	1.52531E-06	1	0	0	1
recurring	213	1	1000	1.52531E-06				
349	217	1	1000	1.04181E-06	1	0	0	1
recurring	217	1	1000	1.04181E-06				
recurring	217	1	1000	1.04181E-06				
recurring	218	1	1000	9.47097E-07				
recurring	218	1	1000	9.47097E-07				
243	219	1	-284.45	-2.44911E-07	1	1	0	0
recurring	219	1	1000	8.60998E-07				
249	220	1	-300.589	-2.35279E-07	1	1	0	0
recurring	220	1	1000	7.82725E-07				
recurring	220	1	1000	7.82725E-07				
20	221	8	-3000	-2.1347E-06	1	0	1	0
recurring	222	1	1000	6.4688E-07				
recurring	222	1	1000	6.4688E-07				
recurring	224	1	1000	5.34612E-07				
150	226	1	-344.234	-1.52092E-07	1	1	0	0
159	226	1	-837.398	-3.69986E-07	3	3	0	0
197	226	1	-471.168	-2.08175E-07	2	2	0	0
315	226	1	-197.119	-8.70927E-08	1	1	0	0

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	226	1	1000	4.41828E-07				
41	227	1	-614.648	-2.46881E-07	2	2	0	0
158	227	1	-884.151	-3.5513E-07	3	3	0	0
316	227	1	-778.635	-3.12748E-07	2	2	0	0
recurring	227	1	1000	4.01662E-07				
156	228	1	-969.517	-3.54016E-07	3	3	0	0
548	228	1	1000	3.65147E-07	1	0	0	1
recurring	228	1	1000	3.65147E-07				
recurring	228	1	1000	3.65147E-07				
65	229	1	-287.575	-9.54611E-08	1	1	0	0
71	229	1	-918.319	-3.04838E-07	3	3	0	0
106	229	1	-1024.88	-3.40211E-07	3	3	0	0
253	229	2	-678.991	-2.25392E-07	2	2	0	0
467	229	1	1000	3.31952E-07	1	0	0	1
542	229	1	1000	3.31952E-07	1	0	0	1
43	230	1	-334.488	-1.0094E-07	1	1	0	0
recurring	230	1	1000	3.01774E-07				
recurring	230	1	1000	3.01774E-07				
24	231	1	-673.747	-1.84836E-07	2	2	0	0
132	231	1	-360.627	-9.89345E-08	1	1	0	0
125	232	1	-680.802	-1.69792E-07	2	2	0	0
recurring	233	1	1000	2.26728E-07				
recurring	233	1	1000	2.26728E-07				
recurring	233	1	1000	2.26728E-07				
77	234	1	-1603.59	-3.30526E-07	5	5	0	0
138	234	1	-1185.54	-2.44359E-07	3	3	0	0
42	235	1	-222.618	-4.17138E-08	1	1	0	0
364	235	1	1000	1.87378E-07	1	0	0	1
376	235	1	1000	1.87378E-07	1	0	0	1
recurring	235	1	1000	1.87378E-07				
recurring	235	1	1000	1.87378E-07				
recurring	237	1	1000	1.54858E-07				
107	238	1	-889.751	-1.25259E-07	3	3	0	0
288	238	1	-269.091	-3.78826E-08	1	1	0	0
recurring	238	1	1000	1.4078E-07				
recurring	238	1	1000	1.4078E-07				
213	239	1	-1331.26	-1.70377E-07	4	4	0	0
431	239	1	1000	1.27982E-07	1	0	0	1
recurring	239	1	1000	1.27982E-07				
406	240	1	1000	1.16347E-07	1	0	0	1
recurring	240	1	1000	1.16347E-07				
recurring	240	1	1000	1.16347E-07				
recurring	240	1	1000	1.16347E-07				
130	241	1	-1102.05	-1.16564E-07	3	3	0	0
recurring	241	1	1000	1.0577E-07				
recurring	242	1	1000	9.61546E-08				
105	243	1	-710.409	-6.20992E-08	2	2	0	0
recurring	243	1	1000	8.74133E-08				
recurring	243	1	1000	8.74133E-08				
81	244	1	-126.324	-1.00385E-08	1	1	0	0
437	244	1	1000	7.94666E-08	1	0	0	1
195	245	1	-969.154	-7.0014E-08	3	3	0	0
244	245	1	-733.952	-5.30225E-08	2	2	0	0
181	246	1	-589.258	-3.86995E-08	2	2	0	0
543	246	1	1000	6.56749E-08	1	0	0	1
recurring	247	1	1000	5.97045E-08				
recurring	247	1	1000	5.97045E-08				
recurring	247	1	1000	5.97045E-08				
recurring	248	1	1000	5.42768E-08				
recurring	248	1	1000	5.42768E-08				
190	249	1	-871.748	-4.30143E-08	3	3	0	0

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	249	1	1000	4.93425E-08				
recurring	250	1	1000	4.48568E-08				
recurring	250	1	1000	4.48568E-08				
28	252	1	-247.398	-9.17148E-09	1	1	0	0
recurring	252	1	1000	3.70718E-08				
recurring	252	1	1000	3.70718E-08				
149	253	1	-425.704	-1.43469E-08	2	2	0	0
327	253	1	1000	3.37016E-08	1	0	0	1
29	254	1	-365.9	-1.12104E-08	1	1	0	0
recurring	254	1	1000	3.06378E-08				
119	255	2	-575.313	-1.60239E-08	2	2	0	0
66	256	1	-1174.64	-2.97425E-08	3	3	0	0
recurring	256	1	1000	2.53205E-08				
365	257	1	1000	2.30187E-08	1	0	0	1
recurring	257	1	1000	2.30187E-08				
183	258	1	-1218.58	-2.55001E-08	4	4	0	0
recurring	258	1	1000	2.0926E-08				
recurring	258	1	1000	2.0926E-08				
recurring	258	1	1000	2.0926E-08				
recurring	259	1	1000	1.90237E-08				
recurring	259	1	1000	1.90237E-08				
recurring	260	1	1000	1.72943E-08				
recurring	260	1	1000	1.72943E-08				
448	261	1	1000	1.57221E-08	1	0	0	1
328	262	1	1000	1.42928E-08	1	0	0	1
recurring	263	1	1000	1.29934E-08				
recurring	263	1	1000	1.29934E-08				
recurring	263	1	1000	1.29934E-08				
282	265	1	-1231.4	-1.32232E-08	4	4	0	0
418	265	1	1000	1.07384E-08	1	0	0	1
recurring	265	1	1000	1.07384E-08				
recurring	265	1	1000	1.07384E-08				
recurring	265	1	1000	1.07384E-08				
recurring	265	1	1000	1.07384E-08				
22	266	1	-753.22	-7.35305E-09	2	2	0	0
recurring	267	1	1000	8.87469E-09				
131	268	1	-863.491	-6.96656E-09	3	3	0	0
recurring	268	1	1000	8.0679E-09				
recurring	268	1	1000	8.0679E-09				
recurring	269	1	1000	7.33445E-09				
recurring	269	1	1000	7.33445E-09				
recurring	270	1	1000	6.66768E-09				
recurring	270	1	1000	6.66768E-09				
recurring	270	1	1000	6.66768E-09				
recurring	270	1	1000	6.66768E-09				
209	271	1	-542.632	-3.28918E-09	2	2	0	0
recurring	271	1	1000	6.06153E-09				
recurring	272	1	1000	5.51048E-09				
recurring	273	1	1000	5.00953E-09				
recurring	273	1	1000	5.00953E-09				
recurring	274	1	1000	4.55412E-09				
recurring	276	1	1000	3.76373E-09				
113	277	1	-332.925	-1.13913E-09	1	1	0	0
recurring	277	1	1000	3.42158E-09				
recurring	277	1	1000	3.42158E-09				
recurring	277	1	1000	3.42158E-09				
63	278	1	-109.889	-3.41812E-10	1	1	0	0
recurring	278	1	1000	3.11052E-09				
recurring	278	1	1000	3.11052E-09				
recurring	279	1	1000	2.82775E-09				
recurring	280	1	1000	2.57068E-09				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	280	1	1000	2.57068E-09				
412	281	1	1000	2.33698E-09	1	0	0	1
recurring	282	1	1000	2.12453E-09				
recurring	282	1	1000	2.12453E-09				
recurring	283	1	1000	1.93139E-09				
recurring	284	1	1000	1.75581E-09				
recurring	286	1	1000	1.45108E-09				
229	287	1	-157.47	-2.07729E-10	1	1	0	0
recurring	287	1	1000	1.31917E-09				
recurring	287	1	1000	1.31917E-09				
recurring	288	1	1000	1.19924E-09				
recurring	288	1	1000	1.19924E-09				
recurring	288	1	1000	1.19924E-09				
recurring	289	1	1000	1.09022E-09				
recurring	289	1	1000	1.09022E-09				
recurring	290	1	1000	9.91109E-10				
recurring	290	1	1000	9.91109E-10				
recurring	291	1	1000	9.01008E-10				
recurring	292	1	1000	8.19098E-10				
235	293	2	-795.588	-5.92422E-10	2	2	0	0
recurring	293	1	1000	7.44635E-10				
recurring	293	1	1000	7.44635E-10				
recurring	293	1	1000	7.44635E-10				
49	294	1	-544.622	-3.68677E-10	2	2	0	0
552	294	1	1000	6.76941E-10	1	0	0	1
recurring	295	1	1000	6.15401E-10				
recurring	295	1	1000	6.15401E-10				
recurring	295	1	1000	6.15401E-10				
recurring	295	1	1000	6.15401E-10				
recurring	295	1	1000	6.15401E-10				
286	296	1	-407.914	-2.2821E-10	2	2	0	0
recurring	297	1	1000	5.08595E-10				
291	298	1	-545.074	-2.5202E-10	2	2	0	0
recurring	298	1	1000	4.6236E-10				
recurring	298	1	1000	4.6236E-10				
recurring	299	1	1000	4.20327E-10				
recurring	299	1	1000	4.20327E-10				
85	300	1	-280.218	-1.07076E-10	1	1	0	0
recurring	300	1	1000	3.82115E-10				
recurring	300	1	1000	3.82115E-10				
recurring	300	1	1000	3.82115E-10				
recurring	300	1	1000	3.82115E-10				
recurring	301	1	1000	3.47378E-10				
recurring	302	1	1000	3.15798E-10				
104	303	3	-805.225	-2.31171E-10	3	3	0	0
157	303	1	-612.019	-1.75704E-10	2	2	0	0
204	303	1	-816.794	-2.34492E-10	3	3	0	0
283	303	1	-854.331	-2.45269E-10	3	3	0	0
384	303	1	1000	2.87089E-10	1	0	0	1
recurring	303	1	1000	2.87089E-10				
recurring	303	1	1000	2.87089E-10				
133	304	1	-622.598	-1.62492E-10	2	2	0	0
582	304	1	1000	2.6099E-10	1	0	0	1
recurring	304	1	1000	2.6099E-10				
recurring	306	1	1000	2.15694E-10				
153	307	1	-1754.7	-3.44071E-10	5	5	0	0
230	307	1	-677.742	-1.32895E-10	2	2	0	0
271	307	1	-871.141	-1.70818E-10	3	3	0	0
recurring	307	1	1000	1.96086E-10				
recurring	307	1	1000	1.96086E-10				
recurring	307	1	1000	1.96086E-10				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
123	308	1	-513.555	-9.15461E-11	2	2	0	0
212	308	1	-718.301	-1.28044E-10	2	2	0	0
recurring	308	1	1000	1.7826E-10				
recurring	308	1	1000	1.7826E-10				
recurring	309	1	1000	1.62054E-10				
88	310	1	-389.787	-5.74242E-11	1	1	0	0
recurring	310	1	1000	1.47322E-10				
recurring	310	1	1000	1.47322E-10				
529	311	1	1000	1.33929E-10	1	0	0	1
recurring	311	1	1000	1.33929E-10				
405	312	1	1000	1.21754E-10	1	0	0	1
recurring	312	1	1000	1.21754E-10				
recurring	312	1	1000	1.21754E-10				
403	313	1	1000	1.10685E-10	1	0	0	1
recurring	313	1	1000	1.10685E-10				
recurring	314	1	1000	1.00623E-10				
40	315	1	-1258.88	-1.15157E-10	4	4	0	0
207	316	1	-913.111	-7.59338E-11	3	3	0	0
303	316	1	-426.39	-3.54583E-11	2	2	0	0
recurring	316	1	1000	8.31594E-11				
139	317	1	-1436.02	-1.08562E-10	4	4	0	0
602	317	1	1000	7.55995E-11	1	0	0	1
recurring	317	1	1000	7.55995E-11				
recurring	317	1	1000	7.55995E-11				
151	318	1	-654.646	-4.49917E-11	2	2	0	0
292	318	1	-384.133	-2.64002E-11	1	1	0	0
recurring	318	1	1000	6.87268E-11				
recurring	318	1	1000	6.87268E-11				
recurring	318	1	1000	6.87268E-11				
314	319	1	-362.996	-2.26796E-11	1	1	0	0
recurring	319	1	1000	6.24789E-11				
recurring	319	1	1000	6.24789E-11				
613	320	1	1000	5.6799E-11	1	0	0	1
recurring	320	1	1000	5.6799E-11				
recurring	320	1	1000	5.6799E-11				
182	321	1	-619.32	-3.19789E-11	2	2	0	0
317	321	1	-621.003	-3.20658E-11	2	2	0	0
recurring	321	1	1000	5.16355E-11				
25	322	1	-1208.53	-5.673E-11	4	4	0	0
191	322	1	-875.108	-4.10787E-11	3	3	0	0
382	322	1	1000	4.69413E-11	1	0	0	1
438	322	1	1000	4.69413E-11	1	0	0	1
recurring	322	1	1000	4.69413E-11				
591	323	1	1000	4.26739E-11	1	0	0	1
recurring	323	1	1000	4.26739E-11				
recurring	323	1	1000	4.26739E-11				
recurring	323	1	1000	4.26739E-11				
100	324	2	-773.772	-3.00181E-11	2	2	0	0
581	324	1	1000	3.87945E-11	1	0	0	1
recurring	324	1	1000	3.87945E-11				
27	325	1	-304.089	-1.07245E-11	1	1	0	0
79	325	1	-334.988	-1.18143E-11	1	1	0	0
recurring	325	1	1000	3.52677E-11				
recurring	325	1	1000	3.52677E-11				
recurring	325	1	1000	3.52677E-11				
recurring	325	1	1000	3.52677E-11				
recurring	325	1	1000	3.52677E-11				
46	326	1	-427.593	-1.37093E-11	2	2	0	0
553	326	1	1000	3.20616E-11	1	0	0	1
recurring	327	1	1000	2.91469E-11				
169	328	1	-623.83	-1.65297E-11	2	2	0	0

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	328	1	1000	2.64972E-11				
recurring	328	1	1000	2.64972E-11				
recurring	329	1	1000	2.40883E-11				
recurring	329	1	1000	2.40883E-11				
38	330	1	-713.726	-1.56295E-11	2	2	0	0
129	330	1	-607.162	-1.32959E-11	2	2	0	0
recurring	330	1	1000	2.18985E-11				
recurring	330	1	1000	2.18985E-11				
recurring	330	1	1000	2.18985E-11				
recurring	330	1	1000	2.18985E-11				
recurring	331	1	1000	1.99077E-11				
287	332	1	-268.042	-4.851E-12	1	1	0	0
345	332	1	1000	1.80979E-11	1	0	0	1
recurring	332	1	1000	1.80979E-11				
recurring	333	1	1000	1.64526E-11				
recurring	333	1	1000	1.64526E-11				
recurring	333	1	1000	1.64526E-11				
116	334	1	-781.775	-1.1693E-11	2	2	0	0
267	334	1	-721.561	-1.07924E-11	2	2	0	0
recurring	334	1	1000	1.4957E-11				
recurring	334	1	1000	1.4957E-11				
247	335	1	-857.379	-1.1658E-11	3	3	0	0
371	335	1	1000	1.35972E-11	1	0	0	1
399	335	1	1000	1.35972E-11	1	0	0	1
415	335	1	1000	1.35972E-11	1	0	0	1
122	336	1	-616.336	-7.6186E-12	2	2	0	0
recurring	336	1	1000	1.23611E-11				
recurring	337	1	1000	1.12374E-11				
recurring	337	1	1000	1.12374E-11				
recurring	337	1	1000	1.12374E-11				
523	338	1	1000	1.02158E-11	1	0	0	1
546	338	1	1000	1.02158E-11	1	0	0	1
recurring	338	1	1000	1.02158E-11				
recurring	338	1	1000	1.02158E-11				
80	339	1	-1129.95	-1.04939E-11	3	3	0	0
recurring	339	1	1000	9.28709E-12				
recurring	340	1	1000	8.44281E-12				
recurring	340	1	1000	8.44281E-12				
202	341	1	-790.389	-6.06646E-12	2	2	0	0
recurring	341	1	1000	7.67528E-12				
recurring	341	1	1000	7.67528E-12				
recurring	342	1	1000	6.97753E-12				
recurring	342	1	1000	6.97753E-12				
recurring	342	1	1000	6.97753E-12				
47	343	1	-354.608	-2.24935E-12	1	1	0	0
recurring	343	1	1000	6.34321E-12				
recurring	343	1	1000	6.34321E-12				
586	344	1	1000	5.76655E-12	1	0	0	1
recurring	344	1	1000	5.76655E-12				
148	346	1	-1141.35	-5.43938E-12	3	3	0	0
309	346	1	-1140.22	-5.434E-12	3	3	0	0
379	346	1	1000	4.76575E-12	1	0	0	1
recurring	346	1	1000	4.76575E-12				
58	347	1	-343.98	-1.49029E-12	1	1	0	0
109	347	1	-490.36	-2.12448E-12	2	2	0	0
270	347	1	-1067.39	-4.62446E-12	3	3	0	0
441	347	1	1000	4.3325E-12	1	0	0	1
447	347	1	1000	4.3325E-12	1	0	0	1
recurring	347	1	1000	4.3325E-12				
recurring	347	1	1000	4.3325E-12				
recurring	347	1	1000	4.3325E-12				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
126	348	1	-850.151	-3.34843E-12	3	3	0	0
210	348	1	-994.248	-3.91598E-12	3	3	0	0
232	348	1	-390.641	-1.53859E-12	1	1	0	0
250	348	1	-647.828	-2.55156E-12	2	2	0	0
608	348	1	1000	3.93863E-12	1	0	0	1
recurring	348	1	1000	3.93863E-12				
recurring	348	1	1000	3.93863E-12				
recurring	348	1	1000	3.93863E-12				
44	349	1	-782.232	-2.80084E-12	2	2	0	0
recurring	349	1	1000	3.58058E-12				
recurring	349	1	1000	3.58058E-12				
414	350	1	1000	3.25507E-12	1	0	0	1
recurring	350	1	1000	3.25507E-12				
recurring	350	1	1000	3.25507E-12				
recurring	350	1	1000	3.25507E-12				
30	351	1	-271.893	-8.04573E-13	1	1	0	0
recurring	351	1	1000	2.95915E-12				
340	352	1	1000	2.69014E-12	1	0	0	1
recurring	352	1	1000	2.69014E-12				
recurring	352	1	1000	2.69014E-12				
recurring	352	1	1000	2.69014E-12				
220	353	1	-281.956	-6.89546E-13	1	1	0	0
recurring	353	1	1000	2.44558E-12				
recurring	353	1	1000	2.44558E-12				
recurring	353	1	1000	2.44558E-12				
recurring	353	1	1000	2.44558E-12				
312	354	1	-1690.82	-3.75913E-12	5	5	0	0
519	354	1	1000	2.22326E-12	1	0	0	1
recurring	354	1	1000	2.22326E-12				
recurring	354	1	1000	2.22326E-12				
155	355	1	-791.478	-1.59969E-12	2	2	0	0
161	355	1	-1248.15	-2.52269E-12	4	4	0	0
264	355	1	-273.614	-5.53013E-13	1	1	0	0
531	355	1	1000	2.02114E-12	1	0	0	1
585	355	1	1000	2.02114E-12	1	0	0	1
recurring	355	1	1000	2.02114E-12				
recurring	355	1	1000	2.02114E-12				
recurring	355	1	1000	2.02114E-12				
recurring	355	1	1000	2.02114E-12				
recurring	355	1	1000	2.02114E-12				
recurring	356	1	1000	1.8374E-12				
124	357	1	-577.139	-9.64033E-13	2	2	0	0
recurring	357	1	1000	1.67037E-12				
recurring	358	1	1000	1.51851E-12				
recurring	358	1	1000	1.51851E-12				
94	359	1	-1274.5	-1.75941E-12	4	4	0	0
512	359	1	1000	1.38047E-12	1	0	0	1
recurring	359	1	1000	1.38047E-12				
recurring	359	1	1000	1.38047E-12				
299	360	1	-818.38	-1.02704E-12	3	3	0	0
recurring	360	1	1000	1.25497E-12				
recurring	360	1	1000	1.25497E-12				
recurring	360	1	1000	1.25497E-12				
recurring	360	1	1000	1.25497E-12				
23	361	1	-1354.09	-1.54486E-12	4	4	0	0
563	361	1	1000	1.14088E-12	1	0	0	1
recurring	361	1	1000	1.14088E-12				
recurring	362	1	1000	1.03717E-12				
recurring	362	1	1000	1.03717E-12				
606	363	1	1000	9.42878E-13	1	0	0	1
recurring	363	1	1000	9.42878E-13				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	363	1	1000	9.42878E-13				
recurring	363	1	1000	9.42878E-13				
120	364	1	-336.471	-2.8841E-13	1	1	0	0
recurring	364	1	1000	8.57161E-13				
recurring	364	1	1000	8.57161E-13				
recurring	365	1	1000	7.79238E-13				
recurring	365	1	1000	7.79238E-13				
recurring	365	1	1000	7.79238E-13				
recurring	366	1	1000	7.08398E-13				
308	367	1	-1464.84	-9.43354E-13	4	4	0	0
recurring	367	1	1000	6.43998E-13				
recurring	367	1	1000	6.43998E-13				
recurring	367	1	1000	6.43998E-13				
recurring	368	1	1000	5.85453E-13				
recurring	368	1	1000	5.85453E-13				
recurring	368	1	1000	5.85453E-13				
recurring	368	1	1000	5.85453E-13				
recurring	369	1	1000	5.3223E-13				
194	370	1	-1545.91	-7.47981E-13	4	4	0	0
423	370	1	1000	4.83845E-13	1	0	0	1
recurring	370	1	1000	4.83845E-13				
recurring	370	1	1000	4.83845E-13				
111	371	1	-948.061	-4.17013E-13	3	3	0	0
186	371	1	-740.015	-3.25503E-13	2	2	0	0
231	371	1	-640.458	-2.81711E-13	2	2	0	0
recurring	371	1	1000	4.39859E-13				
recurring	371	1	1000	4.39859E-13				
75	372	1	-789.93	-3.15871E-13	2	2	0	0
95	372	1	-1029.54	-4.11684E-13	3	3	0	0
154	372	1	-1526.42	-6.10373E-13	4	4	0	0
236	372	1	-144.772	-5.78903E-14	1	1	0	0
251	372	1	-404.997	-1.61947E-13	2	2	0	0
293	372	1	-1576.91	-6.30562E-13	4	4	0	0
recurring	372	1	1000	3.99872E-13				
recurring	372	1	1000	3.99872E-13				
recurring	372	1	1000	3.99872E-13				
118	373	1	-817.566	-2.97202E-13	3	3	0	0
378	373	1	1000	3.6352E-13	1	0	0	1
recurring	373	1	1000	3.6352E-13				
recurring	373	1	1000	3.6352E-13				
128	374	1	-761.933	-2.51798E-13	2	2	0	0
289	374	1	-1596.57	-5.27623E-13	4	4	0	0
311	374	1	-1157.62	-3.82562E-13	3	3	0	0
394	374	1	1000	3.30473E-13	1	0	0	1
410	374	1	1000	3.30473E-13	1	0	0	1
535	374	1	1000	3.30473E-13	1	0	0	1
recurring	374	1	1000	3.30473E-13				
recurring	374	1	1000	3.30473E-13				
263	375	1	-885.989	-2.66178E-13	3	3	0	0
458	375	1	1000	3.0043E-13	1	0	0	1
607	375	1	1000	3.0043E-13	1	0	0	1
193	376	1	-490.225	-1.33889E-13	2	2	0	0
322	376	1	1000	2.73118E-13	1	0	0	1
recurring	376	1	1000	2.73118E-13				
recurring	376	1	1000	2.73118E-13				
61	377	1	-275.007	-6.82812E-14	1	1	0	0
284	377	1	-1909.04	-4.73994E-13	5	5	0	0
411	377	1	1000	2.48289E-13	1	0	0	1
recurring	377	1	1000	2.48289E-13				
recurring	377	1	1000	2.48289E-13				
recurring	377	1	1000	2.48289E-13				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	377	1	1000	2.48289E-13				
recurring	377	1	1000	2.48289E-13				
98	378	2	-405.62	-9.15555E-14	2	2	0	0
144	378	1	-1443.57	-3.25839E-13	4	4	0	0
419	378	1	1000	2.25717E-13	1	0	0	1
481	378	1	1000	2.25717E-13	1	0	0	1
511	378	1	1000	2.25717E-13	1	0	0	1
recurring	378	1	1000	2.25717E-13				
recurring	378	1	1000	2.25717E-13				
recurring	378	1	1000	2.25717E-13				
recurring	378	1	1000	2.25717E-13				
recurring	379	1	1000	2.05198E-13				
recurring	379	1	1000	2.05198E-13				
recurring	380	1	1000	1.86543E-13				
recurring	380	1	1000	1.86543E-13				
recurring	380	1	1000	1.86543E-13				
recurring	380	1	1000	1.86543E-13				
99	381	1	-808.337	-1.37082E-13	3	3	0	0
173	381	1	-991.852	-1.68203E-13	3	3	0	0
225	381	2	-409.244	-6.94016E-14	2	2	0	0
397	381	1	1000	1.69585E-13	1	0	0	1
recurring	381	1	1000	1.69585E-13				
339	382	1	1000	1.54168E-13	1	0	0	1
398	382	1	1000	1.54168E-13	1	0	0	1
424	382	1	1000	1.54168E-13	1	0	0	1
recurring	382	1	1000	1.54168E-13				
recurring	382	1	1000	1.54168E-13				
recurring	382	1	1000	1.54168E-13				
recurring	382	1	1000	1.54168E-13				
160	383	1	-966.2	-1.35416E-13	3	3	0	0
277	383	1	-965.727	-1.35349E-13	3	3	0	0
610	383	1	1000	1.40153E-13	1	0	0	1
recurring	383	1	1000	1.40153E-13				
recurring	383	1	1000	1.40153E-13				
recurring	383	1	1000	1.40153E-13				
recurring	383	1	1000	1.40153E-13				
298	384	1	-936.435	-1.19313E-13	3	3	0	0
301	384	1	-933.214	-1.18902E-13	3	3	0	0
611	384	1	1000	1.27412E-13	1	0	0	1
recurring	384	1	1000	1.27412E-13				
recurring	384	1	1000	1.27412E-13				
recurring	384	1	1000	1.27412E-13				
242	385	1	-561.221	-6.50055E-14	2	2	0	0
524	385	1	1000	1.15829E-13	1	0	0	1
recurring	385	1	1000	1.15829E-13				
recurring	385	1	1000	1.15829E-13				
recurring	385	1	1000	1.15829E-13				
recurring	385	1	1000	1.15829E-13				
recurring	385	1	1000	1.15829E-13				
recurring	385	1	1000	1.15829E-13				
recurring	385	1	1000	1.15829E-13				
206	386	1	-1034.96	-1.0898E-13	3	3	0	0
600	386	1	1000	1.05299E-13	1	0	0	1
recurring	386	1	1000	1.05299E-13				
recurring	387	1	1000	9.57262E-14				
302	388	1	-440.644	-3.83465E-14	2	2	0	0
recurring	388	1	1000	8.70238E-14				
recurring	388	1	1000	8.70238E-14				
601	389	1	1000	7.91126E-14	1	0	0	1
recurring	389	1	1000	7.91126E-14				
recurring	389	1	1000	7.91126E-14				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	389	1	1000	7.91126E-14				
89	390	1	-247.006	-1.77648E-14	1	1	0	0
164	390	1	-296.031	-2.12907E-14	1	1	0	0
341	390	1	1000	7.19205E-14	1	0	0	1
recurring	390	1	1000	7.19205E-14				
recurring	390	1	1000	7.19205E-14				
recurring	390	1	1000	7.19205E-14				
recurring	390	1	1000	7.19205E-14				
280	391	1	-984.52	-6.43702E-14	3	3	0	0
505	391	1	1000	6.53823E-14	1	0	0	1
recurring	391	1	1000	6.53823E-14				
recurring	391	1	1000	6.53823E-14				
388	392	1	1000	5.94384E-14	1	0	0	1
468	392	1	1000	5.94384E-14	1	0	0	1
616	392	1	1000	5.94384E-14	1	0	0	1
recurring	392	1	1000	5.94384E-14				
recurring	392	1	1000	5.94384E-14				
recurring	393	1	1000	5.40349E-14				
recurring	393	1	1000	5.40349E-14				
recurring	393	1	1000	5.40349E-14				
recurring	393	1	1000	5.40349E-14				
69	394	1	-769.922	-3.78206E-14	2	2	0	0
579	394	1	1000	4.91227E-14	1	0	0	1
recurring	394	1	1000	4.91227E-14				
recurring	394	1	1000	4.91227E-14				
recurring	395	1	1000	4.4657E-14				
recurring	395	1	1000	4.4657E-14				
recurring	395	1	1000	4.4657E-14				
84	396	2	-578.326	-2.34784E-14	2	2	0	0
275	396	1	-935.791	-3.79905E-14	3	3	0	0
recurring	396	1	1000	4.05973E-14				
278	397	1	-876.331	-3.23424E-14	3	3	0	0
353	397	1	1000	3.69066E-14	1	0	0	1
570	397	1	1000	3.69066E-14	1	0	0	1
recurring	397	1	1000	3.69066E-14				
recurring	397	1	1000	3.69066E-14				
recurring	397	1	1000	3.69066E-14				
31	398	1	-806.979	-2.70753E-14	3	3	0	0
324	398	1	1000	3.35515E-14	1	0	0	1
recurring	398	1	1000	3.35515E-14				
recurring	398	1	1000	3.35515E-14				
recurring	398	1	1000	3.35515E-14				
recurring	398	1	1000	3.35515E-14				
recurring	399	1	1000	3.05013E-14				
217	400	1	-363.464	-1.00783E-14	1	1	0	0
223	400	2	-516.917	-1.43333E-14	2	2	0	0
285	400	1	-1627.54	-4.51292E-14	5	5	0	0
472	400	1	1000	2.77285E-14	1	0	0	1
recurring	400	1	1000	2.77285E-14				
recurring	400	1	1000	2.77285E-14				
recurring	400	1	1000	2.77285E-14				
108	401	1	-855.781	-2.15723E-14	3	3	0	0
recurring	401	1	1000	2.52077E-14				
recurring	401	1	1000	2.52077E-14				
310	402	1	-1169.91	-2.68098E-14	3	3	0	0
407	402	1	1000	2.29161E-14	1	0	0	1
465	402	1	1000	2.29161E-14	1	0	0	1
556	402	1	1000	2.29161E-14	1	0	0	1
593	402	1	1000	2.29161E-14	1	0	0	1
recurring	402	1	1000	2.29161E-14				
recurring	402	1	1000	2.29161E-14				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	402	1	1000	2.29161E-14				
516	403	1	1000	2.08328E-14	1	0	0	1
recurring	403	1	1000	2.08328E-14				
recurring	403	1	1000	2.08328E-14				
recurring	403	1	1000	2.08328E-14				
380	404	1	1000	1.89389E-14	1	0	0	1
recurring	404	1	1000	1.89389E-14				
recurring	404	1	1000	1.89389E-14				
recurring	404	1	1000	1.89389E-14				
recurring	404	1	1000	1.89389E-14				
recurring	404	1	1000	1.89389E-14				
67	405	1	-955.981	-1.64593E-14	3	3	0	0
96	405	1	-878.177	-1.51197E-14	3	3	0	0
522	405	1	1000	1.72172E-14	1	0	0	1
recurring	405	1	1000	1.72172E-14				
recurring	405	1	1000	1.72172E-14				
290	406	1	-724.472	-1.13394E-14	2	2	0	0
recurring	406	1	1000	1.5652E-14				
recurring	406	1	1000	1.5652E-14				
recurring	406	1	1000	1.5652E-14				
200	407	1	-1054.41	-1.50033E-14	3	3	0	0
432	407	1	1000	1.42291E-14	1	0	0	1
569	407	1	1000	1.42291E-14	1	0	0	1
recurring	407	1	1000	1.42291E-14				
recurring	407	1	1000	1.42291E-14				
recurring	407	1	1000	1.42291E-14				
recurring	407	1	1000	1.42291E-14				
recurring	407	1	1000	1.42291E-14				
recurring	407	1	1000	1.42291E-14				
184	408	1	-962.353	-1.24486E-14	3	3	0	0
189	408	1	-1091.84	-1.41235E-14	3	3	0	0
589	408	1	1000	1.29355E-14	1	0	0	1
recurring	408	1	1000	1.29355E-14				
recurring	408	1	1000	1.29355E-14				
recurring	408	1	1000	1.29355E-14				
recurring	408	1	1000	1.29355E-14				
recurring	408	1	1000	1.29355E-14				
recurring	408	1	1000	1.29355E-14				
recurring	408	1	1000	1.29355E-14				
408	409	1	1000	1.17596E-14	1	0	0	1
499	409	1	1000	1.17596E-14	1	0	0	1
537	409	1	1000	1.17596E-14	1	0	0	1
recurring	409	1	1000	1.17596E-14				
recurring	409	1	1000	1.17596E-14				
326	410	1	1000	1.06905E-14	1	0	0	1
488	410	1	1000	1.06905E-14	1	0	0	1
recurring	410	1	1000	1.06905E-14				
recurring	410	1	1000	1.06905E-14				
recurring	410	1	1000	1.06905E-14				
recurring	410	1	1000	1.06905E-14				
176	411	1	-874.255	-8.49659E-15	3	3	0	0
329	411	1	1000	9.71866E-15	1	0	0	1
363	411	1	1000	9.71866E-15	1	0	0	1
374	411	1	1000	9.71866E-15	1	0	0	1
recurring	411	1	1000	9.71866E-15				
recurring	411	1	1000	9.71866E-15				
295	412	1	-546.566	-4.82899E-15	2	2	0	0
297	412	1	-697.572	-6.16315E-15	2	2	0	0
450	412	1	1000	8.83515E-15	1	0	0	1
recurring	412	1	1000	8.83515E-15				
recurring	412	1	1000	8.83515E-15				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	412	1	1000	8.83515E-15				
recurring	412	1	1000	8.83515E-15				
recurring	412	1	1000	8.83515E-15				
recurring	412	1	1000	8.83515E-15				
recurring	412	1	1000	8.83515E-15				
90	413	1	-480.093	-3.85608E-15	2	2	0	0
recurring	413	1	1000	8.03195E-15				
recurring	413	1	1000	8.03195E-15				
recurring	413	1	1000	8.03195E-15				
recurring	413	1	1000	8.03195E-15				
recurring	413	1	1000	8.03195E-15				
48	414	1	-648.809	-4.73746E-15	2	2	0	0
281	414	1	-1066	-7.78369E-15	3	3	0	0
370	414	1	1000	7.30177E-15	1	0	0	1
389	414	1	1000	7.30177E-15	1	0	0	1
404	414	1	1000	7.30177E-15	1	0	0	1
recurring	414	1	1000	7.30177E-15				
recurring	414	1	1000	7.30177E-15				
recurring	414	1	1000	7.30177E-15				
recurring	414	1	1000	7.30177E-15				
337	415	1	1000	6.63798E-15	1	0	0	1
615	415	1	1000	6.63798E-15	1	0	0	1
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
recurring	415	1	1000	6.63798E-15				
37	416	1	-444.428	-2.68191E-15	2	2	0	0
347	416	1	1000	6.03452E-15	1	0	0	1
387	416	1	1000	6.03452E-15	1	0	0	1
393	416	1	1000	6.03452E-15	1	0	0	1
429	416	1	1000	6.03452E-15	1	0	0	1
459	416	1	1000	6.03452E-15	1	0	0	1
594	416	1	1000	6.03452E-15	1	0	0	1
recurring	416	1	1000	6.03452E-15				
recurring	416	1	1000	6.03452E-15				
385	417	1	1000	5.48593E-15	1	0	0	1
475	417	1	1000	5.48593E-15	1	0	0	1
588	417	1	1000	5.48593E-15	1	0	0	1
recurring	417	1	1000	5.48593E-15				
201	418	1	-1355.65	-6.76091E-15	4	4	0	0
541	418	1	1000	4.98721E-15	1	0	0	1
recurring	418	1	1000	4.98721E-15				
recurring	418	1	1000	4.98721E-15				
103	419	1	-778.957	-3.53166E-15	2	2	0	0
428	419	1	1000	4.53383E-15	1	0	0	1
recurring	419	1	1000	4.53383E-15				
recurring	419	1	1000	4.53383E-15				
recurring	419	1	1000	4.53383E-15				
recurring	419	1	1000	4.53383E-15				
78	420	1	-1247.34	-5.14111E-15	4	4	0	0
146	420	2	-708.159	-2.91879E-15	2	2	0	0
321	420	1	-785.745	-3.23857E-15	2	2	0	0
330	420	1	1000	4.12166E-15	1	0	0	1
457	420	1	1000	4.12166E-15	1	0	0	1
530	420	1	1000	4.12166E-15	1	0	0	1
recurring	420	1	1000	4.12166E-15				
recurring	420	1	1000	4.12166E-15				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	420	1	1000	4.12166E-15				
recurring	420	1	1000	4.12166E-15				
recurring	420	1	1000	4.12166E-15				
52	421	1	-1035.24	-3.87901E-15	3	3	0	0
342	421	1	1000	3.74696E-15	1	0	0	1
362	421	1	1000	3.74696E-15	1	0	0	1
500	421	1	1000	3.74696E-15	1	0	0	1
577	421	1	1000	3.74696E-15	1	0	0	1
recurring	421	1	1000	3.74696E-15				
recurring	421	1	1000	3.74696E-15				
recurring	421	1	1000	3.74696E-15				
196	422	1	-1071.75	-3.65074E-15	3	3	0	0
456	422	1	1000	3.40633E-15	1	0	0	1
recurring	422	1	1000	3.40633E-15				
recurring	422	1	1000	3.40633E-15				
recurring	422	1	1000	3.40633E-15				
recurring	422	1	1000	3.40633E-15				
recurring	422	1	1000	3.40633E-15				
60	423	1	-450.145	-1.39395E-15	2	2	0	0
402	423	1	1000	3.09666E-15	1	0	0	1
480	423	1	1000	3.09666E-15	1	0	0	1
495	423	1	1000	3.09666E-15	1	0	0	1
562	423	1	1000	3.09666E-15	1	0	0	1
574	423	1	1000	3.09666E-15	1	0	0	1
597	423	1	1000	3.09666E-15	1	0	0	1
recurring	423	1	1000	3.09666E-15				
recurring	423	1	1000	3.09666E-15				
recurring	423	1	1000	3.09666E-15				
recurring	423	1	1000	3.09666E-15				
74	424	1	-1037.78	-2.92151E-15	3	3	0	0
110	424	1	-776.134	-2.18493E-15	2	2	0	0
221	424	1	-290.147	-8.16807E-16	1	1	0	0
477	424	1	1000	2.81515E-15	1	0	0	1
recurring	424	1	1000	2.81515E-15				
recurring	424	1	1000	2.81515E-15				
recurring	424	1	1000	2.81515E-15				
68	425	1	-604.88	-1.54803E-15	2	2	0	0
172	425	1	-1139.28	-2.91568E-15	3	3	0	0
351	425	1	1000	2.55923E-15	1	0	0	1
409	425	1	1000	2.55923E-15	1	0	0	1
435	425	1	1000	2.55923E-15	1	0	0	1
620	425	1	1000	2.55923E-15	1	0	0	1
recurring	425	1	1000	2.55923E-15				
recurring	425	1	1000	2.55923E-15				
recurring	425	1	1000	2.55923E-15				
319	426	1	-1153.48	-2.68365E-15	3	3	0	0
369	426	1	1000	2.32657E-15	1	0	0	1
609	426	1	1000	2.32657E-15	1	0	0	1
recurring	426	1	1000	2.32657E-15				
366	427	1	1000	2.11506E-15	1	0	0	1
367	427	1	1000	2.11506E-15	1	0	0	1
368	427	1	1000	2.11506E-15	1	0	0	1
recurring	427	1	1000	2.11506E-15				
recurring	427	1	1000	2.11506E-15				
recurring	427	1	1000	2.11506E-15				
recurring	427	1	1000	2.11506E-15				
recurring	427	1	1000	2.11506E-15				
296	428	1	-1092.12	-2.09991E-15	3	3	0	0
445	428	1	1000	1.92279E-15	1	0	0	1
550	428	1	1000	1.92279E-15	1	0	0	1
recurring	428	1	1000	1.92279E-15				

Table B.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	428	1	1000	1.92279E-15				
recurring	428	1	1000	1.92279E-15				
recurring	428	1	1000	1.92279E-15				
recurring	428	1	1000	1.92279E-15				
26	429	1	-390.346	-6.8232E-16	1	1	0	0
76	429	1	-930.298	-1.62615E-15	3	3	0	0
93	429	1	-1190.3	-2.08063E-15	3	3	0	0
137	429	2	-406.797	-7.11076E-16	2	2	0	0
214	429	1	-347.256	-6.06999E-16	1	1	0	0
279	429	1	-852.989	-1.49101E-15	3	3	0	0
346	429	1	1000	1.74799E-15	1	0	0	1
359	429	1	1000	1.74799E-15	1	0	0	1
482	429	1	1000	1.74799E-15	1	0	0	1
recurring	429	1	1000	1.74799E-15				
117	430	1	-1035.92	-1.64616E-15	3	3	0	0
135	430	1	-528.264	-8.39453E-16	2	2	0	0
145	430	2	-512.495	-8.14395E-16	2	2	0	0
205	430	1	-1517.08	-2.41076E-15	4	4	0	0
392	430	1	1000	1.58908E-15	1	0	0	1
recurring	430	1	1000	1.58908E-15				
recurring	430	1	1000	1.58908E-15				
recurring	430	1	1000	1.58908E-15				
recurring	430	1	1000	1.58908E-15				
127	431	1	-583.013	-8.4223E-16	2	2	0	0
513	431	1	1000	1.44462E-15	1	0	0	1

Appendix C

CP Validation Output

Table C.1: CP approach validation output

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
1	0	0	-10000	-10000	0	0	0	0
3	0	4	-1559.49	-1559.49	4	4	0	0
10	0	2	-593.093	-593.093	2	2	0	0
19	2	8	-3000	-2479.338843	1	0	1	0
12	4	8	-3000	-2049.040366	1	0	1	0
90	10	1	-480.093	-185.0966345	2	2	0	0
91	10	1	-621.017	-239.428937	2	2	0	0
92	10	1	-845.149	-325.8415255	3	3	0	0
108	10	1	-855.781	-329.9406218	3	3	0	0
109	10	1	-490.36	-189.0550074	2	2	0	0
110	10	1	-776.134	-299.2332554	2	2	0	0
112	10	1	-314.042	-121.0767857	1	1	0	0
113	10	1	-332.925	-128.3569996	1	1	0	0
114	10	1	-517.451	-199.4997607	2	2	0	0
115	10	1	-620.457	-239.2130327	2	2	0	0
149	10	1	-425.704	-164.1273205	2	2	0	0
152	10	1	-623.31	-240.3129877	2	2	0	0
188	10	1	-665.039	-256.4013237	2	2	0	0
215	10	1	-496.77	-191.5263399	2	2	0	0
220	10	1	-281.956	-108.7062437	1	1	0	0
229	10	1	-157.47	-60.71150179	1	1	0	0
232	10	1	-390.641	-150.6090161	1	1	0	0
260	10	1	-313.636	-120.9202551	1	1	0	0
262	10	1	-160.934	-62.04702374	1	1	0	0
389	11	1	1000	350.4938995	1	0	0	1
390	11	1	1000	350.4938995	1	0	0	1
391	11	1	1000	350.4938995	1	0	0	1
407	11	1	1000	350.4938995	1	0	0	1
408	11	1	1000	350.4938995	1	0	0	1
409	11	1	1000	350.4938995	1	0	0	1
411	11	1	1000	350.4938995	1	0	0	1
412	11	1	1000	350.4938995	1	0	0	1
413	11	1	1000	350.4938995	1	0	0	1
414	11	1	1000	350.4938995	1	0	0	1
448	11	1	1000	350.4938995	1	0	0	1
451	11	1	1000	350.4938995	1	0	0	1
487	11	1	1000	350.4938995	1	0	0	1
514	11	1	1000	350.4938995	1	0	0	1
519	11	1	1000	350.4938995	1	0	0	1
528	11	1	1000	350.4938995	1	0	0	1
531	11	1	1000	350.4938995	1	0	0	1
559	11	1	1000	350.4938995	1	0	0	1
561	11	1	1000	350.4938995	1	0	0	1
21	12	1	-3000	-955.8924531	1	0	1	0
28	12	1	-247.398	-78.82862704	1	1	0	0
29	12	1	-365.9	-116.5870162	1	1	0	0
31	12	1	-806.979	-257.1283786	3	3	0	0
37	12	1	-444.428	-141.6084571	2	2	0	0
57	12	1	-852.025	-271.4814225	3	3	0	0
59	12	1	-214.832	-68.45209583	1	1	0	0
60	12	1	-450.145	-143.4300694	2	2	0	0
61	12	1	-275.007	-87.62570529	1	1	0	0
62	12	1	-187.141	-59.62888986	1	1	0	0
63	12	1	-109.889	-35.01402193	1	1	0	0
64	12	1	-168.756	-53.77086227	1	1	0	0
134	12	1	-349.996	-111.5195117	1	1	0	0
135	12	1	-528.264	-168.3211903	2	2	0	0
163	12	1	-217.808	-69.40034114	1	1	0	0
164	12	1	-296.031	-94.3245996	1	1	0	0
165	12	1	-565.055	-180.0439367	2	2	0	0

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
176	12	1	-874.255	-278.5645855	3	3	0	0
177	12	1	-848.644	-270.4041317	3	3	0	0
199	12	1	-894.359	-284.9703395	3	3	0	0
214	12	1	-347.256	-110.6464632	1	1	0	0
30	13	1	-271.893	-78.7577172	1	1	0	0
58	13	1	-343.98	-99.63875334	1	1	0	0
82	13	1	-195.15	-56.52800371	1	1	0	0
136	13	1	-450.105	-130.3793856	2	2	0	0
180	13	1	-433.962	-125.7033336	2	2	0	0
216	13	1	-180.138	-52.17956204	1	1	0	0
217	13	1	-363.464	-105.2825741	1	1	0	0
218	13	1	-249.592	-72.29791187	1	1	0	0
219	13	1	-117.357	-33.99414261	1	1	0	0
221	13	1	-290.147	-84.04525079	1	1	0	0
224	13	1	-213.25	-61.77092898	1	1	0	0
225	13	2	-409.244	-118.5434094	2	2	0	0
227	13	1	-240.691	-69.71960922	1	1	0	0
234	13	1	-712.046	-206.2543629	2	2	0	0
238	13	1	-783.78	-227.0331476	2	2	0	0
327	13	1	1000	289.6643797	1	0	0	1
328	13	1	1000	289.6643797	1	0	0	1
330	13	1	1000	289.6643797	1	0	0	1
336	13	1	1000	289.6643797	1	0	0	1
356	13	1	1000	289.6643797	1	0	0	1
358	13	1	1000	289.6643797	1	0	0	1
359	13	1	1000	289.6643797	1	0	0	1
360	13	1	1000	289.6643797	1	0	0	1
361	13	1	1000	289.6643797	1	0	0	1
362	13	1	1000	289.6643797	1	0	0	1
363	13	1	1000	289.6643797	1	0	0	1
433	13	1	1000	289.6643797	1	0	0	1
434	13	1	1000	289.6643797	1	0	0	1
462	13	1	1000	289.6643797	1	0	0	1
463	13	1	1000	289.6643797	1	0	0	1
464	13	1	1000	289.6643797	1	0	0	1
475	13	1	1000	289.6643797	1	0	0	1
476	13	1	1000	289.6643797	1	0	0	1
498	13	1	1000	289.6643797	1	0	0	1
513	13	1	1000	289.6643797	1	0	0	1
75	14	1	-789.93	-208.0132577	2	2	0	0
83	14	2	-546.592	-143.934757	2	2	0	0
97	14	2	-683.903	-180.0930348	2	2	0	0
101	14	1	-671.835	-176.9151532	2	2	0	0
103	14	1	-778.957	-205.1237239	2	2	0	0
119	14	2	-575.313	-151.4978939	2	2	0	0
145	14	2	-512.495	-134.9559512	2	2	0	0
179	14	1	-600.332	-158.0861786	2	2	0	0
181	14	1	-589.258	-155.1700482	2	2	0	0
222	14	1	-340.44	-89.64849222	1	1	0	0
223	14	2	-516.917	-136.120402	2	2	0	0
252	14	1	-509.41	-134.1435743	2	2	0	0
329	14	1	1000	263.3312543	1	0	0	1
357	14	1	1000	263.3312543	1	0	0	1
381	14	1	1000	263.3312543	1	0	0	1
435	14	1	1000	263.3312543	1	0	0	1
479	14	1	1000	263.3312543	1	0	0	1
515	14	1	1000	263.3312543	1	0	0	1
516	14	1	1000	263.3312543	1	0	0	1
517	14	1	1000	263.3312543	1	0	0	1
518	14	1	1000	263.3312543	1	0	0	1
520	14	1	1000	263.3312543	1	0	0	1

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
523	14	1	1000	263.3312543	1	0	0	1
526	14	1	1000	263.3312543	1	0	0	1
533	14	1	1000	263.3312543	1	0	0	1
537	14	1	1000	263.3312543	1	0	0	1
51	15	1	-766.79	-183.5634295	2	2	0	0
99	15	1	-808.337	-193.509451	3	3	0	0
118	15	1	-817.566	-195.7188002	3	3	0	0
146	15	2	-708.159	-169.5276343	2	2	0	0
178	15	1	-688.229	-164.7565507	2	2	0	0
374	15	1	1000	239.3920494	1	0	0	1
400	15	1	1000	239.3920494	1	0	0	1
402	15	1	1000	239.3920494	1	0	0	1
478	15	1	1000	239.3920494	1	0	0	1
480	15	1	1000	239.3920494	1	0	0	1
521	15	1	1000	239.3920494	1	0	0	1
524	15	1	1000	239.3920494	1	0	0	1
551	15	1	1000	239.3920494	1	0	0	1
73	16	1	-847.339	-184.4056543	3	3	0	0
350	16	1	1000	217.6291358	1	0	0	1
382	16	1	1000	217.6291358	1	0	0	1
396	16	1	1000	217.6291358	1	0	0	1
398	16	1	1000	217.6291358	1	0	0	1
417	16	1	1000	217.6291358	1	0	0	1
418	16	1	1000	217.6291358	1	0	0	1
444	16	1	1000	217.6291358	1	0	0	1
477	16	1	1000	217.6291358	1	0	0	1
522	16	1	1000	217.6291358	1	0	0	1
372	17	1	1000	197.8446689	1	0	0	1
445	17	1	1000	197.8446689	1	0	0	1
72	18	1	-857.695	-154.2639848	3	3	0	0
96	18	1	-878.177	-157.9478525	3	3	0	0
371	19	1	1000	163.5079908	1	0	0	1
395	19	1	1000	163.5079908	1	0	0	1
7	24	5	-1852.82	-188.1086585	5	5	0	0
16	29	8	-3000	-189.1182259	1	0	1	0
98	37	2	-405.62	-11.92861467	2	2	0	0
102	37	2	-667.723	-19.63663127	2	2	0	0
193	37	1	-490.225	-14.41670807	2	2	0	0
226	37	1	-241.875	-7.113144504	1	1	0	0
231	37	1	-640.458	-18.83481262	2	2	0	0
244	37	1	-733.952	-21.58431684	2	2	0	0
249	37	1	-300.589	-8.839826329	1	1	0	0
250	37	1	-647.828	-19.05155216	2	2	0	0
251	37	1	-404.997	-11.91029327	2	2	0	0
253	37	2	-678.991	-19.96800455	2	2	0	0
264	37	1	-273.614	-8.046536105	1	1	0	0
266	37	1	-408.439	-12.01151681	2	2	0	0
279	37	1	-852.989	-25.08499852	3	3	0	0
287	37	1	-268.042	-7.882672782	1	1	0	0
294	37	1	-709.776	-20.87334058	2	2	0	0
313	37	1	-419.223	-12.32865645	2	2	0	0
314	37	1	-362.996	-10.67511319	1	1	0	0
100	38	2	-773.772	-20.68668846	2	2	0	0
235	38	2	-795.588	-21.26993624	2	2	0	0
492	38	1	1000	26.73486306	1	0	0	1
525	38	1	1000	26.73486306	1	0	0	1
530	38	1	1000	26.73486306	1	0	0	1
543	38	1	1000	26.73486306	1	0	0	1
548	38	1	1000	26.73486306	1	0	0	1
549	38	1	1000	26.73486306	1	0	0	1
550	38	1	1000	26.73486306	1	0	0	1

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
563	38	1	1000	26.73486306	1	0	0	1
565	38	1	1000	26.73486306	1	0	0	1
578	38	1	1000	26.73486306	1	0	0	1
586	38	1	1000	26.73486306	1	0	0	1
593	38	1	1000	26.73486306	1	0	0	1
612	38	1	1000	26.73486306	1	0	0	1
613	38	1	1000	26.73486306	1	0	0	1
397	39	1	1000	24.30442097	1	0	0	1
401	39	1	1000	24.30442097	1	0	0	1
552	39	1	1000	24.30442097	1	0	0	1
5	40	5	-1722.11	-38.04989672	5	5	0	0
399	40	1	1000	22.09492815	1	0	0	1
534	40	1	1000	22.09492815	1	0	0	1
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
recurring	41		1000	20.08629832				
2	43	3	-1095.78	-18.19021816	3	3	0	0
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	43		1000	16.60024655				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
recurring	44		1000	15.09113322				
14	45	8	-3000	-41.15763606	1	0	1	0
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
recurring	45		1000	13.71921202				
11	46	6	-2059.25	-25.6829885	6	6	0	0
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	46		1000	12.47201093				
recurring	47		1000	11.33819175				
recurring	47		1000	11.33819175				
recurring	49		1000	9.370406407				
recurring	49		1000	9.370406407				
147	50	3	-819.889	-6.98426649	3	3	0	0
20	52	8	-3000	-21.12037507	1	0	1	0
175	52	1	-911.101	-6.41426495	3	3	0	0
184	52	1	-962.353	-6.775085438	3	3	0	0
185	53	1	-652.364	-4.175203747	2	2	0	0
230	53	1	-677.742	-4.337625831	2	2	0	0
237	53	1	-115.588	-0.739776338	1	1	0	0
241	53	1	-721.446	-4.617336398	2	2	0	0
243	53	1	-284.45	-1.82051233	1	1	0	0
245	53	1	-573.998	-3.67365244	2	2	0	0
246	53	1	-539.935	-3.455645368	2	2	0	0
248	53	1	-666.721	-4.267090179	2	2	0	0
265	53	1	-276.076	-1.766917778	1	1	0	0
269	53	1	-508.179	-3.252403359	2	2	0	0
273	53	1	-581.915	-3.72432214	2	2	0	0
274	53	1	-671.468	-4.297471518	2	2	0	0
446	53	1	1000	6.400113659	1	0	0	1
474	53	1	1000	6.400113659	1	0	0	1
483	53	1	1000	6.400113659	1	0	0	1
484	54	1	1000	5.818285144	1	0	0	1
529	54	1	1000	5.818285144	1	0	0	1
536	54	1	1000	5.818285144	1	0	0	1
540	54	1	1000	5.818285144	1	0	0	1
542	54	1	1000	5.818285144	1	0	0	1
544	54	1	1000	5.818285144	1	0	0	1
545	54	1	1000	5.818285144	1	0	0	1
547	54	1	1000	5.818285144	1	0	0	1
564	54	1	1000	5.818285144	1	0	0	1
568	54	1	1000	5.818285144	1	0	0	1
572	54	1	1000	5.818285144	1	0	0	1
573	54	1	1000	5.818285144	1	0	0	1
305	55	1	-881.073	-4.660303588	3	3	0	0

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
604	56	1	1000	4.808500119	1	0	0	1
54	57	1	-914.433	-3.997319263	3	3	0	0
353	58	1	1000	3.973967041	1	0	0	1
144	59	1	-1443.57	-5.215181455	4	4	0	0
24	60	1	-673.747	-2.212767249	2	2	0	0
38	60	1	-713.726	-2.344069091	2	2	0	0
65	60	1	-287.575	-0.944474026	1	1	0	0
69	60	1	-769.922	-2.528631944	2	2	0	0
79	60	1	-334.988	-1.100191133	1	1	0	0
81	60	1	-126.324	-0.414882159	1	1	0	0
127	60	1	-583.013	-1.91477227	2	2	0	0
129	60	1	-607.162	-1.994084113	2	2	0	0
132	60	1	-360.627	-1.184396539	1	1	0	0
133	60	1	-622.598	-2.044780109	2	2	0	0
286	60	1	-407.914	-1.339699828	2	2	0	0
288	60	1	-269.091	-0.883767574	1	1	0	0
290	60	1	-724.472	-2.379361859	2	2	0	0
291	60	1	-545.074	-1.790170339	2	2	0	0
292	60	1	-384.133	-1.261596596	1	1	0	0
297	60	1	-697.572	-2.291014989	2	2	0	0
443	60	1	1000	3.284270281	1	0	0	1
151	61	1	-654.646	-1.95457673	2	2	0	0
212	61	1	-718.301	-2.14463148	2	2	0	0
261	61	1	-765.999	-2.28704341	2	2	0	0
267	61	1	-721.561	-2.154364862	2	2	0	0
323	61	1	1000	2.985700256	1	0	0	1
337	61	1	1000	2.985700256	1	0	0	1
364	61	1	1000	2.985700256	1	0	0	1
368	61	1	1000	2.985700256	1	0	0	1
378	61	1	1000	2.985700256	1	0	0	1
380	61	1	1000	2.985700256	1	0	0	1
426	61	1	1000	2.985700256	1	0	0	1
428	61	1	1000	2.985700256	1	0	0	1
431	61	1	1000	2.985700256	1	0	0	1
432	61	1	1000	2.985700256	1	0	0	1
585	61	1	1000	2.985700256	1	0	0	1
587	61	1	1000	2.985700256	1	0	0	1
589	61	1	1000	2.985700256	1	0	0	1
590	61	1	1000	2.985700256	1	0	0	1
591	61	1	1000	2.985700256	1	0	0	1
596	61	1	1000	2.985700256	1	0	0	1
105	62	1	-710.409	-1.928243939	2	2	0	0
186	62	1	-740.015	-2.008602704	2	2	0	0
263	62	1	-885.989	-2.404815985	3	3	0	0
271	62	1	-871.141	-2.364514461	3	3	0	0
450	62	1	1000	2.71427296	1	0	0	1
511	62	1	1000	2.71427296	1	0	0	1
560	62	1	1000	2.71427296	1	0	0	1
566	62	1	1000	2.71427296	1	0	0	1
116	63	1	-781.775	-1.92904613	2	2	0	0
131	63	1	-863.491	-2.130682066	3	3	0	0
404	63	1	1000	2.467520873	1	0	0	1
485	63	1	1000	2.467520873	1	0	0	1
562	63	1	1000	2.467520873	1	0	0	1
570	63	1	1000	2.467520873	1	0	0	1
128	64	1	-761.933	-1.70916871	2	2	0	0
415	64	1	1000	2.243200793	1	0	0	1
430	64	1	1000	2.243200793	1	0	0	1
283	65	1	-854.331	-1.742214524	3	3	0	0
427	65	1	1000	2.039273448	1	0	0	1
126	66	1	-850.151	-1.576082147	3	3	0	0

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
582	66	1	1000	1.853884953	1	0	0	1
204	67	1	-816.794	-1.376583733	3	3	0	0
425	67	1	1000	1.685349957	1	0	0	1
278	68	1	-876.331	-1.342658558	3	3	0	0
503	68	1	1000	1.532136325	1	0	0	1
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
recurring	68		1000	1.532136325				
233	69	1	-884.661	-1.232201139	3	3	0	0
577	69	1	1000	1.392851204	1	0	0	1
recurring	69		1000	1.392851204				
recurring	69		1000	1.392851204				
recurring	69		1000	1.392851204				
107	70	1	-889.751	-1.126627956	3	3	0	0
532	70	1	1000	1.266228368	1	0	0	1
recurring	70		1000	1.266228368				
recurring	70		1000	1.266228368				
275	71	1	-935.791	-1.077204646	3	3	0	0
406	71	1	1000	1.151116698	1	0	0	1
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
recurring	71		1000	1.151116698				
190	72	1	-871.748	-0.91225789	3	3	0	0
247	72	1	-857.379	-0.897221167	3	3	0	0
574	72	1	1000	1.046469725	1	0	0	1
277	73	1	-965.727	-0.918730971	3	3	0	0
489	73	1	1000	0.951336114	1	0	0	1
546	73	1	1000	0.951336114	1	0	0	1
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
recurring	73		1000	0.951336114				
576	74	1	1000	0.864851013	1	0	0	1
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
recurring	74		1000	0.864851013				
104	75	3	-805.225	-0.633090597	3	3	0	0
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
recurring	75		1000	0.786228193				
6	76	5	-1778.88	-1.271459644	5	5	0	0
76	76	1	-930.298	-0.664933196	3	3	0	0
141	76	3	-937.859	-0.670337443	3	3	0	0
173	76	1	-991.852	-0.708929096	3	3	0	0
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
recurring	76		1000	0.714752903				
375	77	1	1000	0.649775366	1	0	0	1
472	77	1	1000	0.649775366	1	0	0	1
recurring	77		1000	0.649775366				
recurring	77		1000	0.649775366				
22	78	1	-753.22	-0.444930729	2	2	0	0
95	78	1	-1029.54	-0.608154301	3	3	0	0
174	78	1	-952.972	-0.56292521	3	3	0	0
196	78	1	-1071.75	-0.633087954	3	3	0	0
403	78	1	1000	0.590704879	1	0	0	1
111	79	1	-948.061	-0.509112962	3	3	0	0

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
321	79	1	-785.745	-0.42194855	2	2	0	0
394	79	1	1000	0.537004435	1	0	0	1
440	79	1	1000	0.537004435	1	0	0	1
473	79	1	1000	0.537004435	1	0	0	1
495	79	1	1000	0.537004435	1	0	0	1
recurring	79		1000	0.537004435				
recurring	79		1000	0.537004435				
9	80	7	-2774.82	-1.35462786	7	7	0	0
298	80	1	-936.435	-0.457154316	3	3	0	0
410	80	1	1000	0.48818585	1	0	0	1
620	80	1	1000	0.48818585	1	0	0	1
15	81	8	-3000	-1.331415955	1	0	1	0
74	81	1	-1037.78	-0.460572283	3	3	0	0
80	81	1	-1129.95	-0.501477819	3	3	0	0
148	81	1	-1141.35	-0.5065372	3	3	0	0
597	81	1	1000	0.443805318	1	0	0	1
36	82	1	-1104.89	-0.445778235	3	3	0	0
200	82	1	-1054.41	-0.425411605	3	3	0	0
206	82	1	-1034.96	-0.41756432	3	3	0	0
373	82	1	1000	0.40345938	1	0	0	1
379	82	1	1000	0.40345938	1	0	0	1
447	82	1	1000	0.40345938	1	0	0	1
106	83	1	-1024.88	-0.375906772	3	3	0	0
296	83	1	-1092.12	-0.400569144	3	3	0	0
335	83	1	1000	0.366781255	1	0	0	1
499	83	1	1000	0.366781255	1	0	0	1
505	83	1	1000	0.366781255	1	0	0	1
recurring	83		1000	0.366781255				
recurring	83		1000	0.366781255				
recurring	83		1000	0.366781255				
39	84	1	-1368.33	-0.45625254	4	4	0	0
78	84	1	-1247.34	-0.415909937	4	4	0	0
166	84	1	-1003.05	-0.334454489	3	3	0	0
281	84	1	-1066	-0.35544438	3	3	0	0
405	84	1	1000	0.333437504	1	0	0	1
595	84	1	1000	0.333437504	1	0	0	1
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
recurring	84		1000	0.333437504				
66	85	1	-1174.64	-0.356062755	3	3	0	0
228	85	3	-941.051	-0.285256088	3	3	0	0
307	85	1	-1253.46	-0.379955067	4	4	0	0
338	85	1	1000	0.303125004	1	0	0	1
377	85	1	1000	0.303125004	1	0	0	1
465	85	1	1000	0.303125004	1	0	0	1
580	85	1	1000	0.303125004	1	0	0	1
23	86	1	-1354.09	-0.373144124	4	4	0	0
34	86	1	-1293.65	-0.356488783	4	4	0	0
93	86	1	-1190.3	-0.328008811	3	3	0	0
284	86	1	-1909.04	-0.526070689	5	5	0	0
365	86	1	1000	0.275568185	1	0	0	1
606	86	1	1000	0.275568185	1	0	0	1

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	86		1000	0.275568185				
18	87	8	-3000	-0.751549596	1	0	1	0
77	87	1	-1603.59	-0.401725806	5	5	0	0
94	87	1	-1274.5	-0.31928332	4	4	0	0
140	87	1	-1691.54	-0.423758735	5	5	0	0
172	87	1	-1139.28	-0.285408475	3	3	0	0
270	87	1	-1067.39	-0.267398841	3	3	0	0
311	87	1	-1157.62	-0.290002948	3	3	0	0
322	87	1	1000	0.250516532	1	0	0	1
333	87	1	1000	0.250516532	1	0	0	1
392	87	1	1000	0.250516532	1	0	0	1
583	87	1	1000	0.250516532	1	0	0	1
130	88	1	-1102.05	-0.250983404	3	3	0	0
198	88	1	-1292.09	-0.294263551	4	4	0	0
255	88	1	-1073.05	-0.244378877	3	3	0	0
285	88	1	-1627.54	-0.370659706	5	5	0	0
312	88	1	-1690.82	-0.385071239	5	5	0	0
320	88	1	-1305.98	-0.297426892	4	4	0	0
376	88	1	1000	0.227742302	1	0	0	1
393	88	1	1000	0.227742302	1	0	0	1
439	88	1	1000	0.227742302	1	0	0	1
471	88	1	1000	0.227742302	1	0	0	1
527	88	1	1000	0.227742302	1	0	0	1
569	88	1	1000	0.227742302	1	0	0	1
610	88	1	1000	0.227742302	1	0	0	1
recurring	88		1000	0.227742302				
35	89	1	-519.376	-0.107530805	2	2	0	0
85	89	1	-280.218	-0.058015902	1	1	0	0
87	89	1	-183.274	-0.037944766	1	1	0	0
88	89	1	-389.787	-0.080700899	1	1	0	0
89	89	1	-247.006	-0.051139741	1	1	0	0
170	89	1	-654.698	-0.135547663	2	2	0	0
187	89	1	-1965.2	-0.406871974	5	5	0	0
191	89	1	-875.108	-0.181181009	3	3	0	0
192	89	1	-425.205	-0.088033787	2	2	0	0
207	89	1	-913.111	-0.189049092	3	3	0	0
299	89	1	-818.38	-0.169436132	3	3	0	0
429	89	1	1000	0.207038456	1	0	0	1
497	89	1	1000	0.207038456	1	0	0	1
554	89	1	1000	0.207038456	1	0	0	1
584	89	1	1000	0.207038456	1	0	0	1
611	89	1	1000	0.207038456	1	0	0	1
619	89	1	1000	0.207038456	1	0	0	1
68	90	1	-604.88	-0.113848565	2	2	0	0
84	90	2	-578.326	-0.108850657	2	2	0	0
86	90	1	-342.72	-0.064505654	1	1	0	0
202	90	1	-790.389	-0.148764471	2	2	0	0
205	90	1	-1517.08	-0.28553991	4	4	0	0
208	90	1	-896.609	-0.168756858	3	3	0	0
209	90	1	-542.632	-0.102132447	2	2	0	0
289	90	1	-1596.57	-0.300501262	4	4	0	0
300	90	1	-464.742	-0.087472242	2	2	0	0
302	90	1	-440.644	-0.082936594	2	2	0	0
303	90	1	-426.39	-0.080253752	2	2	0	0
334	90	1	1000	0.188216778	1	0	0	1
384	90	1	1000	0.188216778	1	0	0	1
386	90	1	1000	0.188216778	1	0	0	1
387	90	1	1000	0.188216778	1	0	0	1
388	90	1	1000	0.188216778	1	0	0	1
469	90	1	1000	0.188216778	1	0	0	1
486	90	1	1000	0.188216778	1	0	0	1

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
490	90	1	1000	0.188216778	1	0	0	1
491	90	1	1000	0.188216778	1	0	0	1
506	90	1	1000	0.188216778	1	0	0	1
598	90	1	1000	0.188216778	1	0	0	1
recurring	90		1000	0.188216778				
32	91	1	-627.844	-0.107427977	2	2	0	0
168	91	1	-445.478	-0.076224031	2	2	0	0
169	91	1	-623.83	-0.106741157	2	2	0	0
211	91	1	-622.725	-0.106552085	2	2	0	0
213	91	1	-1331.26	-0.22778679	4	4	0	0
295	91	1	-546.566	-0.093520811	2	2	0	0
367	91	1	1000	0.171106162	1	0	0	1
385	91	1	1000	0.171106162	1	0	0	1
501	91	1	1000	0.171106162	1	0	0	1
504	91	1	1000	0.171106162	1	0	0	1
507	91	1	1000	0.171106162	1	0	0	1
508	91	1	1000	0.171106162	1	0	0	1
588	91	1	1000	0.171106162	1	0	0	1
599	91	1	1000	0.171106162	1	0	0	1
601	91	1	1000	0.171106162	1	0	0	1
602	91	1	1000	0.171106162	1	0	0	1
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
recurring	91		1000	0.171106162				
67	92	1	-955.981	-0.148703855	3	3	0	0
117	92	1	-1035.92	-0.161138451	3	3	0	0
203	92	1	-946.562	-0.147238719	3	3	0	0
331	92	1	1000	0.155551057	1	0	0	1
383	92	1	1000	0.155551057	1	0	0	1
467	92	1	1000	0.155551057	1	0	0	1
468	92	1	1000	0.155551057	1	0	0	1
510	92	1	1000	0.155551057	1	0	0	1
512	92	1	1000	0.155551057	1	0	0	1
594	92	1	1000	0.155551057	1	0	0	1
recurring	92		1000	0.155551057				
recurring	92		1000	0.155551057				
recurring	92		1000	0.155551057				
recurring	92		1000	0.155551057				
33	93	1	-1100.16	-0.155573682	3	3	0	0
56	93	1	-1027.64	-0.145318625	3	3	0	0
171	93	1	-972.272	-0.137489034	3	3	0	0
189	93	1	-1091.84	-0.154397151	3	3	0	0
304	93	1	-842.233	-0.119100212	3	3	0	0
366	93	1	1000	0.141410051	1	0	0	1
416	93	1	1000	0.141410051	1	0	0	1
502	93	1	1000	0.141410051	1	0	0	1
recurring	93		1000	0.141410051				
recurring	93		1000	0.141410051				

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	93		1000	0.141410051				
recurring	93		1000	0.141410051				
167	94	1	-1450.25	-0.186436297	4	4	0	0
210	94	1	-994.248	-0.127815146	3	3	0	0
332	94	1	1000	0.128554592	1	0	0	1
355	94	1	1000	0.128554592	1	0	0	1
470	94	1	1000	0.128554592	1	0	0	1
488	94	1	1000	0.128554592	1	0	0	1
603	94	1	1000	0.128554592	1	0	0	1
recurring	94		1000	0.128554592				
recurring	94		1000	0.128554592				
27	95	1	-304.089	-0.035538216	1	1	0	0
42	95	1	-222.618	-0.026016878	1	1	0	0
45	95	1	-443.558	-0.051837653	2	2	0	0
47	95	1	-354.608	-0.041442261	1	1	0	0
120	95	1	-336.471	-0.039322629	1	1	0	0
315	95	1	-197.119	-0.023036866	1	1	0	0
318	95	1	-974.359	-0.113871204	3	3	0	0
466	95	1	1000	0.116867811	1	0	0	1
509	95	1	1000	0.116867811	1	0	0	1
recurring	95		1000	0.116867811				
26	96	1	-390.346	-0.041471711	1	1	0	0
121	96	1	-720.632	-0.07656244	2	2	0	0
125	96	1	-680.802	-0.072330763	2	2	0	0
326	96	1	1000	0.106243465	1	0	0	1
341	96	1	1000	0.106243465	1	0	0	1
344	96	1	1000	0.106243465	1	0	0	1
346	96	1	1000	0.106243465	1	0	0	1
419	96	1	1000	0.106243465	1	0	0	1
614	96	1	1000	0.106243465	1	0	0	1
617	96	1	1000	0.106243465	1	0	0	1
recurring	96		1000	0.106243465				
40	97	1	-1258.88	-0.121588884	4	4	0	0
150	97	1	-344.234	-0.03324783	1	1	0	0
155	97	1	-791.478	-0.076444877	2	2	0	0
159	97	1	-837.398	-0.080880059	3	3	0	0
325	97	1	1000	0.096584968	1	0	0	1
420	97	1	1000	0.096584968	1	0	0	1
424	97	1	1000	0.096584968	1	0	0	1
recurring	97		1000	0.096584968				
4	98	6	-2042.96	-0.179381114	6	6	0	0
123	98	1	-513.555	-0.045092448	2	2	0	0
143	98	4	-1304.33	-0.114526065	4	4	0	0
182	98	1	-619.32	-0.054379093	2	2	0	0
301	98	1	-933.214	-0.081940404	3	3	0	0
339	98	1	1000	0.087804516	1	0	0	1
449	98	1	1000	0.087804516	1	0	0	1
454	98	1	1000	0.087804516	1	0	0	1
458	98	1	1000	0.087804516	1	0	0	1
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
recurring	98		1000	0.087804516				
8	99	6	-2298.04	-0.18343481	6	6	0	0
158	99	1	-884.151	-0.070574955	3	3	0	0
201	99	1	-1355.65	-0.108211084	4	4	0	0
422	99	1	1000	0.079822287	1	0	0	1
481	99	1	1000	0.079822287	1	0	0	1
600	99	1	1000	0.079822287	1	0	0	1
recurring	99		1000	0.079822287				
recurring	99		1000	0.079822287				
recurring	99		1000	0.079822287				
recurring	99		1000	0.079822287				
52	100	1	-1035.24	-0.075122932	3	3	0	0
293	100	1	-1576.91	-0.114429603	4	4	0	0
457	100	1	1000	0.072565716	1	0	0	1
500	100	1	1000	0.072565716	1	0	0	1
recurring	100		1000	0.072565716				
recurring	100		1000	0.072565716				
recurring	100		1000	0.072565716				
183	101	1	-1218.58	-0.0803883	4	4	0	0
351	101	1	1000	0.065968833	1	0	0	1
592	101	1	1000	0.065968833	1	0	0	1
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
recurring	101		1000	0.065968833				
44	102	1	-782.232	-0.046911756	2	2	0	0
46	102	1	-427.593	-0.025643465	2	2	0	0
48	102	1	-648.809	-0.038910157	2	2	0	0
49	102	1	-544.622	-0.032661889	2	2	0	0
122	102	1	-616.336	-0.036962697	2	2	0	0
197	102	1	-471.168	-0.02825673	2	2	0	0
316	102	1	-778.635	-0.046696038	2	2	0	0
442	102	1	1000	0.059971666	1	0	0	1
482	102	1	1000	0.059971666	1	0	0	1
recurring	102		1000	0.059971666				
25	103	1	-1208.53	-0.065888689	4	4	0	0
53	103	1	-1018.21	-0.0555125	3	3	0	0
194	103	1	-1545.91	-0.084282544	4	4	0	0
195	103	1	-969.154	-0.052837982	3	3	0	0
257	103	1	-1116.74	-0.060884326	3	3	0	0
343	103	1	1000	0.054519696	1	0	0	1
345	103	1	1000	0.054519696	1	0	0	1
347	103	1	1000	0.054519696	1	0	0	1

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
348	103	1	1000	0.054519696	1	0	0	1
421	103	1	1000	0.054519696	1	0	0	1
496	103	1	1000	0.054519696	1	0	0	1
615	103	1	1000	0.054519696	1	0	0	1
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
recurring	103		1000	0.054519696				
13	104	8	-3000	-0.148690081	1	0	1	0
43	104	1	-334.488	-0.016578349	1	1	0	0
50	104	1	-950.54	-0.047111957	3	3	0	0
138	104	1	-1185.54	-0.058759346	3	3	0	0
139	104	1	-1436.02	-0.071173977	4	4	0	0
156	104	1	-969.517	-0.04805252	3	3	0	0
160	104	1	-966.2	-0.047888119	3	3	0	0
162	104	1	-1139.3	-0.056467536	3	3	0	0
324	104	1	1000	0.04956336	1	0	0	1
352	104	1	1000	0.04956336	1	0	0	1
493	104	1	1000	0.04956336	1	0	0	1
494	104	1	1000	0.04956336	1	0	0	1
556	104	1	1000	0.04956336	1	0	0	1
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
recurring	104		1000	0.04956336				
17	105	8	-3000	-0.135172801	1	0	1	0
41	105	1	-614.648	-0.027694564	2	2	0	0
55	105	1	-1232.44	-0.055530789	4	4	0	0
71	105	1	-918.319	-0.04137725	3	3	0	0
124	105	1	-577.139	-0.026004498	2	2	0	0
137	105	2	-406.797	-0.018329297	2	2	0	0
157	105	1	-612.019	-0.027576107	2	2	0	0

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
161	105	1	-1248.15	-0.056238644	4	4	0	0
317	105	1	-621.003	-0.027980905	2	2	0	0
342	105	1	1000	0.0450576	1	0	0	1
349	105	1	1000	0.0450576	1	0	0	1
437	105	1	1000	0.0450576	1	0	0	1
438	105	1	1000	0.0450576	1	0	0	1
455	105	1	1000	0.0450576	1	0	0	1
459	105	1	1000	0.0450576	1	0	0	1
461	105	1	1000	0.0450576	1	0	0	1
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
recurring	105		1000	0.0450576				
340	106	1	1000	0.040961455	1	0	0	1
354	106	1	1000	0.040961455	1	0	0	1
370	106	1	1000	0.040961455	1	0	0	1
423	106	1	1000	0.040961455	1	0	0	1
456	106	1	1000	0.040961455	1	0	0	1
460	106	1	1000	0.040961455	1	0	0	1
616	106	1	1000	0.040961455	1	0	0	1
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
recurring	106		1000	0.040961455				
70	107	1	-1634.33	-0.060858668	5	5	0	0
436	107	1	1000	0.037237686	1	0	0	1
recurring	107		1000	0.037237686				
recurring	107		1000	0.037237686				
recurring	107		1000	0.037237686				
recurring	107		1000	0.037237686				
369	108	1	1000	0.033852442	1	0	0	1
recurring	108		1000	0.033852442				
recurring	109		1000	0.030774947				
recurring	109		1000	0.030774947				
recurring	109		1000	0.030774947				
recurring	109		1000	0.030774947				
recurring	109		1000	0.030774947				
recurring	109		1000	0.030774947				
recurring	110		1000	0.027977225				
recurring	110		1000	0.027977225				
319	111	1	-1153.48	-0.029337427	3	3	0	0
recurring	111		1000	0.025433841				
142	112	3	-1156.51	-0.026740446	3	3	0	0
154	112	1	-1526.42	-0.035293385	4	4	0	0
236	112	1	-144.772	-0.003347371	1	1	0	0
239	112	3	-944.905	-0.021847785	3	3	0	0
240	112	1	-645.47	-0.014924347	2	2	0	0
259	112	1	-1093.75	-0.02528933	3	3	0	0
618	112	1	1000	0.023121673	1	0	0	1
recurring	112		1000	0.023121673				
recurring	112		1000	0.023121673				
recurring	112		1000	0.023121673				

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
242	113	1	-561.221	-0.011796699	2	2	0	0
254	113	1	-824.291	-0.017326352	3	3	0	0
256	113	1	-1251.09	-0.02629754	4	4	0	0
258	113	1	-1272.67	-0.026751146	4	4	0	0
268	113	1	-2014.17	-0.042337255	6	6	0	0
280	113	1	-984.52	-0.020694318	3	3	0	0
308	113	1	-1464.84	-0.030790502	4	4	0	0
309	113	1	-1140.22	-0.023967086	3	3	0	0
310	113	1	-1169.91	-0.024591161	3	3	0	0
535	113	1	1000	0.021019703	1	0	0	1
539	113	1	1000	0.021019703	1	0	0	1
recurring	113		1000	0.021019703				
recurring	113		1000	0.021019703				
recurring	113		1000	0.021019703				
recurring	113		1000	0.021019703				
recurring	113		1000	0.021019703				
recurring	113		1000	0.021019703				
272	114	1	-637.2	-0.012176141	2	2	0	0
276	114	1	-1188.73	-0.022715229	3	3	0	0
282	114	1	-1231.4	-0.023530602	4	4	0	0
306	114	1	-1307.22	-0.024979433	4	4	0	0
453	114	1	1000	0.019108821	1	0	0	1
555	114	1	1000	0.019108821	1	0	0	1
558	114	1	1000	0.019108821	1	0	0	1
567	114	1	1000	0.019108821	1	0	0	1
607	114	1	1000	0.019108821	1	0	0	1
608	114	1	1000	0.019108821	1	0	0	1
609	114	1	1000	0.019108821	1	0	0	1
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
recurring	114		1000	0.019108821				
153	115	1	-1754.7	-0.030482044	5	5	0	0
441	115	1	1000	0.017371655	1	0	0	1
538	115	1	1000	0.017371655	1	0	0	1
541	115	1	1000	0.017371655	1	0	0	1
553	115	1	1000	0.017371655	1	0	0	1
557	115	1	1000	0.017371655	1	0	0	1
571	115	1	1000	0.017371655	1	0	0	1
575	115	1	1000	0.017371655	1	0	0	1
579	115	1	1000	0.017371655	1	0	0	1
581	115	1	1000	0.017371655	1	0	0	1
605	115	1	1000	0.017371655	1	0	0	1
recurring	115		1000	0.017371655				
recurring	115		1000	0.017371655				
recurring	115		1000	0.017371655				
recurring	115		1000	0.017371655				
452	116	1	1000	0.015792414	1	0	0	1
recurring	116		1000	0.015792414				
recurring	116		1000	0.015792414				
recurring	116		1000	0.015792414				

Table C.1 continued from previous page

activity id	start	duration	cash flow	npv	r1	r2	r3	r4
621	117	1	1000	0.01435674	1	0	0	1
recurring	117		1000	0.01435674				
recurring	117		1000	0.01435674				
recurring	117		1000	0.01435674				
recurring	117		1000	0.01435674				