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Cash flow optimization for construction engineering portfolios

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CASH FLOW OPTIMIZATION FOR CONSTRUCTION ENGINEERING PORTFOLIOS

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Abstract

One of the main issues in construction projects is finance; proper cash-flow management is necessary to insure that a construction project finishes within time, on budget, and yielding a satisfying profit. Poor financial management might put the contractor, or the owner, in a situation where they are unable to finance the project due to insufficient liquidity, or where they are engaged in excessive loans to finance the project, decreasing the profit, and even creating unsettled debts. Engagement with a portfolio of large construction projects, like infrastructure projects, makes attention to finance more critical, due to large budgets and long project durations, which also requires attention to the time value of money when the project spans over many years and the work environment has a high inflation rate.

This thesis aims at the analysis and optimization of the cash-flow request for large engineering portfolios from the contractor's point of view. A computational model, with a friendly user interface, was created to achieve that. The user is able to create a portfolio of projects, and create activities in them with different relationship types, lags, constraints, and costs, as similar to commercial scheduling software. Parameters necessary for the renumeration are also considered, which include the down payment percentage, duration between invoices, duration for payment, retention percentage, etc. The model takes into consideration the time value of money, calculated with an interest rate assigned to the projects by the user; this could be the inflation rate or the (Minimum Attractive Rate of Return) MARR of the contractor. Optimization is done with the objective of maximizing the Net Present Value (NPV) for the projects as a whole, discounted at the start of the portfolio. The variables for the optimization are lags that are assigned for each activity, which, after rescheduling, delays the activities after their early start with the value of those lags, and thus creates a modified cash flow for the project. Optimization of those variables, within scheduling constraints results in a near-optimum NPV. Verification of the model was done using sets of portfolios, and the validation was done using an actual construction portfolio from real life. The results were satisfactory and matched initial expectations. The NPV was successfully optimized to a near optimum. A sensitivity analysis of the model was conducted and it showed that the model behaves as expected for different inputs. A time test was performed, taking into consideration the effect of the size and complexity of a portfolio on the calculation time for the model, and it showed

that the speed was satisfactory, though it should be improved. Overall, the conclusion is that the model delivers its goal of maximizing the Net Present Value of a large portfolio as a whole.

Contents

List of Figures

List of Tables

List of Abbreviations

ES Early Start

EF Early Finish

LS Late Start

LF Late Finish

OS Optimized Start

OF Optimized Finish

TF Total Float

FF Free Float

PV Present Value

FV Future Value

NPV Net Present Value

i Interest Rate

IRR Internal Rate of Return

MARR Minimum Attractive Rate of Return

Chapter 1

Introduction

This chapter will provide a background on the topic of cash flow analysis, then it will provide the problem statement, the scope of work, the methodology followed, and finally detailed outline of the thesis.

1.1 Background

Just as other businesses operating in any field, a contracting company has to make profit, which means that it has to have strategic goals that are reasonable in light of future risks and resource constraints. A construction project is an investment; the contractor is paying the expenses for the construction and receiving the revenues in form of invoices from the owner, which means that the contractor will typically be financing the project in some durations, as an overdraft. Revenues are received for monthly invoices issued by the contractor. The full revenue, including profit or loss, is finalized with the final payment from the owner at the end of the project, or , in case of disputes, after the dispute resolution.
Figure 1.1 shows the relationship between major stakeholders in a construction project in a traditional delivery method, where the owner enters into contractual agreement with the contractor, and the engineer (the consultant), separately. There is a non contractual relationship between the contractor and the engineer, because the engineer supervises and inspects the work, and also approves drawings, materials, and invoices.
During the project, the contractor pays the expenses of the construction work, which is the Cash-out from the point of view of the contractor, and, as shown in Figure 1.2, the contractor receives payments for the work done for each invoice, which is typically issued monthly. These payments are the Cash-in from the point of view of the contractor. The amount of payments is calculated as the direct cost multiplied by a mark-up. The calculation of the price can have many forms and calculation methods. The general idea, however, is that the price of a product should include the cost of the product, plus an amount for profit, plus overhead or indirect cost which is the cost of doing business, plus

an amount added for risk. This can be summed in what is shown in Figure 1.2, such as $Price = Direct_{C}ost + Profit + Contingency + Indirect_{C}ost_{a}nd_{O}verhead$.

Payments are received once the invoices issued by the contractor are approved by the

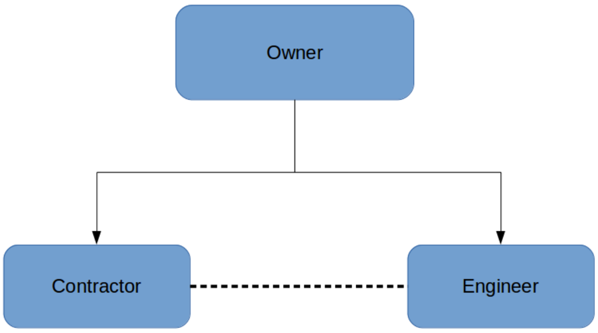


Figure 1.1: Relationship between the owner, contractor, and engineer in a traditional delivery method.

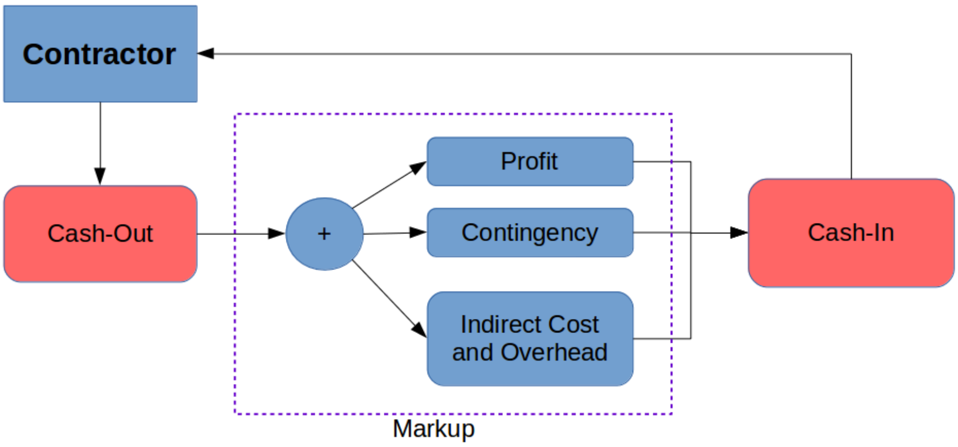


Figure 1.2: Cash-in Cash-out distribution.

engineer, according to the time bars shown in Figure 1.3 which shows the typical general case in a project. This process should be agreed and written in the contract between the employer and the contractor, as well as the time interval between invoices, allowed time for the engineer to approve, and the deadline for the engineer to pay. This whole process can be more generalized, as shown in Figure 1.4, where the downpayment and the retention (if applicable in a project) are included. Due to the nature of the cash flow in construction projects, there is a delay between the cash out for the contractor, where payments are made by the contractor for the work being done, and the actual receipt of payment as per the submitted invoice for that work, which is the cash in. This duration includes the time for approval of the invoice by the engineer, plus the duration until the owner sends actual payment. This raises problems concerning liquidity and profitability because the contractor's cash flow will most probably be in the red for some durations during the project. To answer this issue, analysis of the cash-in cash-out curves

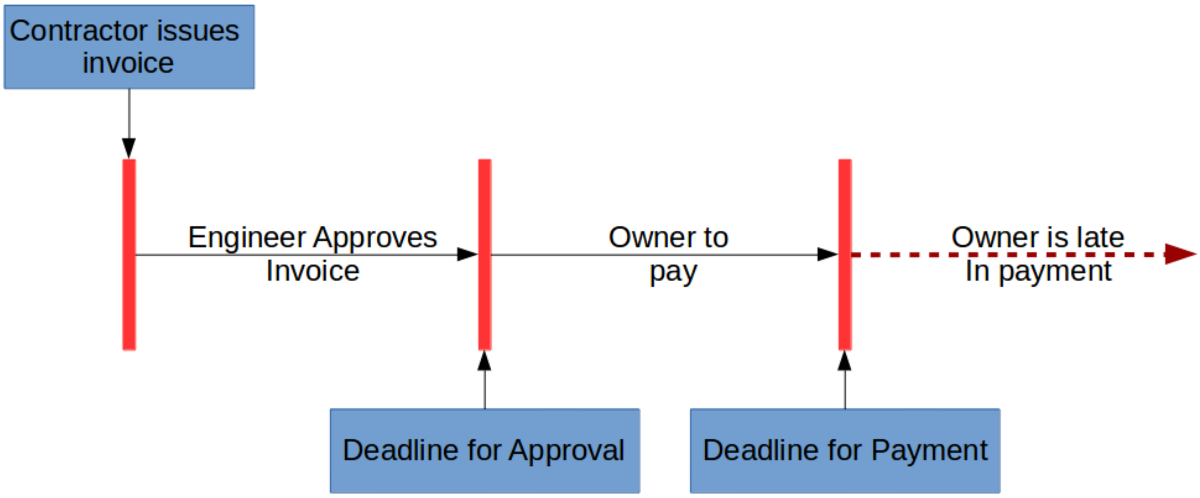


Figure 1.3: Typical payment method in construction projects.

is required. An example of these curves for a construction project Shown in Figure 1.5, is . The cash-out is typically an S-shaped curve, and it accounts for the cumulative direct costs up to a certain point in time. The direct costs mentioned include material, labor and equipment costs. Therefore, the cumulative cash-out curve at the end of the project equals the total cost of the project from the point of view of the contractor. The cash-in curve is a stepped curve where each rise or step in the curve means the contractor has received payment from the owner. The first step will occur at the start of the project if there is a down-payment. After that, each step means a payment of an invoice, then , at the end of the project the final payment including the retention if applicable. At the end of the project, the cumulative cash-in should equal the contract price. As shown in Figure 1.6, the total cost accounts for the direct and indirect costs. The former was explained earlier as the expenses for labor, material, and equipment. While the indirect cost is any expense indirectly related to a certain activity but relevant to the site, like generators or equipment or fuel, and also the overhead of the company, where it might include rent and expenses for an office or headquarters.

The previously mentioned mark-up percentage is a factor that accounts for the profit and risk, and may in some cases consider indirect costs. When choosing the mark-up, which is done during tendering, attention should be given to the companies **Minimum Attractive Rate of Return (MARR)**, project risks, inflation, currency, finance, ...etc.(Peterson, 2009)

Further analysis of the cash flow curves by calculating the difference between the cash-out and the cash-in yields the overdraft, which indicates the finance of the project. In other words, if the cumulative cash-out is higher than the cumulative cash-in at some point in time, it means that the contractor has financed more cash into the project than the cash received from invoices and down-payment. The opposite case, where the cumulative

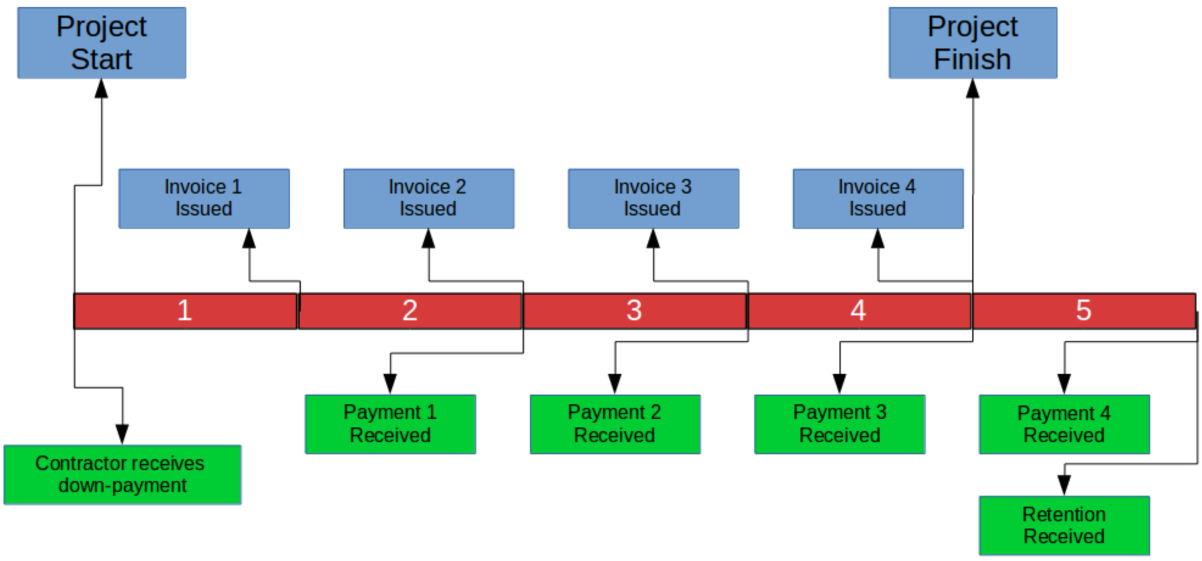


Figure 1.4: Example of a time-line showing cash flow in a construction project.

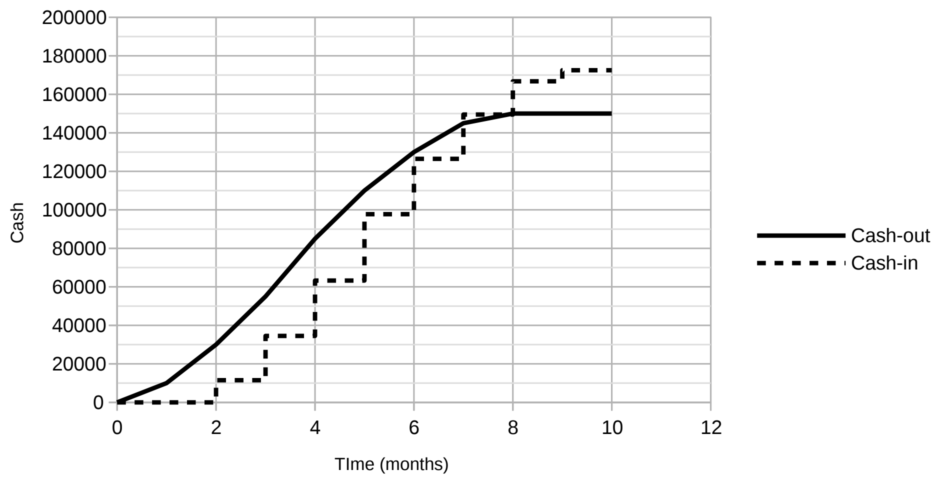


Figure 1.5: Typical Cumulative Cash-In Cash-Out Curves for a Construction Project.

cash-in of higher than the cumulative cash-out, means that the contractor has received more money that the cost incurred, which should be the case at the end of the project, provided that the project is profitable.

This sums up the cash flow analysis of a construction project. But, of course, a contracting company has more than one project in progress or under analysis for possible future bidding. This introduces the concept of **Project Portfolio Management (PPM)**. PPM is the centralized management of the enterprise's company for a group of projects, this ensures better resource and risk allocation between projects. As analysis at the project-level may not correctly reflect the risks at the enterprise-level, a multiple projects approach, however, would be more fit. When analysing the cash flow for a portfolio as a whole, there can be further detailed analysis of the company's profitability, liquidity, and expected risks, which ensures better decisions and strategy by the contractor. (Purnus

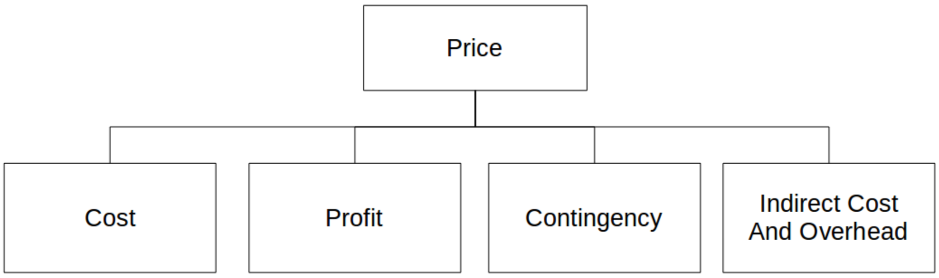


Figure 1.6: Flow Chart for Items included in The Price

and Constanta-Nicoleta, 2015) (Pinto, 2010).

1.2 Problem Statement

The Contractor needs to calculate and analyze the cash flow at the portfolio level. The analysis at a portfolio level is needed because it aims at the success of the company's profile as a whole, while analysis at the project level would aim at the success of each individual project separately, which may not result in the company's goals as a whole. This is especially important when resources are shared between projects and limited.Decisions based on a portfolio level assessment may, for example, result is a low profit for a project deliberately, or even a loss, in order to maximize the benefits from another project. Such analysis should provide information on the overdraft, liquidity needed, and profitability at the enterprise level to be able to balance the available resources and cash between multiple projects. This analysis needs to account for inflation and time value of money for proper prediction of the future cash flow needs. Therefore, there is a need for a computational model that can provide such analysis as well as optimize the cash flow request for a portfolio of construction projects.

1.3 Objective

This thesis aims at the analysis and optimization of the cash-flow request for large engineering portfolios from the contractor's point of view. A computational model, with a friendly user interface, was created to achieve that. The objective of the optimization is to maximize the Net Present Value of the cash flow from the point of view of a contractor.

1.4 Scope of Work

The scope of work of this thesis is as follows:

- Develop a computational model for the analysis and optimization of cash flow for construction engineering portfolios. The model needs to account for:
  - Interest Effect
  - The time value of money
  - Interaction with Oracle Primavera
- Develop a friendly graphical user interface for the model
- Verification the model using sets of randomly generated projects
- Validation the model using an actual real-life portfolio

1.5 Research Methodology

This thesis has the following research methodology:

Step 1: Model Development: The model was developed in Python, and it includes a friendly user interface.

Step 2: Verification: Verification was done to ensure that the model performs correctly

Step 3: Sensitivity Analysis: A sensitivity analysis was done to analyze the effect of different parameters on the final results. This was done to ensure that the model performs correctly as well.

Step 4: CPU Time Test: A test on the CPU time needed to solve portfolios of different sizes was done to measure the relation between the CPU time and the complexity of projects, and to ensure that the model performs within a satisfactory time.

Step 5: Validation: A validation was done using a very large and real construction portfolio. This was done to ensure that the model performs correctly within a real-life work-flow. Another validation was also done on an updated project to test the use of the model for controlling the cash flow of projects.

1.6 Detailed Outline

The synopsis of this work is as follows:

Chapter 1 Introduction This is the introduction, which is the current chapter, has introduced a background summary of the field targeted. A problem statement and a scope of work has been declared as well.

Chapter 2 Literature Review This chapter will cover a number of previous research works in the fields of portfolios, financial analysis, time-cost trade-off, and resource-based and financial-based scheduling.

Chapter 3 Model Development This chapter shows the development of the model.

Chapter 4 Results and Discussion This chapter shows the results and discussion of the results of the model. This includes the verification, validation, sensitivity analysis, and CPU time analysis.

Chapter 5 Conclusion and Recommendations This chapter concludes the thesis, discusses the main outcomes, and provides some recommendations for future research.

Chapter 2

Literature Review

The literature review will attempt to cover a range of previous research in the fields of project portfolio management, and cash-flow and resources analysis and optimization.

2.1 Project Portfolio management

There is a number of research in the field of construction portfolios including: (Platje, Seidel, and Wadman, 1994) where the concept of portfolio management was introduced and a practical framework was created; (Han et al., 2004) which focused on the financial risk management for international portfolios and highlighted its significance to the success of a contractor on a corporate level, which was also discussed by (Sanchez et al., 2009), where a research gap in that area, in comparison with project-level risk management, was highlighted; (Purnus and Constanta-Nicoleta, 2015) presented a complete case study for cash flow analysis for a portfolio. The studies range between general studies, financial analysis, risk analysis, project selection, and others. This section will attempt to cover a selection of them.

2.1.1 Project and Portfolio Planning Cycle: Project-based Management for the Multi-project Challenge

(Platje, Seidel, and Wadman, 1994) published a paper regarding the challenge of multi-project management. The research is somewhat inclined towards Research and Development projects, but the concepts are also applicable in the construction industry. The authors present an implementation of the traditional Plan-Do-Check-Action management cycle in the multiple-projects environment, and a case study on an research and development programme in a company, which has the cycle shown Figure 2.1. The cycle is based on three parties in the organization, which is shown in Figure 2.1. Those are:

Project Leaders - Project Managers who are responsible for realizing the project goals and resource allocation.

Department Heads - Resource Managers who are responsible for efficiency and effectiveness of resources use, as well as quality control.

Management - Programme Directors who are responsible for setting and realizing of overall programme goals

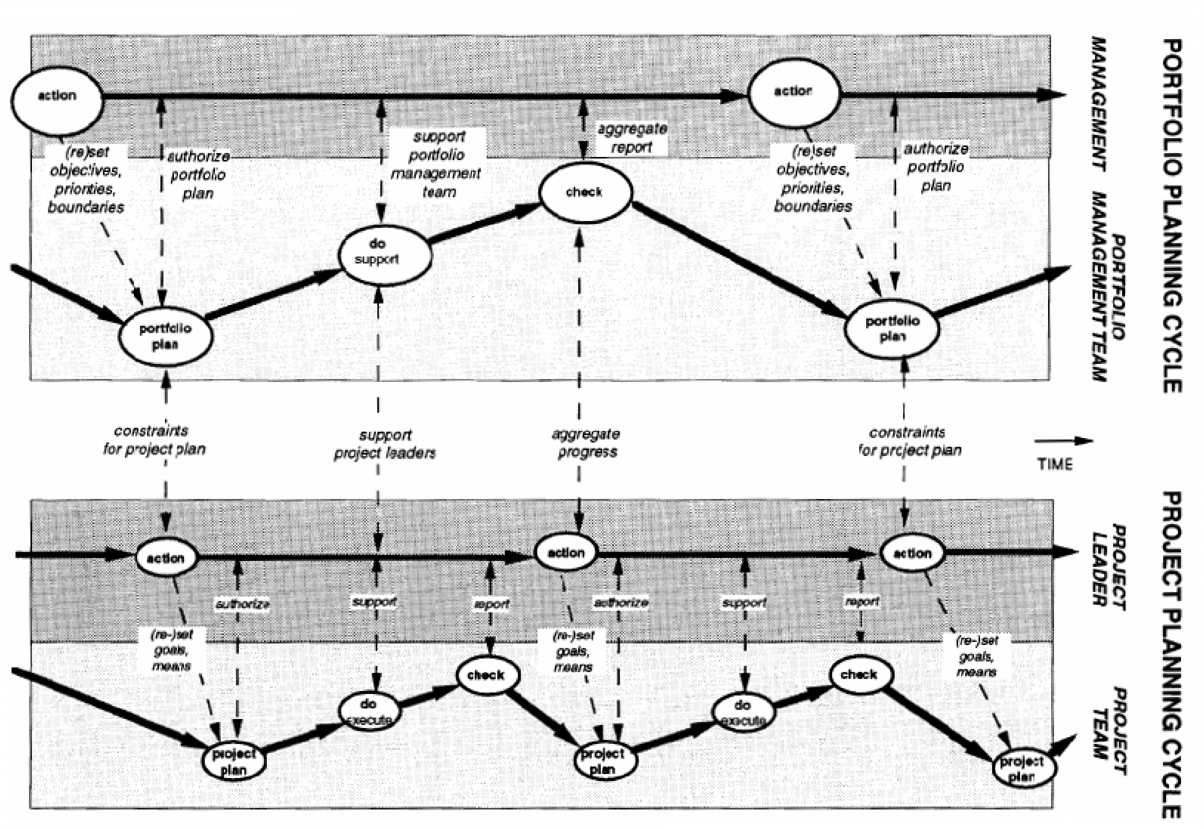


Figure 2.1: Multiple Project Planning Phase as shown by Platje et al For A Research and Development Programme(Platje, Seidel, and Wadman, 1994)

The Operation Breakdown Structure (OBS) and the Project Breakdown Structure (PBS) are therefore interlinked. The cycle is therefore as follows:

Action The management sets the priorities.

Plan The team develops a plan in an iterative process between managment, project leaders, and department heads, as well as the projects' sponsors - owners.

Do The team members execute the plan.

Check The team members report to the management for monitoring.

Action The management takes corrective actions and update as required.

This multi-project approach has the benefit of better resource allocation between projects, and aims towards organizational goals as a whole, instead of project constrained success. However, communication is more complicated. Communication and delegation should be properly and clearly planned.

2.1.2 Multi-criteria Financial Portfolio Risk Management for International Projects

In a paper by (Han et al., 2004), the authors studied the portfolio financial risk assessment for international projects. The goal was to introduce a framework of project-selection for multinational contractors, integrating the risks at the project level and the corporate levels. The authors note that a profit-oriented goal at the project-level does not reflect the overall risks at the corporate level, and goals of the company. The risks in a portfolio are distributed, reflecting the state of mind of *"not keeping all of your eggs in one basket"*. The return on the portfolio is a weighted average of the return on the individual projects. The authors use the Net Present Value (NPV) to reflect the portfolio's expected return, where the expected return is a three-point approximation of the worst, normal, and best expected NPV. The paper uses the Value at Risk (VaR), which is the worst expected loss of the portfolio within a given confidence interval, in an attempt to capture the risk. The paper introduces a decision model for portfolio selection for international contractors, incorporating three parts; financial risk analysis for cash flow analysis and estimating multi-criteria values such as NPV, Var, and efficiency (ROI), part2 to evaluate and integrate these values, and part 3 for the selection of the optimum portfolio. A case study was done on a list of 7 projects in 7 different countries, and a set of 5 possible projects resulted. In summary, the authors conclude that; the NPV, ROI, and VaR can reflect the benefits and risks of a portfolio; a higher profit ratio dooes not always guarantee a higher NPV; The NPV is essential and lowered the deviation and the VaR; A company can make a more inclusive decision based of the selection within a portfolio as a whole rather than selection of projects on individual basis. The authors note the limitation of this research is that it is applicable to large international contractors, application to medium to small contractors is recommended for future research. Another recommendation is to research into incorporating the risks at the project and the corporate level in a sequential manner, and the take into consideration current risks to incorporate a contingency against total risk exposure.

2.1.3 Risk Management Applied to Projects, Programs, and Portfolios

(Sanchez et al., 2009) did a thorough literature review paper on risk management at three levels; Project, Program, and Portfolio. The authors state the risk assessment at those levels are interdependent and should be co-ordinated. However, in practice, project risk management has been linked to the individual project level with less attention to the other levels, which doesn't reflect the strategic goals of the company. The authors show that, despite large literature, there is a gap between risk management applied to project level, and the organizational level. The authors expose some area of open research gaps; there is a need to implement continuous control and monitoring, this is needed for all three levels. Another gap in all levels taking into account vulnerabilities. Some other areas for portfolio and program are adapted from the project level analysis, but research written specifically for these upper levels is not complete. It should be noted however that a all-around generic solution may not be satisfactory, as each level's needs and criteria is different. Overall, the authors point at several open research areas are the program and portfolio risk management.

2.2 Cash Flow Analysis

This section shall cover some of the research in the field of financial analysis of construction projects. There are many research works in that field; to count a few: (Au and Hendrickson, 1985) which introduces cash-flow analysis and proit calculations for construction projects; (Kaka and Price, 1993) which focused in the modeling and prediction of the cost curves for contractors, which was also studied by (Hwee and Tiong, 2002) in combination with risk analysis using a number factors that affect the cash flow; cash flow forecasting for contractors was also analyzed by (Park, Han, and Russell, 2005); (Odeyinka and Kaka, 2005) evaluated the contractor's satisfaction with payment terms, and their impact on the construction cash flow by conducting surveys; (Khosrowshahi, 2007) continued the research into cash flow forcasting by implementing a decision making model for construction cash flow management on the corporate level; (Gorog, 2009) presented a comprehensive and copyrighted model for the analysis and control of cash flows for construction project, to be used by contractors; (Cui, Hastak, and Halpin, 2010) presented a system dynamics model for the project cash flow management, and analyzing different financial strategies. (Jiang, Issa, and Malek, 2011) presented a Pareto optimality multi-objective model, for the analysis of cash flows and financial strategies, to be used as a decision making tool; (Kishore, Abraham, and Sinfield, 2011) used fuzzzy logic systems for cash flow analysis, for portfolios; (Lee, Lim, and Arditi, 2012) presented a stochastic financing analysis for construction projects, where simulation of projects is done in

Matlab using stochastic schedules, to handle uncertainties in activity durations and costs, which was also done by (Maravas and Pantouvakis, 2012); (Huang et al., 2013) produced a decition making system for financial prequalification of contractors using simulation; (Zayed and Liu, 2014) studied the complexity of financial management of construction projects and created a list of the most relevant financial parameters; finally, (Purnus and Constanta-Nicoleta, 2015) presented a complete insight into cash flow analysis, which proved to be an excellent reference. This section will attempt to cover a number of them,

2.2.1 Profit Measures for Construction Projects

A paper by (Au and Hendrickson, 1985) proposed cash flow analysis and profit measurement methods for construction projects. This paper was published in 1985, so these methods are relevantly old and proven. Those are the calculation include the cash in which is the receipts received by the contractor, the cash out which is the expenses spent by the contractor on the construction works, and the difference between them which is the overdraft. The author proposes calculations for to account for the time value of time, and the cost of finance as shown in the two following equations:

$$NPV_{t=0} = \sum_{t=0}^{n} A_t(1+i)^{-t} \tag{2.1}$$

$$NFV_{t=n} = \sum_{t=0}^{n} A_t(1+i)^{t} \tag{2.2}$$

where NPV and NFV are the Net Present Value and Net Future Value, respectively, A_t is the net cash flow for time period t, and i can be set as the Minimum Attractive Rate of Return (MARR) for the company.

Furthermore, the Internal Rate of Return (IRR) can be calculated by letting $NPV = 0$ or $NFV = 0$ and calculating the i which becomes the IRR. However the author advises against using the MIRR as an indication of profitability, because the fact that almost all construction project are heavily dependant of borrowed resources, the MIRR would be therefore misleading.

The author then presents calculations for overdraft finance, loan interests, and inflation. Stoppage of work is also considered. The author's conclusions can be summed up that: The IRR is not a correct profit measure, the gross profit as measured by the residual net cash flow at the end of the profit does not take into account the project's finance, long-term loans may be a better finance decision than overdraft in long large-scale profits, and finally sharing of financial risks should be shared by the owner and the contractor may be less costly to the owner.

2.2.2 Systems Analysis of Project Cash Flow Management Strategies

A system dynamics approach for cash flow analysis of construction projects was proposed by (Cui, Hastak, and Halpin, 2010). A diagram of this system is shown shown in Figure 2.2. System dynamics is an approach to model complex systems, focusing on system behaviour over time. It has been used to model social, economic, and environmental systems. The model presented by the authors was tested on a case study, which was a storage house.

System dynamics proved useful in modelling the dynamic nature of the finance in construction projects. The model of a "cash balance module", a "material disbursement module", and a "project operation module". The "cash balance module" is the outer frame and is connected to the other modules. It includes cash flow from operating and financing activities for the period of the project construction. The "material disbursement module" includes cash with respect to material invoices, payments, etc. The "project operation module" handles rework, errors, changes in scope, etc. Other modules are included to handle labour payments, subcontractors payment.

The model can be used to perform what-if analysis using different cash flow management strategies: Front-end loading strategies include billing of mobilization costs, unbalanced pricing by overpricing activities done earlier in the project and under pricing later activities (which is generally unacceptable unless the risk is minor on the employer), and finally billing of materials prior to their installation (stored on site, in accordance with contract). Back-end loading strategies include trade credit, where the contractor receives material from suppliers and pays for them later after a grace period, and subcontracting, where the contractor assigns part of the work to sub-contractors but pays for them later (according to the invoices between them) and may even pay the retainage to the subcontractors when retainage is received from the employer.

A setback of the model, according to the authors, is its uniqueness for different projects, requiring some modification to the equations used. Also, a software package, VESIM DSS verision 5.5, was used, so some changes in the software parameters are needed as well. The author recommends an unbounded software package to for better further research into the financial impacts of different cash strategies. (Cui, Hastak, and Halpin, 2010)

2.2.3 Analyzing the Impact of Negative Cash Flow on Construction Performance in The Dubai Area

(Al-Jabouri, Al-Aomar, and Bahri, 2012) presented a study into the patterns and effect of negative cash flow on construction project in the Dubai Area. The study was done on

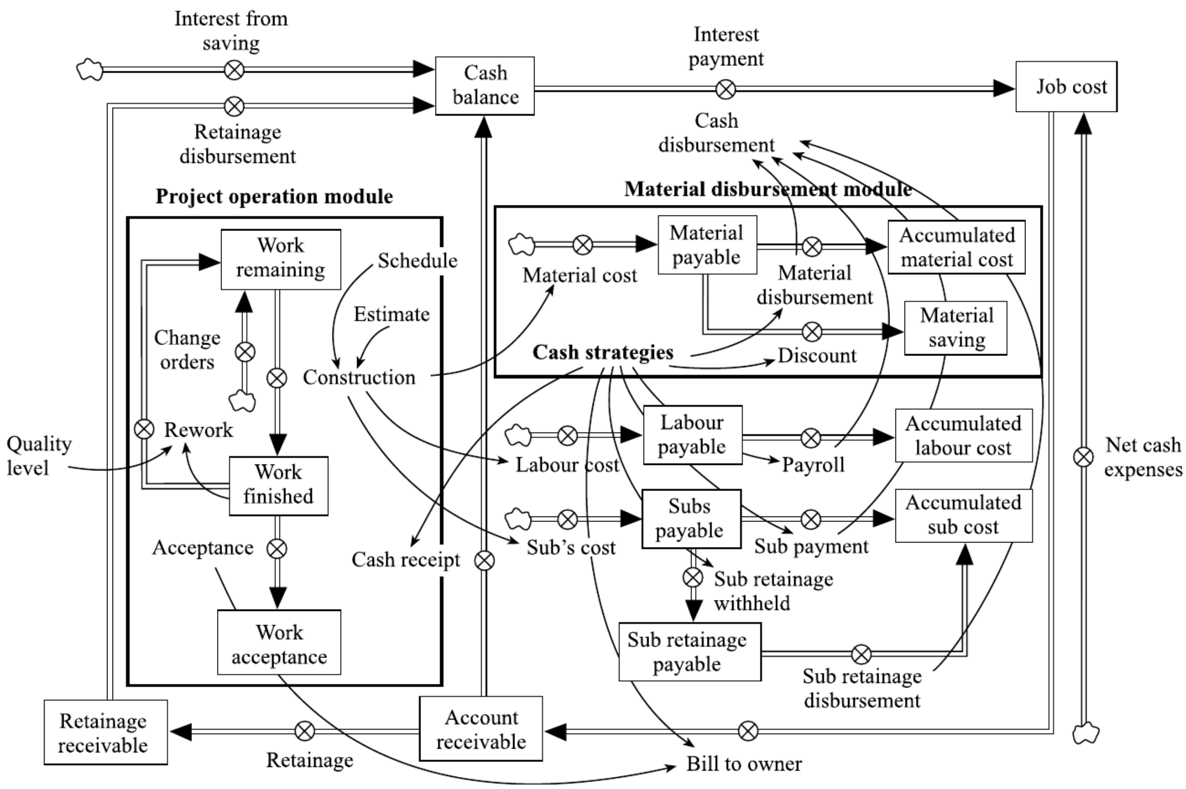


Figure 2.2: System dynamics model for project cash flow management (Cui, Hastak, and Halpin, 2010).

40 ongoing projects int he Dubai Area, and 4 of them were thoroughly a studied. The analysis was for the Cash disbursements, cash receipts, and accumulated cash flow. It was found that there was a negative cash flow for 30 to 70% of the project duration in the projects studied, and the shortage values ranged between 2 to 4 times the monthly expenses. The author mentions that some contractors are able to reduce the extent of negative cash flow by rescheduling cased on cash flow constraint. The author recommends attention to negative cash flow, cooperation between the contractor, employer, and other project stakeholders. The author also recommends more practical research using actual data to better understand the impact of cash flows.

2.2.4 Financial Management of the Construction Projects: A Proposed Cash Flow Analysis Model at Project Portfolio Level

Purnus and Bodea (Purnus and Constanta-Nicoleta, 2015) have presented a complete cash flow analysis as a case study on 5 projects as shown in Table 2.1. The projects have different start dates as well, as shown in Figure 2.3. The cash flow was calculated and is shown in Figure 2.4. The projects of 5 infrastructure projects awarded during 2013 and

Table 2.1: Projects and portfolio contract price as studied by Purnus and Bodea (Purnus and Constanta-Nicoleta, 2015)

Project	Duration	Contract Price (Euro)	Project Type	Contract
1	21 months	15,518,964	Waste Water Plant	FIDIC 1999 Yellow Book
2	14 months	7,027,800	Waste Water Plant	FIDIC 1999 Yellow Book
3	24 months	5,527,942	Waste Water Plant	FIDIC 1999 Yellow Book
4	14 months	11,687,742	Rehabilitation of a water supply and waste water network	FIDIC 1999 Red Book
5	11 months	7,475,872	Rehabilitation of a road	FIDIC 1999 Red Book
Portfolio	36 months	47,238,320	-	-

2014 to a middle-sized construction company. Projects Their contract conditions were based on FIDIC 1999 conditions of contract for buildings and engineering work designed by the employer (Red Book) and FIDIC 1999 Conditions of Contract for Plant and Design-Build for Electrical and Mechanical Plant (Yellow Book). Due to the overlapping of the projects, the works done during Ocober 2014 through August 2015 are over 2,000,000 Euros, with a peak of 5,626,187 Euros in July 20. Figure 2.4 shows cumulative cash flow of the portfolio. This is the combination of cash-in and cash-out where the negative values indicate the overdraft expected on part of the contractor, and the positive values indicate the profit. Figure 2.5 shows a cash flow combining finance, income, costs and return of finance after running multiple scenarios. The goal is to keep that cash flow positive at all time. The paper highlights the necessity of a detailed cash flow analysis on the portfolio level, and recommends probabilistic analysis and risk management.

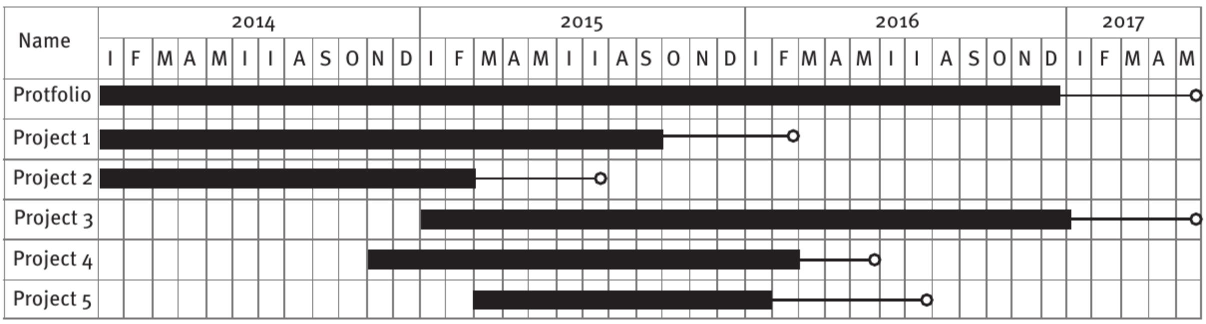


Figure 2.3: Gantt chart of the portfolio studied by Purnus and Bodea (Purnus and Constanta-Nicoleta, 2015)

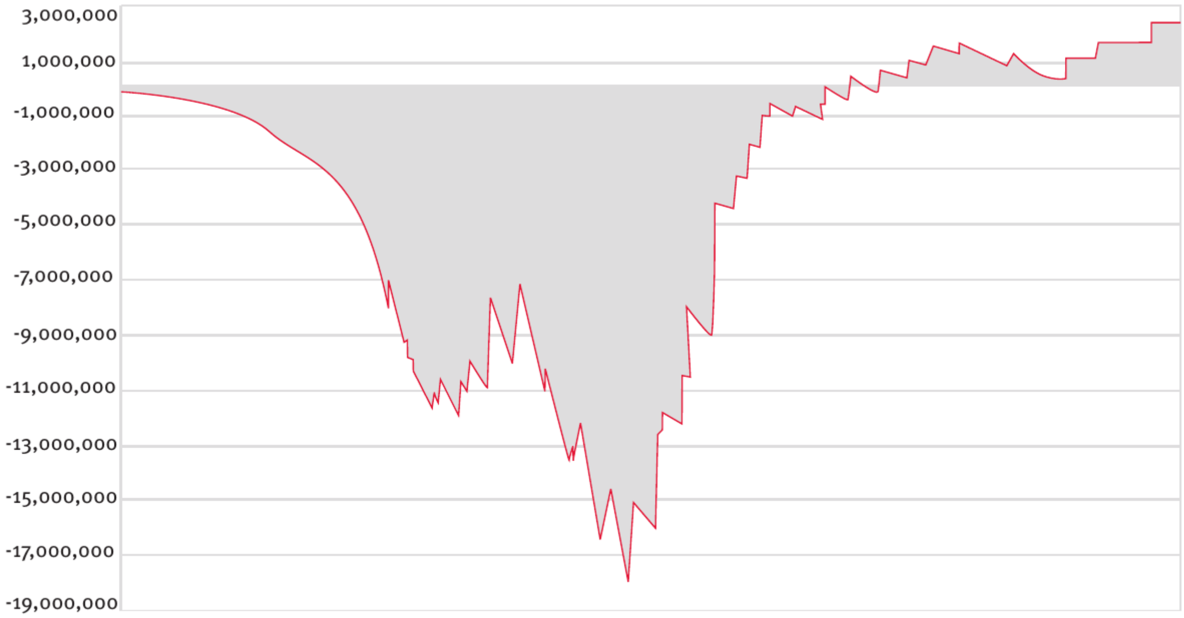


Figure 2.4: cash flow of the portfolio(Purnus and Constanta-Nicoleta, 2015)

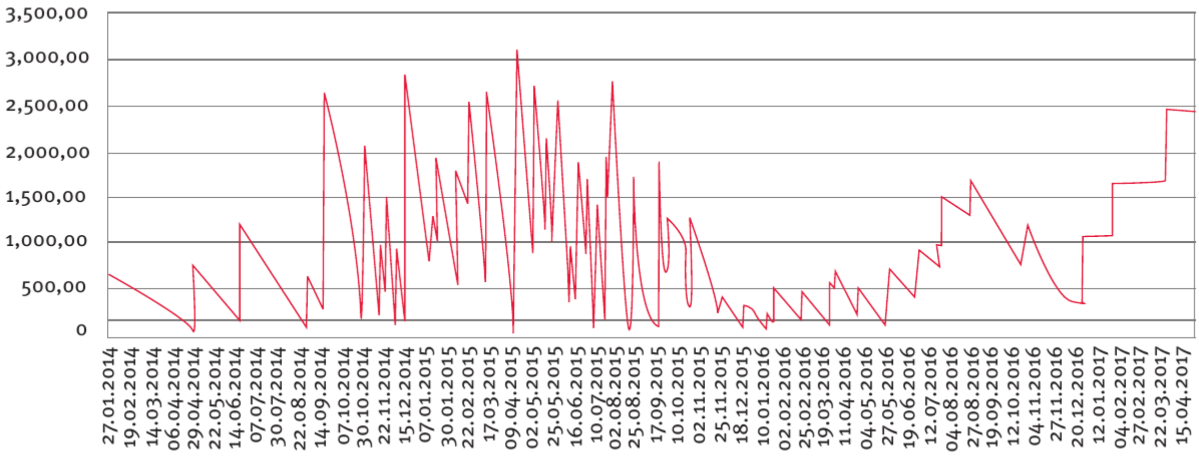


Figure 2.5: Finance of the portfolio (Purnus and Constanta-Nicoleta, 2015)

2.3 Optimization and Resource/Finance Based Scheduling

In continuity of the previous section, many researchers studied the optimization of resource constrained construction projects, or resource-constrained scheduling, or time cost trade-off. Their are many techniques, methods, and optimization algorithms in this area. This section will attempt to caver a few. To name some research works in this area; (Li, 1996) is one of the oldest papers to handle the optimization problem for construction schedules; (Hegazy, 1999) introduced the optimization of resource allocation and leveling using genetic algorithms; (El-Rayes and Moselhi, 2001) used dynamic programming formulation to optimum resource usage; (Elazouni and Metwally, 2007) used genetic algorithms for a time-cost trade-off, (Liu and Wang, 2008) created a model for resource-contrained scheduling, time-cost trade-off for non-serial repetitive projects was optimized using genetic algorithms and dynamic programing by (Ezeldin and Soliman, 2009), (Liu and WAng, 2009) studied profit optimization for linear projects; (Elazouni, 2009); (El-Rayes and Jun, 2009) presented a heuristic method for multi-project finance based scheduling; (Christodoulou, 2010) presented a new approach for resource-constrained scheduling using Ant Colony Artificial Agents; (Jun and El-Rayes, 2011) presented a multi-objective model for resource leveling and allocation; (Lucko, 2011) used singularity functions for resource optimization; (Abido and Elazouni, 2011b) presented a heuristic for multi project finance-based scheduling; (Abido and Elazouni, 2011b) used a strength Pareto evolutionary algorithm for creating optimum finance-based schedules; (Lucko, 2013) presented a decision making model using singularity functions and genetic algorithms for financial decision making, based on the time value of money;; (Alghazi, Elazouni, and Selim, 2013) presented a continuity into finance-based scheduling using genetic algorithms; (Li and Li, 2013) used self-adaptive ant colony optimization for time-cost optimization; (Menesi, Galzarpoor, and Hegazy, 2013) used constrained programming for large scale projects; (Tang, Liu, and Sun, 2014) continued research into linear scheduling method using constrained programming; (Elazouni and Abido, 2014) presented a strength Pareto evolutionary algorithm for the optimization of finance requirements, resource levelingm and profit; another paper by(Elazouni, Alghazi, and Selim, 2015) presented meta-heuristics for finance-based scheduling; (Su and Lucko, 2015) used singularity functions for optimum present value scheduling; (Kim, Walewski, and Cho, 2016) used a modified niched pareto genetic algorithm for scheduling; finally, (Elbeltagi et al., 2016) used particle swarm for multi objective schedule optimization.

2.3.1 Optimization of Resource Allocation and Leveling Using Genetic Algorithms

Hegazy (Hegazy, 1999) presented a paper in 1999 regarding an algorithm for resource allocation inside a MS Project™. The method relies on the fact that a user can already input "priorities" for activities in MS Project™, those can be from lowest to highest, and are used by the program to prioritize the levelling of resources in a heuristic method. The algorithm proposed in the paper is a genetic algorithm written in Visual Basic for Applications (VBA), which is built in the program, to optimize those priorities in order to get the optimum objective result, which can be combination of minimum project duration, minimum resource fluctuation, and minimum utilization period of resources. The algorithm starts by initiating the schedule, setting the priority to lowest for all activities, then looping on the activities by setting the priority to highest and calculating the objective functions for each. The genetic algorithm is shown in Figure 2.6. The algorithm proposed has the advantage of being an add-on to a popular commercial software already used extensively in the construction industry. However, the processing time was quite high, as the author reported that four experiments took 50 to 120 minutes, but it should be noted that it was done on a Pentium 233 MMX Computer. Finally, the author recommends the application of a similar method using a more efficient programming language.

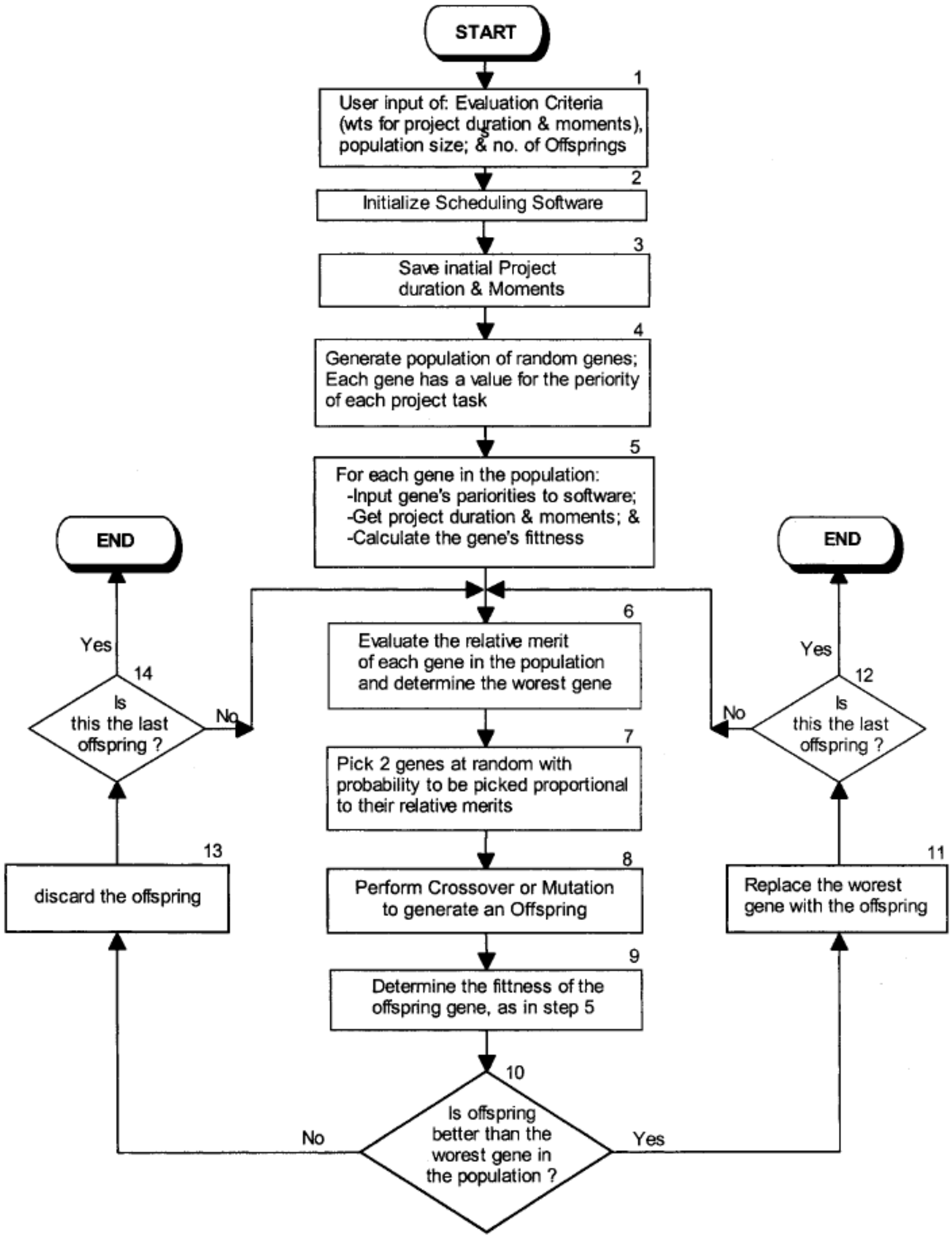


Figure 2.6: Genetic Algorithm levelling algorithm as proposed by Hegazy (Hegazy, 1999)

2.3.2 Expanding Finance-Based Scheduling to Devise Overall-Optimized Project Schedules

Technical notes by (Elazouni and Metwally, 2007) presented the implementation of a model for finance based scheduling model implemented in Visual Basic. Time-cost trade-off (TCT) is done, due to the fact that finance based sccheduling results in longer schedules than unconstrained ones. So the work included TCT analysis, resource allocation, and resource levelling, acheived through Genetic Algorithms. The model was tested a small 5 activities project.

2.3.3 Heuristic Method for Multi-Project Finance-Based Scheduling

In another paper by (Elazouni, 2009), a heuristic method scheduling multiple project subject to cash constraints. The proposed heuristic method starts by determining the cash available to schedule activities during a given period; identifies all possible schedules; determines cash requirements and the impact of project completion, selects the best schedule; updates the cash flow; proceeds to the next periods, one period at a time till all activities are scheduled. The method was validated by comparing with previous results solved by the author using integer programming, and the solutions were very comparable. The author claims that the advantage of this heuristic method is is flexibility, and ability to schedule practical-size projects.

2.3.4 Scheduling Resource-Constrained Projects with Ant Colony Optimization Artificial Agents

Research into scheduling resource-constrained projects using Ant Colony Optimization (ACO) was done by (Christodoulou, 2010). ACO is a population-based artificial agent which is inspired by the collective behavior of ants as they optimize their path between their nest and their food. Ants, in real life, leafe a trail of pheromones on their path, and this trail steers the suceeding ants in the direction of the stronger pheromone concentrations, so each at has a higher probability of following the path chosen by the majority of the preceding ants. The ACO method is applied on a resource constrained network, the effects of resource availability on the critical path and project completion time is examined. The search for the shortest path, as usual for ACO, is substiduted with the search for the longest path, which is the Critical Path for the construction schedule, according to the Critical Path (CPM) method. This is done by treating the duration as negative numbers within the ACO. The method is tested on a small project o 17 activities, accuracy of 100% for the unconstrained project and a 97% accuracy for the resource constrained project. The author claims that the ACO method, though iterative, is more suitable in parallel computing due to its branching nature. Testing into large projects with more than 1000 activities is in progress.

2.3.5 Multi-objective Optimization of Resource Leveling and Allocation during Construction Scheduling

(Jun and El-Rayes, 2011) proposed a model for resource optimization implemented into MS Project ™as an extension written in the programming language $C\sharp$.net. A summary of the optimization model is shown in Figure 2.7. The model can have one of 2 metrics as objectives: Release and Rehire (RRH), or Resource Idle Days (RID). The decision variables are the Priority Value (P_n) and Start Day (S_n), the former is used to define the scheduling sequence of each activity while the latter is used to shift the activity. Each of those variables, for every activity n is used as a chromosome for the genetic algorithm. An example run was done using the data tested for validation by Hegazy (Hegazy, 1999) as described in a previous section.

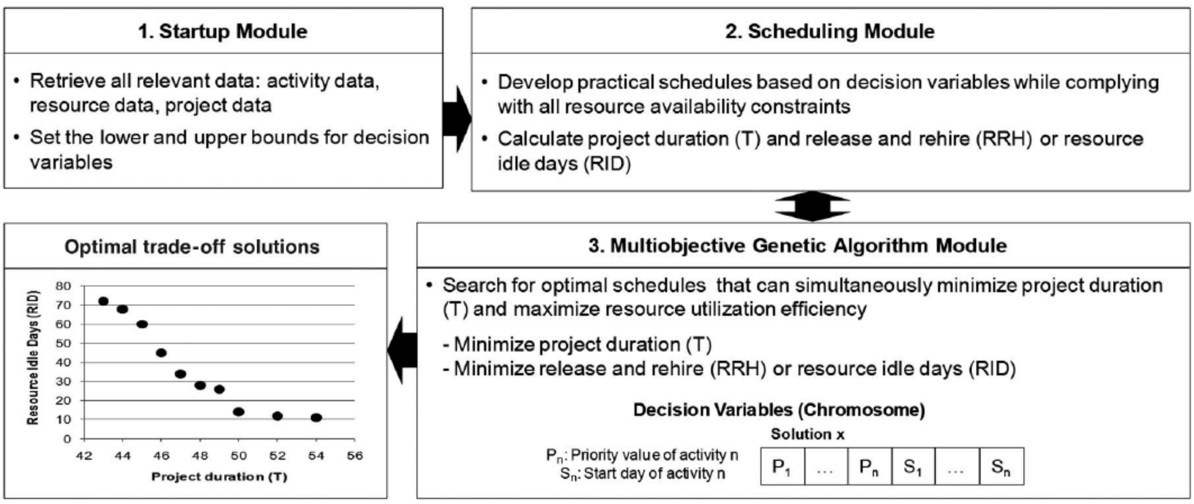


Figure 2.7: Optimization model done by Jun et al (Jun and El-Rayes, 2011)

2.3.6 Multi-objective Evolutionary Finance-Based Scheduling: Entire Projects' Portfolio and Individual Projects within a Portfolio

Two papers by the same authors presented a multi-objective scheduling model for portfolios and individual projects within a portfolio(Abido and Elazouni, 2011a)(Abido and Elazouni, 2011b). The authors proposed a multi-objective evolutionary scheduling model using a strength pareto evolutionary algorithm shown in Figure 2.8 and fuzzy logic, and applied on 5 projects consisted of 25, 30, 225, 240, and 260 activities each. The decision variables are the start times of the projects' activities. The formulation of the multiple objectives include maximizing the profit, and minimizing the duration, financing cost, and credit.

The algorithm works as follows:

1. Generate an initial population into an empty external Pareto-optimal set.
2. Update the external Pareto-optimal set as follows:
   (a) Search the population for the non-dominated solutions and copy them to the external Pareto set
   (b) Search the external Pareto set for the non-dominated solutions and remove all dominated solutions from the set
   (c) Reduce the set by means of clustering in case the number of the solutions externally stored in the Pareto set exceeds a pre-specified maximum size
3. calculate the fitness values of solutions in both external Pareto set and the population as follows:
   (a) Assign the strength s for each solution in the external set. The strength is proportional to the number of solutions covered by that solution.
   (b) The fitness of each solution in the population is the sum of the strengths of all external Pareto solutions which dominate that solution. A small positive number is added to the resulting sum to guarantee that Pareto solutions are most likely to be selected by the mating pool.
4. Select two solutions at random out of the combined population and external set solutions, compare their fitness, select the better one, and copy it to the mating pool.
5. Generate a random number between 0 and 1 and compare it with the preset crossover probability, Pc. If r is less than P c, then carry out the crossover operator. Repeat for mutation operator.

6. Check for stopping criteria to terminate otherwise copy new population to old population and go to Step 2. In this study, the search will be stopped if the generation counter exceeds its maximum number.

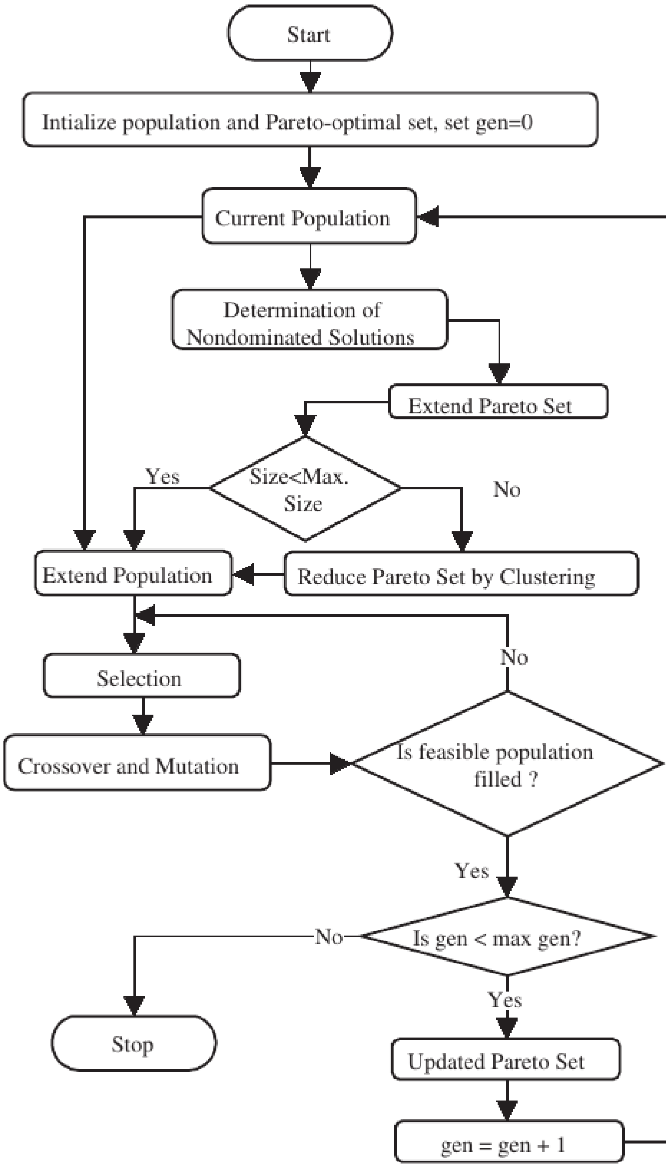


Figure 2.8: Computational flow for the strength Pareto evolutionary algorithm(Abido and Elazouni, 2011b)

2.3.7 Improved Genetic Algorithm Finance-Based Scheduling

Alghazi et al (Alghazi, Elazouni, and Selim, 2013) proposed a Genetic Algorithm (GA), coded in Matlab ™. The objective is to tackle the problem of infeasible chromosomes in resource levelling using GA. The chromosomes are assigned as the start of each activity in a project, and infeasible chromosomes occur when a chromosome, representing the start of an activity, creates a conflict with the logical relationships between activities or when the resource constraint is not met. The authors presented a chromosome-repairing GA and stated that stated that it outperformed replaced-chromosome GAs with limited computational effort. The results were verified using a 10 cash-constrained 30-activity problems. The flowchart of the chromosome-repairing GA is shown in Figure 2.9.

2.3.8 Fast and Near-Optimum Schedule Optimization for Large-Scale Projects

Menesi et al. (Menesi, Galzarpoor, and Hegazy, 2013) presented a Constrained Programming (CP) Model in an attempt to reach optimum results for large projects quickly. The authors argue that focus on optimization of large scale projects (more than 1,000 activities) is lacking in research, though most construction projects, in reality, have large schedules. The model proposed was implemented in *IBM ILOG CPLEX Optimization Studio*, and produced near-optimum solutions for 1,000 and 2,000 activities projects in minutes, performing better than meta-heuristic models such as Genetic Algorithms. The authors also challenge other researches to improve upon the results with 1 percent deviation for projects consisting of 1,000 activities or more, on a personal computer.

2.3.9 Enhanced Trade-off of Construction Projects: Finance-Resource-Profit

Another paper by (Elazouni and Abido, 2014), where the Trade-off between finance requirements, resource leveling, and anticipated profit are optimized. A Strength Pareto evolutionary algorithm (SPEA) is implemented for the trade-off, by solving a a network of nine multi-mode activities and obtain the associated Pareto-optimal front, which comprised fifty solutions, in order to help the decision maker take the best balance. In addition, a fuzzy logic algorithm was implemented to compare the balance between those results. The author recommends research into invloving large-sized practival projects within a portfolio.

2.3.10 Finance-based Scheduling using meta-heuristics: discrete versus continuous optimization problems

(Elazouni, Alghazi, and Selim, 2015) compared the performance of genetic algorithms (GA), simulated annealing (SA) and shuffled frog-leaping algorithm (SFLA) in solving discrete and continuous variable optimization problems of finance-based scheduling. This was tested on projects of 30, 120, and 210 activities. SA outperformed the SFLA and GA in terms of quality of results and computational cost with small networks of 20 activities, and resulted in the shorted durations for larger networks of 120 and 210 activities. The author recommends further researchers to use finance-based scheduling, due to its discrete or continuous nature, to use it as a test bed for testing the performance of new developments of meta-heuristics.

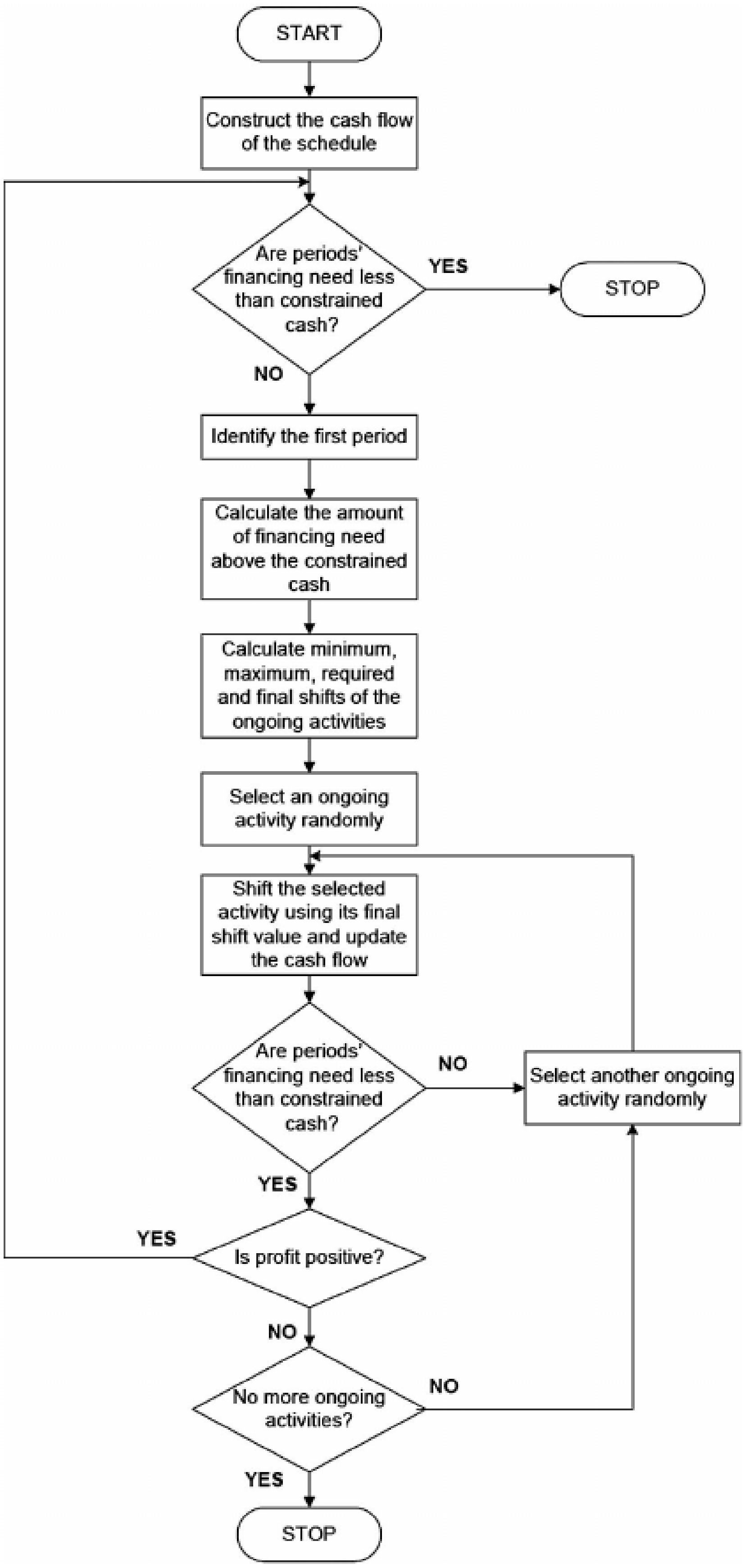


Figure 2.9: Flow chart of the chromosome-repairing GA (Alghazi, Elazouni, and Selim, 2013)

2.4 Outcomes From Literature Review

After conducting the literature review, it was found that the financial analysis on the portfolio and corporate levels is less tackled by research than analysis on the project level. It was also agreed among researchers that portfolio level analysis is more indicative on the success on the corporate level, as it includes multiple projects as a whole, rather than single projects, which is the case in any construction company because most finance and resources are shared between projects. It was also found that the time value of money has a great effect on cash flows, and the two most used parameters to indicate the profit from a project under that methodology is the Net Present Value, and the Internal Rate of Return, however, it was found that the Net Present Value is more appropriate. Regarding the complexity and size of the projects used as case studies in literature, most of them were small schedules with a limited number of activities, few papers handled large projects with up to a thousand activities, which may be impractical in real life because large projects, and when handled as portfolios, have much higher numbers of activities; huge schedules are unavoidable when handling large portfolios. Regarding optimization, there are many studies into different optimization techniques and algorithms. The most significant one to this thesis in the method used by (Hegazy, 1999), where lags where added before each activity to allow the model to delay each of them, and optimization was done resource allocation and leveling; the same concept was adopted in this thesis.

Chapter 3

Model Development

This Chapter covers the complete model development. This includes the inputs and outputs. The programing language used, which is Python, is described. The calculations and process are explained for the scheduling, cash flow analysis, time value of money, and optimization. Finally, the development of the Graphical User Interface (GUI) is described. The entire Python Code used is available in Appendix A.

3.1 Assumptions

As expected in any model development, some assumptions must be made. Those are the following:

- The cost of each activity was assumed to be uniformly distributed along each activity's duration, in contrast real life cases where the cost can be front allocated, or back allocated, or have any other distribution.

- The costs and expenses that are delayed after an activity or before it, such as in the case of paying for a supplier after a duration of time from an activity, or before the activity was neglected. Though they could be added in the model as separate activities that have delays between them.

- Payment of invoices, retention, and down-payments was assumed to be always on time, neither late nor early than the contractual time bars. Delays are completely out of scope.

- The retention was assumed to be paid completely after the Defects Liability Period. In other situation it could be paid in half at construction completion and half after the defects liability period.

3.2 Model Inputs and Outputs

The user is able to input project parameters for the projects, activities, and the relationships between the activities. The inputs are as follows:

- Projects (The interface is shown in Figure 3.8):

  Project ID A unique id for each project

  Project Name The name or description of the project

  Start The start date of the project

  Interest The interest percentage used, this can be the Minimum Attractive Rate of Return (MARR) for the company and should at least account for the expected Inflation.

  Mark-up The mark-up percentage for the project. This should account for profit and contingency.

  Down-payment The down-payment percentage for the project

  Invoice Interval The interval between issuing of invoices. This is typically set as monthly.

  Payment Period The time period in days between issuing an invoice and receiving the payment for that invoice.

  Retention The retention percentage for the project. This amount is deducted from the invoices and received [by the contractor at the end of the project.

  Retention Period The time period in days between the end of a project and the receipt of the retention payment.

- Activities (The interface is shown in Figure 3.10):

  Project ID The ID of the project containing the activity. This id should match the id provided for a project.

  Activity ID A unique ID for the activity. The ID should be unique for each activity within the same project.

  Activity Name A name, WBS name, or description for the activity

  Duration The duration in days for the activity

  Cost The direct cost for the activity

- Relationships (The interface is shown in Figure 3.11):

Project ID The project ID for the project containing the predecessor and successor activities

Activity1 ID The ID of the predecessor activity

Activity2 ID The ID of the successor activities

Type The type of the relationship. This can be Finish-to-Start, Finish-to-Finish, Start-to-Start, or Start-to-Finish.

For the outputs, the model was built with a Graphical User Interface (GUI), which will be discussed thoroughly in a later section. The GUI allows the user to create the elements of the portfolio with the inputs just mentioned. It also allows the user to preview tables containing all fields for the elements, whether the portfolio, the projects, the activities, or the relationships. The GUI can also preview Gantt Charts, cash flow plots, overdrat plots, for the non-optimized and the the optimized portfolio, with discounted values or non-discounted values.
In addition, the program can output tables for the portfolio elements including the portfolio, projects, activities, relationships, cash flow, and trial calculations. The data is exported in comma separated values (csv) formats and Excel spreadsheet format. The complete log is exported in a text file. The plots and gantt charts in every mentioned form is exported in PDF or SVG files, for the pupose of previewing or compiling in a report, such as this thesis.

3.3 Input from Primavera

Projects can be imported from Otacle's Primavera. It should be noted that Primavera is not friendly to add-ins and mods. Another competitor, MS Project, for example, is more modifiable through the availability of developer tools in Visual Basic for Applications (VBA) within MS Project and other MS Office tools. However, Primavera is and has been more dominant in Egypt, so this thesis required the use of Primavera due to the actual work environment. The original projects used for the validation in this thesis were done in Oracle Primavera. To import the projects from Primavera into the model, a workaround is needed; the user has to export the projects from Primaverain spreadsheet xls format, but first the export options must be edited by the user to add the primary constraint, primary constraint date, original duration, Budgeted total cost, and the calendar name to the exported spreadsheet. To import into the mmodel, an algorithm was coded to import the projects from those xls spreadsheets.

3.4 Programming Language and Packages Used

The programming language used in this work is Python. Python is a relatively new programming language. It is a free and open source high-level scripting language. It's high-level, dynamic, allows for procedural and object-oriented programming among other paradigms. It has a community based development environment which resulted in a vast library of third party packages (Foundation, 2016). Though execution of python code is normally slower than other counterparts like C++ or JAVA, it is however known to be relatively easier, more readable, and faster for prototyping. It was ranked as fourth in the "Top 10 languages in 2015" listing by IEEE (IEEE, 2015). This programming language was chosen in this work due to its faster prototyping process because relatively simple and readable. This allowed for better experimentation during building the model with ease and wasting less time. In other words, It is faster to code in Python in comparison with other languages. The only disadvantage is that Python, due to the fact that it's a high-level language, is normally slower, in means of execution time, than otehr languages like C or C++ for example, which are lower level and "closer to the hardware". Fortunately, most of the critical packages in Python are coded and optimized in C to lower that effect. It should be noted that the "slower time" discussed here is more relevant to real time systems and computationally demanding softwares, which isn't too much of a nuisance within the scope of this thesis. The entire Python Code used is available in Appendix A. Python has a very good standard library with an excellent documentation and friendly community of developers. There are a lot of packages built for Python spaning over a lot of useful functions. Several packages built for the Python environment were used in this thesis. All of them are open source and easily installed. The packages used outside of the Python standard library or otherwise notable are listed below, according to their functions:

Database Management "sqlite3" was used for the database. It is part of the standard library, requires instructions syntax similar to MySQL. It has less capabilities than some other databases but none of those capabilities were required for the purpose of this work. It is also file-based as opposed to a server database, which limits to only one connection per database, but allows for higher read-write speeds.

Graphical User Interface "tkinter" was used because it's already part of the standard library, as well as simple and good enough for prototyping

Plotting "matplotlib" was used for plotting high quality svg files. It is a well known plotting library in the scientific community and has an excellent range of capabilities

Other external packages "xlsxwriter" and "xlrd" are 2 packages that are not included in the standard library. They were used for reading and writing to excel files. This is needed to import excel files exported from primavera, and the standard library can only manipulate csv files.

3.5 Database

A relational database was used to store and handle data. The database used is Sqlite3, which is an open source file based database system, readily available in the Python standard library. Being connected to a single file on the hardisk, unlike MySQL which is a server, it is faster but allows for one connection at a time. The tables and column fields are listed below. The column fields can be considered as the variables used in the calculation, and many of them are the model inputs.
A complete list is as follows:

1. trials
   (a) trialid (INT)
   (b) initialnpv (FLOAT)
   (c) trialnpv (FLOAT)
   (d) bestnpv (FLOAT)
2. projects
   (a) projectid (TEXT)
   (b) projectname (TEXT)
   (c) start (NUM)
   (d) finish (NUM)
   (e) duration (INT)
   (f) interest (REAL)
   (g) markup (REAL)
   (h) retentionperiod (INT)
   (i) retention (REAL)
   (j) invoiceinterval (INT)
   (k) paymentperiod (INT)
   (l) downpayment (REAL)
   (m) cost (REAL)
   (n) price (REAL)
   (o) totalactivities (INT)
   (p) criticalactivities (INT)
   (q) cashinpv (REAL)
   (r) cashoutpv (REAL)
   (s) npv (REAL)
   (t) maxoverdraftdisc (REAL)
   (u) minoverdraftdisc (REAL)
   (v) cashinpvopt (REAL)
   (w) cashoutpvopt (REAL)
   (x) npvopt (REAL)
   (y) maxoverdraftdiscopt (REAL)
   (z) minoverdraftdiscopt (REAL)
3. activities
   (a) projectid (TEXT)
   (b) activityid (TEXT)
   (c) activityname (TEXT)
   (d) duration (INT)
   (e) cost (REAL)
   (f) es (INT)
   (g) ef (INT)
   (h) ls (INT)
   (i) lf (INT)
   (j) ff (INT)
   (k) tf (INT)
   (l) lag (INT)
   (m) os (INT)
   (n) of (INT)

4. relationships
   (a) projectid (TEXT)
   (b) activity1id (TEXT)
   (c) activity2id (TEXT)
   (d) type (TEXT)
5. cashflow
   (a) date (INT)
   (b) projectid (TEXT)
   (c) cashout (REAL)
   (d) invoice (REAL)
   (e) cashin (REAL)
   (f) cashoutcum (REAL)
   (g) cashincum (REAL)
   (h) overdraft (REAL)
   (i) cashoutdisc (REAL)
   (j) cashindisc (REAL)
   (k) cashoutcumdisc (REAL)
   (l) cashincumdisc (REAL)
   (m) overdraftdisc (REAL)
6. cashflowall
   (a) date (INT)
   (b) projectid (TEXT)
   (c) cashout (REAL)
   (d) invoice (REAL)
   (e) cashin (REAL)
   (f) cashoutcum (REAL)
   (g) cashincum (REAL)
   (h) overdraft (REAL)
   (i) cashoutdisc (REAL)
   (j) cashindisc (REAL)
   (k) cashoutcumdisc (REAL)
   (l) cashincumdisc (REAL)
   (m) overdraftdisc (REAL)
7. cashflowopt
   (a) date (INT)
   (b) projectid (TEXT)
   (c) cashout (REAL)
   (d) invoice (REAL)
   (e) cashin (REAL)
   (f) cashoutcum (REAL)
   (g) cashincum (REAL)
   (h) overdraft (REAL)
   (i) cashoutdisc (REAL)
   (j) cashindisc (REAL)
   (k) cashoutcumdisc (REAL)
   (l) cashincumdisc (REAL)
   (m) overdraftdisc (REAL)
8. cashflowallopt
   (a) date (INT)
   (b) projectid (TEXT)
   (c) cashout (REAL)
   (d) invoice (REAL)
   (e) cashin (REAL)
   (f) cashoutcum (REAL)
   (g) cashincum (REAL)
   (h) overdraft (REAL)
   (i) cashoutdisc (REAL)
   (j) cashindisc (REAL)
   (k) cashoutcumdisc (REAL)
   (l) cashincumdisc (REAL)
   (m) overdraftdisc (REAL)
9. portfolio

   (a) portfolioid (TEXT)
   (b) start (NUM)
   (c) finish (NUM)
   (d) duration (INT)
   (e) numberofprojects (INT)
   (f) numberofactivities (INT)
   (g) cost (REAL)
   (h) price (REAL)
   (i) cashinpv (REAL)
   (j) cashoutpv (REAL)
   (k) npv (REAL)
   (l) maxoverdraftdisc (REAL)
   (m) minoverdraftdisc (REAL)
   (n) cashinpvopt (REAL)
   (o) cashoutpvopt (REAL)
   (p) npvopt (REAL)
   (q) maxoverdraftdiscopt (REAL)
   (r) minoverdraftdiscopt (REAL)

10. big

   (a) projectid (TEXT)
   (b) activity1id (TEXT)
   (c) activity2id (TEXT)
   (d) type (TEXT)
   (e) activity1es (INT)
   (f) activity1ef (INT)
   (g) activity1ls (INT)
   (h) activity1lf (INT)
   (i) activity1os (INT)
   (j) activity1of (INT)
   (k) activity1duration (INT)
   (l) activity2es (INT)
   (m) activity2ef (INT)
   (n) activity2ls (INT)
   (o) activity2lf (INT)
   (p) activity2os (INT)
   (q) activity2of (INT)
   (r) activity2duration (INT)

3.6 Scheduling Calculations

The scheduling calculations follow a simple Critical Path Method (CPM) technique. The calculations are done in two steps where one is a forward run and the other is a backward run. The forward run's goal is to set the Early Start (ES) and Early Finish (EF) of each activity in the schedule. A flow chart of the front-run in show, with some simplification, in Figure 3.1. The explanation of the part were an activity itself is calculated is shown in Equation 3.1. A summary of the forward run is executed roughly as follows:

```
Clear all previous data
For each project:
 ES for activities with no predecessors = Project Start
 EF for activities with no predecessors = ES + duration
 While there are unscheduled activities:
  acts = activities with at least one calculated predecessor
  For each in acts:
   If all predecessors are calculated:
    if relationship type = FS:
```

```
10.         ES = max(EFpredecessor, constraint)
11.        if relationship type = SS:
12.         ES = max(ESpredecessor, constraint)
13.        if relationship type = FF:
14.         ES = max(EFpredecessor - duration, constraint)
15.        if relationship type = SF:
16.         ES = max(ESpredecessor - duration, constraint)
17.       EF = ES + duration
18. Set Project Finish = max(EF)
```

In explanation of the preceding pseudo code and Figure 3.1, which provide a very rough summary of the forward run phase, first, the old calculations, if available, are deleted. Then a loop is started for each project on its own, which was found to be the better in computational effort than scheduling the portfolio as a bulk. Activities with no preceding activities are set at the project start. Then a list of activities with at least one calculated predecessor is retrieved from the database, then each one in that list is neglected if one or more of its predecessors is not calculated. This was done to get a balance between the speed of the database system to retrieve a simple query vs. its slowness to retrieve multiple sub queries, and the aforementioned power vs. slowness of Python. Lines 9 to 16 are a very logical set of instructions; an activity once its predessors are known, and its time constraint is already set in the database (Start on or before a date, or finish on or after a date,.etc), has its ES set according to the relationship type, which can be Finish to Start, Start to Start, Start to Finish, or Finish to Finish. These logical relationships are shown in Equation 3.1. And Finally the EF is set as the sum of the start and the activity's duration, and the project finish time is set.

$$ES_{activity} = \text{MAX OF} \begin{cases} EF_{predecessor} & : \text{ where relationship type is FS} \\ ES_{predecessor} & : \text{ where relationship type is SS} \\ EF_{predecessor} - DUR_{activity} & : \text{ where relationship type is FF} \\ ES_{predecessor} - DUR_{activity} & : \text{ where relationship type is SF} \end{cases} \tag{3.1}$$

The next run is the backward run, and its goal is to set the Free Floats (FF) and the Total Floats (TF) for the activities. The TF is essential to the upcoming optimization phase. The backward run if very similar in nature to the Front Run. A flowchart of that process is shown in Figure 3.2. The part where an activity is calculated is shown, with some simplification, in Figure 3.2. A rough summary of the backward-run process is shown in the following pseudo-code:

```
For each project:
 LF for activities with no successor = Project Finish
 LS for activities with no successor = LF - duration
```

```
While there are unscheduled activities:
 acts = list of activities with at least one calculated successor
 For each in acts:
  If all successor are calculated:
   if relationship type = FS:
    LF = min(LSsuccessor, constraint)
   if relationship type = SS:
    LF = min(LSsuccessor + duration, constraint)
   if relationship type = FF:
    LF = min(LFsuccessor, constraint)
   if relationship type = SF:
    LF = min(LFsuccessor + duration, constraint)
  LS = LF - duration
  TF = LS - ES
```

To explain Figure 3.2 and the previus pseudo-code. The backward run is very similar to the forward run. First the activities that have no successors can be calculated, as their $LF = EF = Project_F inish$. The calculations are then looped on each project, and on each activity. in comparison with the fron-run, the difference is that the ES is replaced by the LF, and it is set as the minimum of the successors LS or LF, according to the relationship type. The calculations according to logical relationships are different and are shown in Equation **??**.

$$LF_{activity} = \text{MIN OF} \begin{cases} LS_{successor} & : \text{where relationship type is FS} \\ LS_{successor} + DUR_{activity} & : \text{where relationship type is SS} \\ LF_{successor} & : \text{where relationship type is FF} \\ LF_{successor} + DUR_{activity} & : \text{where relationship type is SF} \end{cases} \tag{3.2}$$

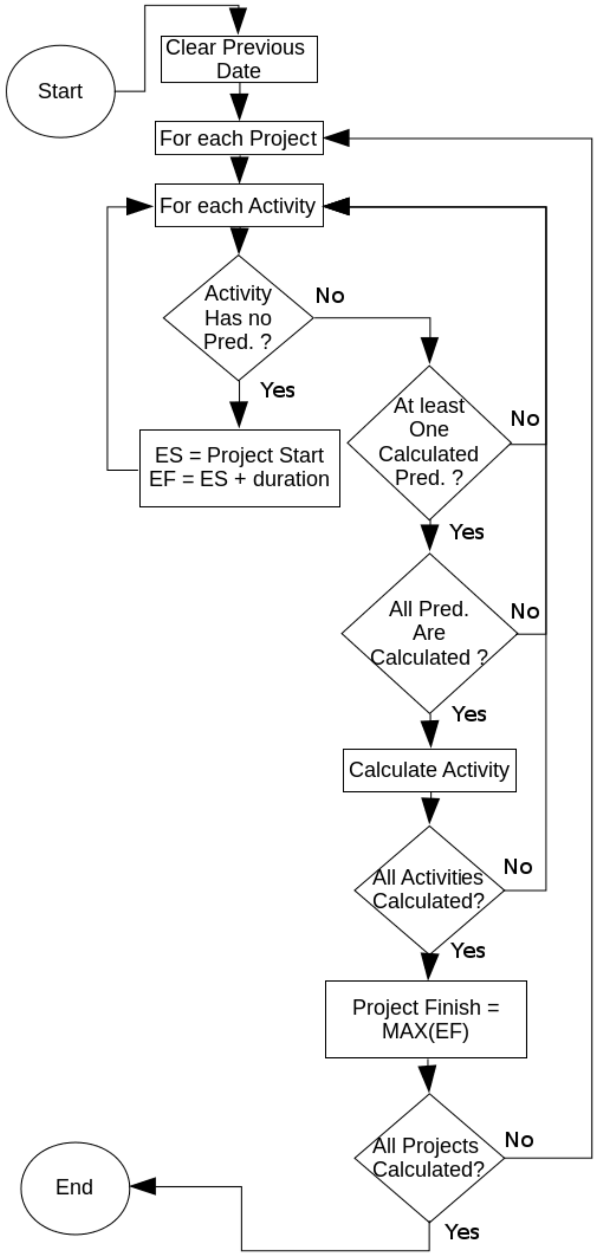


Figure 3.1: Flowchart for the Scheduling Front-Run

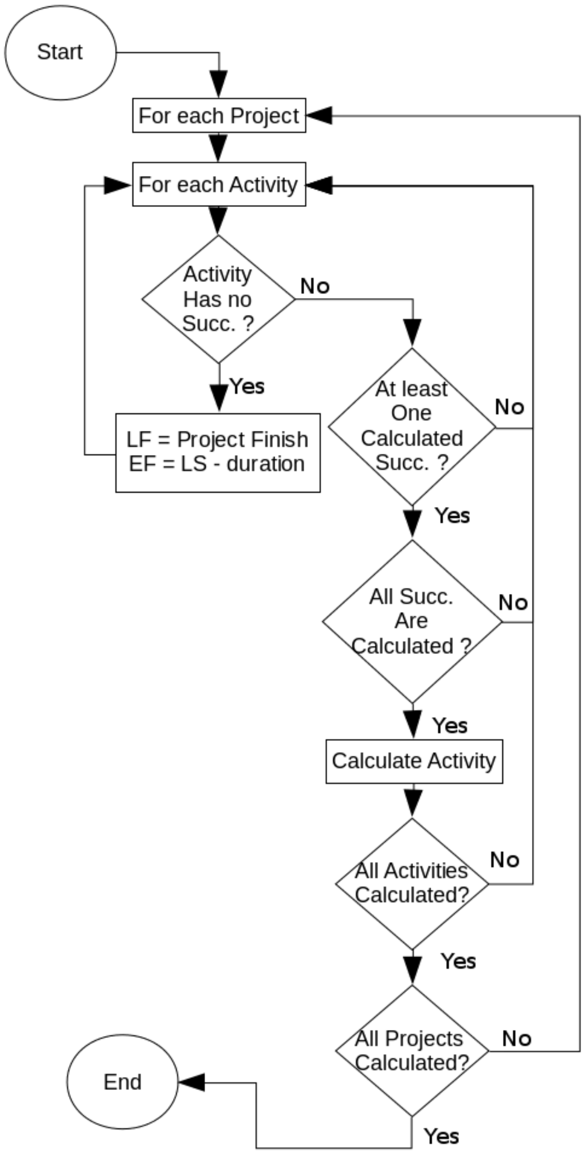


Figure 3.2: Flowchart for the Scheduling Back-Run

3.7 Cash Flow Calculation

Once the schedule has been calculated, the cash flow can be easily calculated. A flowchart of the process is shown in Figure 3.3, and a pseudo-code summarizing the process is as follows:

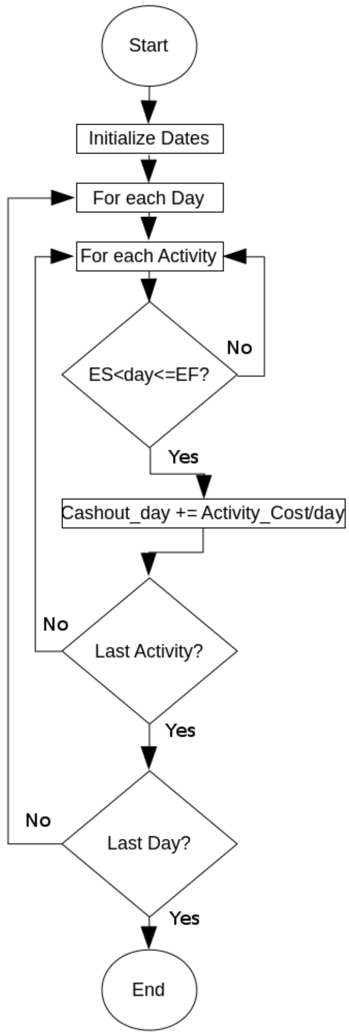


Figure 3.3: Flowchart for The Cashflow calculation

```
1. Portfolio finish = max(project finish + retention period)
2. For each day in range(Portfolio start, Portfolio finish):
3.  For each activity:
4.   IF (activity ES < day <= activity EF):
5.    cahout for this day += activity cost per day
```

So, first the range of days is established, which starts at the start of the portfolio and ends at the finish of the last project plus its retention period. Then a loop is done for each day in that range, and each activity, to sum the cost per day. Next, to calculate the cash in, the cash out is summed monthly then assigned as a bulk minus retention and down payment, plus the markup, on the day of actual payment. The sum of the cash in is calculated as shown in Equation 3.3.

$$\begin{aligned} Cashin_{PaymentDay} =& (InvoiceSum * Markup) \\ & - (Invoicesum/TotalPrice * DownpaymentSum) \\ & - (Invoicesum * TotalPrice/RetentionSum) \end{aligned} \tag{3.3}$$

Where:

$$PaymentDay = EndOfinvoiceinterval + PaymentPeriod \tag{3.4}$$

$$DownPaymentSum = TotalProjectPrice * Downpayment\% \tag{3.5}$$

$$RetentionSum = TotalProjectPrice * Retention\% \tag{3.6}$$

The calculation of the payments follows the agreement that the down payment and retention values are deducted from the invoices by by a weighted average for each invoice. Next the down payment with a value as shown in Equation 3.5 is added to on the day of the start of the project, and the retention with a sum as calculated in Equation 3.6 is added at day when the retention is due for payment. The cash in and the cash out is now calculated. Next, the cash in cumulative and the cash out cumulative are calculated. The overdraft is calculated as the difference between them. Simply:

$$CashInCumulative = \sum_{PortfolioStart}^{PortfolioFinish} (CashIn_{day}) \tag{3.7}$$

$$CashOutCumulative = \sum_{PortfolioStart}^{PortfolioFinish} (CashOut_{day}) \tag{3.8}$$

$$Overdraft = CashInCumulative - CashOutCumulative \tag{3.9}$$

3.8 Time Value of Money Calculations

The calculations of the Present Value (PV) and the Net Present Value (NPV) is straightforward. Generally, the PV is calculated as shown in Equation 3.10. The PV in the model is calculated according to Equation 3.12, which was gotten from Equation 3.11. It should be noted that the PV is calculated at the start of the portfolio, and that the interest rate is yearly. The idea is that cash loses value with time, meaning that a sum or money has a different value depending of the time it is calculated, whether due to investment, or inflation. In the case of a contractor,the value of getting a sum of money soon, is higher that getting that same amount of money later, for example 1000 pounds having a value, or a buying power, now, that is higher than it will have in the future. This is the time value of money. The final number that measures the value of the portfolio from that point of view, is the NPV, and is shown in Equation 3.13. The NPV is calculated as the sum of the discounted overdraft for the whole portfolio, and i is the yearly interest, which is the inflation rate of the Minimum Attractive Rate of Return (MARR) of the company.

$$PV = \sum \frac{Cost}{(1 + Interest)^n} \tag{3.10}$$

$$FV = PV * (1 + \frac{i}{365})^{(}Day - PortfolioStart) \tag{3.11}$$

$$PV = \frac{FV}{(1 + \frac{i}{365})^{(}Day - PortfolioStart)} \tag{3.12}$$

$$NPV = \sum_{PortfolioStart}^{PortfolioFinish} (PV(Overdraft)_{day}) \tag{3.13}$$

3.9 Optimization

Optimization is done by first assigning lags to activities. The lags are a duration inserted to delay each activity for a number of days. The lags are assigned such as:

$$0 <= Lag_i <= TF_i \tag{3.14}$$

It should be noted that each activity can be delayed within its total float (TF). Since critical activities have a TF of 0 days, it will always be assigned a Lag of 0 days, which retains its critical state. This can be visualized as shown in Figure 3.4 where activities B and D where assigned Lags, while Activities A, C, and F are critical activities and were assigned a Lag of 0 days. Activity E became a critical activity and was assigned a Lag of 0 days as well. The previous part allowed for the creation of an new schedule to be used

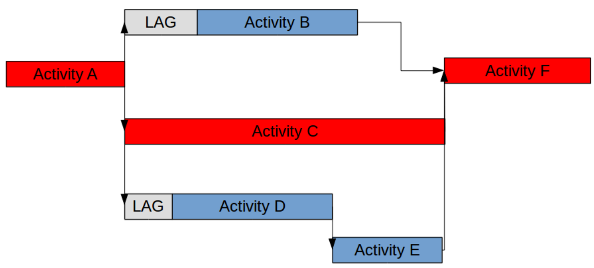


Figure 3.4: Example of an optimization trial

as a trial. The schedule then undergoes a front calculation to calculate the OS of each activity, then a the cash flow is calculated using OS and OF instead of the early starts (ES) and early finishes (EF) which was previously done to the normal schedule.

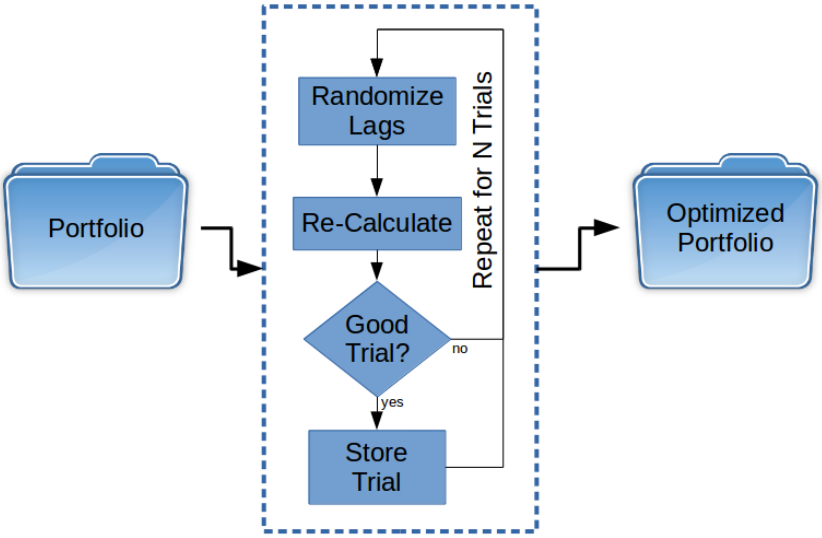


Figure 3.5: Flowchart of the optimization process

The previous part allowed for the creation of an new schedule to be used as a trial. The schedule then undergoes a front calculation to calculate the new OS for each activity. This is dependant on the relationships between activities as follows:

$$OS_{activity} = \text{MAX OF} \begin{cases} ES_{activity} + Lag_{activity} \\ OF_{predecessor} & : \text{ where relationship type is FS} \\ OS_{predecessor} & : \text{ where relationship type is SS} \\ OF_{predecessor} - DUR_{activity} & : \text{ where relationship type is FF} \\ OS_{predecessor} - DUR_{activity} & : \text{ where relationship type is SF} \end{cases} \tag{3.15}$$

What follows is the cash flow calculation just as done previously in the normal cash flow analysis but using the OS and OF instead of the ES and EF. A new Net Present Value (NPV) is calculated for the trial, then it is compared with the highest NPV reached in a previous trial or the initial NPV of the un-optimized schedule if no previous trial was done. If the NPV is a new highest, the trial is stored in the schedule and a new trial begins. To sum up, the steps are as follows:

Step 1: If not previously done, the portfolio is calculated for scheduling and cash-flow.

Step 2: The lags are initiated as per Equation 3.14

step 3: The OS and OF of each activity is calculated as per Equation 3.15

Step 4: The cash-flow is calculated using OS and OF

Step 5: Compare new NPV with last best NPV or initial portfolio NPV if this is the first trial. If current trial is a new optimum: store it, otherwise: discard it.

Step 6: Proceed to Step 2 again if number of trials done is less than the targeted number of trials. Otherwise, finish.

3.10 Graphical User Interface (GUI)

A GUI was developed, as specified in the Methodology, using a package called "Tkinter" from the Python standard library. It can be used to create new projects and activities, delete them if necessary, display tables containing them, and it can display plots for the Gantt charts and the cash flow. A screen shot of the GUI on startup is shown in Figure 3.6. The main tool-bar in the top area of the window has seven menus.

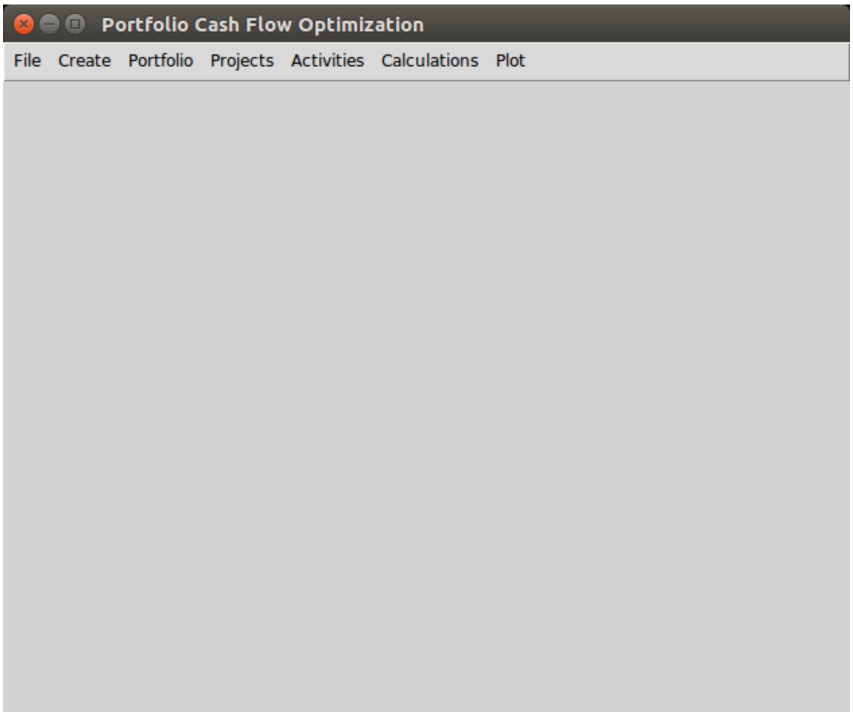


Figure 3.6: Graphical User Interface (GUI) on start-up

The fist menu, as shown in Figure 3.7, allows the user to: clear all data; create a new random portfolio, for testing or used as a demo; import validation portfolio, which is a large portfolio used for the validation of the model; "Database Info" will display information about the database, number of projects and activities and relationships, and other useful information; clean database is self explanatory, it will delete create a new empty database, "Export" will export spearsheets, csv files, plots in PDF format, and logs in txt format for the portfolio and the calculations; "Verify" and "Validate" buttons are used to automate the verification and validation process by importing, calculating, optimizing, and exporting.

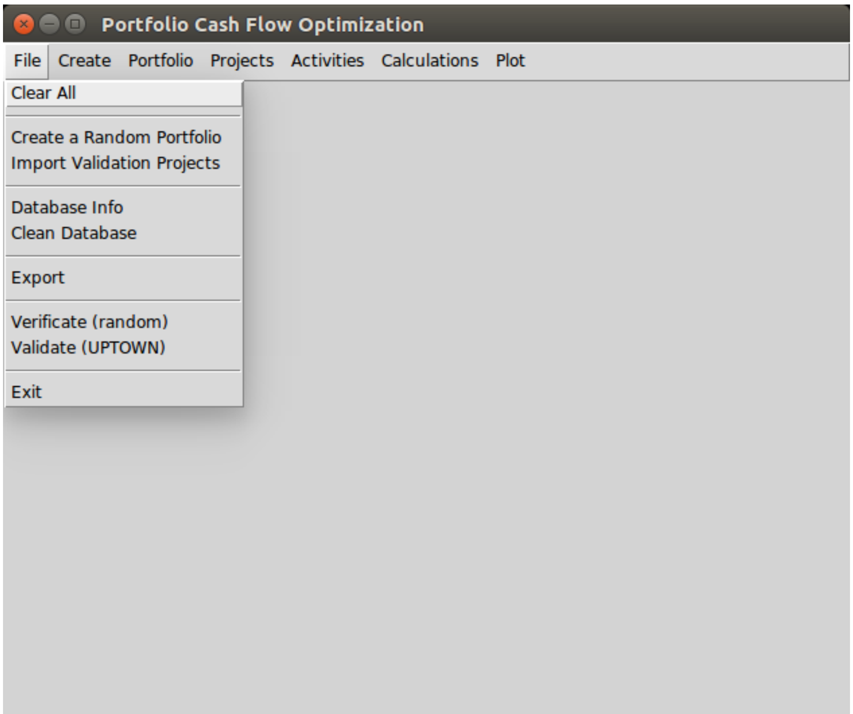


Figure 3.7: GUI: File Menu

The "Create" menu allows for the creation of new projects, activities, or relationships, as shown in Figure 3.8. Each button will show its respective item creation window. The window for the creation of a new project is shown in Figure 3.9, and it requires the project id, name, start, interest, markup %, downpayment %, Invoice interval in days (the time duration between invoices), payment period, retention %, and the retention duration. The window for a new activity is shown in Figure 3.10 and it requires the project for the activity, the activity ID, name, duration in days, and the cost. Finally, the window for a new relationship is shown in Figure 3.11 and it required the project id, the preceding activity id, the successive activity id, and the relationship type, which can be FS, SS, SF, or SS.

Figures 3.13 and 3.14 show the menus that enable the user to see a table of the portfolio, activities, or the relationships. Each one shows its respective table that lists the parameters for each item, these include the inputs and outputs. Figure 3.15 shows the "Calculations" menu, which executes the calculation or the optimization. The calculation must be done for the portfolio before the optimization, in case the portfolio wasn't calculated before, otherwise the optimization will fail to run. Finally, Figure 3.16 shows the plots menu, which enables the user to see many plots for the portfolio, which includes the Gantt charts, cash flows, and overdrafts, optimized or not optimized, as well as discounted to their Present Value, or not discounted.

Examples of the previously mentioned tables are shown in Figures 3.17, 3.18, and 3.19 . First, Figure 3.17 shows the table for the activities, which includes all activities in the

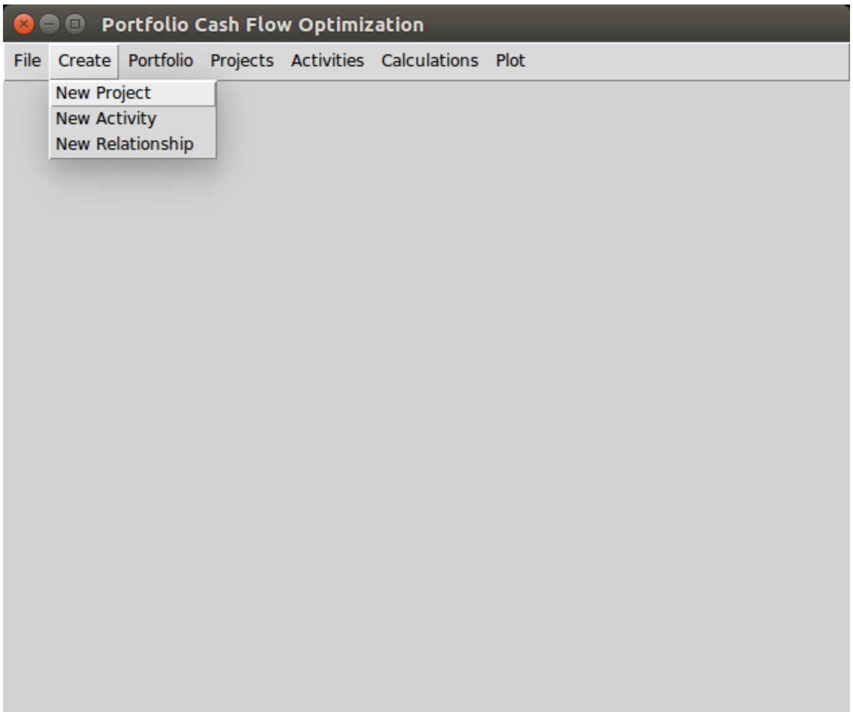


Figure 3.8: GUI: Create New Project Window

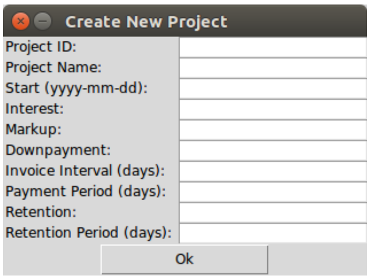


Figure 3.9: GUI: Create New Activity Window

portfolio. All parameters and properties for the activities are shown in that table, including the IDs, names, durations, CPM calculations, lags from the optimization algorithm, and others. Similarly, Figures 3.17 and 3.18 show the tables for the portfolio and the prejects, respectively. Again, the tables include all properties for all items. The tables shown in the figures can be scrolled vertically and horizontally to see the remaining items and fields.Also, the user is able to delete selected items

Figure 3.20 shows the Gantt chart for all activities in the portfolio ar their earliest start state. Activities in red are critical activities. Green activities are non-criticalm and their total float marjed in a thin blue bar. Arrows mark the relationships between the activities, where the head of the arrow points to the successor. The location of the arrow on each activity depends on the type of the relationships, so for example a Finish to Start will have an arrow from the end of the predecessor to the start of the successor, and others realtionship types have similar logic.

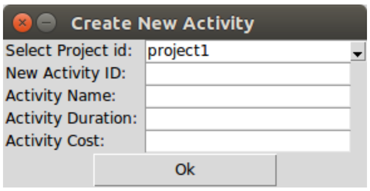


Figure 3.10: GUI: Create New Activity Window

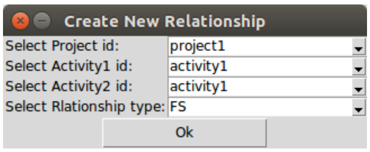


Figure 3.11: GUI: Create New Relationship Window

Figures 3.21 and 3.22, show plots of the overdraft vs. time. The first shows the plot for a random portfolio, while the other shows an overlay of the optimizes overdraft on the non-optimized for the same portfolio. Finally, Figure 3.23, shows an optimized Gantt Chart; the thin grey bars span from the Early Start to the Late Finish of each activity. The activity bars are marked in green or red depending on their criticality. This visualization ensures that the user can easily understand the effect of the optimization on the schedule.

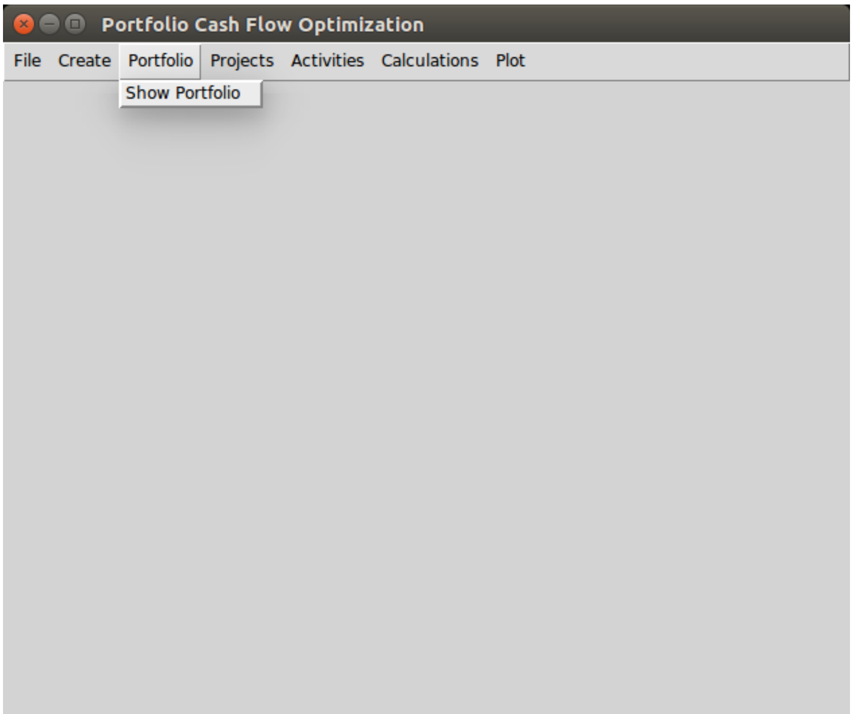


Figure 3.12: GUI: Portfolio Menu

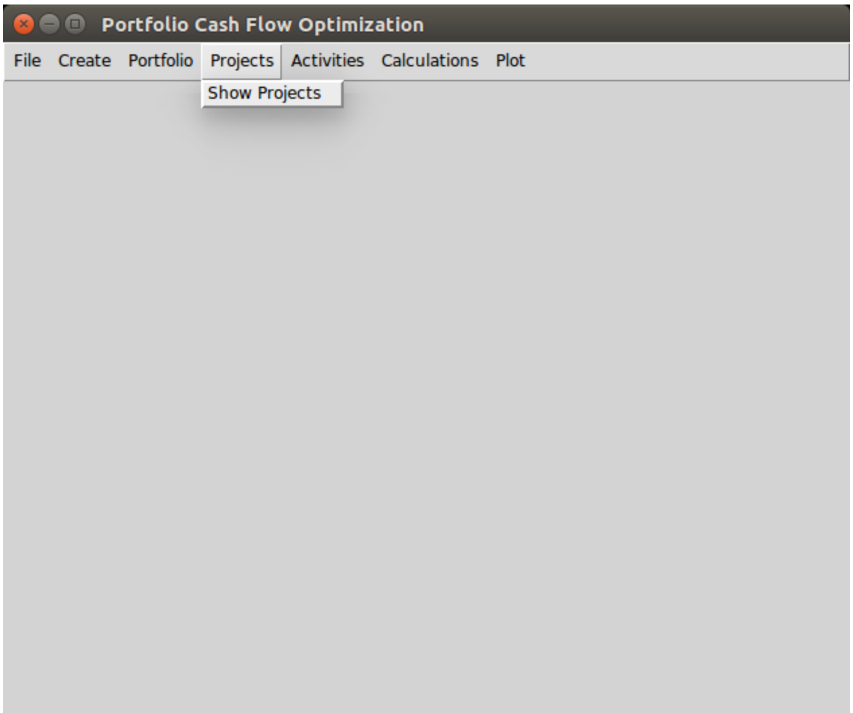


Figure 3.13: GUI: Projects Menu

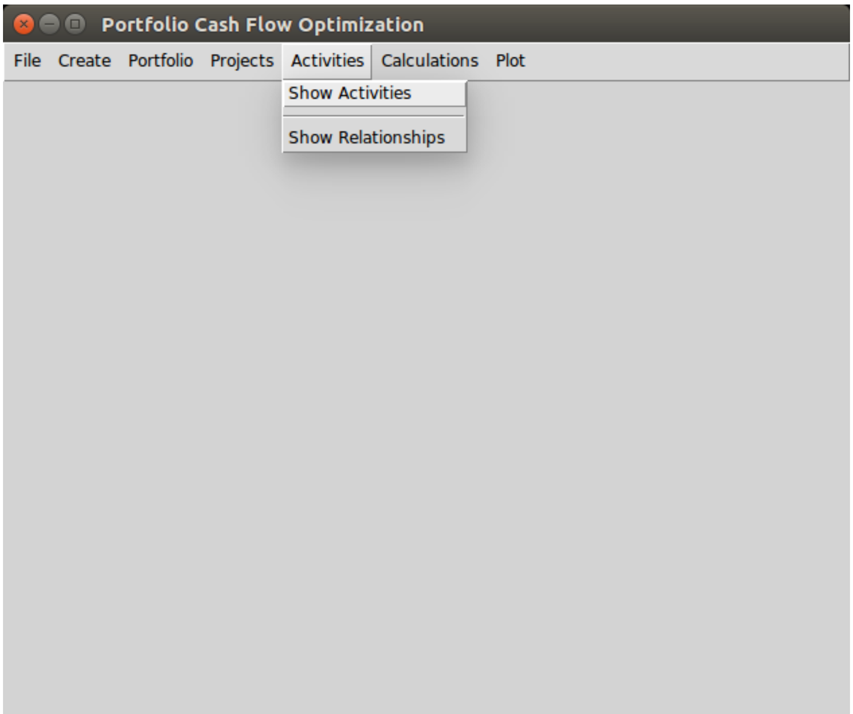


Figure 3.14: GUI: Activities Menu

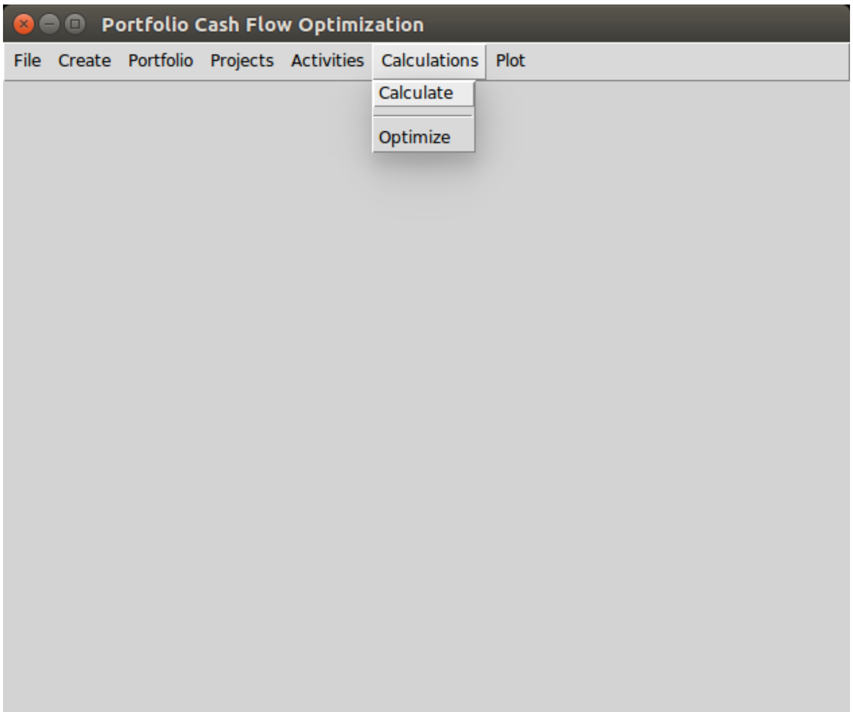


Figure 3.15: GUI: Calculations Menu

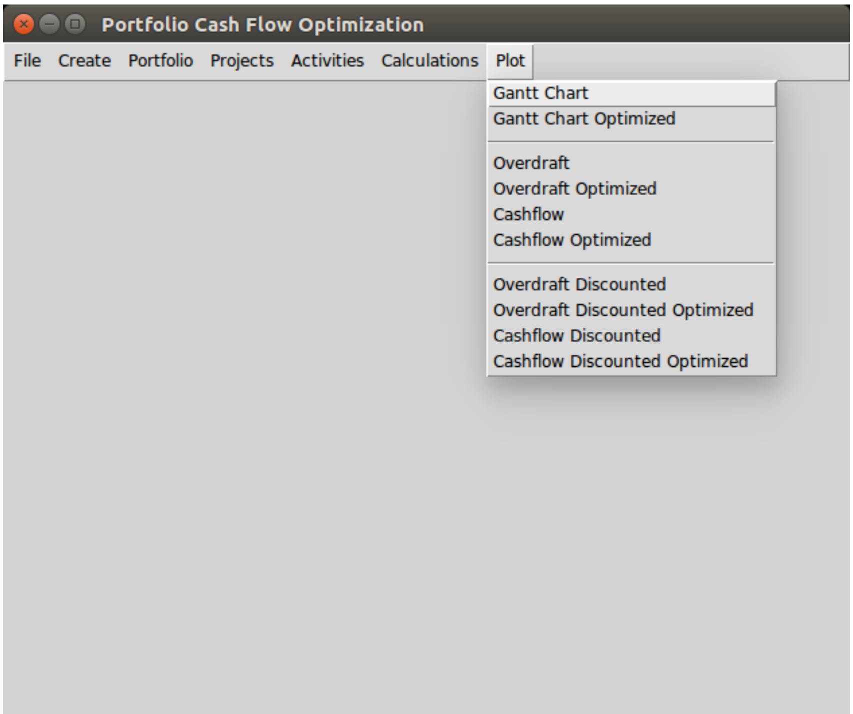
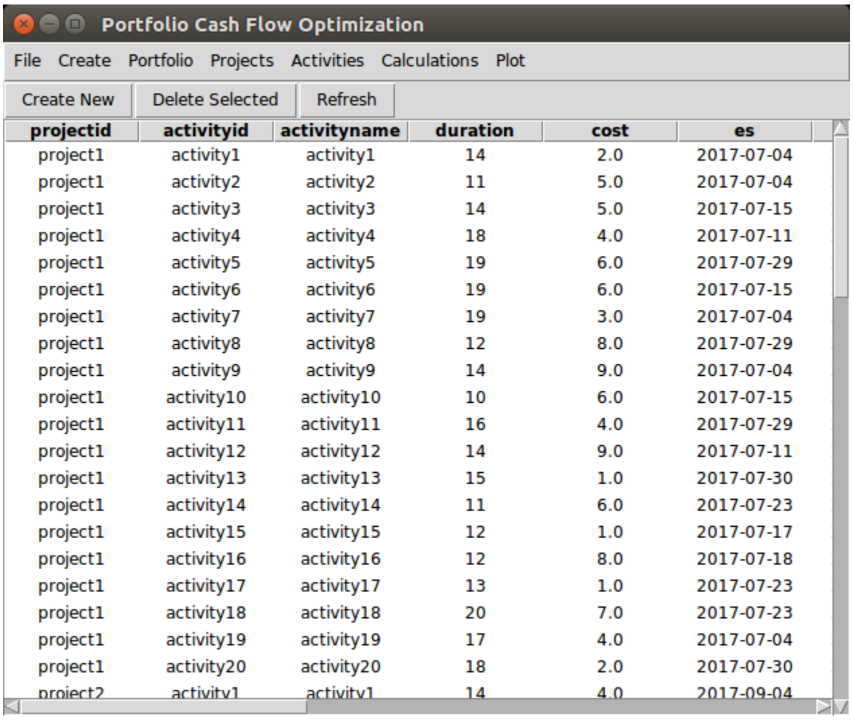


Figure 3.16: GUI: Plot Menu



projectid	activityid	activityname	duration	cost	es
project1	activity1	activity1	14	2.0	2017-07-04
project1	activity2	activity2	11	5.0	2017-07-04
project1	activity3	activity3	14	5.0	2017-07-15
project1	activity4	activity4	18	4.0	2017-07-11
project1	activity5	activity5	19	6.0	2017-07-29
project1	activity6	activity6	19	6.0	2017-07-15
project1	activity7	activity7	19	3.0	2017-07-04
project1	activity8	activity8	12	8.0	2017-07-29
project1	activity9	activity9	14	9.0	2017-07-04
project1	activity10	activity10	10	6.0	2017-07-15
project1	activity11	activity11	16	4.0	2017-07-29
project1	activity12	activity12	14	9.0	2017-07-11
project1	activity13	activity13	15	1.0	2017-07-30
project1	activity14	activity14	11	6.0	2017-07-23
project1	activity15	activity15	12	1.0	2017-07-17
project1	activity16	activity16	12	8.0	2017-07-18
project1	activity17	activity17	13	1.0	2017-07-23
project1	activity18	activity18	20	7.0	2017-07-23
project1	activity19	activity19	17	4.0	2017-07-04
project1	activity20	activity20	18	2.0	2017-07-30
project2	activity1	activity1	14	4.0	2017-09-04

Figure 3.17: GUI: Activities Table

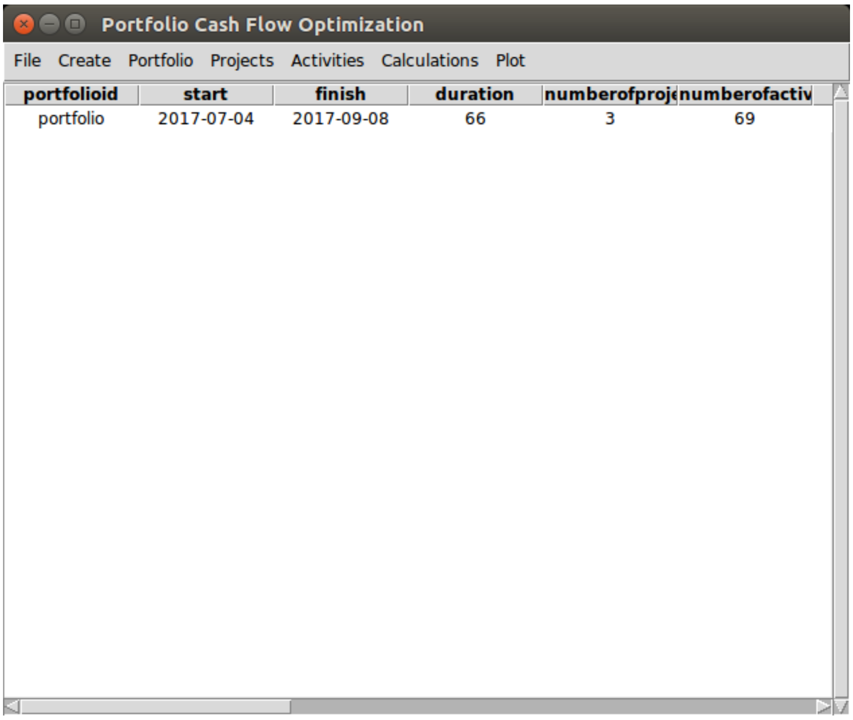


Figure 3.18: GUI: Portfolio Table

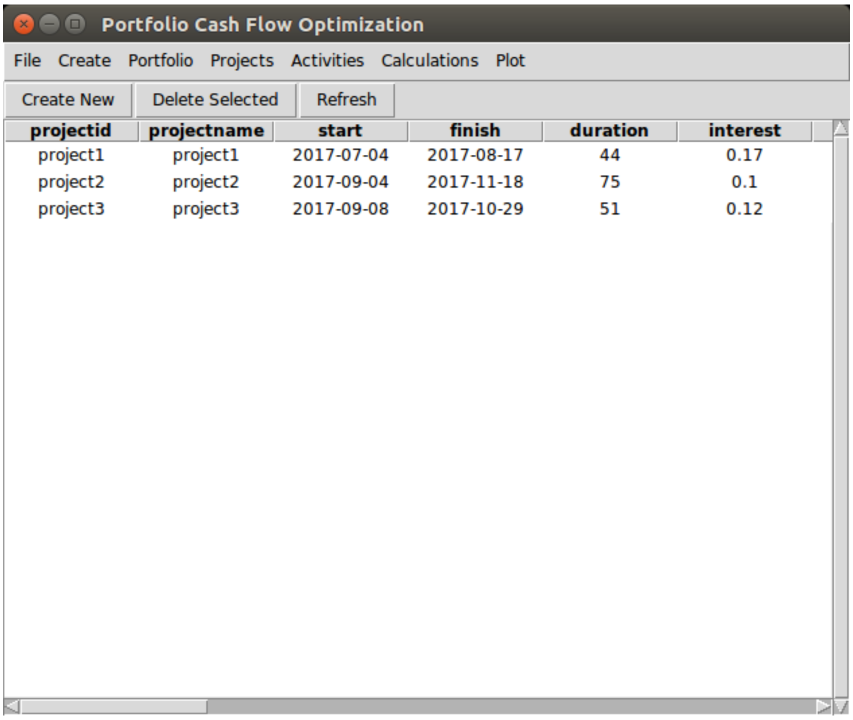


Figure 3.19: GUI: Projects Table

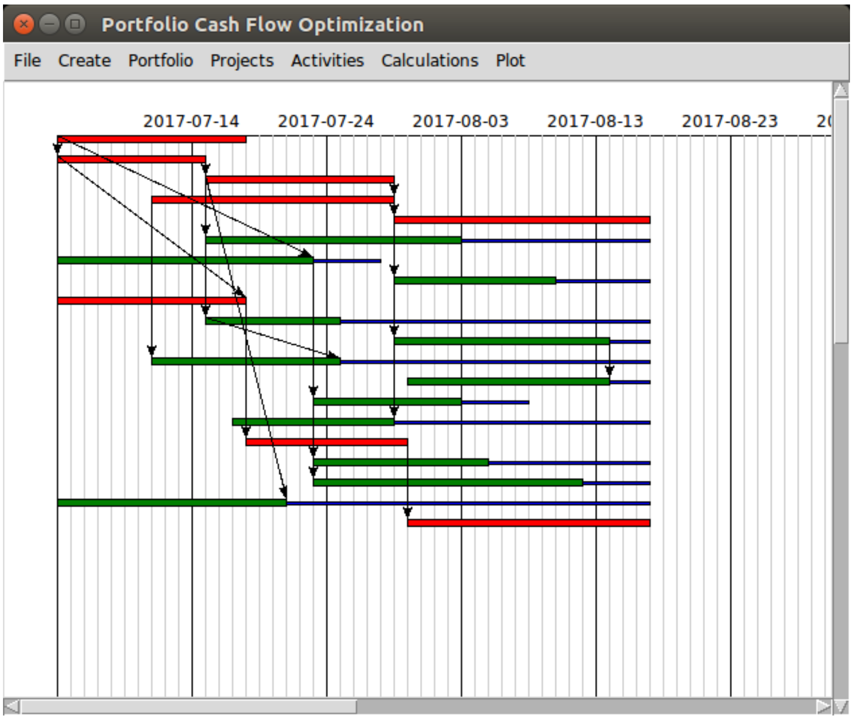


Figure 3.20: GUI: Gantt Chart

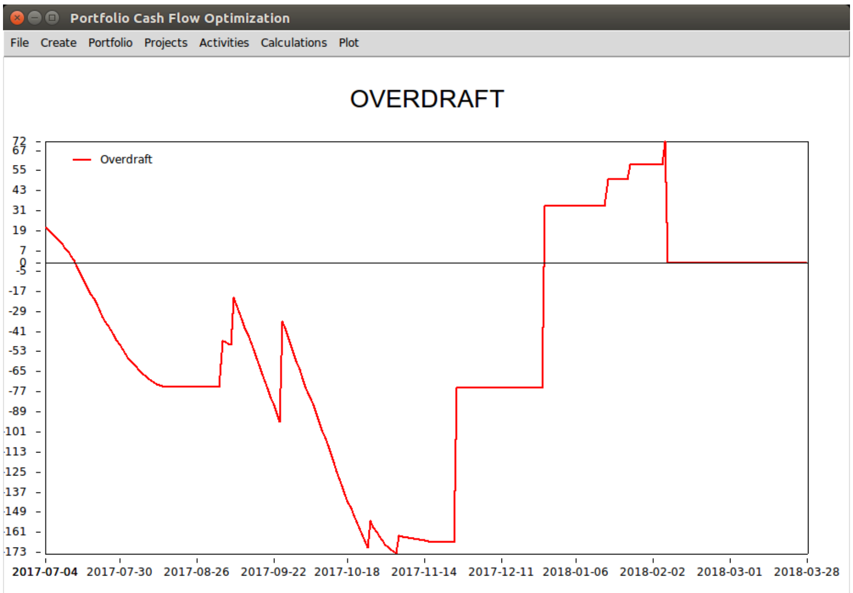


Figure 3.21: GUI: Overdraft Plot

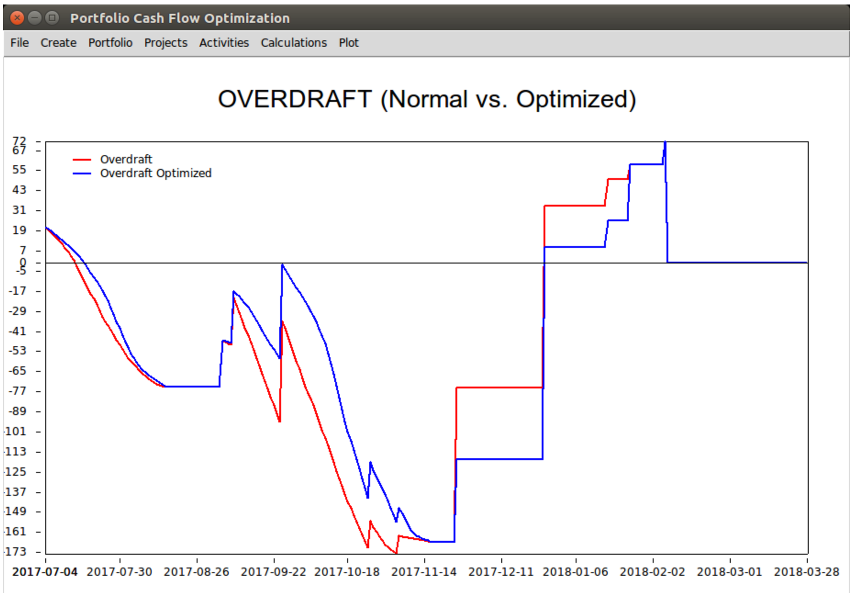


Figure 3.22: GUI: Optimized Overdraft Plot

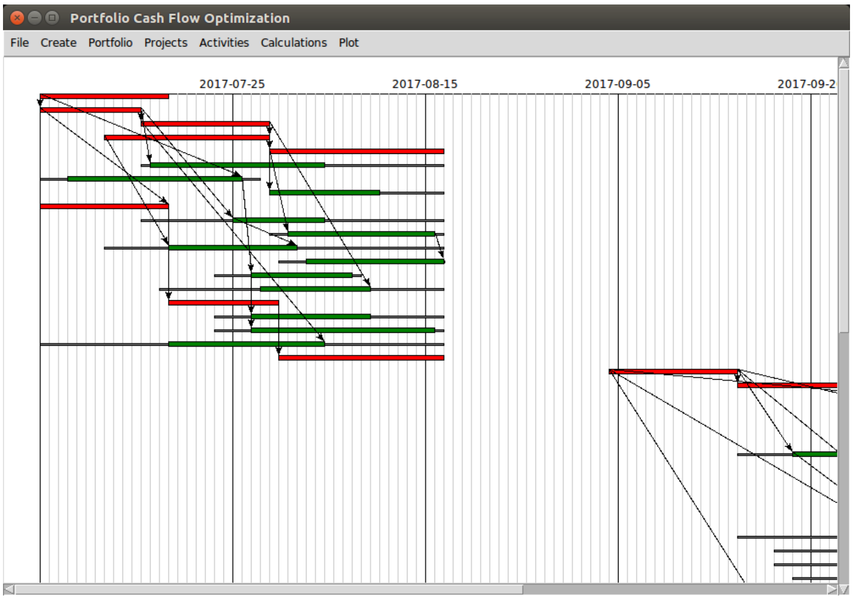


Figure 3.23: GUI: Optimized Gantt Chart

Chapter 4

Results and Discussion

This chapter will cover the results of the model. This includes the verification which was done using randomized sets of portfolios, the sensitivity analysis using the interest rate and the cost as the parameters under study, a CPU time test. Finally, the results of the validation, which was done using a real and very large portfolio, are described and discussed. The entire Python Code used is available in Appendix A.

4.1 Verification

4.1.1 Verification Method

Verification was done using randomly generated sets of portfolios. An algorithm was written to generate random portfolios with random number of projects, activities, and all needed parameters. The randomized portfolios then undergo analysis and optimization. For the sake of verification, the portfolios generated had 3 projects each, where each project had a random number of activities between 25 to 30 activities. The start of each project was randomized for up to 300 days from the start of the portfolio. Each activity, except one activity had a random number of predecessors where the probability of having one relationship was 75% and the probability of having 2 relationships was 25%, while the relationship type was equally randomized. Other parameters for duration, costs, and financial parameters were randomized as well. The stopping criteria is an improvement of 0.002% on a moving average of the last 3 best trials, or 20 trials with no improvement. Various other settings were tried as well, including the financial parameters to test the model, but they are fixed for the examples given in this section. The randomization of the parameters for the verification created random portfolios with different durations, number of activities, and relationship types, which tested the performance of the model thoroughly.

4.1.2 Verification Results

For the purpose of this thesis, five verification trials are presented. More were done to and they resulted in the same conclusion. Figure 4.1 shows the 5 portfolios used for the verification, and as mentioned earlier they are completely randomized. The Gantt charts of the portfolios are shown in Figure 4.2, showing the start and end of each project in each of the five portfolios. The activities contained in them as shown in Figure 4.3. As the portfolios are random, they have a random number of activities, and the criticality ratio is also variable. Figure 4.4 shows the Gantt chart of the projects, where each project has a random start dates, duration, and finish dates. The activities contained in the projects, as shown in Figure 4.3, are also randomized. So, generally this methodology allows for the rigor testing of the model under different conditions.
Moving fast forward to the optimization, then to the optimized cash flows. Figure 4.5 shows the optimization process in an informative plot where the trial NPV is plotted against the number of trials. It can be noted that the model converges in all cases. In some rare cases, the optimum NPV occurs when the activities have an early start state, therefore the model won't improve, otherwise the model converges. The optimized cash flow in shown in Figure 4.6. The optimized overdraft is shown in Figure 4.7.

4.1.3 Verification Discussion

The methodology of the verification allowed for the rigor testing of the model, by creating custom randomized portfolios to test different costs, interests, number of activities, different relationship types, etc. The random sets used are shown in Figure 4.1, and were successfully randomized; the number of activities are different and the number of critical activities are different for each project. As shown in Figure 4.3, the model successfully scheduled the activities in each project according to their assigned relationships, which are indicated by arrows, and as shown in Figure 4.2, the model succeeded in calculating the start and end of each portfolio according to the scheduling of the activities in them.
Next, for the cash flow analysis, Figures 4.6 and 4.7 show that the calculation of the cash flow and overdraft, before optimization, was successful; the cash out has an shape similar to an S-curve, to some extent, which is typical to constriction project, and the end of the cash-out sums up to the total cost of the portfolio; the cash in has steps matching the down-payments, invoice payments, and retention receipts at the end of the projects, and the curve ends with a value equal to the total price of the portfolio; while the overdraft is correct as it matches the difference between the cash in and the cash out curves, with an end value that matches the profit from the portfolio.
In the same Figures (4.6 and 4.7), the discounted value, the Present Value (PV), of the cash flow curves and the overdraft curves are increasingly lower than the Future Value (FV) curves for each point in time as the time increases. This is due to the power of the

time value of money because a sum of money will have a lower value as time progresses. Finally, for the optimization, the trials are shown in Figure 4.5, and Net Present Value (NPV) which is the objective of the optimization, is converging to a maximized value in progression with the number of trials. The stopping criteria for the max number of trials, which was 20 trials, was the deciding factor in the sets under study. The optimized Gantt charts for the projects are shown in 4.4, where the activity Optimized Start (OS) was set to a value in their total float, and the relationships between them were also respected. The effect of the optimization is shown for the cash flow in Figure 4.6 and for the overdraft in Figure 4.7. The optimization seems to have generally modified the start of the activities in a way that would balance between receiving cash as early as possible, while at the same time reducing the peaks in the overdraft. So the NPV, as an indicator, may have solved multiple objectives. This seems logical because in real life, a contractor would rather receive cash early, for investment in other projects, and at the same time should attempt to reduce maximum overdraft to reduce the investment from the company's resources or external loans. In overall regarding the optimization, it is successfully converging and had positive effects on the cash flow of the portfolio. The outcomes of the verification are satisfying; the cash flows and the overdrafts have typical shapes for construction projects. Checks on the values were matching. The optimization process converged in all cases. The optimization seemed to find a balance between getting payments early for maximum time value of money, and getting a lower negative cash flow, as it is noted that the peaks in the cash flow are affected by the optimization.

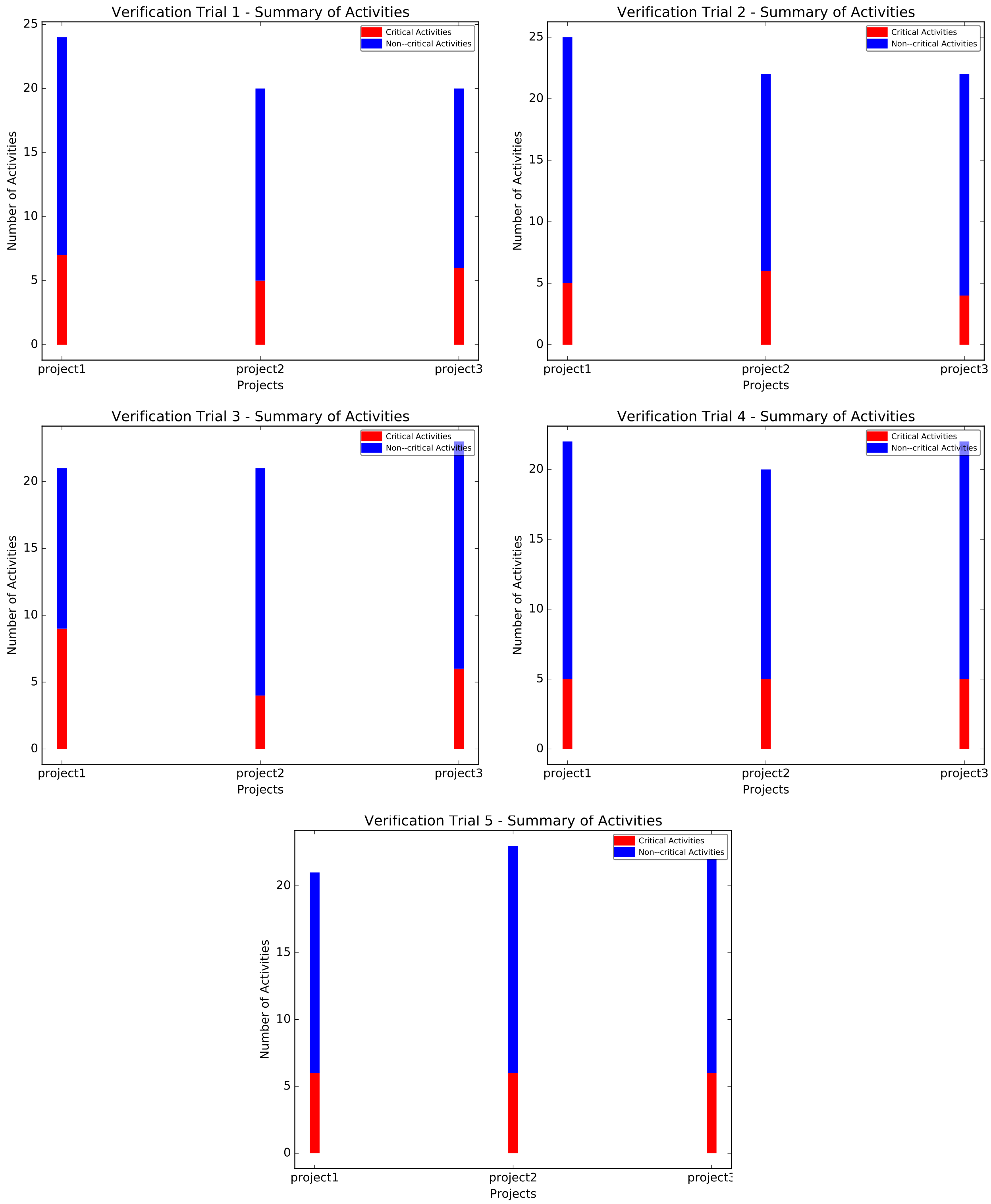


Figure 4.1: Summary of the five portfolios used and their project Gantt charts

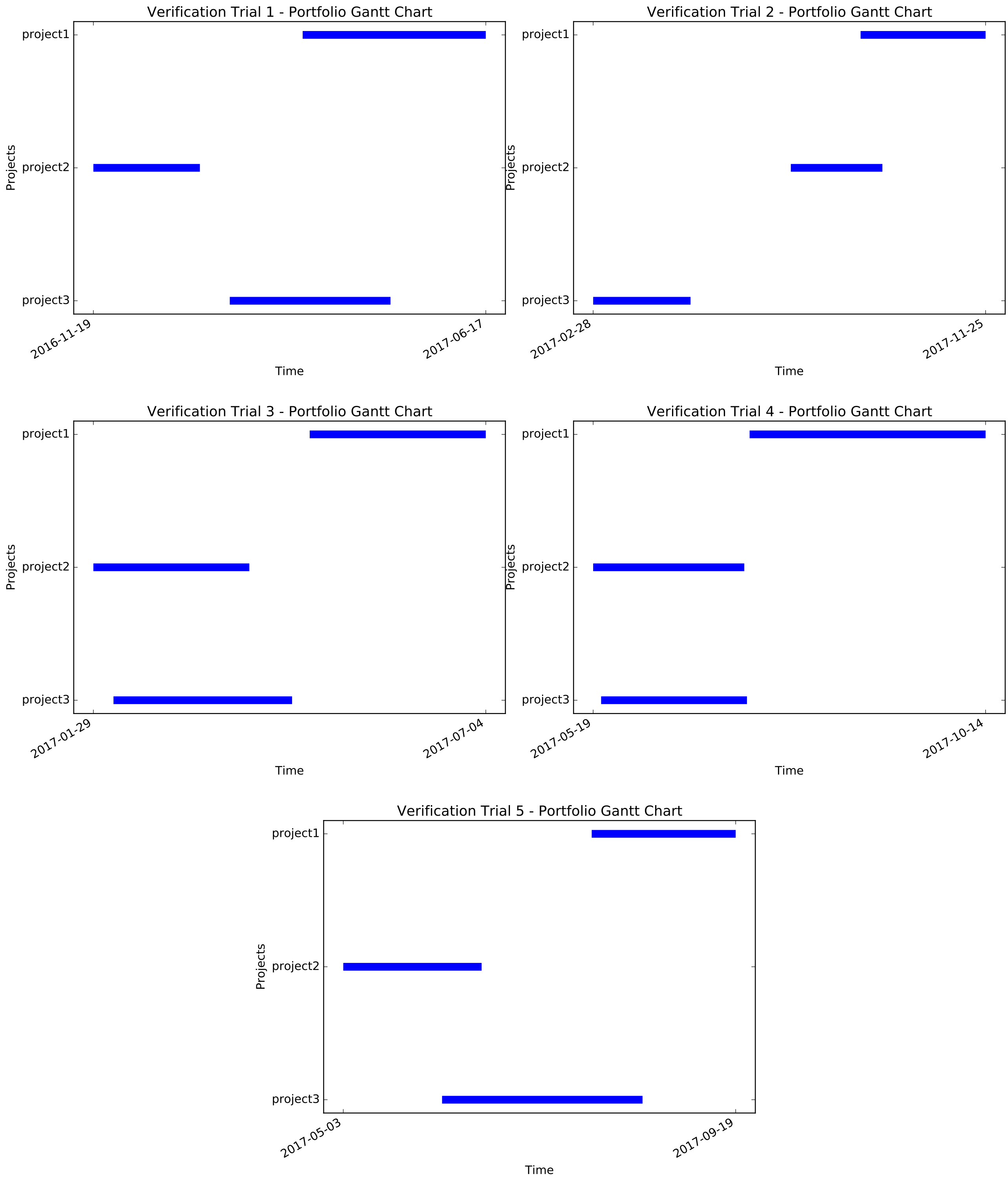


Figure 4.2: Summary of the five portfolios used and their project Gantt charts

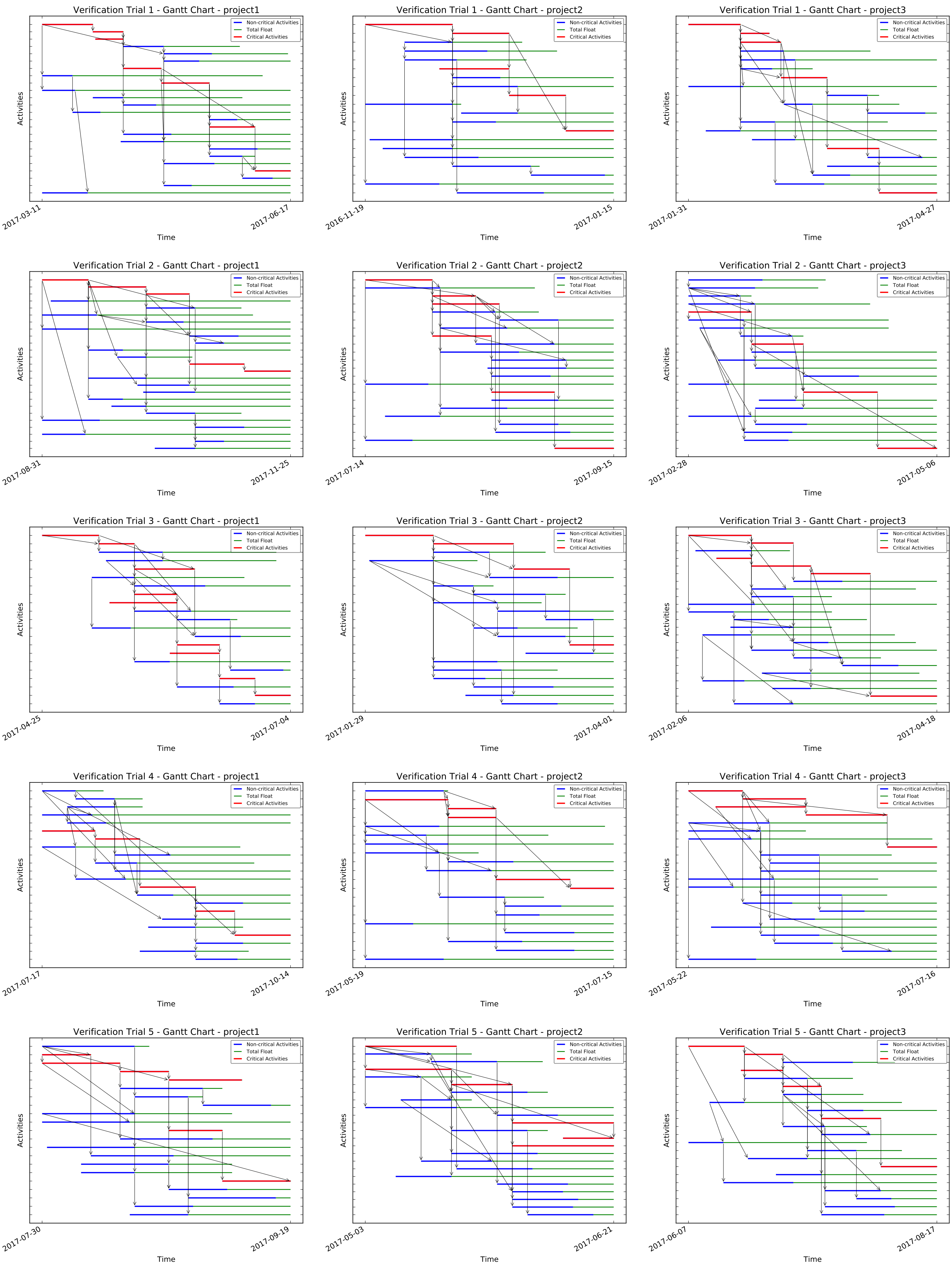


Figure 4.3: Gantt charts for the verification projects

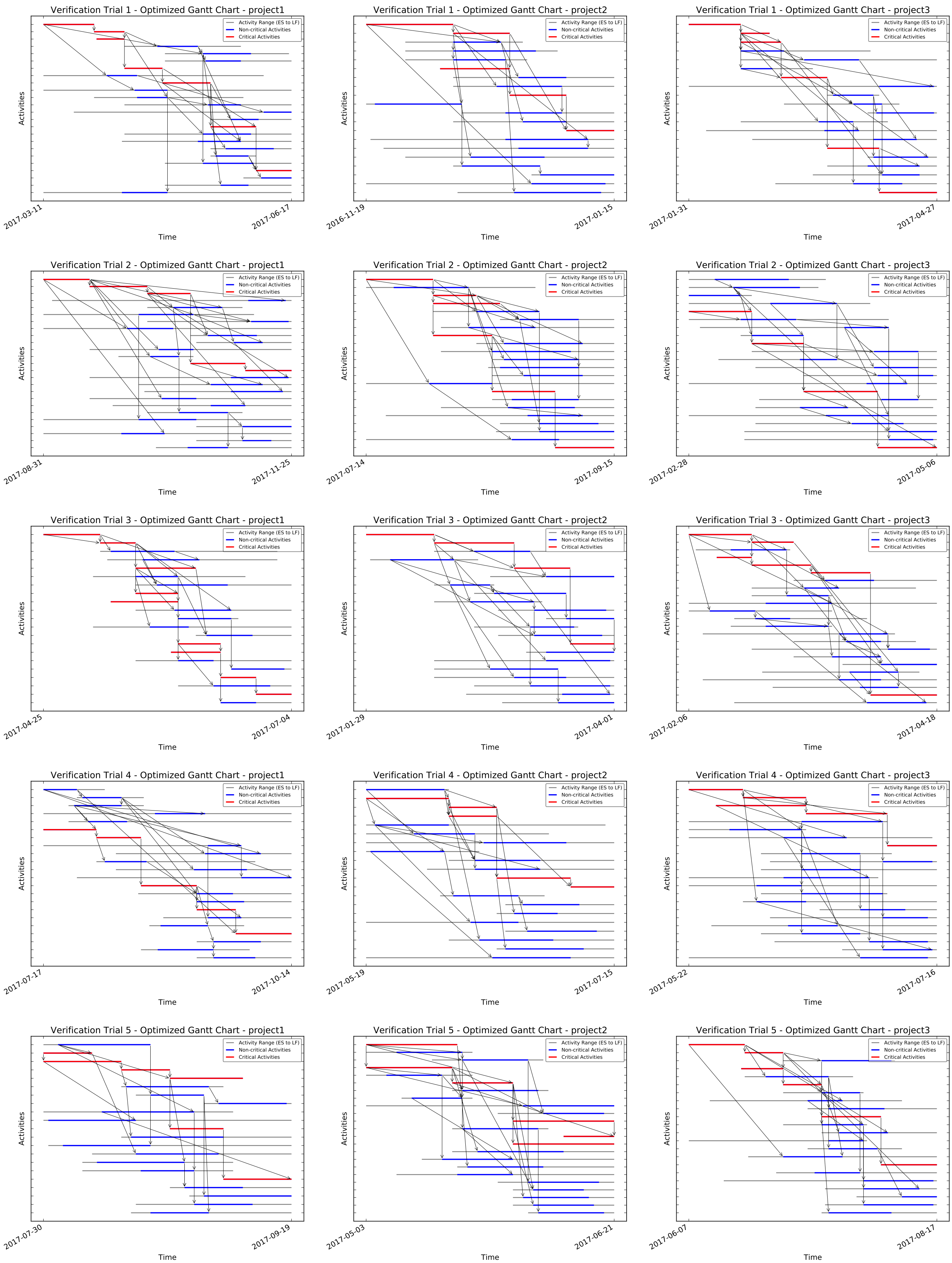


Figure 4.4: Optimized Gantt charts for the verification projects

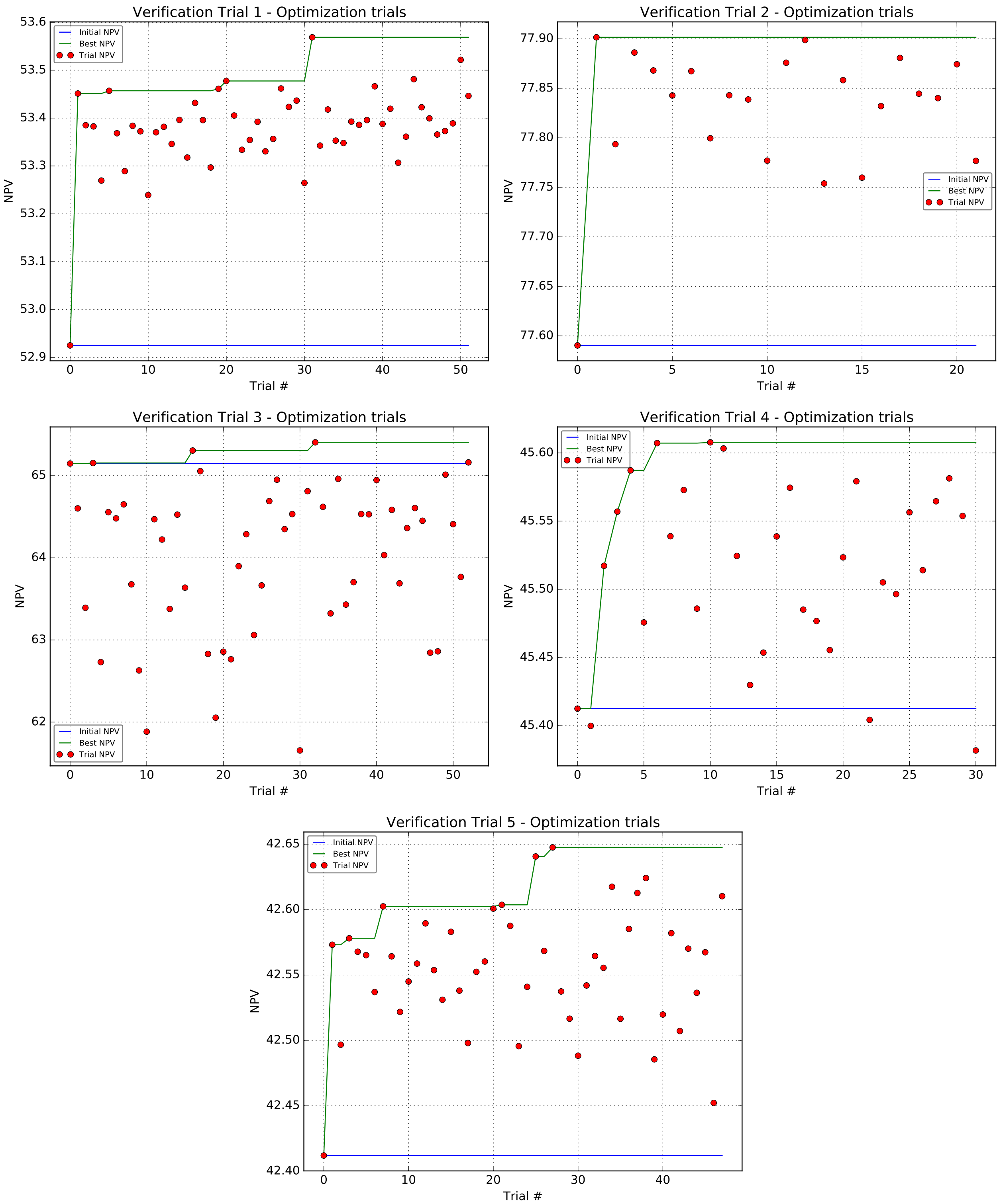


Figure 4.5: Optimization trials for each on the 5 portfolios

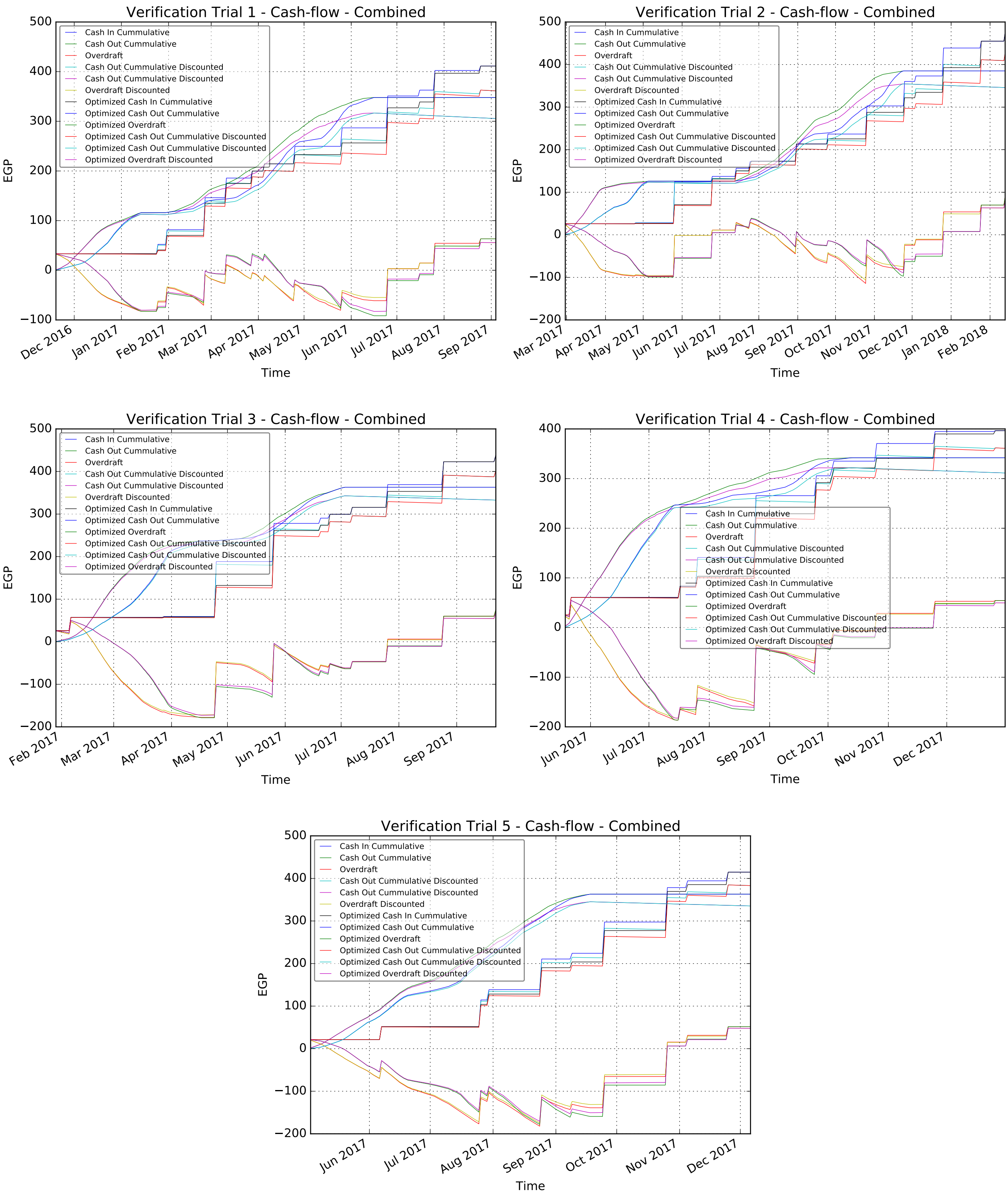


Figure 4.6: Optimized Cash Flow for the Portfolios

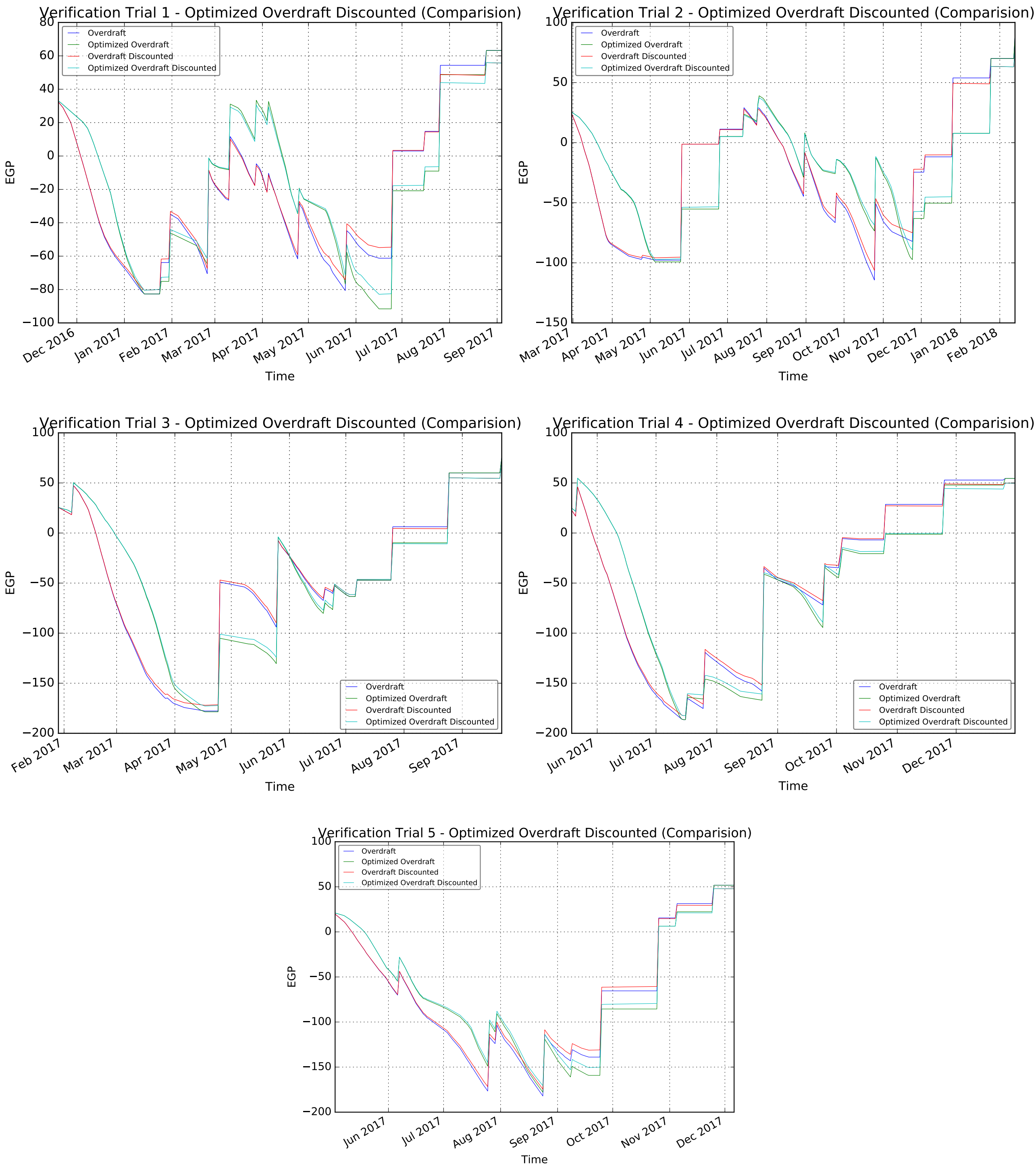


Figure 4.7: Optimized Overdraft for the Portfolios

4.2 Sensitivity Analysis

4.2.1 Sensitivity Analysis Method

A sensitivity analysis was conducted to ensure that the final main result, the Net Present Value (NPV), is calculated correctly according to other parameters. Two parameters were chosen, they are the interest rate and the cost, and their implication on the NPV for a chosen portfolio was tested. The interest was tested from 0 to 50 per cent, with increments of 2 per cent. This parameter was initialized for each project in the portolio, and the NPV was calculated for each. While, for the sensitivity analysis of the the cost, the costs for the activities was incremented for up to 200 per cent of the original cost, with increments of 10 per cent. This increased the cost of the portfolio and the NPV was calculated as such.

4.2.2 Sensitivity Analysis Results

The results for the Interest Rate sensitivity analysis is shown in Figure 4.9, the plot shows a slight second degree curve. while for the sensitivity analysis for the cost which is shown in Figure 4.8, the plot resulted in a straight first degree line. An overlay of the sensitivity analysis for the interest rate and the cost combined is shown in 4.10. The same plot but with the NPV measured in percentage increase, for easier analysis, is shown in Figure 4.11.

4.2.3 Sensitivity Analysis Discussion

The charts obtained from the sensitivity analysis of the cost and interest rate against the NPV matches expectations perfectly. To begin with the sensitivity analysis for the interest rate, it was expected to be a curve, because ,as discussed before in Section 3.8, the NPV is calculated generally as shown in Equation 4.1. So, due to the fact that the interest is raised to the power of the time period, it has a curve. As for the sensitivity analysis for the cost, and again in accordance with Equation 4.1, the relationship between the cost and the NPV is linear, therefore the plot shows a straight line. This concludes that the model behaves correctly regarding these main parameters.

$$NPV = \sum \frac{Cost}{(1 + Interest)^n} \tag{4.1}$$

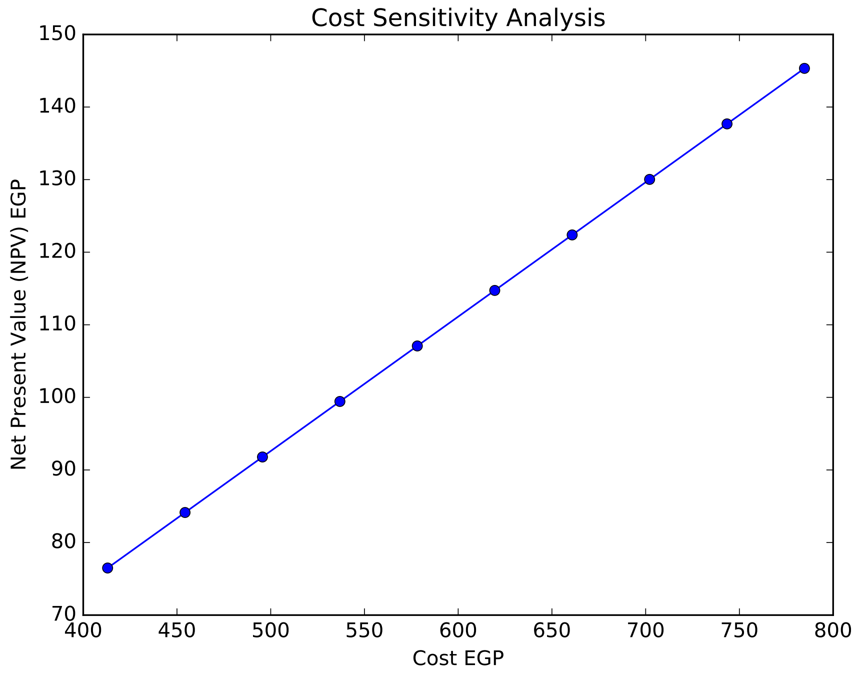


Figure 4.8: Cost Sensitivity Analysis

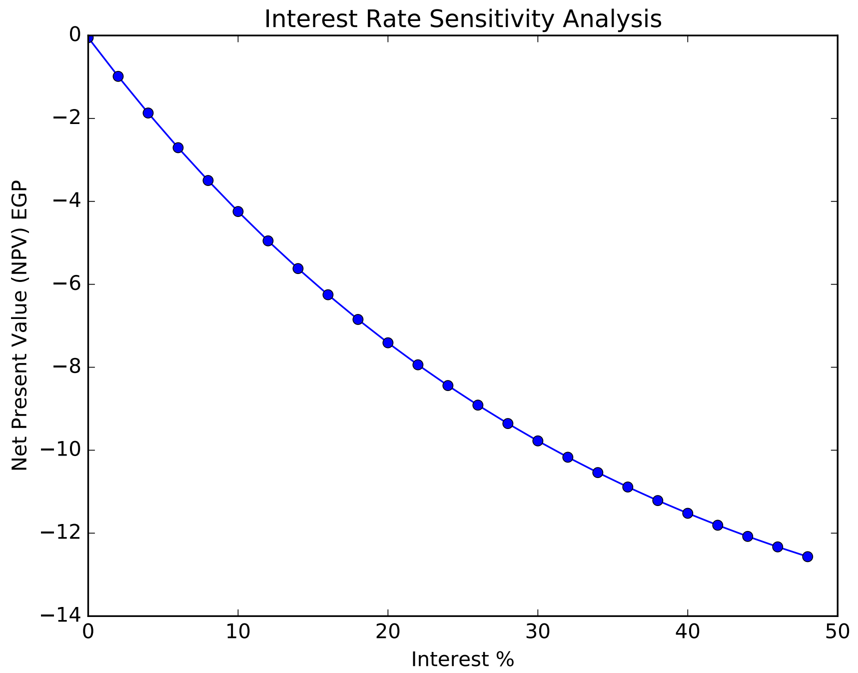


Figure 4.9: Interest Rate Sensitivity Analysis

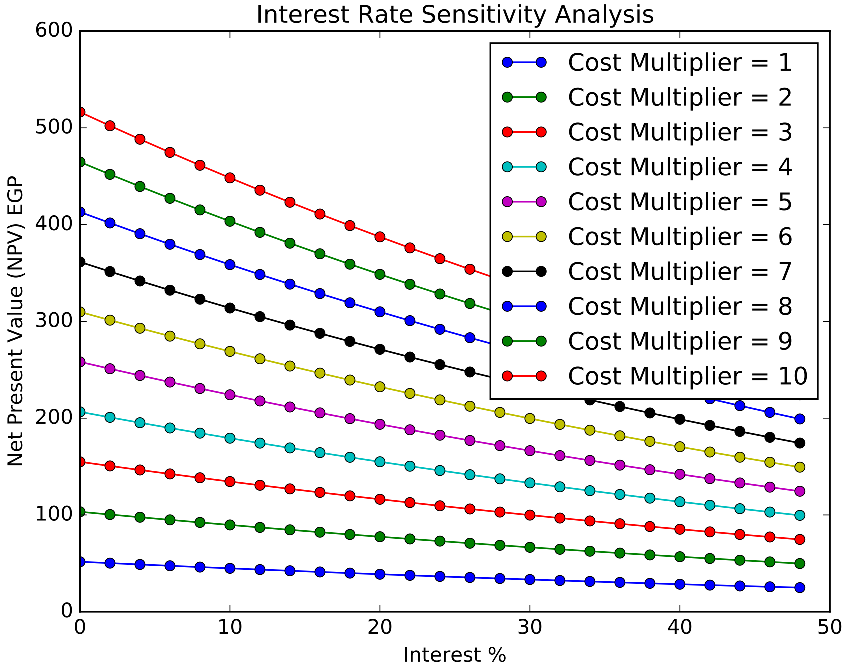


Figure 4.10: Overlay of The Sensitivity Analysis Results for Interest Rate and Cost

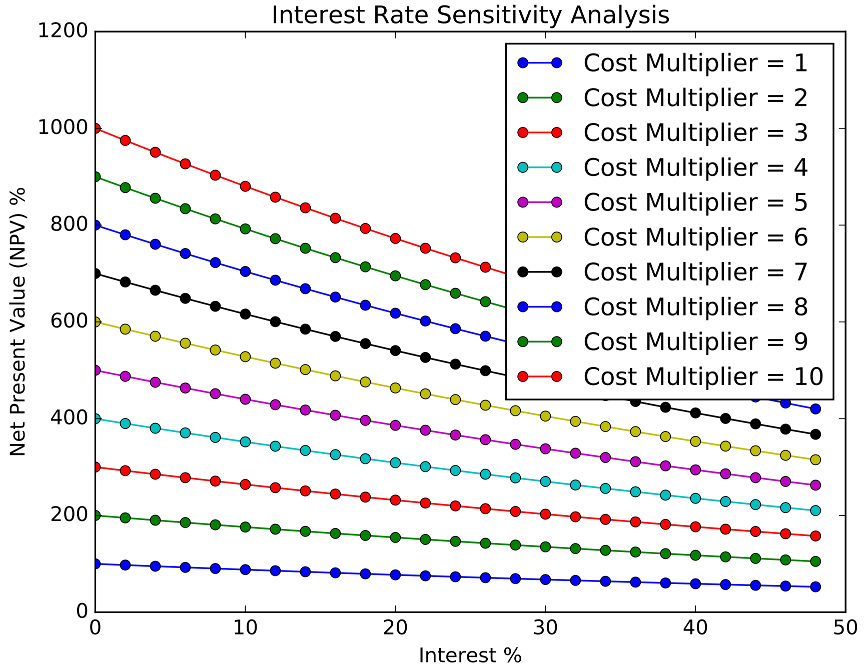


Figure 4.11: Overlay of The Sensitivity Analysis Results for Interest Rate and Cost in percentage increase

4.3 NPV Improvement Test

4.3.1 NPV Testing Method

This test was done to indicate the impact of the model on the improvement of the NPV. This was done by using the same methodology for the verification, but repeated or a number of trials to get different optimized NPVs. Portfolios were generated randomly with the following conditions: each portfolio had three projects, and each project had 20 to 25 activities. Each project's start date was set randomly for up to 300 days from the start of the first project. The interest, markup, and down-payment percentages were set as 10 to 20%, 15 to 25%, and 15 to 25%, respectively. The payment period and the retention period were set to 56 and 80 days, respectively. The test was done for 200 trials and the values were recorded.

4.3.2 NPV Testing Results

This results of the test are shown on Figure 4.12. The x-axis shows the improvement as $NPV_{Optimized}/NPV_{Original}$. It shows that most of the numbers lie between 0.5% to 1% improvement. For some projects, that value increased for up to 2.5%.

4.3.3 NPV Testing Discussion

The test showed that the improvement in the NPV that the model can achieve relies heavily on the nature of the project, this is includes the number of activities, the relationships between them, and the available float, as well as the financial parameters for the projects. In some projects, the optimized NPV is the original NPV, which means that the early start and finish state of the activities is the optimum case and no improvement can be made. Generally, the percentage of improvement for the NPV is small, but for large projects it is significant as a sum of money.

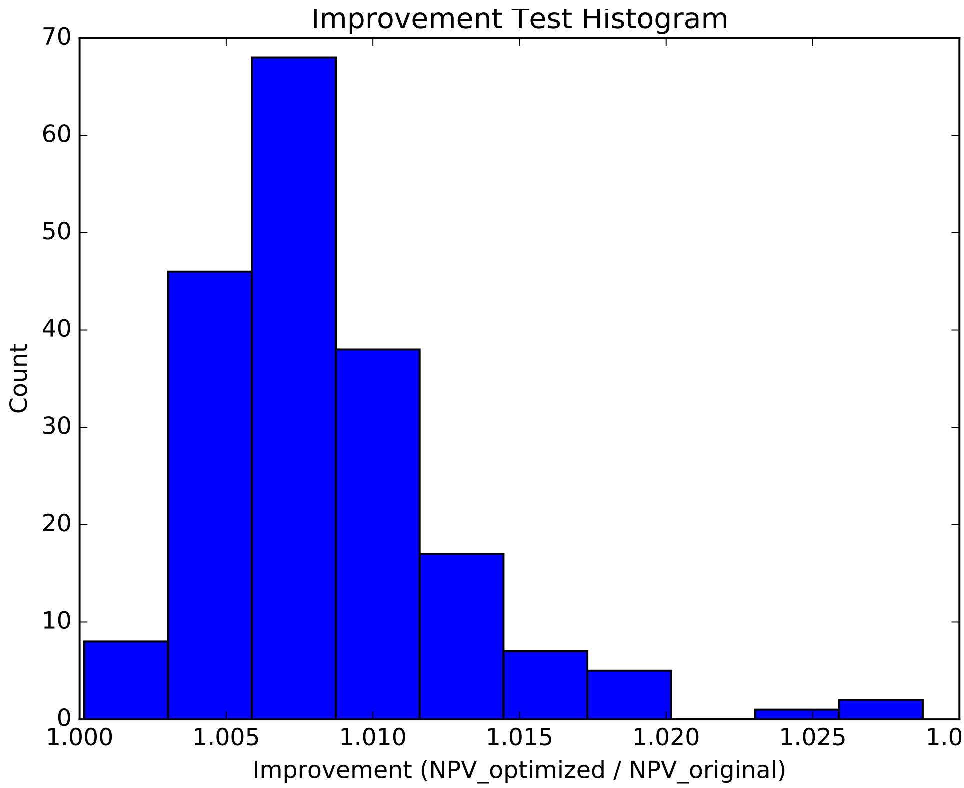


Figure 4.12: Histogram of Improvement in NPV for the trials.

4.4 CPU Time Test

4.4.1 CPU Time Test Method

A test for the CPU time was done to relate it to the size of the portfolios. Trials were done for random portfolios where each one had 3 projects that contained between 50 and 2000 activities. The stopping criteria was the same as the verification, and the randomization of the relationships was done in the same way as well. The time to optimize each project was recorded. In order to compare those time durations with the size of the projects, Correlation was done between time, number of activities, number of relationships, number of activities + number of relationships, and the number of activities * number of relationships.

4.4.2 CPU Time Test Results

The correlation results are shown in Table 4.1. There is a fair and approximately equal correlation between time and the other variables. A plot between CPU Time Vs. Number of Activities + Number of Relationships is shown in Figure 4.13. There is a positive correlation between those variables, but the deviation increases as the number of activities and relationships increase.

Table 4.1: Correlations for CPU time tests

Correlation	Number of Activities	Number of Relationships	Number of Activities X Number of Relationships	Number of Activities + Number of Relationships	Time (secs)
Number of Activities	1	-	-	-	-
Number of Relationships	0.999	1	-	-	-
Number of Activities X Number of Relationships	0.987	0.987	1	-	-
Number of Activities + Number of Relationships	0.999	0.999	0.987	1	-
Time (secs)	0.656	0.658	0.652	0.657	1

4.4.3 CPU Time Test Discussion

The results obtained from the CPU time test have an expected positive trend; as the number of activities and relationships increase, the complexity increases and the CPU time increases. The spread of the time as the complexity increases, however, is a intriguing; it could be due to the random nature of the inputs, and/or the random nature of the solver. It is noted that in large projects, such as the one in the validation of this thesis, there may be multiple complicated relationships for activities, meaning that a single activity has a high number of relationships. This condition increases the computational effort in the model heavily. Overall, the CPU time obtained using this model is satisfactory,

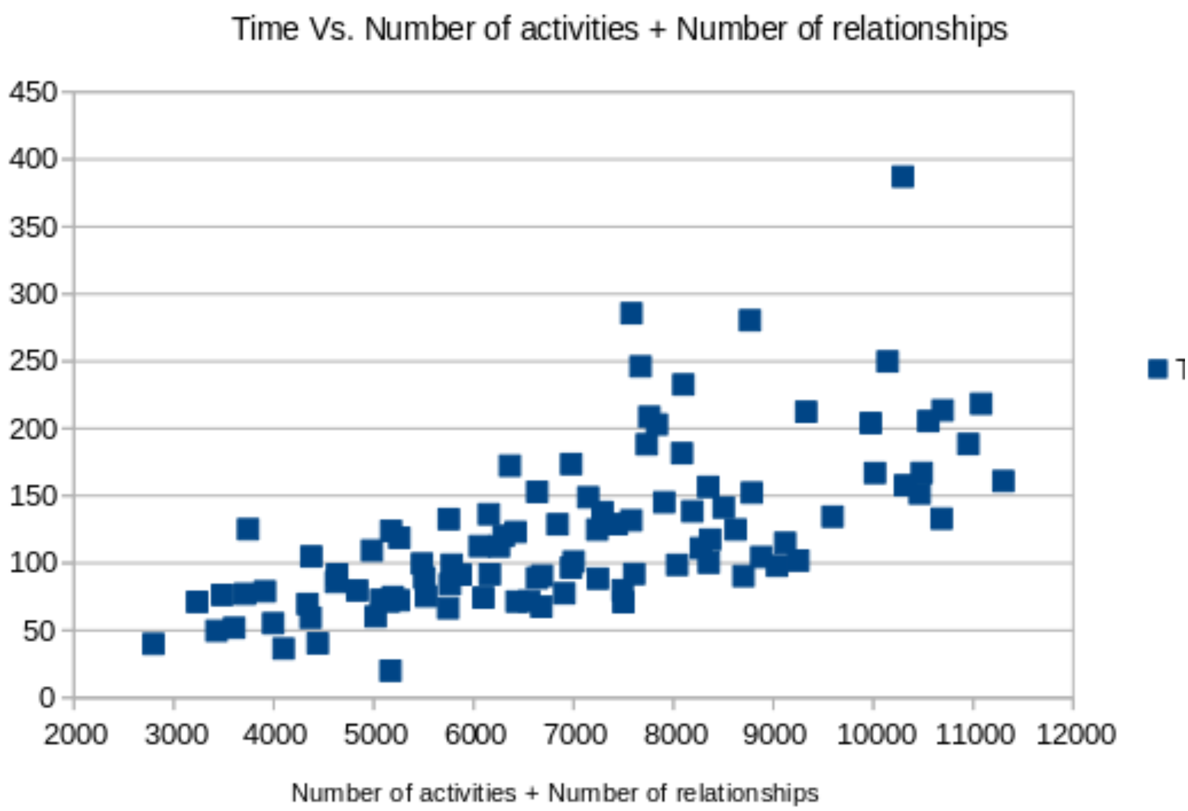


Figure 4.13: CPU Time Vs. Number of Activities + Number of Relationships

4.5 Validation

4.5.1 Validation Method

Validation was done a portfolio of projects, from actual projects by a contractor. General Information about the projects used are shown in Table 4.2 and Figure 4.15. The portfolio includes three residential projects in Cairo, under construction at the same construction company. Two of them are Villas and the third is apartment buildings. Further details are confidential as per the request of the company. The validation is test of a real and applicable situation. The portfolio used is a relatively very large one; The total number of activities is 28,994 activities, distributed as 6489, 8073, and 14432 activities for each of the projects. The total number of relationships is 69,717 relationship. The stopping criteria is an improvement of 0.002% on a moving average of the last 3 best trials, or 20 trials with no improvement.

4.5.2 Validation Results

The results for the validation are shows in Figures 4.17, 4.20, and 4.21. The initial NPV was 432,964,013. The Optimized NPV was 433,150,506. The improvement was 186,493,

Table 4.2: Projects used for the validation

-	Start	finish	Cost	Total Activities
Project 1	03/25/13	03/25/15	102,000,002.57	6,489
Project 2	01/01/14	02/19/16	128,190,586.00	8,073
Project 3	10/11/14	04/27/17	272,000,000.00	14,432

which is an 0.04% improvement from the initial NPV. This result was achieved in 4 hours and 39 minutes. The validation was redone with different stopping criteria, by increasing the max number of trials without improvement to 20 trials, but no significant improvement was achieved. All optimization Plots are shown in the following figures.

4.5.3 Validation Discussion

The schedule was calculated successfully, and the cash flow as well. The cash flow, as shown in Figure 4.16, has a typical shape of a cash flow for a construction project. The cash in has steps that follow the invoicing of th three projects. It should be noted, as mentioned before, that this portfolio is huge and is computationally intensive. Moving on to the optimization, the cash flow was optimized as shown in Figure 4.17. The number of trials is small, but a notable improvement in the NPV was achieved. The optimized cash flow is shown in Figure 4.20, and the optimized overdraft is shown in Figure 4.21. It is noted that there is a trend that favors early payment, but not excessively, which seems to be logical, as early payment would make benefit from a higher time value of money, but, on the other hand, increased cash out in respect to the cash in would result in a harmful and excessive negative cash flow. So, it seems that some sort of balance is being achieved. Overall, the main concern after finishing the validation is the long time spent for calculating the project, in specific in the scheduling process. This is the reason that made evolutionary algorithms unfavorable due to them required an initial population, which would in turn require extensive computational power and weeks of computer time. The use of an algorithm or a heuristic that doesn't necessarily be deterministic but would have a satisfactory accuracy would be valuable, especially if it allow for parallel computation.

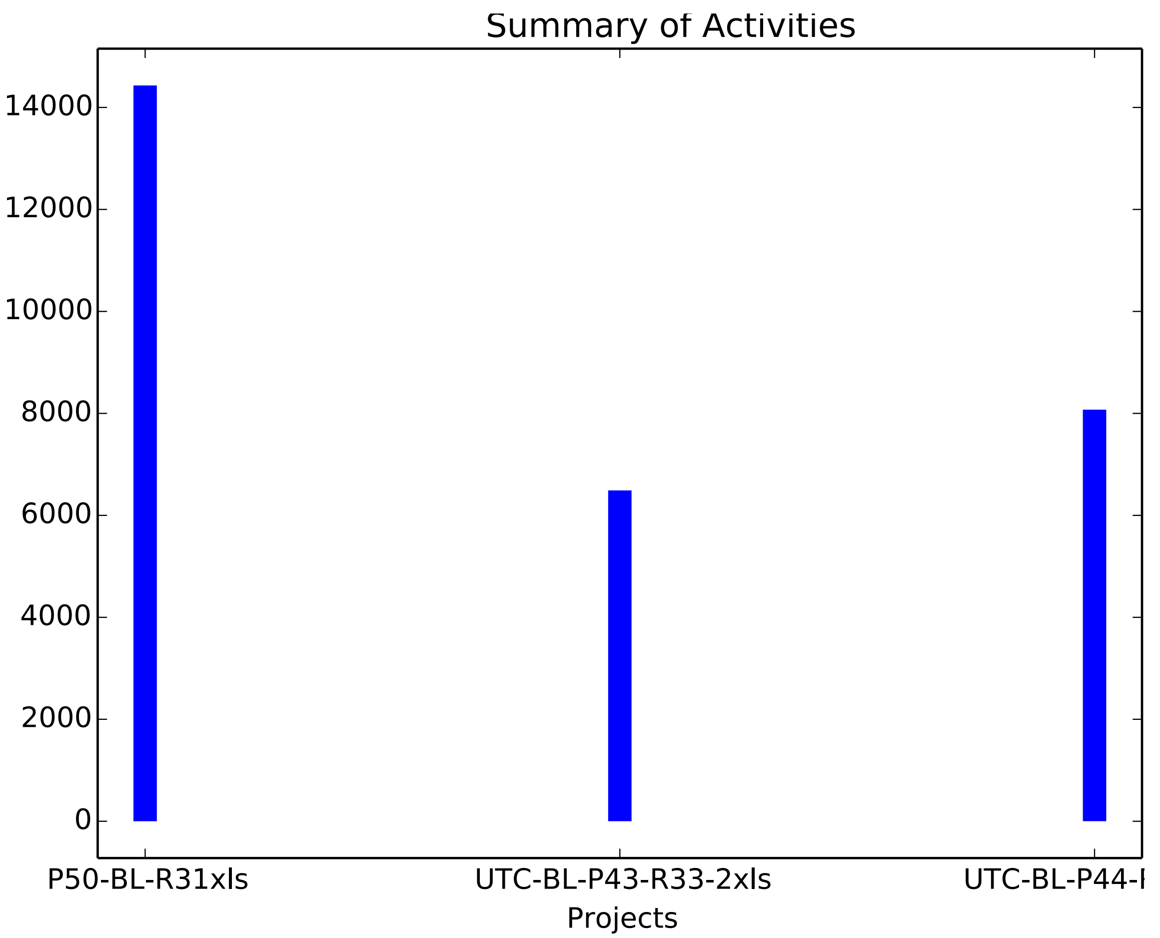


Figure 4.14: Summary of the Portfolio used for validation

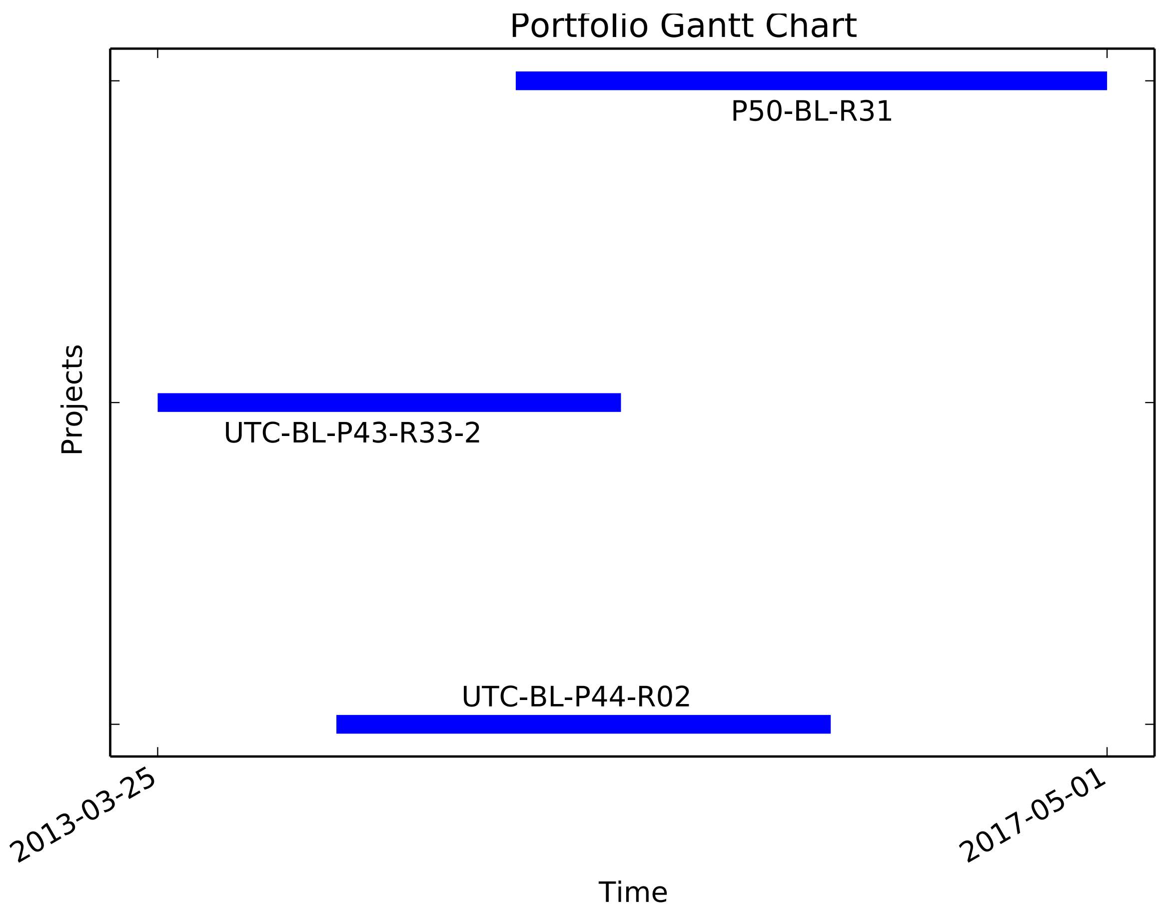


Figure 4.15: Portfolio Gantt Chart

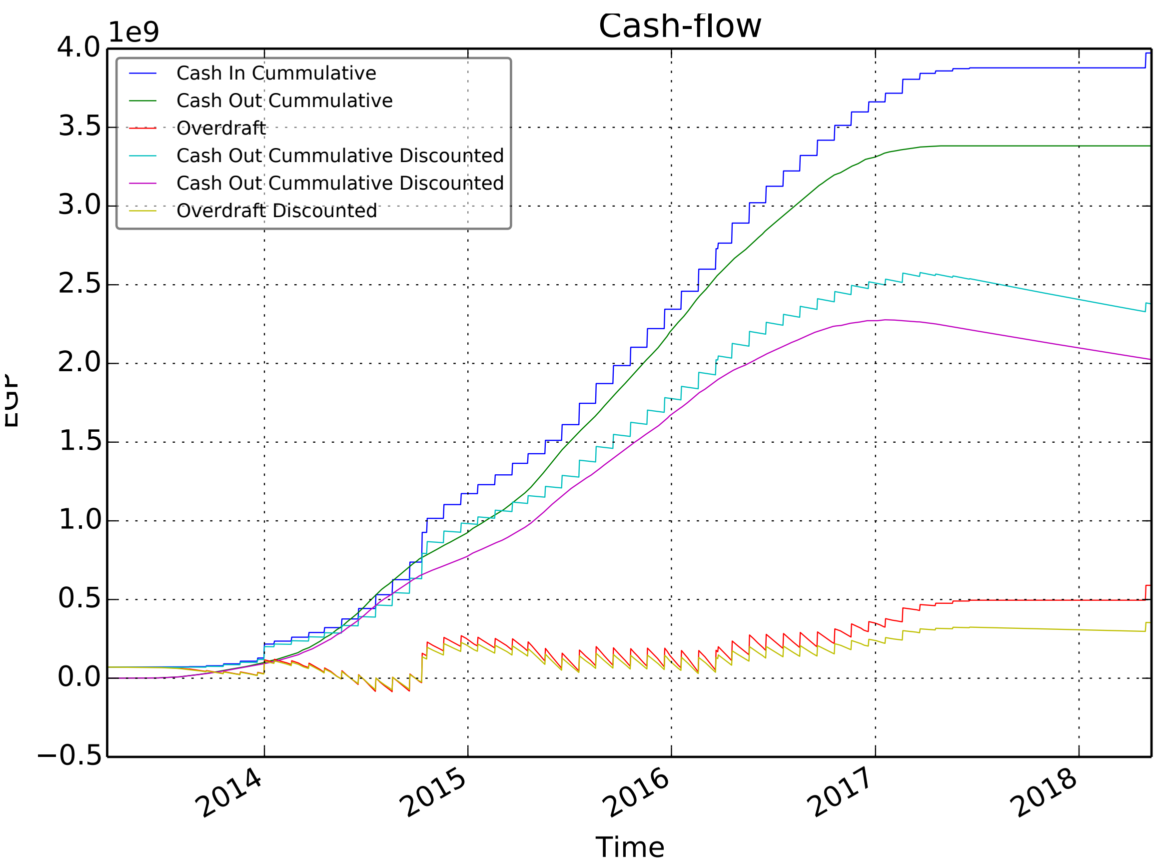


Figure 4.16: Portfolio Gantt Chart

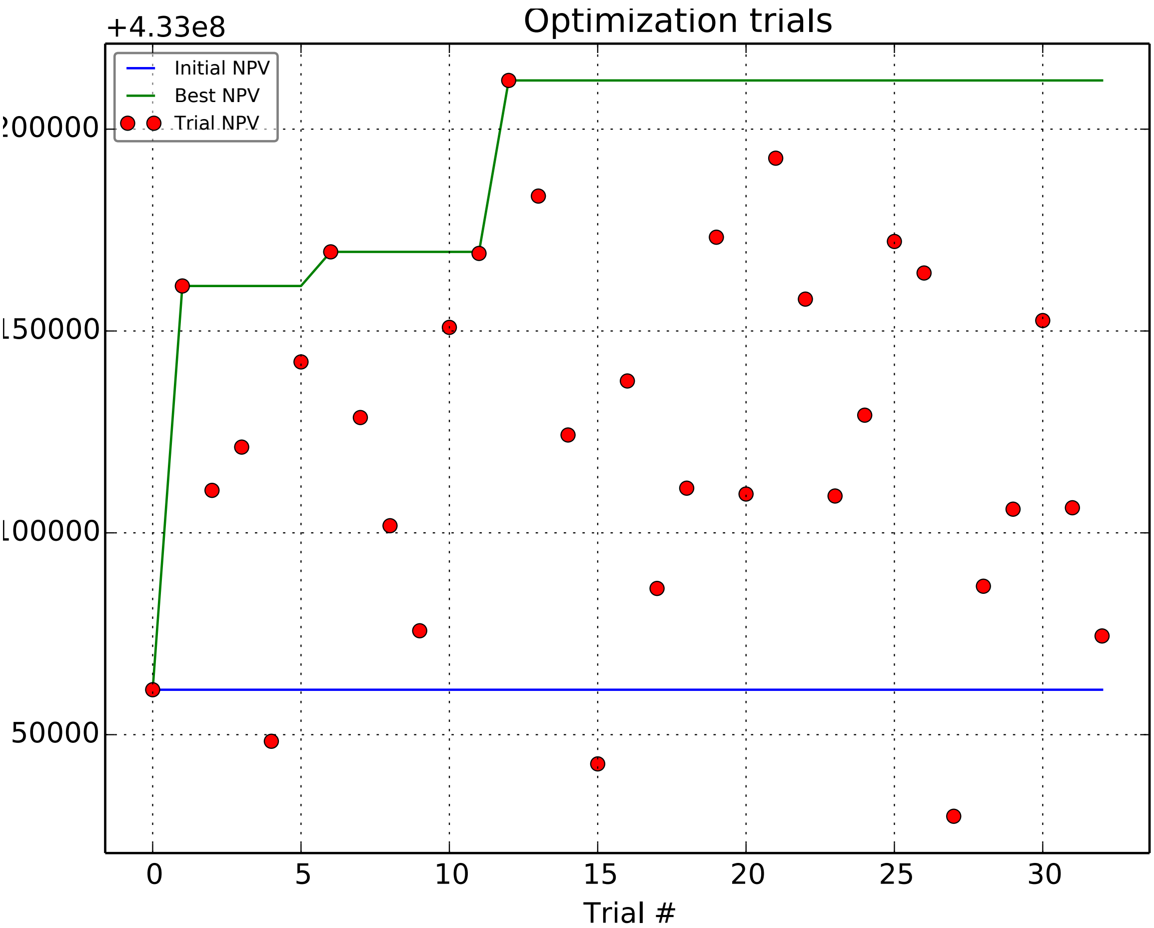


Figure 4.17: Optimization trials for the validation

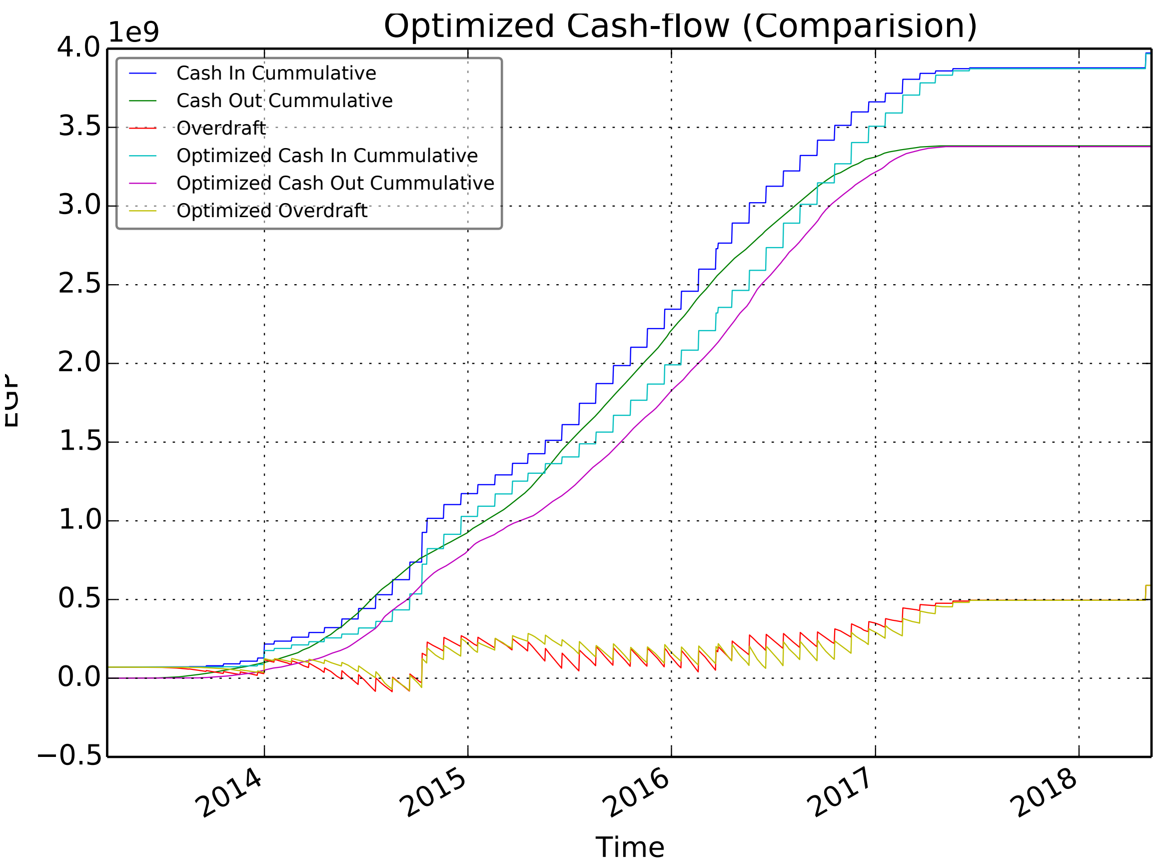


Figure 4.18: Optimized Cash Flow

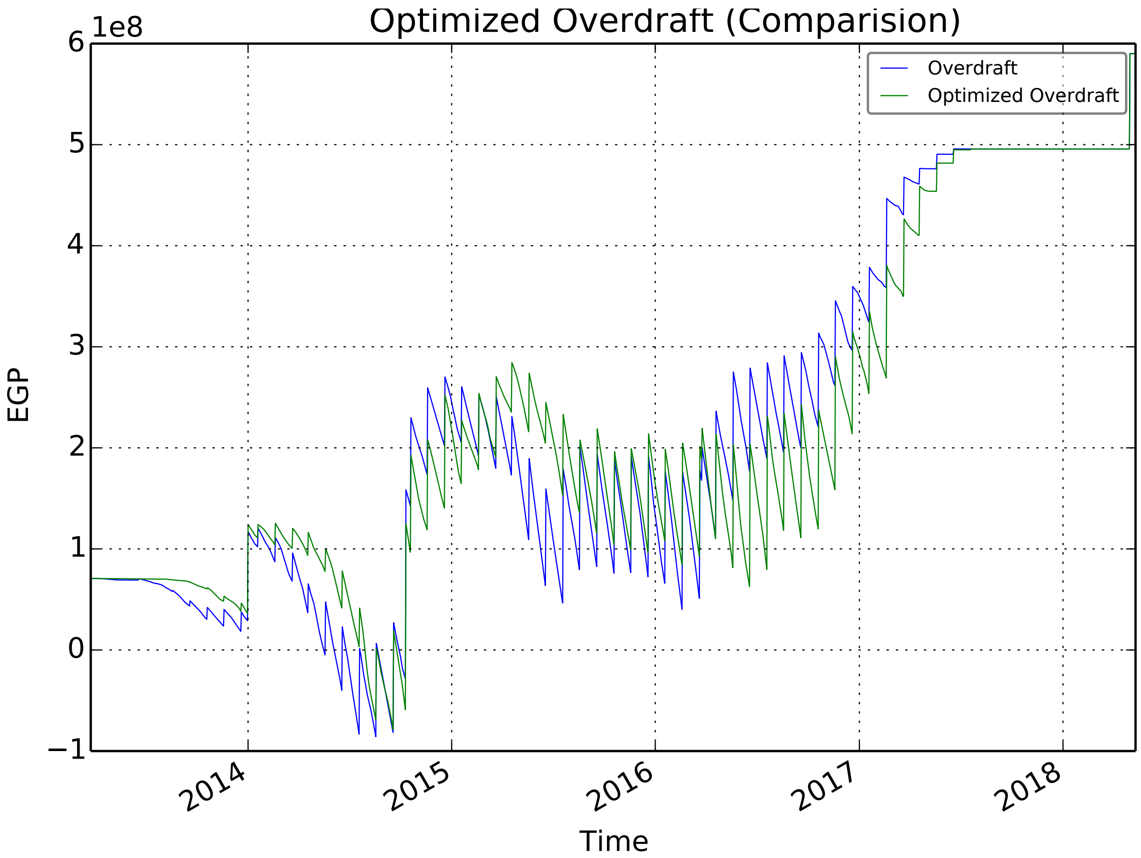


Figure 4.19: Optimized Overdraft

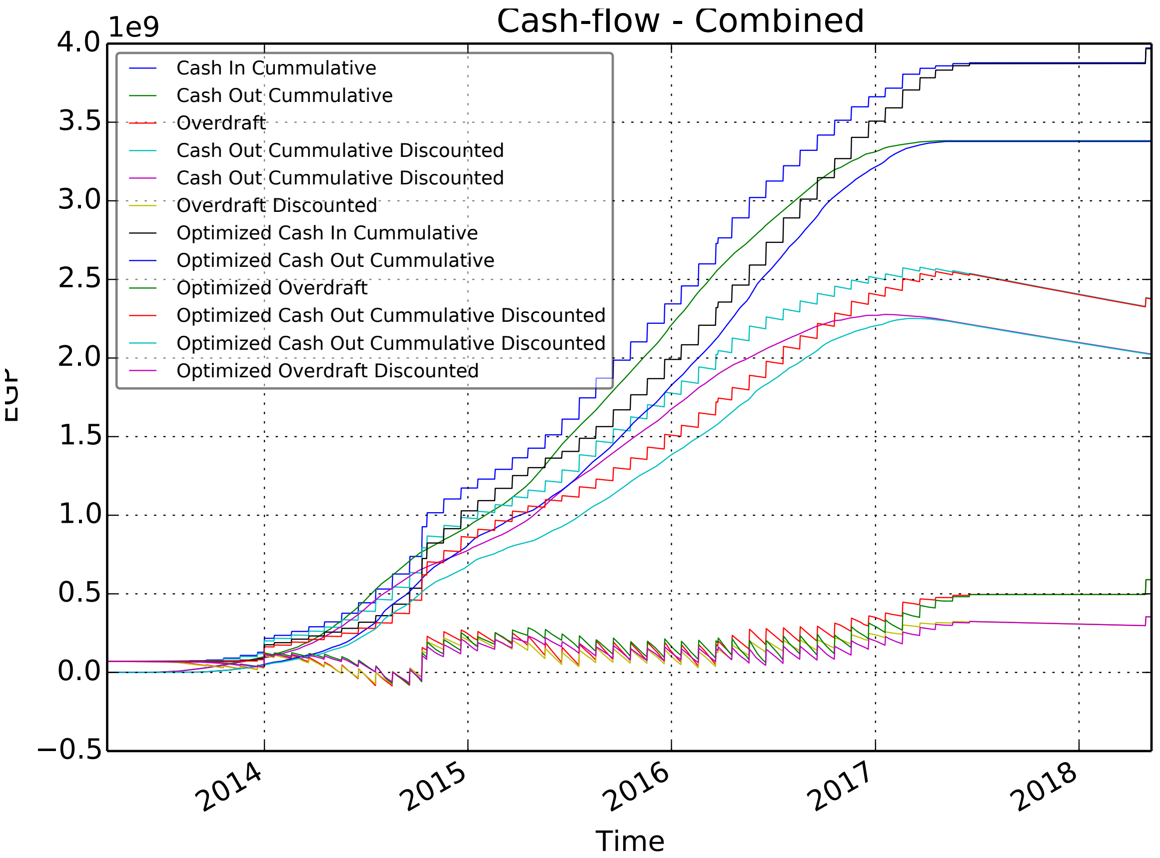


Figure 4.20: Optimized Cash Flow for the validation Portfolio

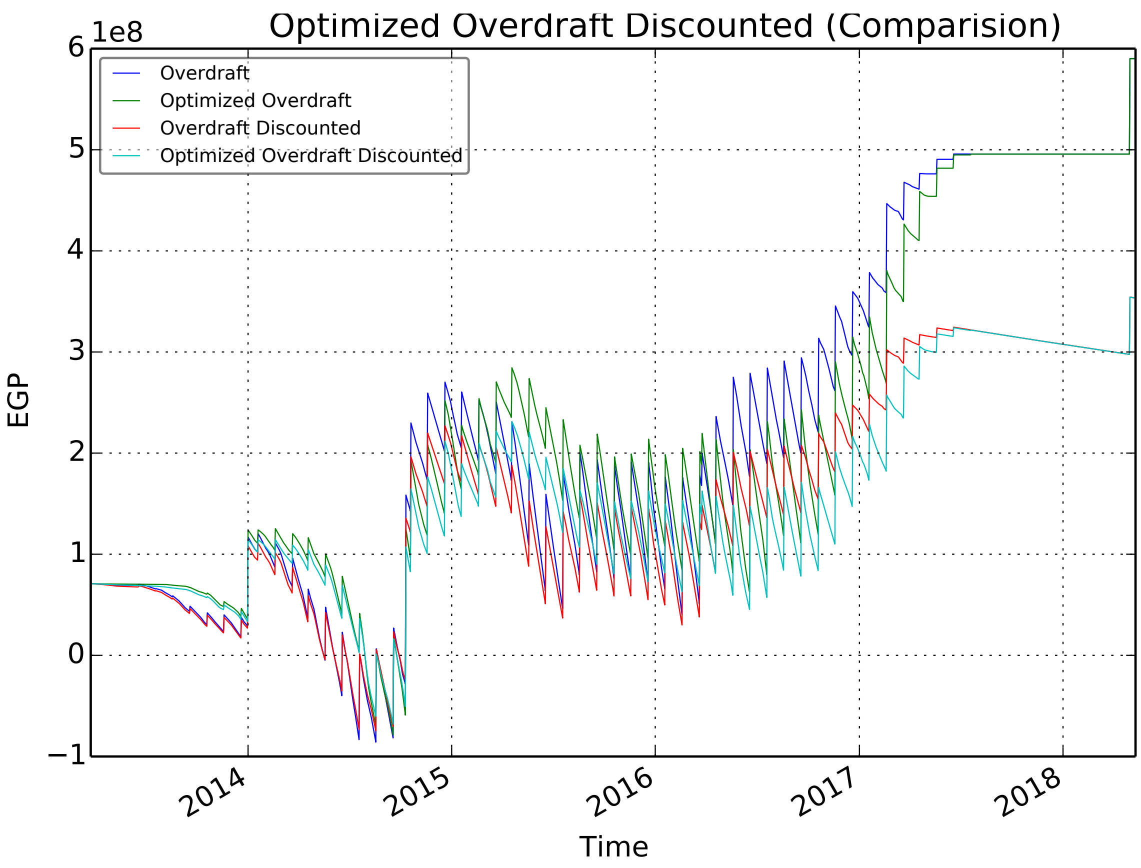


Figure 4.21: Optimized Overdraft for the validation Portfolio

4.6 Validation with Updated Schedule

4.6.1 Validation Method

Another validation was done for a project with an updated schedule. The model was executed for the updated schedule. The project is a landscape construction project in Cairo. The schedule has 477 activities. That project start was 2014-03-13 and the Finish was expected to be 2016-29-07, as the update date for the schedule was May 2016. The Baseline start and finish were dates were 2014-03-13 and 2014-11-13, respectively. So, currently time is at large. The % Schedule completion was 94.7% at the update time in May 2016, and the % schedule completed was 99.2%. The costs of the activities were changed for confidentiality as requested by the data provider. The Total Cost was 15,644,990 EGP and the Total price was 18,773,988 EGP.

4.6.2 Validation Results and Discussion

The cash flow was calculated for the updated schedule. The resulting cash flow is shown in Figure 4.22. The curves show an S curve trend. The NPV was found to be 2,570,178 EGP. It should be noted that the curve begins at a positive value that equals the downpayment value, and the curve extends till the receipt of the retention. Overall, this validation showed that the model can handle updated schedules. These can be utilized to to calculate the actual NPV and Discounted values of the cash flow, which can be used to indicate the success (or failure) of a project during construction.

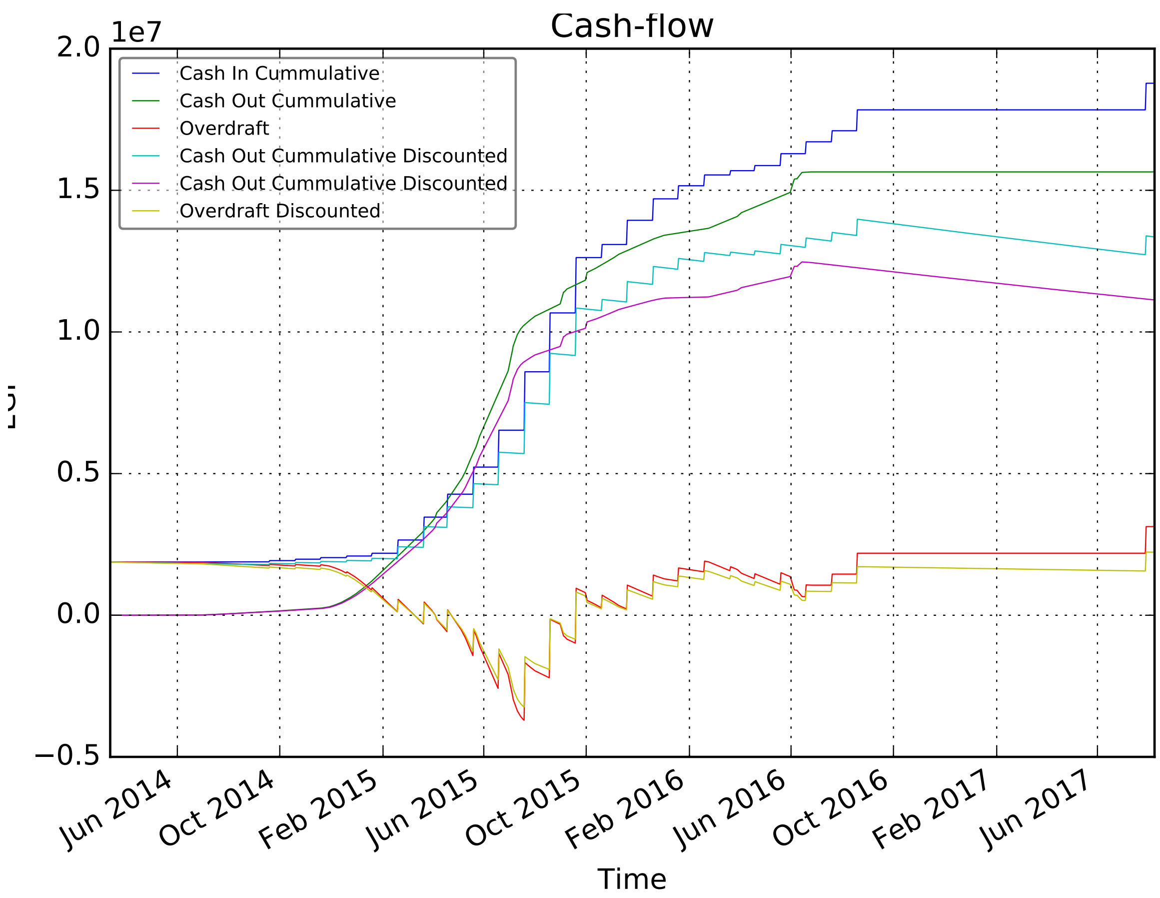


Figure 4.22: Portfolio Gantt Chart

Chapter 5

Conclusion and Recommendations

This chapter will conclude the thesis regrading the model and Graphical User Interface (GUI), the optimization, the results of the verification, validation, and CPU time. Finally, limitations and recommendations for the future research are advised.

5.1 Conclusion

Taking the point of view of the contractor in a construction project, the developed model and Graphical User Interface (GUI) can be used to perform analysis and optimization of the cash flow of a portfolio of construction project. The analysis includes the Cash In, Cash out, and the Overdraft, which are calculated according to the time schedule, the financial parameters and contractual time bars like the down-payment, retention, invoice interval,..etc. The time value is also taken into consideration as an interest rate, which can be the inflation rate or the Minimum Attractive Rate of Return (MARR) for the contractor. The optimization had the objective of reducing the Net Present Value (NPV) of the whole portfolio. This had the effect of increasing the profit of the contractor for all the projects as a whole, taking into effect the time value of money. Excessive overdraft is also reduced as an effect. The model achieved its targeted scope.

5.1.1 Model and GUI

The scope was achieved by creating a model that can do the analysis and optimization of construction portfolios. Python proved to be a good choice for prototyping and fast implementation. The computational time wasn't greatly affected, since most of the packages used are coded in C. A friendly Graphical User Interface was also created. It allows the user to create a portfolio, projects in it, activities in the project, and relationships between the activities. The user can also modify financial parameters and contractual time bars.

5.1.2 CPU Time

A test for the CPU time was done and described in Section 4.4. There is a fair correlation between the CPU time and the number of projects of course. But it seems that the CPU time is greatly affected by the structure of the projects; projects where there are several complicated relationships between activities, especially where one activity has multiple relationships, seem to be more computationally costly, in addition to there large size. This was more apparent in the validation. Generally, the CPU time is satisfactory, for small and large projects.

5.1.3 Verification

The verification was described in Section 4.1.1. The trials were done for random projects to verify the results and effectiveness of the algorithm. The model converged in all cases. It should be noted that in some cases, the optimum NPV for the project would occur when all activities start as soon as possible, meaning the optimum start is the early start. It should also be noted that the user should not create relationships between activities that are cyclic, meaning that, for example, 2 activities cannot be the predecessors of each other, and the same applies to longer chains of activities. Otherwise the model will keep calculating in an endless loop.

5.1.4 Validation

The validation was done for a large portfolio of real projects from a single construction company. The portfolio had, approximately, 29 thousand activities with 70 thousand relationships between them. Further details were described in 4.5.1. The model converged in a relatively satisfactory time, compared to the size of the portfolio. It was noticed that the bottleneck for the model is the calculation of the activity start and ends. This due to the large number of activities and relationships, in addition to the fact that some activities had multiple relationships that connected to many activities and complicated the calculations.

5.1.5 Optimization Algorithm

The verification and the validation shows that the bottleneck was the calculation of the activities' start and finish dates, especially when the relationships connect too many activities, which complicates the computations and makes the whole process slower. Due to this issue and the very large number of variables, as shown in the validation, the use of evolutionary algorithms (EA) is unfeasible; the model would be unable to create a first population for the EA in a satisfactory time. The optimization technique used in this model is a form of Brute Forcing, as discussed in 3.9, and it proved to be satisfactory for a large project, as shown in the validation, and also for smaller projects, as shown in the verification.

5.1.6 Sensitivity Analysis

A sensitivity analysis was performed for the model, taking into consideration the Interest Rate and Cost parameters' effect on the Net Present Value (NPV). The results showed consistency with the equations provided. The increase in the interest rate increased the NPV with a curved shape while the increase in the cost increased the NPV linearly. This behavior was consistent with the the given equations and the behavior of the time value of money.

5.2 Limitations

Due to assumptions that were utilized in the model development, the limitations are:

- The cost of each activity was assumed to be uniformly distributed along each activity's duration, in contrast real life cases where the cost can be front allocated, or back allocated, or have any other distribution. These options should be added to simulate real situations.

- The costs and expenses that are delayed after an activity or before it, such as in the case of paying for a supplier after a duration of time from an activity, or before the activity was neglected. Though they could be added in the model as separate activities that have delays between them.

- Payment of invoices, retention, and down-payments was assumed to be always on time, neither late nor early than the contractual time bars. Delays are completely out of scope. This limitation could be fixed by adding the the model the liabilities and delay penalties. This could result in situations where, after optimizations, delay damages will be paid, but the profit is higher.

- The retention was assumed to be paid completely after the Defects Liability Period. In some situations, however, it could be paid in half at construction completion and half after the defects liability period.

- Financial situations for loans, bonds, procurement agreements, and similar items were not considered, though they can be added as separate activities with their costs.

- Exhaustive numeration was used for the optimization, though it leads to a global near-optimum solution, it is slower and more computationally cumbersome than other higher-level methods, such as evolutionary algorithms.

- There is a bottleneck when calculating large schedules, due to their size and complexity, and it greatly affects optimization process as well, leading to long calculation time.
- The options included in the model for the payments, invoicing, advanced payment, and retention, are limited.
- The model doesn't do resource leveling.

5.3 Recommendations

Researchers in this topic are advised to notice the limitations of the model. The most important limitation is the bottleneck for the optimization of large projects in the proposed model, in the calculation of the start and finish times for activities, which increases the overall time the optimizations significantly because optimization trials require recalculation of the schedule. Practical schedules, specially for large construction portfolios, are expected to have thousands of activities, just as the one used for the validation, therefore a faster algorithm is needed, at least for the sake of optimization. This algorithm doesn't have to be deterministic or very accurate, but it needs to be accurate enough and much quicker in order to allow for faster optimization or the use of more complicated optimization algorithms, followed by an accurate calculation of the resulting model after optimization.

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Appendices

Appendix A

Python Code

```python
'''
Cash Flow Optimmization for Construction Engineering Portfolios
Author: Gasser Galal Ali
This code was developped for the purpose of the
fullfilment of the requirements of the thesis for the degree
of Master of Science in Construction Engineering at The
American University in Cairo.
This code may not be fully or partially used without written
approval of the author

'''

import sqlite3, re, os, datetime, functools, math, random, sys, webbrowser, csv
import xlsxwriter, xlrd
import matplotlib.pyplot as plt
import tkinter as tk
import tkinter.ttk as ttk

def log(text):
    global log file name
    print(text)
    f = open(log file name,'a+')
    f.write(text + '\n')
    f.close()

def pause():
    input("Paused. Press Enter to resume.")
    print("Resuming...")

def adddays(date, days, calendar):
    # Function to add or subtract days from a date with days off included, the daysoff should be a tuple of 0 to 6 where 0 is Monday
    condition = True
    counter = 0
    output = date
    if calendar == None or '7d' in calendar.lower() or '7 d' in calendar.lower():
        listofdaysoff = ()
    elif '6d' in calendar.lower() or '6 d' in calendar.lower():
        listofdaysoff = (4,)
    elif '5d' in calendar.lower() or '5 D' in calendar.lower():
        listofdaysoff = (4,5)
    else:
        print('    [!] unrecognized calendar :' + calendar)
        listofdaysoff = ()
    while condition and days != 0:
        if days > 0:
            output += datetime.timedelta(1)
        else:
            output += datetime.timedelta(-1)
        if output.weekday() not in listofdaysoff:
            counter += 1
        if counter == abs(days):
            condition = False
    return output

def new database(): # Deploys a new database file. DELETES OLD FILE IF FOUND
    log('Deploying Database')
    global conn
    conn.commit()
    conn.close()
    if os.path.exists(database file name):
        os.remove(database file name)
        log(" - Removed old file")
    conn = sqlite3.connect(database file name)
    conn.execute("PRAGMA default cache size = 500000;")
    conn.commit()
    conn.execute("CREATE TABLE projects (projectid TEXT UNIQUE NOT NULL, projectname TEXT,start DATE, finish DATE, duration INT, interest FLOAT, markup FLOAT,
```

```
retentionperiod INT, retention FLOAT, invoiceinterval INT, paymentperiod INT, downpayment FLOAT, cost FLOAT, price FLOAT, totalactivities INT, criticalactivities INT, cashinpv FLOAT, cashoutpv FLOAT, npv FLOAT, maxoverdraftdisc FLOAT, minoverdraftdisc FLOAT, cashinpvopt FLOAT, cashoutpvopt FLOAT, npvopt FLOAT, maxoverdraftdiscopt FLOAT, minoverdraftdiscopt FLOAT);")
        conn.execute("CREATE INDEX projectsindex ON projects (projectid);")
        conn.execute("CREATE TABLE activities (projectid TEXT, activityid TEXT, activityname TEXT, duration INT, cost FLOAT, es INT, ef INT, ls INT, lf INT, ff INT, tf INT, lag INT, os INT, of INT, primaryconstraint TEXT, primaryconstraintdate DATE, calendar TEXT);")
        conn.execute("CREATE INDEX activitiesindex ON activities (activityid);")
        conn.execute("CREATE TABLE relationships (projectid TEXT, activity1id TEXT, activity2id TEXT, type TEXT, rlag INT);")
        conn.execute("CREATE INDEX relationshipsindex ON relationships (projectid,activity1id,activity2id,type);")
        conn.execute("CREATE TABLE cashflow (date INT, projectid TEXT, cashout FLOAT, invoice FLOAT, cashin FLOAT, cashoutcum FLOAT, cashincum FLOAT, overdraft FLOAT, cashoutdisc FLOAT, cashindisc FLOAT, cashoutcumdisc FLOAT, cashincumdisc FLOAT, overdraftdisc FLOAT)")
        conn.execute("CREATE INDEX cashflowindex ON cashflow (date, projectid);")
        conn.execute("CREATE TABLE cashflowall (date INT, projectid TEXT, cashout FLOAT, invoice FLOAT, cashin FLOAT, cashoutcum FLOAT, cashincum FLOAT, overdraft FLOAT, cashoutdisc FLOAT, cashindisc FLOAT, cashoutcumdisc FLOAT, cashincumdisc FLOAT, overdraftdisc FLOAT)")
        conn.execute("CREATE INDEX cashflowallindex ON cashflowall (date, projectid);")
        conn.execute("CREATE TABLE cashflowopt (date INT, projectid TEXT, cashout FLOAT, invoice FLOAT, cashin FLOAT, cashoutcum FLOAT, cashincum FLOAT, overdraft FLOAT, cashoutdisc FLOAT, cashindisc FLOAT, cashoutcumdisc FLOAT, cashincumdisc FLOAT, overdraftdisc FLOAT)")
        conn.execute("CREATE INDEX cashflowoptindex ON cashflowopt(date, projectid);")
        conn.execute("CREATE TABLE cashflowallopt (date INT, projectid TEXT, cashout FLOAT, invoice FLOAT, cashin FLOAT, cashoutcum FLOAT, cashincum FLOAT, overdraft FLOAT, cashoutdisc FLOAT, cashindisc FLOAT, cashoutcumdisc FLOAT, cashincumdisc FLOAT, overdraftdisc FLOAT)")
        conn.execute("CREATE INDEX cashflowoptallindex ON cashflowallopt (date, projectid);")
        conn.execute("CREATE TABLE portfolio (portfolioid TEXT UNIQUE NOT NULL, start DATE, finish DATE, duration INT, numberofprojects INT, numberofactivities INT, cost FLOAT, price FLOAT, cashinpv FLOAT, cashoutpv FLOAT, npv FLOAT, maxoverdraftdisc FLOAT, minoverdraftdisc FLOAT, cashinpvopt FLOAT, cashoutpvopt FLOAT, npvopt FLOAT, maxoverdraftdiscopt FLOAT, minoverdraftdiscopt FLOAT)")
        conn.execute("INSERT INTO portfolio (portfolioid) VALUES ('portfolio');")
        conn.execute("CREATE TABLE trials (trialid INT, initialnpv FLOAT, trialnpv FLOAT, bestnpv FLOAT)")
        conn.execute("CREATE INDEX trialindex ON trials(trialid);")
        conn.execute("CREATE view big AS SELECT relationships.*, activities1.es AS activity1es, activities1.ef AS activity1ef, activities1.ls AS activity1ls, activities1.lf AS activity1lf, activities1.os AS activity1os, activities1.of AS activity1of, activities1.duration AS activity1duration, activities2.es AS activity2es, activities2.ef AS activity2ef, activities2.ls AS activity2ls, activities2.lf AS activity2lf, activities2.os AS activity2os, activities2.of AS activity2of, activities2.duration AS activity2duration FROM relationships INNER JOIN activities AS activities1 ON relationships.projectid = activities1.projectid AND relationships.activity1id = activities1.activityid INNER JOIN activities AS activities2 ON relationships.projectid = activities2.projectid AND relationships.activity2id = activities2.activityid;")
        conn.commit()
        log(' - Done')

def print_table(name): # Prints a table from the database, input "all" for all tables
    if name in ['all','All','ALL']:
        tables = [a for a in get("Select name FROM sqlite_master WHERE type = 'table';")]
    else:
        tables = [name]
    for table in tables:
        heads = []
        for a in conn.execute("PRAGMA table_info(%s);" %table):
```

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            heads.append(a[1])
        log('\n\nTABLE: %s' % name)
        log(heads)
        for c in conn.execute("select * from %s;" %table):
            log(c)
        log('=========== end of table ============')

def database info(): # prints some database info
    log("Number of projects: %s project"%conn.execute("SELECT COUNT(*) FROM projects;").fetchall()[0][0])
    log("Number of activities: %s activity"%conn.execute("SELECT COUNT(*) FROM activities;").fetchall()[0][0])
    log("Number of relationships: %s relationship"%conn.execute("SELECT COUNT(*) FROM relationships;").fetchall()[0][0])
    log("Distinct relationships: %s"%[a[0] for a in conn.execute("SELECT DISTINCT type FROM relationships;").fetchall()])
    projects = [a[0] for a in conn.execute("SELECT projectid FROM projects;").fetchall()]
    for projectid in projects:
        number of activities = conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ?;",(projectid,)).fetchall()[0][0]
        number of critical activities = conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ? AND tf = 0;",(projectid,)).fetchall()[0][0]
        log(' - '+projectid + ' -> ' + str(number of activities) + ' activitiy -> ' + str(number of critical activities) + ' critical activity')

def project create(projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod): # Create a new Project
    conn.execute("INSERT INTO projects \
    (projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod) VALUES ('%s','%s','%s','%s','%s','%s','%s','%s','%s','%s')"%(projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod))

def activity create(projectid,activityid,activityname,duration,cost): # Create a new Activity in a Project
    conn.execute("INSERT INTO activities (projectid,activityid,activityname,duration,cost) VALUES ('%s','%s','%s','%s','%s');"% (projectid,activityid,activityname,duration,cost))

def relationship create(projectid,activity1id,activity2id,relationship type): # Create a new Relationship between 2 Activities
    conn.execute("INSERT INTO relationships (projectid,activity1id,activity2id,type) VALUES (?,?,?,?);", (projectid,activity1id,activity2id,relationship type))

def create a portfolio(): # Creates a sample portfolio for testing
    log('Creating a random Portfolio')
    number of projects = 3
    min number of activities = 20
    max number of activities = 25
    for p in range(1,number of projects+1):
        number of activities = random.randint(min number of activities, max number of activities)
        projectid = 'project' + str(p)
        projectname = projectid
        start = (datetime.date.today() + datetime.timedelta(days = random.randint(10, 300))).isoformat()
        interest = random.randint(10,20)/ 100
        markup = random.randint(15,25)/100
        downpayment = random.randint(15,25)/100
        invoiceinterval = 'monthly'
        paymentperiod = 56
        retention = 0.1
        retentionperiod = 80
        conn.execute("INSERT INTO projects (projectid,projectname,start,interest,markup,downpayment,invoiceinterval,payme
```

```
        ntperiod,retention,retentionperiod) VALUES (?,?,?,?,?,?,?,?,?,?)", (projectid, projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod))
        for a in range(1,number of activities+1):
            projectid = projectid
            activityid =  'activity' + str(a)
            activityname = activityid
            duration = random.randint(10,20)
            cost = random.randint(1,10)
            conn.execute("INSERT INTO activities (projectid,activityid,activityname,duration,cost) VALUES (?,?,?,?,?);", (projectid,activityid,activityname,duration,cost))
            if a > 1:
                for i in range([1,1,1,2][random.randint(0,3)]): # number of relationships for each activity
                    for r in [random.randint(1,a-1)]:
                        projectid = projectid
                        activity1id = 'activity' + str(r)
                        activity2id = activityid
                        #~ relationship type = ['fs','sf','ss','ff'][random.randint(0,3)]
                        relationship type = ['fs','fs','fs','sf','ss','ff'][random.randint(0,5)]
                        conn.execute("INSERT INTO relationships (projectid,activity1id,activity2id,type) VALUES (?,?,?,?)", (projectid,activity1id,activity2id,relationship type))
    conn.commit()
    log(' - Done.')

def create a portfolio2(number of projects,min number of activities,max number of activities): # Creates a sample portfolio for testing
    log('Creating a random Portfolio')
    for p in range(1,number of projects+1):
        number of activities = random.randint(min number of activities,max number of activities)
        projectid = 'project' + str(p)
        projectname = projectid
        start = (datetime.date.today() + datetime.timedelta(days = random.randint(10,300))).isoformat()
        interest = random.randint(10,20)/ 100
        markup = random.randint(15,25)/100
        downpayment = random.randint(15,25)/100
        invoiceinterval = 'monthly'
        paymentperiod = 56
        retention = 0.1
        retentionperiod = 80
        conn.execute("INSERT INTO projects (projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod) VALUES (?,?,?,?,?,?,?,?,?,?)", (projectid, projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod))
        for a in range(1,number of activities+1):
            projectid = projectid
            activityid =  'activity' + str(a)
            activityname = activityid
            duration = random.randint(10,20)
            cost = random.randint(1,10)
            conn.execute("INSERT INTO activities (projectid,activityid,activityname,duration,cost) VALUES (?,?,?,?,?);", (projectid,activityid,activityname,duration,cost))
            if a > 1:
                for i in range([1,1,1,2][random.randint(0,3)]): # number of relationships for each activity random between 1 and 2
                    for r in [random.randint(1,a-1)]:
                        projectid = projectid
                        activity1id = 'activity' + str(r)
                        activity2id = activityid
                        #~ relationship_type =
```

```
                          ['fs','sf','ss','ff'][random.randint(0,3)]
                          relationship type = ['fs','fs','fs','sf','ss','ff'][random.randint(0,5)]
                          conn.execute("INSERT INTO relationships (projectid,activity1id,activity2id,type) VALUES (?,?,?,?)", (projectid,activity1id,activity2id,relationship type))
    conn.commit()
    log(' - Done.')

def clean database(): # clean redundant elements
    print('Cleaning Database')
    global conn
    conn.execute('DELETE FROM activities WHERE projectid NOT IN (SELECT projectid FROM projects);')
    conn.execute('DELETE FROM relationships WHERE projectid NOT IN (SELECT projectid FROM projects);')
    conn.execute('DELETE FROM relationships WHERE activity1id NOT IN (SELECT activityid FROM activities WHERE activities.projectid = relationships.projectid);')
    conn.execute('DELETE FROM relationships WHERE activity2id NOT IN (SELECT activityid FROM activities WHERE activities.projectid = relationships.projectid);')
    conn.commit()
    print(' - Done')

def import uptown projects():
    # importing uptown cairo files
    log('Importing UPTOWN projects...')
    global conn
    # Find files
    path = './projectsfromprimavera/'
    files = []
    for a in os.listdir(path):
        if 'xl' in a:
            files.append(path+a)
    # Cycle through the files
    for file in files:
        # Create New Project
        projectid = file.replace(path,'')
        projectid = projectid.replace('.','')
        projectname = projectid
        start = 0
        interest = 0.1
        markup = 0.2
        downpayment = 0.1
        invoiceinterval = 'monthly'
        paymentperiod = 50
        retention = 0.05
        retentionperiod = 365
        conn.execute("INSERT INTO projects (projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod) VALUES (?,?,?,?,?,?,?,?,?,?);", (projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod))
        # open the workbook
        wb = xlrd.open workbook(file)
        sheet names = wb.sheet names()
        needed sheets = ['TASK', 'TASKPRED']
        #open the task sheet
        sheet = wb.sheet by name("TASK")
        # get the indexes for needed rows
        r = sheet.row values(1)
        activityidindex = r.index('Activity ID')
        activitynameindex = r.index('Activity Name')
        startindex = r.index('(*)Start')
        endindex = r.index('(*)Finish')
        durationindex = r.index('Original Duration(h)')
        costindex = r.index('(*)Budgeted Total Cost($)')
```

```
        primaryconstraintindex = r.index('Primary Constraint')
        primaryconstraintdateindex = r.index('Primary Constraint Date')
        calendarindex = r.index('Calendar Name')

        for i in range(2,sheet.nrows): # Loop on each row to get each activity
            r = sheet.row values(i)
            activityid = r[activityidindex]
            activityname = r[activitynameindex]
            duration = r[durationindex]
            calendar = r[calendarindex]
            if calendar == '':
                calendar = None
            cost = float(r[costindex]) / (random.randint(15, 20) / 100)

            # handle the primary constraint
            if r[primaryconstraintindex] == '': # find out if there is a primary constraint
                primaryconstraint = None
                primaryconstraintdate = None;
            else:
                primaryconstraint = r[primaryconstraintindex]
                constdate = [int(a) for a in re.split("[: /]", r[primaryconstraintdateindex])[0:3]] # this syntax is used to break the dates
                primaryconstraintdate = datetime.date(constdate[2],constdate[0],constdate[1])

            if r[startindex] == '':
                start = [int(a) for a in re.split("[: /]", r[endindex])[0:3]] # this syntax is used to break the dates
                es = datetime.date(start[2],start[0],start[1])
                ef = es
            elif r[endindex] == '':
                start = [int(a) for a in re.split("[: /]", r[startindex])[0:3]] # this syntax is used to break the dates
                es = datetime.date(start[2],start[0],start[1])
                ef = es
            else:
                start = [int(a) for a in re.split("[: /]", r[startindex])[0:3]] # this syntax is used to break the dates
                end = [int(a) for a in re.split("[: /]", r[endindex])[0:3]] # this syntax is used to break the dates
                es = datetime.date(start[2],start[0],start[1])
                ef = datetime.date(end[2],end[0],end[1])

            conn.execute("INSERT INTO activities (projectid,activityid,activityname,duration,cost,es,ef,primaryconstraint,primaryconstraintdate,calendar) VALUES (?,?,?,?,?,?,?,?,?,?);",(projectid,activityid,activityname,duration,cost,es,ef,primaryconstraint,primaryconstraintdate,calendar))

        #  update the projects with the new start
        conn.execute("UPDATE projects SET start = (SELECT DATE(MIN(JULIANDAY(es))) FROM activities WHERE projects.projectid=activities.projectid and activities.es IS NOT NULL);")
        # open the ralationships sheet
        sheet = wb.sheet by name('TASKPRED')
        r = sheet.row values(1)
        activity1index = r.index('Predecessor')
        activity2index = r.index('Successor')
        relationshiptypeindex = r.index('Relationship Type')
        rlagindex = r.index('Lag(h)')
        for i in range(2,sheet.nrows):
            r = sheet.row values(i)
            activity1id = r[activity1index]
            activity2id = r[activity2index]
            relationship type = r[relationshiptypeindex]
            rlag = r[rlagindex]
```

```
            conn.execute("INSERT INTO relationships (projectid,activity1id,activity2id,type, rlag) VALUES (?,?,?,?,?);", (projectid,activity1id,activity2id,relationship type,rlag))
    conn.commit()
    log('Done.')

def pv(interest, days): # Function to calculate the present value inside SQLite
    return math.pow(1+interest/365,days)

def parse date(date isoformat): # parse a date formated as an iso format string 'yyyy-mm-dd' into a date object
    try:
        year = int(date isoformat.split("-")[0])
    except:
        log(' ! error in year in "%s"'%date isoformat)
        return 'null'
    try:
        month = int(date isoformat.split("-")[1])
    except:
        log(' ! error in year in "%s"'%date isoformat)
        return 'null'
    try:
        day = int(date isoformat.split("-")[2])
    except:
        log(' ! error in year in "%s"'%date isoformat)
        return 'null'
    return datetime.date(year,month,day)

def calculate(scope): # calculate schedule and cashflow, the scope can be "normal" or "opt"
    log("SCHEDULING STARTED")
    starttime = datetime.datetime.now()
    if scope in ['normal']:
        cond = ''
    elif scope in ['opt']:
        cond = 'opt'
    else:
        log(' [!] Error in parameter for calculate function')
    if cond == '':
        conn.execute("UPDATE activities SET es = NULL, ef = NULL, ls = NULL, lf = NULL, ff = NULL, tf = NULL, os = NULL, of = NULL, lag = NULL;") # clear previous results
        conn.execute("Update projects set finish = NULL, duration = NULL;")
        conn.execute('Update portfolio set  start = NULL, finish = NULL, duration = NULL;')
    projects = [a[0] for a in conn.execute("SELECT projectid FROM projects").fetchall()]

    if cond == '': # FRONT AND BACK CALCULATION for the early start and finish
        for projectid in projects: # loop for each project NOTE: Foor some reason, it may better to do it this way
            log(' > %s Project %s/%s with %s activity'%(datetime.datetime.now() - starttime,projects.index(projectid) + 1, len(projects),conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ?;",(projectid,)).fetchall()[0][0]))
            conn.execute("UPDATE activities SET es = (SELECT start FROM projects WHERE projectid = ?) WHERE projectid = ? AND activityid NOT IN (SELECT activity2id FROM relationships WHERE relationships.projectid = ?);",(projectid,projectid,projectid))
            conn.execute("UPDATE activities SET ef = DATE(JULIANDAY(es) + duration) WHERE projectid = ? AND es IS NOT NULL;",(projectid,))
            while conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ? AND es IS NULL;",(projectid,)).fetchall()[0][0] > 0: # loop while there are unscheduled activities
                log(' + %s New front -  Remaining activities = %s activitiy'%(datetime.datetime.now() - starttime,conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ? AND es IS NULL;",(projectid,)).fetchall()[0][0]))
```

```
acts = [a[0] for a in conn.execute("SELECT DISTINCT(activity2id) FROM big WHERE projectid = ? AND activity2es IS NULL AND activity1es IS NOT NULL;",(projectid,)).fetchall()]
log("     -> Focusing on %s activity"%len(acts))
count = 0
for activityid in acts: # loop on each unscheduled activity
    d = conn.execute('SELECT activity1es,activity1ef,activity2duration,type, rlag FROM big WHERE projectid = ? AND activity2id = ?;',(projectid,activityid)).fetchall()
    if None not in[a[0] for a in d]: # check if all needed data in there
        es1l = [a[0] for a in d]
        ef1l = [a[1] for a in d]
        dur2l = [a[2] for a in d]
        rtypel = [a[3] for a in d]
        rlags = [a[4] for a in d]
        project start = parse date(conn.execute("SELECT start FROM projects WHERE projects.projectid = ?",(projectid,)).fetchall()[0][0])
        if None not in es1l + ef1l + dur2l + rtypel and d != []: # If this is true, then the activity can be scheduled because all its predessessors are set
            es1l = [parse date(a) for a in es1l]
            ef1l = [parse date(a) for a in ef1l]
            possible es2 = [project start]
            for es1,ef1,dur2,rtype,rlag in zip(es1l,ef1l,dur2l,rtypel,rlags):
                if rlag == None:
                    rlag = 0
                if rtype in ['fs','FS','fS','Fs']:
                    possible es2.append(ef1 + datetime.timedelta(rlag))
                if rtype in ['ss','SS','sS','Ss']:
                    possible es2.append(es1 + datetime.timedelta(rlag))
                if rtype in ['ff','FF','fS','Fs']:
                    possible es2.append(ef1 - datetime.timedelta(dur2) + datetime.timedelta(rlag))
                if rtype in ['sf','SF','sF','Fs']:
                    possible es2.append(es1 - datetime.timedelta(dur2) + datetime.timedelta(rlag))
                es2 = max(possible es2) # get the max of the possible es2

            # compare if there is a constraint of the activity
            primaryconstraint, primaryconstraintdate,duration,calendar = conn.execute("SELECT primaryconstraint,primaryconstraintdate,duration,calendar FROM activities WHERE projectid = ? AND activityid = ?",(projectid,activityid)).fetchall()[0]
            if primaryconstraint != None:
                primaryconstraintdate = parse date(primaryconstraintdate)
                if primaryconstraint == "Finish On or Before" and es2 + datetime.timedelta(duration) > primaryconstraintdate:
                    es2 = primaryconstraintdate - datetime.timedelta(duration)
                elif primaryconstraint == "Start On or After" and es2 < primaryconstraintdate:
                    es2 = primaryconstraintdate
            ef2 = adddays(es2,duration,calendar)

            #add the new calculated early start
            conn.execute("UPDATE activities SET es = ? WHERE projectid = ? AND activityid = ?;",(es2.isoformat(),projectid,activityid))
            conn.execute("UPDATE activities SET ef = ? WHERE projectid = ? AND activityid = ?;",(ef2.isoformat(),projectid,activityid))
```

```
                count += 1
            log("      -> set %s activity "%count)
        # write the new project finish dates
        log(" + %s Writing project finish dates"%(datetime.datetime.now() - starttime,))
        conn.execute("UPDATE projects SET finish = (SELECT DATE(MAX(JULIANDAY(ef))) FROM activities WHERE activities.projectid = ?) WHERE projectid = ?;",(projectid,projectid))
        conn.execute("UPDATE projects SET duration = JULIANDAY(finish) - JULIANDAY(start) WHERE projectid = ?;",(projectid,))
        # write the new values in the portfolio
        conn.execute("UPDATE portfolio SET start = (SELECT DATE(MIN(JULIANDAY(start))) FROM projects);")
        conn.execute("UPDATE portfolio SET finish = (SELECT DATE(MAX(JULIANDAY(start))) FROM projects);")
        conn.execute("UPDATE portfolio SET duration = JULIANDAY(finish) - JULIANDAY(start);")
        conn.execute("UPDATE portfolio SET numberofprojects = (SELECT COUNT(*) from projects);")
        conn.execute("UPDATE portfolio SET numberofactivities = (SELECT COUNT(*) from activities);")
        # Back calculations
        conn.execute("UPDATE activities SET lf = (SELECT finish FROM projects WHERE projectid = ?) WHERE projectid = ? AND activityid NOT IN (SELECT activity1id FROM relationships WHERE relationships.projectid = ?);",(projectid,projectid,projectid))
        conn.execute("UPDATE activities SET ls = DATE(JULIANDAY(lf) - duration) WHERE projectid = ? AND lf IS NOT NULL;",(projectid,))
        while conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ? AND ls IS NULL;",(projectid,)).fetchall()[0][0] > 0: # loop while there are unscheduled activities
            log(' + %s New back '%(datetime.datetime.now() - starttime,))
            acts = [a[0] for a in conn.execute("SELECT DISTINCT(activity1id) FROM big WHERE projectid = ? AND activity1ls IS NULL AND activity2ls IS NOT NULL;",(projectid,)).fetchall()]
            log("      -> Focusing on %s activity"%len(acts))
            count = 0
            for activityid in acts: # loop on each unscheduled activity
                d = conn.execute('SELECT activity2ls,activity2lf, activity1duration,type, rlag FROM big WHERE projectid = ? AND activity1id = ?;',(projectid,activityid)).fetchall()
                if None not in [a[0] for a in d]:
                    ls2l = [a[0] for a in d]
                    lf2l = [a[1] for a in d]
                    dur1l = [a[2] for a in d]
                    rtypel = [a[3] for a in d]
                    rlags = [a[4] for a in d]
                    project_finish = parse_date(conn.execute("SELECT finish FROM projects WHERE projects.projectid = ?",(projectid,)).fetchall()[0][0])
                    if None not in ls2l + lf2l and d != []: # If this is true, then the activity can be scheduled because all its predessessors are set
                        ls2l = [parse_date(a) for a in ls2l]
                        lf2l = [parse_date(a) for a in lf2l]
                        possible_lf1 = [project_finish]
                        for ls2,lf2,dur1,rtype,rlag in zip(ls2l,lf2l,dur1l,rtypel,rlags):
                            if rlag == None:
                                rlag = 0
                            if rtype in ['fs','FS','fS','Fs']:
                                possible_lf1.append(ls2 + datetime.timedelta(rlag))
                            if rtype in ['ss','SS','sS','Ss']:
                                possible_lf1.append(ls2 + datetime.timedelta(dur1) + datetime.timedelta(rlag))
                            if rtype in ['ff','FF','fS','Fs']:
                                possible_lf1.append(lf2 + datetime.timedelta(rlag))
                            if rtype in ['sf','SF','sF','Fs']:
```

```
                                    possible lf1.append(lf2 + datetime.timedelta(dur1) + datetime.timedelta(rlag))
                                lf1 = min(possible lf1)

                            # compare if there is a constraint of the activity
                            primaryconstraint, primaryconstraintdate,duration, calendar = conn.execute("SELECT primaryconstraint, primaryconstraintdate,duration,calendar FROM activities WHERE projectid = ? AND activityid = ?",(projectid, activityid)).fetchall()[0]
                            if primaryconstraint != None:
                                primaryconstraintdate = parse date(primaryconstraintdate)
                                if primaryconstraint == "Finish On or Before" and lf1 > primaryconstraintdate:
                                    lf1 = primaryconstraintdate
                                elif primaryconstraint == "Start On or After" and lf1 - datetime.timedelta(duration) < primaryconstraintdate:
                                    lf1 = primaryconstraintdate + datetime.timedelta(duration)
                            ls = adddays(lf1,-duration,calendar)

                            conn.execute("UPDATE activities SET lf = ? WHERE projectid = ? AND activityid = ?;",(lf1.isoformat(), projectid,activityid))
                            conn.execute("UPDATE activities SET ls = ? WHERE projectid = ? AND activityid = ?;",(ls.isoformat(), projectid,activityid))
                            count += 1
                log("      -> set %s activity "%count)
            conn.execute("UPDATE activities SET tf = JULIANDAY(lf) - JULIANDAY(ef) WHERE projectid = ?;",(projectid,)) # calculate the total float
        # update projects
        conn.execute("UPDATE projects SET totalactivities = (SELECT COUNT(*) FROM activities WHERE projects.projectid = activities.projectid);")
        conn.execute("UPDATE projects SET criticalactivities = (SELECT COUNT(*) FROM activities WHERE projects.projectid = activities.projectid AND activities.tf = 0);")
        conn.commit()
        conn.execute('VACUUM;')
        conn.commit()
        log(' + %s Done.'%(datetime.datetime.now() - starttime,))

    elif cond == 'opt':# FRONt CALCULATION ONLY FOR THE OPTIMUM. This will not randomize the lags, it will only calculate upon them
        for projectid in projects: # loop for each project
            log(' > %s Project %s/%s with %s activity'%(datetime.datetime.now() - starttime,projects.index(projectid) + 1, len(projects),conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ?;",(projectid,)).fetchall()[0][0]))
            conn.execute("UPDATE activities SET os = DATE((SELECT JULIANDAY(start) FROM projects WHERE projectid = ?) + lag) WHERE projectid = ? AND activityid NOT IN (SELECT activity2id FROM relationships WHERE relationships.projectid = ?);",(projectid,projectid,projectid))
            conn.execute("UPDATE activities SET of = DATE(JULIANDAY(os) + duration) WHERE projectid = ? AND os IS NOT NULL;",(projectid,))
            while conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ? AND os IS NULL;",(projectid,)).fetchall()[0][0] > 0: # loop while there are unscheduled activities
                log(' + %s New front -  Remaining activities = %s activitiy'%(datetime.datetime.now() - starttime,conn.execute("SELECT COUNT(*) FROM activities WHERE projectid = ? AND os IS NULL;", (projectid,)).fetchall()[0][0]))
                acts = [a[0] for a in conn.execute("SELECT DISTINCT(activity2id) FROM big WHERE projectid = ? AND activity2os IS NULL AND activity1os IS NOT NULL;",(projectid,)).fetchall()]
                log("      -> Focusing on %s activity"%len(acts))
```

```
            count = 0
            for activityid in acts: # loop on each unscheduled activity
                d = conn.execute('SELECT activity1os,activity1of, activity2duration,type, rlag FROM big WHERE projectid = ? AND activity2id = ?;',(projectid,activityid)).fetchall()
                os1l = [a[0] for a in d]
                of1l = [a[1] for a in d]
                dur2l = [a[2] for a in d]
                rtypel = [a[3] for a in d]
                rlags = [a[4] for a in d]
                lag,  es2 = conn.execute('SELECT lag, es FROM activities WHERE projectid = ? AND activityid = ?;',(projectid,activityid)).fetchall()[0]
                lag = int(lag)
                es2 = parse date(es2)
                project start = parse date(conn.execute("SELECT start FROM projects WHERE projects.projectid = ?",(projectid,)).fetchall()[0][0])
                if None not in os1l + of1l + dur2l + rtypel and d != []: # If this is true, then the activity can be scheduled because all its predessessors are set
                    os1l = [parse date(a) for a in os1l]
                    of1l = [parse date(a) for a in of1l]
                    possible os2 = [project start,es2 + datetime.timedelta(lag)]
                    for os1,of1,dur2,rtype,rlag in zip(os1l,of1l,dur2l,rtypel,rlags):
                        if rlag == None:
                            rlag = 0
                        if rtype in ['fs','FS','fS','Fs']:
                            possible os2.append(of1 + datetime.timedelta(rlag))
                        if rtype in ['ss','SS','sS','Ss']:
                            possible os2.append(os1 + datetime.timedelta(rlag))
                        if rtype in ['ff','FF','fS','Fs']:
                            possible os2.append(of1 - datetime.timedelta(dur2) + datetime.timedelta(rlag))
                        if rtype in ['sf','SF','sF','Fs']:
                            possible os2.append(os1 - datetime.timedelta(dur2) + datetime.timedelta(rlag))
                        os2 = max(possible os2)

                    # compare if there is a constraint of the activity
                    primaryconstraint, primaryconstraintdate,duration,calendar = conn.execute("SELECT primaryconstraint, primaryconstraintdate,duration,calendar FROM activities WHERE projectid = ? AND activityid = ?",(projectid, activityid)).fetchall()[0]
                    if primaryconstraint != None:
                        primaryconstraintdate = parse date(primaryconstraintdate)
                        if primaryconstraint == "Finish On or Before" and os2 + datetime.timedelta(duration) > primaryconstraintdate:
                            os2 = primaryconstraintdate - datetime.timedelta(duration)
                        elif primaryconstraint == "Start On or After" and os2 < primaryconstraintdate:
                            os2 = primaryconstraintdate
                    of = adddays(os2,duration,calendar)

                    conn.execute("UPDATE activities SET os = ? WHERE projectid = ? AND activityid = ?;",(os2.isoformat(),projectid,activityid))
                    conn.execute("UPDATE activities SET lag = JULIANDAY(os) - JULIANDAY(es) WHERE projectid = ? AND activityid = ?;",(projectid,activityid))
                    conn.execute("UPDATE activities SET of = ? WHERE projectid = ? AND activityid = ?;",(of.isoformat(),projectid,activityid))
                    count += 1
            log("     -> set %s activity "%count)
# -----------------------------------------------------------------
log('Calculating Cash flow ')
```

```
    if cond == '':
        # Calculate cost and price of projects
        conn.execute("UPDATE projects SET cost = (SELECT SUM(cost) FROM activities
        WHERE projects.projectid = activities.projectid);")
        conn.execute("UPDATE projects SET price = cost * (1+markup);")
    # Initiate the cash flow table
    conn.execute("DELETE FROM cashflow%s;"%cond)
    conn.execute("DELETE FROM cashflowall%s;"%cond)
    # create the dates ------------------------------------
    first date = conn.execute("SELECT DATE(MIN(JULIANDAY(es))) FROM activities;").
    fetchall()[0][0]
    finish date = conn.execute("SELECT DATE(MAX(JULIANDAY(ls))) FROM activities;").
    fetchall()[0][0]
    max payment period = int(conn.execute("SELECT MAX(paymentperiod) FROM projects;"
    ).fetchall()[0][0])
    max retention period = int(conn.execute("SELECT MAX(retentionperiod) FROM
    projects;").fetchall()[0][0])
    first date = datetime.date(int(first date.split("-")[0]),int(first date.split("-"
    )[1]),int(first date.split("-")[2]))
    finish date = datetime.date(int(finish date.split("-")[0]),int(finish date.split(
    "-")[1]),int(finish date.split("-")[2]))
    last date = finish date + datetime.timedelta(max(max payment period,
    max retention period)+10)
    curr date = first date
    projects = [a[0] for a in conn.execute("SELECT projectid FROM projects;")]
    while curr date <= last date:
        for project in projects:
            conn.execute("INSERT INTO cashflow%s (date,projectid) VALUES (?,?);"%cond
            ,(curr date.isoformat(),project))
        curr date += datetime.timedelta(1)
    log("  + %s Filled cash flow with dates"%(datetime.datetime.now() - starttime,))
    for projectid in projects: # loop for each project NOTE: For some reason, it may
    better to do it this way
        log(" - Calculating cash project %s/%s"%(projects.index(projectid)+1,len(
        projects)))
        # Fill cash out
        if cond == '':
            conn.execute("UPDATE cashflow%s SET cashout = (SELECT SUM(cost/duration)
            FROM activities WHERE projectid = ? AND cashflow%s.date >= activities.%s
            and cashflow%s.date < activities.%s) WHERE projectid = ?;"%(cond,cond,
            'es',cond,'ef'),(projectid,projectid))
        elif cond == 'opt':
            conn.execute("UPDATE cashflow%s SET cashout = (SELECT SUM(cost/duration)
            FROM activities WHERE projectid = ? AND cashflow%s.date >= activities.%s
            and cashflow%s.date < activities.%s) WHERE projectid = ?;"%(cond,cond,
            'os',cond,'of'),(projectid,projectid))
        conn.execute("UPDATE cashflow%s SET cashout = 0 WHERE cashout IS NULL AND
        projectid = ?;"%cond,(projectid,))
        log("  + %s Calculated cash out"%(datetime.datetime.now() - starttime,))
        conn.execute("UPDATE cashflow%s SET cashin = 0 WHERE projectid = ?;"%cond,(
        projectid,))
        # Fill the invoices issued without considering the downpayment and retention
        #~ conn.execute("UPDATE cashflow%s SET cashin = cashin + (SELECT
        SUM(cashout) * (1+(SELECT markup from projects WHERE projectid = ?)) FROM
        cashflow%s as c2 WHERE projectid = ? AND DATE(cashflow%s.date,'start of
        month') = DATE(c2.date,'start of month')) WHERE date = DATE(date,'start of
        month','+1 month','-1 day') AND projectid =
        ?;"%(cond,cond,cond),(projectid,projectid,projectid))

        conn.execute("UPDATE cashflow%s SET cashin = cashin + (SELECT SUM(cashout)
        FROM cashflow%s as c2 WHERE projectid = ? AND
        DATE(JULIANDAY(cashflow%s.date) - (SELECT paymentperiod FROM projects WHERE
        projectid = ?),'start of month','+1 month','-1 day') = DATE(c2.date,'start
        of month','+1 month','-1 day')) WHERE DATE(JULIANDAY(date) - (SELECT
        paymentperiod FROM projects WHERE projectid = ?)) = DATE(JULIANDAY(date) -
        (SELECT paymentperiod FROM projects WHERE projectid = ?),'start of
        month','+1 month','-1 day') AND projectid = ?;"%(cond,cond,cond),(projectid,
        projectid,projectid,projectid,projectid))
```

```
            # increse profit deduction for downpayment and retention
            conn.execute("UPDATE cashflow%s SET cashin = cashin * (1+(SELECT markup from projects WHERE projectid = ?)) WHERE projectid = ? AND cashin != 0;"%cond,(projectid,projectid))
            conn.execute("UPDATE cashflow%s SET cashin = cashin - ((cashin / (SELECT price FROM projects WHERE projectid = ?)) * ((SELECT downpayment*price FROM projects WHERE projectid = ?) + (SELECT retention*price FROM projects WHERE projectid = ?))) WHERE cashin != 0 AND projectid = ?;"%(cond,),(projectid,projectid,projectid,projectid))
            # Fill the downpayments
            conn.execute("UPDATE cashflow%s SET cashin = cashin + (SELECT downpayment*price FROM projects WHERE projectid = ?) WHERE date = (SELECT start FROM projects WHERE projectid = ?) AND projectid = ?;"%(cond,),(projectid,projectid,projectid))
            # Fill the retention received
            conn.execute("UPDATE cashflow%s SET cashin = cashin + (SELECT retention*price FROM projects WHERE projectid = ?) WHERE date=(SELECT DATE(JULIANDAY(finish)+retentionperiod) FROM projects WHERE projectid = ?) AND projectid = ?;"%(cond,),(projectid,projectid,projectid))
            log("  + %s Calculated cash in"%(datetime.datetime.now() - starttime,))
            # Fill cash out cumulative
            conn.execute("UPDATE cashflow%s SET cashoutcum = (SELECT SUM(cashout) FROM cashflow%s as temp WHERE projectid = ? AND JULIANDAY(cashflow%s.date) >= JULIANDAY(temp.date)) WHERE projectid = ?;"%(cond,cond,cond), (projectid, projectid))
            # Fill cash in cumulative
            conn.execute("UPDATE cashflow%s SET cashincum = (SELECT SUM(cashin) FROM cashflow%s as temp WHERE projectid = ? AND JULIANDAY(cashflow%s.date) >= JULIANDAY(temp.date)) WHERE projectid = ?;"%(cond,cond,cond), (projectid, projectid))
            log("  + %s Calculated cummulative"%(datetime.datetime.now() - starttime,))
            # Fill the overdraft
            conn.execute("UPDATE cashflow%s SET overdraft = cashincum - cashoutcum WHERE projectid = ?;"%cond,(projectid,))
            #Fill the discounted values
            conn.create function("pv",2,pv) # Creates a new function in SQLITE to calculate the present value
            conn.execute("UPDATE cashflow%s SET cashoutdisc = cashout / pv((SELECT interest from projects WHERE projectid = ?),JULIANDAY(date) - (SELECT MIN(JULIANDAY(start)) FROM projects)) WHERE projectid = ?;"%(cond,), (projectid, projectid))
            conn.execute("UPDATE cashflow%s SET cashindisc = cashin / pv((SELECT interest from projects WHERE projectid = ?),JULIANDAY(date) - (SELECT MIN(JULIANDAY(start)) FROM projects)) WHERE projectid = ?;"%(cond,), (projectid,projectid))
            conn.execute("UPDATE cashflow%s SET cashoutcumdisc = cashoutcum / pv((SELECT interest from projects WHERE projectid = ?),JULIANDAY(date) - (SELECT MIN(JULIANDAY(start)) FROM projects)) WHERE projectid = ?;"%(cond,), (projectid, projectid))
            conn.execute("UPDATE cashflow%s SET cashincumdisc = cashincum / pv((SELECT interest from projects WHERE projectid = ?),JULIANDAY(date) - (SELECT MIN(JULIANDAY(start)) FROM projects)) WHERE projectid = ?;"%(cond,), (projectid, projectid))
            conn.execute("UPDATE cashflow%s SET overdraftdisc = overdraft / pv((SELECT interest from projects WHERE projectid = ?),JULIANDAY(date) - (SELECT MIN(JULIANDAY(start)) FROM projects)) WHERE projectid = ?;"%(cond,), (projectid, projectid))
            log("  + %s Calculated discounted"%(datetime.datetime.now() - starttime,))
        # fill into the cashflow all table
        conn.execute("DELETE FROM cashflowall%s;"%cond)
        # create the dates
        first date = conn.execute("SELECT DATE(MIN(JULIANDAY(start))) FROM projects;").fetchall()[0][0]
        last date = conn.execute("SELECT DATE(MAX(MAX(JULIANDAY(finish)+paymentperiod),MAX(JULIANDAY(finish)+retentionperiod)) + 50) FROM projects;").fetchall()[0][0]
        first_date = datetime.date(int(first_date.split("-")[0]),int(first_date.split("-"
```

```
)[1]),int(first date.split("-")[2]))
    last date = datetime.date(int(last date.split("-")[0]),int(last date.split("-")[1]),int(last date.split("-")[2]))
    curr date = first date
    while curr date <= last date:
        conn.execute("INSERT INTO cashflowall%s (date) VALUES ('%s')"%(cond,curr date.isoformat()))
        curr date += datetime.timedelta(1)
    # fill in the values in the
    conn.execute("UPDATE cashflowall%s SET projectid = 'all';"%cond)
    for col in ['cashin','cashout','cashincum','cashoutcum','cashindisc','cashoutdisc','cashincumdisc','cashoutcumdisc','overdraft','overdraftdisc']:
        conn.execute("UPDATE cashflowall%s SET %s = (SELECT SUM(%s) FROM cashflow%s WHERE cashflow%s.date = cashflowall%s.date);"%(cond,col,col,cond,cond,cond))
    # Fill the present values and the npv into the projects table
    conn.execute("UPDATE projects SET cashinpv%s = (SELECT SUM(cashindisc) FROM cashflow%s WHERE cashflow%s.projectid = projects.projectid);"%(cond,cond,cond))
    conn.execute("UPDATE projects SET cashoutpv%s = (SELECT SUM(cashoutdisc) FROM cashflow%s WHERE cashflow%s.projectid = projects.projectid);"%(cond,cond,cond))
    conn.execute("UPDATE projects SET npv%s = cashinpv%s - cashoutpv%s;"%(cond,cond,cond))
    conn.execute("UPDATE projects SET maxoverdraftdisc%s = (SELECT MAX(overdraftdisc) FROM cashflow%s WHERE cashflow%s.projectid = projects.projectid);"%(cond,cond,cond))
    conn.execute("UPDATE projects SET minoverdraftdisc%s = (SELECT MIN(overdraftdisc) FROM cashflow%s WHERE cashflow%s.projectid = projects.projectid);"%(cond,cond,cond))
    # FILL the cashflow values in the portfolio table
    if cond == '':
        conn.execute("UPDATE portfolio SET cost = (SELECT SUM(cost) FROM projects);")
        conn.execute("UPDATE portfolio SET price = (SELECT SUM(price) FROM projects);")
    conn.execute("UPDATE portfolio SET cashinpv%s = (SELECT SUM(cashindisc) FROM cashflowall%s);"%(cond,cond))
    conn.execute("UPDATE portfolio SET cashoutpv%s = (SELECT SUM(cashoutdisc) FROM cashflowall%s);"%(cond,cond))
    conn.execute("UPDATE portfolio SET npv%s = cashinpv%s - cashoutpv%s;"%(cond,cond,cond))
    conn.execute("UPDATE portfolio SET maxoverdraftdisc%s = (SELECT MAX(overdraftdisc) FROM cashflowall%s);"%(cond,cond))
    conn.execute("UPDATE portfolio SET minoverdraftdisc%s = (SELECT MIN(overdraftdisc) FROM cashflowall%s);"%(cond,cond))
    conn.commit()
    conn.execute("VACUUM;")
    conn.commit()
    log(" + %s Done."%(datetime.datetime.now() - starttime,))

def export(): # export a lot of files for further analysis
    log("Exporting")
    if not os.path.exists(export folder):
        os.mkdir(export folder)
    # Remove old files

    files = os.listdir(export folder)
    for file in files:
        try:
            os.remove(export folder+file)
        except:
            log(' [!] Error removing file "%s" from export folder!'%file)
    log(' - Removed old files from export folder')

    # export database summary
    txtfile = export folder + 'summary.txt'
    with open(txtfile,'w') as f:
        tablenames = [a[0] for a in conn.execute("Select name FROM sqlite master WHERE type='table' or type='view';").fetchall()]
        for name in tablenames:
            f.write(' -> '+name+'\n')
            columnnames = [a[1] for a in conn.execute("PRAGMA table_info(%s);" %name)]
```

```
                columntypes = [a[2] for a in conn.execute("PRAGMA table info(%s);" %name)]
                for col,t in zip(columnnames,columntypes):
                    f.write('        -> '+col + ' -> '+ t +'\n')

        # Export excel file
        excel file = export folder + 'output.xlsx'
        log(' - Exporting to Excel File "%s"' %excel file)
        wb = xlsxwriter.Workbook(excel file)
        bold = wb.add format({'bold': True})
        for table in [a[0] for a in conn.execute("SELECT name FROM sqlite master WHERE type='table';").fetchall()]:
            ws = wb.add worksheet(table)
            ws.repeat rows(0)
            ws.freeze panes(1, 1)
            ws.set portrait()
            ws.set paper(4)
            ws.center horizontally()
            ws.center vertically()
            ws.set footer('&CPage &P of &N')
            ws.fit to pages(1, 0)
            row = 0
            col = 0
            heads = [a[0] for a in conn.execute("PRAGMA table info(%s);" %table)]
            for head in heads:
                ws.write(row,col,head,bold)
                col += 1
                ws.set column(0,col,15)
            row = 1
            sql = 'SELECT * FROM %s;'%table
            for each in conn.execute(sql).fetchall():
                col = 0
                for cell in each:
                    ws.write(row,col,cell)
                    col += 1
                row += 1
        conn.close
        wb.close()

        # export csv file for every table
        log(" - Exporting csvs")
        tables = [a[0] for a in conn.execute("SELECT name FROM sqlite master WHERE type='table';").fetchall()]
        for table in tables:
            with open(export folder+'%s.csv'%table,'w',newline='') as csvfile:
                w = spamwriter = csv.writer(csvfile)
                data = conn.execute("PRAGMA table info(%s);" %table).fetchall()
                data = [a[1] for a in data]
                w.writerow(data)
                data = conn.execute("SELECT * FROM %s;"%table)
                for r in data:
                    w.writerow(r)

        # export portfolio charts
        log(" - Exporting portfolio charts")
        export file name = export folder + 'portfoliosummary' + figure export format
        data = conn.execute("SELECT projectid,totalactivities,criticalactivities FROM projects;").fetchall()
        projectids = [a[0] for a in data]
        totalactivities = [int(a[1]) for a in data]
        criticalactivities = [int(a[2]) for a in data]
        noncriticalactivities = [a[1] - a[0] for a in zip(criticalactivities, totalactivities)]
        lw = 10
        plt.vlines(range(len(projectids)),[0 for a in projectids], criticalactivities, color = 'red', label = 'Critical Activities', lw = lw)
        plt.vlines(range(len(projectids)),criticalactivities,totalactivities, color = 'blue', label = 'Non--critical Activities', lw = lw)
        plt.xlabel('Projects')
```

```python
    plt.ylabel('Number of Activities')
    plt.title(title + 'Summary of Activities')
    plt.xticks(range(len(projectids)),projectids)
    plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
    plt.margins(0.05)
    plt.savefig(export_file_name,transparent=True)
    plt.close('all')

    # export gantt charts for portfolio and projects
    log(' - Exporting Gantt Charts')
    projects = conn.execute("SELECT projectid, start, finish FROM projects;").fetchall()
    projects.reverse()
    projectids = [a[0] for a in projects]
    projectstarts = [parse_date(a[1]) for a in projects]
    projectfinishes = [parse_date(a[2]) for a in projects]
    fig, ax = plt.subplots(1)
    lw = 8
    color = 'blue'
    ax.hlines(range(len(projectids)),projectstarts,projectfinishes,lw=lw, color = color)
    fig.autofmt_xdate()
    plt.xlabel('Time')
    plt.ylabel('Projects')
    plt.yticks(range(len(projectids)),projectids)
    xticks = [min(projectstarts) ,max(projectfinishes)]
    plt.xticks(xticks,xticks)
    plt.title(title + 'Portfolio Gantt Chart')
    plt.margins(0.05)
    plt.savefig(export_folder+'portfolioganttchart'+figure_export_format,transparent=True)
    plt.close('all')
    for p in projectids:
        export_file_name = 'ganttchart' + p + figure_export_format
        data = conn.execute("SELECT activityid,es,ef,lf FROM activities WHERE projectid = '%s';"%p).fetchall()
        data.reverse()
        activityid = [a[0] for a in data]
        activityn = range(len(activityid))
        adict = {}
        for aid, an in zip(activityid, activityn):
            adict[aid] = an
        es = [parse_date(a[1]) for a in data]
        ef = [parse_date(a[2]) for a in data]
        lf = [parse_date(a[3]) for a in data]
        fig, ax = plt.subplots(1)
        lw = 2
        ax.hlines(activityn,es,ef,lw=lw, color = color, label= 'Non-critical Activities')
        if None not in lf:
            ax.hlines(activityn,ef, lf,lw=lw/1.5, color = 'green', label = 'Total Float')
            critaid = []
            ces = []
            cef= []
            clf = []
            for a in zip(range(len(activityid)),es,ef,lf):
                if a[2] == a[3]:
                    critaid.append(a[0])
                    ces.append(a[1])
                    cef.append(a[2])
                    clf.append(a[3])
            ax.hlines(critaid,ces,cef,lw=lw, color = 'red', label= 'Critical Activities')
        plt.yticks(activityn,['' for a in activityid], size = 2)
        fig.autofmt_xdate()
        # add arrows for the relationships
        data = conn.execute("SELECT activitylid, activityles, activitylef,
```

```
        activity2id, activity2es, activity2ef, type FROM big WHERE projectid = '%s';" %p).fetchall()
        for activity1id, activity1es, activity1ef, activity2id, activity2es, activity2ef, rtype in zip([a[0] for a in data], [parse date(a[1]) for a in data], [parse date(a[2]) for a in data], [a[3] for a in data], [parse date(a[4]) for a in data], [parse date(a[5]) for a in data], [a[6] for a in data]):
            activity1n = adict[activity1id]
            activity2n = adict[activity2id]
            if rtype in ['fs','FS','fS','Fs']:
                plt.annotate("", xy=(activity1ef, activity1n), xycoords='data', xytext=(activity2es, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
            if rtype in ['ss','SS','sS','Ss']:
                plt.annotate("", xy=(activity1es, activity1n), xycoords='data', xytext=(activity2es, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
            if rtype in ['ff','FF','fS','Fs']:
                plt.annotate("", xy=(activity1ef, activity1n), xycoords='data', xytext=(activity2ef, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
            if rtype in ['sf','SF','sF','Fs']:
                plt.annotate("", xy=(activity1es, activity1n), xycoords='data', xytext=(activity2ef, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
        plt.xlabel('Time')
        xticks = [min(es) ,max(ef)]
        plt.xticks(xticks,xticks)
        plt.ylabel('Activities')
        plt.title(title + 'Gantt Chart - ' + p)
        plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
        plt.margins(0.05)
        plt.savefig(export folder+export file name,transparent=True)
        plt.close('all')

    # Export cashflow charts
    log(" - Exporting cashflow")
    data = conn.execute("SELECT date,cashincum,cashoutcum,overdraft,cashincumdisc,cashoutcumdisc,overdraftdisc from cashflowall;").fetchall()
    dates = [a[0] for a in data]
    dates = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in dates]
    cashincum = [a[1] for a in data]
    cashoutcum = [a[2] for a in data]
    overdraft = [a[3] for a in data]
    cashincumdisc = [a[4] for a in data]
    cashoutcumdisc = [a[5] for a in data]
    overdraftdisc = [a[6] for a in data]
    plt.close('all')
    fig, ax = plt.subplots(1)
    lw = 0.5
    for a, l in ((cashincum,'Cash In Cummulative'),(cashoutcum,'Cash Out Cummulative'),(overdraft,'Overdraft'),(cashincumdisc,'Cash Out Cummulative Discounted'),(cashoutcumdisc,'Cash Out Cummulative Discounted'),(overdraftdisc,'Overdraft Discounted')):
        ax.plot(dates,a,label = l, lw=lw)
    fig.autofmt xdate()
    plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
    plt.xlabel('Time')
    plt.ylabel('EGP')
    plt.title(title + 'Cash-flow')
    plt.grid(True)
    plt.savefig(export folder+'cashflow'+figure export format,transparent=True)
    plt.close('all')

    # export chart of trials
    log(" - Exporting chart for the trials")
    data = conn.execute("SELECT trialid, initialnpv, trialnpv, bestnpv FROM trials;"
```

```
    ).fetchall()
    trialid = [a[0] for a in data]
    initialnpv = [a[1] for a in data]
    trialnpv = [a[2] for a in data]
    bestnpv = [a[3] for a in data]
    fig, ax = plt.subplots(1)
    lw = 0.5
    for a, l in ((initialnpv,'Initial NPV'), (bestnpv,'Best NPV')):
        ax.plot(trialid,a, label = l, lw= 2 * lw)
    ax.plot(trialid, trialnpv, 'o', label = 'Trial NPV', lw=lw)
    plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
    plt.xlabel('Trial #')
    plt.ylabel('NPV')
    plt.title(title + 'Optimization trials')
    plt.grid(True)
    plt.margins(0.05)
    plt.savefig(export folder+'optimization trials'+figure export format,transparent=True)
    plt.close('all')

    # export optimization gantt chart
    try:
        log(' - Exporting Optimized Gantt Charts')
        projects = conn.execute("SELECT projectid, start, finish FROM projects;").fetchall()
        for p in projectids:
            export file name = 'optimizedganttchart' + p + figure export format
            data = conn.execute("SELECT activityid,es,ef,lf,os,of FROM activities WHERE projectid = '%s';"%p).fetchall()
            data.reverse()
            activityid = [a[0] for a in data]
            activityn = range(len(activityid))
            adict = {}
            for aid, an in zip(activityid, activityn):
                adict[aid] = an
            es = [a[1] for a in data]
            ef = [a[2] for a in data]
            lf = [a[3] for a in data]
            ost = [a[4] for a in data]
            of = [a[5] for a in data]
            es = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in es]
            ef = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in ef]
            lf = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in lf]
            ost = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in ost]
            of = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in of]
            fig, ax = plt.subplots(1)
            lw = 2
            ax.hlines(range(len(activityid)),es,lf,lw=0.7*lw, color = 'grey', label='Activity Range (ES to LF)')
            #~ ax.hlines(range(len(activityid)),of,lf,lw=0.7*lw, color = 'grey', label= 'Total Float')
            ax.hlines(range(len(activityid)),ost,of,lw=lw, color = 'blue', label='Non-critical Activities')
            if None not in lf:
                critaid = []
                ces = []
                cef= []
                clf = []
                for a in zip(range(len(activityid)),es,ef,lf):
                    if a[2] == a[3]:
                        critaid.append(a[0])
                        ces.append(a[1])
                        cef.append(a[2])
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                        clf.append(a[3])
                ax.hlines(critaid,ces,cef,lw=lw, color = 'red', label= 'Critical Activities')
            plt.yticks(range(len(activityid)),['' for a in activityid], size = 2)
            fig.autofmt xdate()
            # add arrows for the relationships
            data = conn.execute("SELECT activity1id, activity1os, activity1of, activity2id, activity2os, activity2of, type FROM big WHERE projectid = '%s';"%p).fetchall()
            for activity1id, activity1os, activity1of, activity2id, activity2os, activity2of, rtype in zip([a[0] for a in data], [parse date(a[1]) for a in data], [parse date(a[2]) for a in data], [a[3] for a in data], [parse date(a[4]) for a in data], [parse date(a[5]) for a in data], [a[6] for a in data]):
                activity1n = adict[activity1id]
                activity2n = adict[activity2id]
                if rtype in ['fs','FS','fS','Fs']:
                    plt.annotate("", xy=(activity1of, activity1n), xycoords='data', xytext=(activity2os, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
                if rtype in ['ss','SS','sS','Ss']:
                    plt.annotate("", xy=(activity1os, activity1n), xycoords='data', xytext=(activity2os, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
                if rtype in ['ff','FF','fS','Fs']:
                    plt.annotate("", xy=(activity1of, activity1n), xycoords='data', xytext=(activity2of, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
                if rtype in ['sf','SF','sF','Fs']:
                    plt.annotate("", xy=(activity1os, activity1n), xycoords='data', xytext=(activity2of, activity2n), textcoords='data', arrowprops=dict(arrowstyle="<-", lw = 0.2))
            plt.xlabel('Time')
            plt.ylabel('Activities')
            plt.title(title + 'Optimized Gantt Chart - ' + p)
            xticks = [min(es) ,max(ef)]
            plt.xticks(xticks,xticks)
            plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
            plt.margins(0.05)
            plt.savefig(export folder+export file name,transparent=True)
            plt.close('all')
    except Exception as e:
        log("    - Failed to export optimized gantt charts, skipping")

    # export optimization gantt chart without relationship arrows
    try:
        log(' - Exporting Optimized Gantt Charts without relationship arrows')
        projects = conn.execute("SELECT projectid, start, finish FROM projects;").fetchall()
        for p in projectids:
            export file name = 'optimizedganttchartnoarrows' + p + figure export format
            data = conn.execute("SELECT activityid,es,ef,lf,os,of FROM activities WHERE projectid = '%s';"%p).fetchall()
            data.reverse()
            activityid = [a[0] for a in data]
            activityn = range(len(activityid))
            adict = {}
            for aid, an in zip(activityid, activityn):
                adict[aid] = an
            es = [a[1] for a in data]
            ef = [a[2] for a in data]
            lf = [a[3] for a in data]
            ost = [a[4] for a in data]
            of = [a[5] for a in data]
            es = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in es]
            ef = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in ef]
```

```
            lf = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in lf]
            ost = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in ost]
            of = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in of]
            fig, ax = plt.subplots(1)
            lw = 2
            ax.hlines(range(len(activityid)),es,lf,lw=0.7*lw, color = 'grey', label='Activity Range (ES to LF)')
            #~ ax.hlines(range(len(activityid)),of,lf,lw=0.7*lw, color = 'grey', label= 'Total Float')
            ax.hlines(range(len(activityid)),ost,of,lw=lw, color = 'blue', label='Non-critical Activities')
            if None not in lf:
                critaid = []
                ces = []
                cef= []
                clf = []
                for a in zip(range(len(activityid)),es,ef,lf):
                    if a[2] == a[3]:
                        critaid.append(a[0])
                        ces.append(a[1])
                        cef.append(a[2])
                        clf.append(a[3])
                ax.hlines(critaid,ces,cef,lw=lw, color = 'red', label= 'Critical Activities')
            plt.yticks(range(len(activityid)),['' for a in activityid], size = 2)
            fig.autofmt xdate()
            plt.xlabel('Time')
            plt.ylabel('Activities')
            plt.title(title + 'Optimized Gantt Chart - ' + p)
            xticks = [min(es) ,max(ef)]
            plt.xticks(xticks,xticks)
            plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
            plt.margins(0.05)
            plt.savefig(export folder+export file name,transparent=True)
            plt.close('all')
    except Exception as e:
        log("    - Failed to export optimized gantt charts, skipping")

    # Export optimized cashflow charts
    try:
        log(" - Exporting optimized cashflow")
        data = conn.execute("SELECT date,cashincum,cashoutcum,overdraft,cashincumdisc,cashoutcumdisc,overdraftdisc from cashflowall;").fetchall()
        dates = [a[0] for a in data]
        dates = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in dates]
        cashincum = [a[1] for a in data]
        cashoutcum = [a[2] for a in data]
        overdraft = [a[3] for a in data]
        cashincumdisc = [a[4] for a in data]
        cashoutcumdisc = [a[5] for a in data]
        overdraftdisc = [a[6] for a in data]
        data = conn.execute("SELECT date,cashincum,cashoutcum,overdraft,cashincumdisc,cashoutcumdisc,overdraftdisc from cashflowallopt;").fetchall()
        datesopt = [a[0] for a in data]
        datesopt = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in datesopt]
        cashincumopt = [a[1] for a in data]
        cashoutcumopt = [a[2] for a in data]
        overdraftopt = [a[3] for a in data]
        cashincumdiscopt = [a[4] for a in data]
        cashoutcumdiscopt = [a[5] for a in data]
        overdraftdiscopt = [a[6] for a in data]
```

```python
        plt.close('all')

        fig, ax = plt.subplots(1)
        lw = 0.5
        for a, l in ((cashincum,'Cash In Cummulative'),(cashoutcum,'Cash Out Cummulative'),(overdraft,'Overdraft'),(cashincumdisc,'Cash Out Cummulative Discounted'),(cashoutcumdisc,'Cash Out Cummulative Discounted'),(overdraftdisc,'Overdraft Discounted')):
            ax.plot(dates,a,label = l, lw=lw)
        for a, l in ((cashincumopt,'Optimized Cash In Cummulative'),(cashoutcumopt,'Optimized Cash Out Cummulative'),(overdraftopt,'Optimized Overdraft'),(cashincumdiscopt,'Optimized Cash Out Cummulative Discounted'),(cashoutcumdiscopt,'Optimized Cash Out Cummulative Discounted'),(overdraftdiscopt,'Optimized Overdraft Discounted')):
            ax.plot(dates,a,label = l, lw=lw)
        fig.autofmt_xdate()
        plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
        plt.xlabel('Time')
        plt.ylabel('EGP')
        plt.title(title + 'Cash-flow - Combined')
        plt.grid(True)
        plt.savefig(export_folder+'optimized_cashflow_combined'+figure_export_format, transparent=True)
        plt.close('all')

        fig, ax = plt.subplots(1)
        lw = 0.5
        for a, l in ((cashincum,'Cash In Cummulative'),(cashoutcum,'Cash Out Cummulative'),(overdraft,'Overdraft')):
            ax.plot(dates,a,label = l, lw=lw)
        for a, l in ((cashincumopt,'Optimized Cash In Cummulative'),(cashoutcumopt,'Optimized Cash Out Cummulative'),(overdraftopt,'Optimized Overdraft')):
            ax.plot(dates,a,label = l, lw=lw)
        fig.autofmt_xdate()
        plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
        plt.xlabel('Time')
        plt.ylabel('EGP')
        plt.title(title + 'Optimized Cash-flow (Comparision)')
        plt.grid(True)
        plt.savefig(export_folder+'optimized_cashflow_fv'+figure_export_format, transparent=True)
        plt.close('all')

        fig, ax = plt.subplots(1)
        lw = 0.5
        for a, l in ((overdraft,'Overdraft'), (overdraftopt,'Optimized Overdraft')):
            ax.plot(dates,a,label = l, lw=lw)
        fig.autofmt_xdate()
        plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
        plt.xlabel('Time')
        plt.ylabel('EGP')
        plt.title(title + 'Optimized Overdraft (Comparision)')
        plt.grid(True)
        plt.savefig(export_folder+'optimized_cashflow_overdraft'+figure_export_format,transparent=True)
        plt.close('all')

        fig, ax = plt.subplots(1)
        lw = 0.5
        for a, l in ((overdraft,'Overdraft'), (overdraftopt,'Optimized Overdraft'), (overdraftdisc,'Overdraft Discounted'), (overdraftdiscopt,'Optimized Overdraft Discounted')):
            ax.plot(dates,a,label = l, lw=lw)
        fig.autofmt_xdate()
        plt.legend(loc='best',fancybox=True,framealpha=0.5, fontsize = 8)
        plt.xlabel('Time')
        plt.ylabel('EGP')
        plt.title(title + 'Optimized Overdraft Discounted (Comparision)')
```

```
        plt.grid(True)
        plt.savefig(export folder+'optimized cashflow overdraft discounted'+figure export format,transparent=True)
        plt.close('all')
    except Exception as e:
        log("    - Could not export optimized cashflow, skipping")

    log(" - Done")

def optimize(): # optimize
    log("OPTIMIZING")
    global conn
    starttime = datetime.datetime.now()
    # Create list of table names
    tables = [a[0] for a in conn.execute("Select name FROM sqlite master WHERE type='table';").fetchall()]
    tables.remove('trials')
    tablesbackup = [a+'bck' for a in tables]
    # initiate the npv with the current npv using es and ef
    initialnpv = conn.execute("SELECT npv FROM portfolio;").fetchall()[0][0]
    bestnpv = initialnpv
    trialnpv = bestnpv
    conn.execute("DELETE FROM trials;")
    conn.commit()
    conn.execute("INSERT INTO trials (trialid, initialnpv, trialnpv, bestnpv) VALUES ('%s','%s','%s','%s');"%(0,initialnpv,trialnpv,bestnpv))
    # start the trials
    trialid = 0
    condition = True
    while condition:
        trialid += 1
        log(' <> %s Trial %s'%(datetime.datetime.now() - starttime,trialid))
        conn.execute("UPDATE activities SET lag = NULL;")
        conn.execute("UPDATE activities SET os = NULL;")
        conn.execute("UPDATE activities SET of = NULL;")
        conn.execute("UPDATE activities SET lag = 0 WHERE cost = 0 OR tf = 0;") # activities that are critical or have no cost don't need to be optimized'
        conn.execute("UPDATE activities SET os = es WHERE lag = 0;")
        conn.execute("UPDATE activities SET of = ef WHERE lag = 0;")
        # randomize the lags, must be done outside of the database because the random function in sqlite3 is biased
        for projectid in [a [0] for a in conn.execute("SELECT projectid FROM projects;").fetchall()]:
            for activityid in [a[0] for a in conn.execute("SELECT activityid from activities WHERE projectid = '%s' AND tf > 0 AND cost > 0;"%projectid).fetchall()]:
                tf = conn.execute("SELECT tf FROM activities WHERE projectid = '%s' AND activityid = '%s';"%(projectid, activityid)).fetchall()[0][0]
                lag = random.randint(0, tf)
                conn.execute("UPDATE activities SET lag = '%s' WHERE projectid = '%s' AND activityid = '%s'"%(lag, projectid, activityid)) # update the lag
        # calculate the new schedule for the trial using the new lags
        calculate('opt')
        # get current opt npv and compare
        trialnpv = conn.execute("SELECT npvopt FROM portfolio;").fetchall()[0][0]
        if trialnpv > bestnpv: # check if the current trial yields a better result and store it
            bestnpv = trialnpv
            for table, bck in zip(tables,tablesbackup):
                conn.execute("DROP TABLE IF EXISTS %s;"%bck)
                conn.execute("CREATE TABLE %s AS SELECT * FROM %s;"%(bck,table))
            d = [a[0] for a in conn.execute("select DISTINCT(bestnpv) from trials Order BY bestnpv DESC LIMIT 2;").fetchall()]
            if len(d) >= 2:
                if (bestnpv / (sum(d)/len(d))) < optimization stoppingpercentage:
                    condition = False
        if conn.execute("SELECT COUNT(bestnpv) FROM trials WHERE bestnpv = (SELECT
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        MAX(bestnpv) from trials);").fetchall()[0][0] >= optimization.stoppingmaxtrials:
            condition = False
        conn.execute("INSERT INTO trials (trialid, initialnpv, trialnpv, bestnpv) VALUES ('%s','%s','%s','%s');"%(trialid,initialnpv,trialnpv,bestnpv))
        log(' <> %s Trial %s ended. Trial NPV = %s, Best NPV = %s'%(datetime.datetime.now() - starttime,trialid, trialnpv, bestnpv))
    if bestnpv > initialnpv:
        for table,bck in zip(tables,tablesbackup):
            conn.execute("DROP TABLE IF EXISTS %s;"%table)
            conn.execute("CREATE TABLE %s AS SELECT * FROM %s;"%(table,bck))
            conn.execute("DROP TABLE IF EXISTS %s;"%bck)
    conn.commit()
    conn.execute("VACUUM;")
    conn.commit()
    log(' <> %s Optimization ended after %s trial. Initial NPV = %s, Optimized NPV = %s'%(datetime.datetime.now() - starttime,trialid, initialnpv, bestnpv))

def verificate():
    new database()
    create a portfolio()
    #~ import uptown projects()
    database info()
    calculate("normal")
    optimize()
    export()
    database info()

def validate():
    new database()
    #~ create a portfolio()
    import uptown projects()
    database info()
    calculate("normal")
    optimize()
    export()
    database info()

# -------- GUI PART ------------
class Drop_menu: # generic drop list menu for the GUI, because the one in tkinter sucks
    def show(self):
        try:
            self.menu.destroy()
        except:
            pass
        self.menu = tk.OptionMenu(self.master, self.var, *self.options)
        self.menu.pack()

    def options(self, options):
        self.options = options
        if len(options) > 0:
            self.var.set(options[0])
        else:
            self.var.set('')

    def __init__(self, master):
        self.master = master
        self.var = tk.StringVar()
        self.options = []

class Gantt_chart: # Gantt chart for the whole portfolio normal or otimized
    margin = 40
    lw = 2
    project = 'all'
    deltat = 10
    deltaa = 15
    barwidth = 5
    def show(self):
```

```python
        global conn
        self.canvas.delete('all')
        data = conn.execute("SELECT projectid, activityid, es, ef, lf FROM activities;").fetchall()
        activityindex = {}
        for n, projectid, activityid in zip([a for a in range(len(data))], [a[0] for a in data], [a[1] for a in data]):
            activityindex[projectid + activityid] = n
        esl = [parse_date(a[2]) for a in data]
        efl = [parse_date(a[3]) for a in data]
        lfl = [parse_date(a[4]) for a in data]
        na = len(data)
        mint = min(esl)
        maxt = max(lfl)
        totalt = (maxt - mint).days
        self.canvas['scrollregion'] = (0, 0, (totalt * self.deltat) + 2*self.margin, (na * self.deltaa) + 2 * self.margin)
        # margins
        self.canvas.create_rectangle((self.margin, self.margin), (self.margin + totalt * self.deltat, self.margin + na * self.deltaa))
        for a in range(1, totalt):
            self.canvas.create_line(((self.margin + a * self.deltat, self.margin), (self.margin + a * self.deltat, self.margin + na * self.deltaa)), fill = 'grey80')
            if a % 10 == 0:
                self.canvas.create_text((self.margin + a * self.deltat, self.margin - 10), anchor = 'center', text = str(mint + datetime.timedelta(a)))
                self.canvas.create_line(((self.margin + a * self.deltat, self.margin), (self.margin + a * self.deltat, self.margin + na * self.deltaa)), fill = 'black')
        # add activities
        for n, es, ef, lf in zip([a for a in range(len(data))], esl,efl,lfl):
            if ef == lf:
                self.canvas.create_rectangle(((self.margin + (es - mint).days * self.deltat, self.margin + n * self.deltaa),(self.margin + (ef - mint).days * self.deltat, self.margin + n * self.deltaa + self.barwidth)), fill = 'red')
            else:
                self.canvas.create_rectangle(((self.margin + (es - mint).days * self.deltat, self.margin + n * self.deltaa),(self.margin + (ef - mint).days * self.deltat, self.margin + n * self.deltaa + self.barwidth)), fill = 'green')
                self.canvas.create_rectangle(((self.margin + (ef - mint).days * self.deltat, self.margin + n * self.deltaa + 0.3 * self.barwidth),(self.margin + (lf - mint).days * self.deltat, self.margin + n * self.deltaa + 0.7 * self.barwidth)), fill = 'blue')
        # add relatiobships
        data = conn.execute("SELECT activity1id, activity1es, activity1ef, activity2id, activity2es, activity2ef, type, projectid FROM big").fetchall()
        for activity1id, activity1es, activity1ef, activity2id, activity2es, activity2ef, rtype, projectid in zip([a[0] for a in data], [parse_date(a[1]) for a in data], [parse_date(a[2]) for a in data], [a[3] for a in data], [parse_date(a[4]) for a in data], [parse_date(a[5]) for a in data], [a[6] for a in data], [a[7] for a in data]):
            activity1n = activityindex[projectid + activity1id]
            activity2n = activityindex[projectid + activity2id]
            if rtype in ['fs','FS','fS','Fs']:
                self.canvas.create_line(((self.margin + (activity1ef - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2es - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')
            if rtype in ['ss','SS','sS','Ss']:
                self.canvas.create_line(((self.margin + (activity1es - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2es - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')
            if rtype in ['ff','FF','fS','Fs']:
                self.canvas.create_line(((self.margin + (activity1ef - mint).days *
```

```
                self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2ef - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')
            if rtype in ['sf','SF','sF','Fs']:
                self.canvas.create_line(((self.margin + (activity1es - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2ef - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')

    def show_opt(self):
        global conn
        self.canvas.delete('all')
        data = conn.execute("SELECT projectid, activityid, es, ef, os, of, lf FROM activities;").fetchall()
        activityindex = {}
        for n, projectid, activityid in zip([a for a in range(len(data))], [a[0] for a in data], [a[1] for a in data]):
            activityindex[projectid + activityid] = n
        esl = [parse_date(a[2]) for a in data]
        efl = [parse_date(a[3]) for a in data]
        osl = [parse_date(a[4]) for a in data]
        ofl = [parse_date(a[5]) for a in data]
        lfl = [parse_date(a[6]) for a in data]
        na = len(data)
        mint = min(esl)
        maxt = max(lfl)
        totalt = (maxt - mint).days
        self.canvas['scrollregion'] = (0, 0, (totalt * self.deltat) + 2*self.margin, (na * self.deltaa) + 2 * self.margin)
        # margins
        self.canvas.create_rectangle((self.margin, self.margin), (self.margin + totalt * self.deltat, self.margin + na * self.deltaa))
        for a in range(1, totalt):
            self.canvas.create_line(((self.margin + a * self.deltat, self.margin), (self.margin + a * self.deltat, self.margin + na * self.deltaa)), fill = 'grey80')
            if a % 21 == 0:
                self.canvas.create_text((self.margin + a * self.deltat, self.margin - 10), anchor = 'center', text = str(mint + datetime.timedelta(a)))
                self.canvas.create_line(((self.margin + a * self.deltat, self.margin), (self.margin + a * self.deltat, self.margin + na * self.deltaa)), fill = 'black')
        # add activities
        for n, es, ef, os, of, lf in zip([a for a in range(len(data))], esl, efl, osl, ofl, lfl):
            if ef == lf:
                self.canvas.create_rectangle(((self.margin + (es - mint).days * self.deltat, self.margin + n * self.deltaa),(self.margin + (ef - mint).days * self.deltat, self.margin + n * self.deltaa + self.barwidth)), fill = 'red')
            else:
                self.canvas.create_rectangle(((self.margin + (es - mint).days * self.deltat, self.margin + n * self.deltaa + 0.3 * self.barwidth),(self.margin + (os - mint).days * self.deltat, self.margin + n * self.deltaa + 0.7 * self.barwidth)), fill = 'grey')
                self.canvas.create_rectangle(((self.margin + (os - mint).days * self.deltat, self.margin + n * self.deltaa),(self.margin + (of - mint).days * self.deltat, self.margin + n * self.deltaa + self.barwidth)), fill = 'green')
                self.canvas.create_rectangle(((self.margin + (of - mint).days * self.deltat, self.margin + n * self.deltaa + 0.3 * self.barwidth),(self.margin + (lf - mint).days * self.deltat, self.margin + n * self.deltaa + 0.7 * self.barwidth)), fill = 'grey')
        # add relatiobships
        data = conn.execute("SELECT activity1id, activity1os, activity1of, activity2id, activity2os, activity2of, type, projectid FROM big").fetchall()
        for activity1id, activity1os, activity1of, activity2id, activity2os, activity2of, rtype, projectid in zip([a[0] for a in data], [parse_date(a[1])
```

```
            for a in data], [parse date(a[2]) for a in data], [a[3] for a in data], [parse date(a[4]) for a in data], [parse date(a[5]) for a in data], [a[6] for a in data], [a[7] for a in data]):
                activity1n = activityindex[projectid + activity1id]
                activity2n = activityindex[projectid + activity2id]
                if rtype in ['fs','FS','fS','Fs']:
                    self.canvas.create line(((self.margin + (activity1of - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2os - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')
                if rtype in ['ss','SS','sS','Ss']:
                    self.canvas.create line(((self.margin + (activity1os - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2os - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')
                if rtype in ['ff','FF','fS','Fs']:
                    self.canvas.create line(((self.margin + (activity1of - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2of - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')
                if rtype in ['sf','SF','sF','Fs']:
                    self.canvas.create line(((self.margin + (activity1os - mint).days * self.deltat, self.margin + activity1n * self.deltaa),(self.margin + (activity2of - mint).days * self.deltat, self.margin + activity2n * self.deltaa)), arrow = 'last')

    def   init  (self, master, normal or opt):
        self.frame = tk.Frame(master, bg = 'white')
        self.frame.pack(fill = 'both', expand = True)
        self.canvas = tk.Canvas(self.frame, bg = 'white')
        self.yscr = tk.Scrollbar(self.frame, orient = 'vertical', command = self.canvas.yview)
        self.xscr = tk.Scrollbar(self.frame, orient = 'horizontal', command = self.canvas.xview)
        self.canvas.configure(xscrollcommand = self.xscr.set, yscrollcommand = self.yscr.set)
        self.yscr.pack(fill = 'y', side = 'right')
        self.xscr.pack(fill = 'x', side = 'bottom')
        self.canvas.pack(fill = 'both', expand = True, side = 'left')
        if normal or opt == 'normal':
            self.show()
        elif normal or opt == 'opt':
            self.show opt()

class Table: # this is generic a table widget made using using ttk.treeview
    width = 100
    global conn
    def delete(self, *arg):
        if self.table.focus() != '':
            data = {}
            for name, value in zip(self.table['columns'], self.table.item(self.table.focus())['values']):
                data[name] = value
            if self.table scope == 'projects':
                conn.execute("Delete FROM projects WHERE projectid = ?;",(data['projectid'], ))
            elif self.table scope == 'activities':
                conn.execute("Delete FROM activities WHERE projectid = ? AND activityid = ?;",(data['projectid'], data['activityid']))
            elif self.table scope == 'relationships':
                conn.execute("Delete FROM relationships WHERE projectid = ? AND activity1id = ? AND activity2id = ? AND type = ?",(data['projectid'], data['activity1id'], data['activity2id'], data['type']))
            self.refresh()
        conn.commit()

    def create(self):
        Form_new(self.master, self.table_scope)
```

```
            self.refresh()

    def refresh(self):
        for child in self.bottomframe.winfo_children():
            child.destroy()
        self.table = ttk.Treeview(self.bottomframe)
        self.table['show'] = 'headings'
        self.table['selectmode'] = 'browse'
        self.yscr = tk.Scrollbar(self.bottomframe, orient = "vertical", command = self.table.yview)
        self.xscr = tk.Scrollbar(self.bottomframe, orient = "horizontal", command = self.table.xview)
        self.yscr.pack(fill = 'y', side = "right")
        self.xscr.pack(fill = 'x', side = "bottom")
        self.table["yscrollcommand"] = self.yscr.set
        self.table["xscrollcommand"] = self.xscr.set
        self.table.pack(fill = "both", side = 'left')
        # get the data
        global conn
        cur = conn.cursor()
        cur.execute("SELECT * FROM %s"%self.table_scope)
        headings = [a[0] for a in cur.description]
        data = cur.fetchall()
        # set the columns
        self.table['columns'] = headings
        self.table['displaycolumns'] = headings
        for head in headings:
            self.table.column(head, width = self.width, minwidth = self.width, stretch = False, anchor = 'center')
            self.table.heading(head, text = head)
        # set the data
        for r in data:
            self.table.insert("", 'end', values = r)

    def __init__(self, master, table_scope):
        self.master = master
        self.table_scope = table_scope
        self.frame = tk.Frame(master, bg = 'white')
        self.frame.pack(fill='both', expand = True)
        self.topframe = tk.Frame(self.frame)
        self.topframe.pack(fill = 'x')
        self.bottomframe = tk.Frame(self.frame)
        self.bottomframe.pack(fill = 'both', expand = True)
        # Create the buttons at the top
        if self.table_scope in ('projects', 'activities', 'relationships'):
            tk.Button(self.topframe, text = 'Create New', command = self.create).pack(side = 'left')
            tk.Button(self.topframe, text = 'Delete Selected', command = self.delete).pack(side = 'left')
            tk.Button(self.topframe, text = 'Refresh', command = self.refresh).pack(side = 'left')
        self.refresh()

class Plot: # this is for generic financial plotting with dates on the x-axis
    title = ''
    data = []
    lw = 2
    colors = ['red', 'blue', 'green', 'brown', 'orange']

    def clear(self):
        self.title = ''
        self.data = []
        self.canvas.delete('all')
        self.show()

    def scalex(self,x):
        newx = (self.width + self.margin) + x * (self.width - self.margin - self.margin)/(self.widthself.maxx - self.minx)
```

```
    def scaley(self, y):
        newy = (self.height + self.topmargin) + y * (self.width - self.margin - self.
        margin)/(self.widthself.maxx - self.minx)

    def show(self, *ev):
        self.height = self.master.winfo height()
        self.width = self.master.winfo width()
        self.margin = max(0.05 * self.width, 0.05 * self.width)
        self.topmargin = 2 * self.margin
        self.canvas.delete('all')
        if self.data == []: # break if empty
            return 0
        # set the boundaries
        allx = []
        ally = []
        for plot in self.data:
            allx += plot['x']
            ally += plot['y']
        self.minx = min(allx)
        self.miny = min(ally)
        self.maxx = max(allx)
        self.maxy = max(ally)
        # create the borders
        self.canvas.create line(((self.margin, self.height - self.margin), (self.
        width-self.margin, self.height - self.margin)))
        self.canvas.create line(((self.margin, self.topmargin), (self.width-self.
        margin, self.topmargin)))
        self.canvas.create line(((self.margin, self.height - self.margin), (self.
        margin, self.topmargin)))
        self.canvas.create line(((self.width - self.margin, self.height - self.margin
        ), (self.width-self.margin, self.topmargin)))
        # plot the lines
        for plot in self.data:
            x = [(a - self.minx)/(self.maxx - self.minx) * (self.width - self.margin
            - self.margin) for a in plot['x']]
            y = [(1 - (a - self.miny)/(self.maxy - self.miny)) * (self.height - self.
            margin - self.topmargin) for a in plot['y']]
            x = [a + self.margin for a in x]
            y = [a + self.topmargin for a in y]
            x = [int(a) for a in x]
            y = [int(a) for a in y]
            self.canvas.create line([a for a in zip(x,y)], width = self.lw, fill =
            plot['color'])
        # plot line at zero
        y = (1 - (0 - self.miny)/(self.maxy - self.miny)) * (self.height - self.
        margin - self.topmargin)
        y = y + self.topmargin
        y = int(y)
        self.canvas.create line(((self.margin, y),(self.width - self.margin, y)))
        # create legend
        self.legendx = self.margin + 20
        self.legendy = self.topmargin + 20
        loc = self.legendy
        for plot in self.data:
            self.canvas.create line(((self.legendx + 10, loc),(self.legendx + 30, loc
            )), fill = plot['color'], width = self.lw)
            self.canvas.create text((self.legendx + 40, loc), text = plot['title'],
            anchor = 'w')
            loc += 15
        # add title
        self.canvas.create text((self.width/2, self.topmargin/2), text = self.title,
        font = ("arial",20), anchor = 'center')
        # add the ticks
        for a in [self.minx, self.maxx] + [self.minx + datetime.timedelta( a * (self.
        maxx - self.minx).days / 10) for a in range(10)]:
            location = (a - self.minx)/(self.maxx - self.minx) * (self.width - self.
            margin - self.margin)
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            location = location + self.margin
            location = int(location)
            self.canvas.create_line((location, self.height - self.margin + 5), (location, self.height - self.margin + 10))
            self.canvas.create_text((location, self.height - self.margin + 20), text = str(a), anchor = 'center')
        for a in [a for a in range(int(self.miny), int(self.maxy), int((self.maxy - self.miny) / 20))] + [int(self.maxy)] + [0]:
            location = (1 - (a - self.miny)/(self.maxy - self.miny)) * (self.height - self.margin - self.topmargin)
            location = location + self.topmargin
            location = int(location)
            self.canvas.create_line((self.margin - 5, location), (self.margin - 10, location))
            self.canvas.create_text((self.margin - 20, location), text = str(a), anchor = 'e')

    def add_plot(self, title, x, y):
        plot = {}
        plot['title'] = title
        for a in y:
            if a == None:
                y[y.index(a)] = 0
        plot['x'] = x
        plot['y'] = y
        plot['color'] = self.colors[len(self.data)]
        self.data.append(plot)
        self.show()

    def set_title(self, title):
        self.title = title
        self.show

    def __init__(self, master):
        self.frame = tk.Frame(master)
        self.frame.pack(fill = 'both', expand = True)
        self.master = master
        self.canvas = tk.Canvas(self.frame, bg = 'white')
        self.canvas.pack(fill = 'both', expand = True)
        self.canvas.bind("<Configure>",self.show)
        self.show()

class Form_new: # a new window to create new stuff
    def ok(self, *arg):
        if self.focus == 'activities':
            projectid = self.projectid_selector.get()
            activityid = self.activityid.get()
            activityname = self.activityname.get()
            duration = self.duration.get()
            cost = self.cost.get()
            conn.execute("INSERT INTO activities (projectid,activityid,activityname,duration,cost) VALUES (?,?,?,?,?);", (projectid,activityid,activityname,duration,cost))
        elif self.focus == 'projects':
            projectid = self.projectid.get()
            projectname = self.projectname.get()
            start = self.start.get()
            interest = self.interest.get()
            markup = self.markup.get()
            downpayment = self.downpayment.get()
            invoiceinterval = self.invoiceinterval.get()
            paymentperiod = self.paymentperiod.get()
            retention = self.retention.get()
            retentionperiod = self.retentionperiod.get()
            conn.execute("INSERT INTO projects (projectid,projectname,start,interest,markup,downpayment,invoiceinterval,paymentperiod,retention,retentionperiod) VALUES (?,?,?,?,?,?,?,?,?,?)", (projectid, projectname,start,interest,markup,downpayment,invoiceinterval,
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```
            paymentperiod,retention,retentionperiod))
        elif self.focus == 'relationships':
            projectid = self.projectid_selector.get()
            activity1id = self.activity1_selector.get()
            activity2id = self.activity2_selector.get()
            relationship_type = self.type_selector.get()
            conn.execute("INSERT INTO relationships (projectid,activity1id,activity2id,type) VALUES (?,?,?,?)", (projectid, activity1id,activity2id,relationship_type))
        conn.commit()
        self.root.destroy()

    def selected_a_project(self, *ev):
        global conn
        try:
            activities = [a[0] for a in conn.execute("SELECT activityid FROM activities WHERE projectid = ?;", (str(self.project_selector.get()), )).fetchall()]
            self.activity1_selector['values'] = activities
            self.activity1_selector.set(activities[0])
            self.activity2_selector['values'] = activities
            self.activity2_selector.set(activities[0])
        except:
            pass

    def create_entry(self, description, widget_name):
        tk.Label(self.root, text = description).grid(column = 0, row = self.row, sticky = 'w')
        exec("self.%s = ttk.Entry(self.root)"%widget_name)
        exec("self.%s.grid(column = 1, row = self.row, sticky = 'w')"%widget_name)
        self.row += 1

    def __init__(self, master, projects_or_activities_or_relationships):
        self.focus = projects_or_activities_or_relationships
        self.master = master
        self.root = tk.Toplevel(self.master)
        if self.focus == 'projects': title = 'Create New Project'
        if self.focus == 'activities': title = 'Create New Activity'
        if self.focus == 'relationships': title = 'Create New Relationship'
        self.root.title(title)
        self.root.geometry('+300+100')
        self.root.resizable(height = False, width = False)
        self.row = 0
        if self.focus in ['activities', 'relationships']:
            tk.Label(self.root, text = 'Select Project id:').grid(column = 0, row = self.row, sticky = 'w')
            self.project_selector = ttk.Combobox(self.root)
            try:
                projects = [a[0] for a in conn.execute("SELECT projectid FROM projects;").fetchall()]
                self.project_selector['values'] = projects
                self.project_selector.set(projects[0])
            except:
                self.project_selector['values'] = []
            self.project_selector.bind("<<ComboboxSelected>>", self.selected_a_project)
            self.project_selector.grid(column = 1, row = self.row, sticky = 'w')
            self.row += 1
        if self.focus in ['activities']:
            for name, widget in [["New Activity ID: ", "activityid"], ['Activity Name: ','activityname'], ['Activity Duration: ', 'duration'], ['Activity Cost: ', 'cost']]:
                self.create_entry(name, widget)
        if self.focus in ['projects']:
            for name, widget in [['Project ID: ', 'projectid'], ['Project Name: ', 'projectname'], ['Start (yyyy-mm-dd): ', 'start'], ['Interest: ', 'interest'], ['Markup: ', 'markup'], ['Downpayment: ', 'downpayment'], ['Invoice Interval (days): ', 'invoiceinterval'], ['Payment Period (days): ', 'paymentperiod'], ['Retention: ', 'retention'], ['Retention
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                Period (days): ', 'retentionperiod']]:
                    self.create_entry(name, widget)
            if self.focus in ['relationships']:
                tk.Label(self.root, text = 'Select Activity1 id:').grid(column = 0, row = self.row, sticky = 'w')
                self.activity1_selector = ttk.Combobox(self.root)
                self.activity1_selector.grid(column = 1, row = self.row, sticky = 'w')
                self.row += 1
                tk.Label(self.root, text = 'Select Activity2 id:').grid(column = 0, row = self.row, sticky = 'w')
                self.activity2_selector = ttk.Combobox(self.root)
                self.activity2_selector.grid(column = 1, row = self.row, sticky = 'w')
                self.row += 1
                tk.Label(self.root, text = 'Select Rlationship type:').grid(column = 0, row = self.row, sticky = 'w')
                self.type_selector = ttk.Combobox(self.root)
                self.type_selector['values'] = ('FS', 'SS', 'FF', 'SF')
                self.type_selector.set('FS')
                self.type_selector.grid(column = 1, row = self.row, sticky = 'w')
                self.row += 1
            tk.Button(self.root, text = "Ok", command = self.ok, width = 15).grid(column = 0, row = self.row, columnspan = 2)
            self.root.bind("<KeyPress-Return>", self.ok)
            self.selected_a_project()

class Main_window:
    def clear(self):
        for child in self.frame.winfo_children():
            child.destroy()

    def create_table_from_sql(self,table_scope):
        self.clear()
        self.table = Table(self.frame, table_scope)

    def show_gantt_chart(self, normal_or_opt):
        self.clear()
        Gantt_chart(self.frame, normal_or_opt)

    def show_plot(self, arg):
        self.clear()
        global conn
        data = conn.execute("SELECT date,cashincum,cashoutcum,overdraft,cashincumdisc,cashoutcumdisc,overdraftdisc from cashflowall;").fetchall()
        dates = [a[0] for a in data]
        dates = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in dates]
        cashincum = [a[1] for a in data]
        cashoutcum = [a[2] for a in data]
        overdraft = [a[3] for a in data]
        cashincumdisc = [a[4] for a in data]
        cashoutcumdisc = [a[5] for a in data]
        overdraftdisc = [a[6] for a in data]
        data = conn.execute("SELECT date,cashincum,cashoutcum,overdraft,cashincumdisc,cashoutcumdisc,overdraftdisc from cashflowallopt;").fetchall()
        datesopt = [a[0] for a in data]
        datesopt = [datetime.date(int(a.split('-')[0]),int(a.split('-')[1]),int(a.split('-')[2])) for a in datesopt]
        cashincumopt = [a[1] for a in data]
        cashoutcumopt = [a[2] for a in data]
        overdraftopt = [a[3] for a in data]
        cashincumdiscopt = [a[4] for a in data]
        cashoutcumdiscopt = [a[5] for a in data]
        overdraftdiscopt = [a[6] for a in data]
        plot = Plot(self.frame)
        if arg == 'overdraft':
            plot.clear()
```

```
            plot.add plot('Overdraft', dates, overdraft)
            plot.set title("OVERDRAFT")
        elif arg == 'overdraftopt':
            plot.clear()
            plot.add plot('Overdraft', dates, overdraft)
            plot.add plot('Overdraft Optimized', dates, overdraftopt)
            plot.set title("OVERDRAFT (Normal vs. Optimized)")
        elif arg == 'cashflow':
            plot.clear()
            plot.add plot('CashIn cumulative', dates, cashincum)
            plot.add plot('CashOut cumulative', dates, cashoutcum)
            plot.set title("Cash-Flow")
        elif arg == 'cashflowopt':
            plot.clear()
            plot.add plot('CashIn cumulative', dates, cashincum)
            plot.add plot('CashOut cumulative', dates, cashoutcum)
            plot.add plot('CashIn cumulative Optimized', dates, cashincumopt)
            plot.add plot('CashOut cumulative Optimized', dates, cashoutcumopt)
            plot.set title("Cash-Flow (Normal vs. Optimized)")
        elif arg == 'overdraftdisc':
            plot.clear()
            plot.add plot('Overdraft Discounted', dates, overdraftdisc)
            plot.set title("OVERDRAFT Discounted")
        elif arg == 'overdraftdiscopt':
            plot.clear()
            plot.add plot('Overdraft Discounted', dates, overdraftdisc)
            plot.add plot('Overdraft Discounted Optimized', dates, overdraftdiscopt)
            plot.set title("OVERDRAFT Discounted (Normal vs. Optimized)")
        elif arg == 'cashflowdisc':
            plot.clear()
            plot.add plot('CashIn cumulative Discounted', dates, cashincumdisc)
            plot.add plot('CashOut cumulative Discounted', dates, cashoutcumdisc)
            plot.set title("Cash-Flow Discounted")
        elif arg == 'cashflowdiscopt':
            plot.clear()
            plot.add plot('CashIn cumulative Discounted', dates, cashincumdisc)
            plot.add plot('CashOut cumulative Discounted', dates, cashoutcumdisc)
            plot.add plot('CashIn cumulative Discounted Optimized', dates,
            cashincumdiscopt)
            plot.add plot('CashOut cumulative Discounted Optimized', dates,
            cashoutcumdiscopt)
            plot.set title("Cash-Flow Discounted (Normal vs. Optimized)")

    def initiate toolbar(self):
        self.menubar = tk.Menu(self.root)
        self.root['menu'] = self.menubar
        for menu in ('file', 'create','portfolio','projects','activities',
        'calculations', 'plot'):
            menu = menu.lower()
            label = menu.capitalize()
            exec("self.menubar.%s = tk.Menu(self.menubar, tearoff = 0)"%menu)
            exec("self.menubar.add cascade(label = '%s', menu = self.menubar.%s)"%(
            label,menu))
        self.menubar.file.add command(label = 'Clear All', command = new database)
        self.menubar.file.add separator()
        self.menubar.file.add command(label = 'Create a Random Portfolio', command =
        create a portfolio)
        self.menubar.file.add command(label = 'Import Validation Projects', command =
         import uptown projects)
        self.menubar.file.add separator()
        self.menubar.file.add command(label = 'Database Info', command = database info)
        self.menubar.file.add command(label = 'Clean Database', command =
        clean database)
        self.menubar.file.add separator()
        self.menubar.file.add command(label = 'Export', command = export)
        self.menubar.file.add separator()
        self.menubar.file.add command(label = 'Verificate (random)', command =
        verificate)
```

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        self.menubar.file.add command(label = 'Validate (UPTOWN)', command = validate)
        self.menubar.file.add separator()
        self.menubar.file.add command(label = 'Exit', command = self.root.destroy)
        self.menubar.create.add command(label = 'New Project', command = functools.partial(Form new, self.root, "projects"))
        self.menubar.create.add command(label = 'New Activity', command = functools.partial(Form new, self.root, "activities"))
        self.menubar.create.add command(label = 'New Relationship', command = functools.partial(Form new, self.root, "relationships"))
        self.menubar.portfolio.add command(label = 'Show Portfolio', command = functools.partial(self.create table from sql,"portfolio"))
        self.menubar.projects.add command(label = 'Show Projects', command = functools.partial(self.create table from sql,"projects"))
        self.menubar.activities.add command(label = 'Show Activities', command = functools.partial(self.create table from sql,"activities"))
        self.menubar.activities.add separator()
        self.menubar.activities.add command(label = 'Show Relationships', command = functools.partial(self.create table from sql,"relationships"))
        self.menubar.calculations.add command(label = 'Calculate', command = functools.partial(calculate,"normal"))
        self.menubar.calculations.add separator()
        #~ self.menubar.calculations.add command(label = 'Optimize (10 trials)', command = functools.partial(optimize,10))
        #~ self.menubar.calculations.add command(label = 'Optimize (20 trials)', command = functools.partial(optimize,20))
        #~ self.menubar.calculations.add command(label = 'Optimize (50 trials)', command = functools.partial(optimize,50))
        #~ self.menubar.calculations.add command(label = 'Optimize (100 trials)', command = functools.partial(optimize,100))
        self.menubar.calculations.add command(label = 'Optimize', command = optimize)
        self.menubar.plot.add command(label = 'Gantt Chart', command = functools.partial(self.show gantt chart, 'normal'))
        self.menubar.plot.add command(label = 'Gantt Chart Optimized', command = functools.partial(self.show gantt chart, 'opt'))
        self.menubar.plot.add separator()
        self.menubar.plot.add command(label = 'Overdraft', command = functools.partial(self.show plot, 'overdraft'))
        self.menubar.plot.add command(label = 'Overdraft Optimized', command = functools.partial(self.show plot, 'overdraftopt'))
        self.menubar.plot.add command(label = 'Cashflow', command = functools.partial(self.show plot, 'cashflow'))
        self.menubar.plot.add command(label = 'Cashflow Optimized', command = functools.partial(self.show plot, 'cashflowopt'))
        self.menubar.plot.add separator()
        self.menubar.plot.add command(label = 'Overdraft Discounted', command = functools.partial(self.show plot, 'overdraftdisc'))
        self.menubar.plot.add command(label = 'Overdraft Discounted Optimized', command = functools.partial(self.show plot, 'overdraftdiscopt'))
        self.menubar.plot.add command(label = 'Cashflow Discounted', command = functools.partial(self.show plot, 'cashflowdisc'))
        self.menubar.plot.add command(label = 'Cashflow Discounted Optimized', command = functools.partial(self.show plot, 'cashflowdiscopt'))

    def  init  (self):
        self.root = tk.Tk()
        self.root.minsize(500,500)
        self.root.geometry('1400x900+200+0')
        self.root.title("Portfolio Cash Flow Optimization")
        self.initiate toolbar()
        self.frame = tk.Frame(self.root, bg = 'lightgrey')
        self.frame.pack(fill = 'both', expand = True)
        self.root.mainloop()

def time test():
    number of cases = 100 # this is the number of cases to try
    test numbers = []
    n activities = []
    n_relationships = []
```

```
    n activitiesxrelationships = []
    n activitiesprelationships = []
    times = []
    for test in range(1,number of cases + 1):
        new database()
        create a portfolio2(3,50,2000) # change this to change the min and max number of activities
        startt = datetime.datetime.now()
        calculate('normal')
        optimize()
        endt = datetime.datetime.now()
        time = (endt  - startt).total seconds()
        activitiesn = conn.execute('SELECT COUNT(*) FROM activities').fetchall()[0][0]
        relationshipsn = conn.execute('SELECT COUNT(*) FROM relationships').fetchall()[0][0]
        test numbers.append(test)
        n activities.append(activitiesn)
        n relationships.append(relationshipsn)
        n activitiesxrelationships.append(activitiesn * relationshipsn)
        n activitiesprelationships.append(activitiesn + relationshipsn)
        times.append(time)
    filename = 'time test.csv'
    with open(filename,'w') as csv file:
        csvw = csv.writer(csv file)
        csvw.writerow(['Test #', 'Number of activities', 'Number of relationships', 'Number of activities x Number of relationships', 'Number of activities + Number of relationships', 'Time (secs)'])
        for row in zip(test numbers,n activities,n relationships, n activitiesxrelationships,n activitiesprelationships,times):
            csvw.writerow(row)

def sensitivity analysis():
    new database()
    create a portfolio()
    conn.execute('Alter Table activities add column originalduration int(10);')
    conn.execute('Update activities set originalduration = duration;')
    npvs = []
    interests = []
    conn.execute('Update activities set duration = originalduration * 10')
    interest = 0
    while interest <= 0.5:
        conn.execute('Update projects set interest = %s;'%interest)
        calculate('normal')
        npvs.append(float(conn.execute('select npv from portfolio;').fetchall()[0][0]))
        interests.append(interest*100)
        interest += 0.02
    plt.plot(interests,npvs, 'o-')
    plt.xlabel("Interest %")
    plt.ylabel('Net Present Value (NPV) EGP')
    plt.title("Interest Rate Sensitivity Analysis")
    plt.savefig("interest.pdf")
    plt.close()
    #~ # ----------------------- Cost
    new database()
    create a portfolio()
    conn.execute('Alter Table activities add column originalcost float(10);')
    conn.execute('Update activities set originalcost = cost;')
    costs = []
    npvs = []
    m = 1
    while m <= 2:
        conn.execute('Update activities set cost = originalcost * %s'%m)
        calculate('normal')
        npvs.append(float(conn.execute('select npv from portfolio;').fetchall()[0][0]))
        costs.append(conn.execute('select sum(cost) from activities;').fetchall()[0][0])
        m += 0.1
    plt.plot(costs,npvs, 'o-')
```

```
plt.xlabel("Cost EGP")
plt.ylabel('Net Present Value (NPV) EGP')
plt.title("Cost Sensitivity Analysis")
plt.savefig("cost.pdf")
plt.close()
# ----------------------- Cost + interest
new database()
create a portfolio()
conn.execute('Alter Table activities add column originalduration int(10);')
conn.execute('Update activities set originalduration = duration;')
conn.execute('Alter Table activities add column originalcost float(10);')
conn.execute('Update activities set originalcost = cost;')
conn.execute('Update activities set duration = originalduration * 2')
m = 1
while m <= 10:
    npvs = []
    interests = []
    costs = []
    interest = 0
    conn.execute('Update activities set cost = originalcost * %s'%m)
    while interest <= 0.5:
        conn.execute('Update projects set interest = %s;'%interest)
        calculate('normal')
        npvs.append(float(conn.execute('select npv from portfolio;').fetchall()[0][0]))
        interests.append(interest*100)
        interest += 0.02
    label = "Cost Multiplier = " + str(m)
    plt.plot(interests,npvs, 'o-', label=label)
    m += 1
plt.xlabel("Interest %")
plt.ylabel('Net Present Value (NPV) EGP')
plt.legend()
plt.title("Interest Rate Sensitivity Analysis")
plt.savefig("interestpluscost.pdf")
webbrowser.open("interestpluscost.pdf")
#~ # ----------------------- Cost + interest - percentage
new database()
create a portfolio()
conn.execute('Alter Table activities add column originalduration int(10);')
conn.execute('Update activities set originalduration = duration;')
conn.execute('Alter Table activities add column originalcost float(10);')
conn.execute('Update activities set originalcost = cost;')
conn.execute('Update activities set duration = originalduration * 2')
conn.execute('Update projects set interest = 0;')
calculate('normal')
initial npv = float(conn.execute('select npv from portfolio;').fetchall()[0][0])
m = 1
while m <= 10:
    npvs = []
    interests = []
    costs = []
    interest = 0
    conn.execute('Update activities set cost = originalcost * %s'%m)
    while interest <= 0.5:
        conn.execute('Update projects set interest = %s;'%interest)
        calculate('normal')
        npvs.append(float(conn.execute('select npv from portfolio;').fetchall()[0][0]) / initial npv * 100)
        interests.append(interest*100)
        interest += 0.02
    label = "Cost Multiplier = " + str(m)
    plt.plot(interests,npvs, 'o-', label=label)
    m += 1
plt.xlabel("Interest %")
plt.ylabel('Net Present Value (NPV) %')
plt.legend()
plt.title("Interest Rate Sensitivity Analysis")
```

```
    plt.savefig("interestpluscostpercent.pdf")
    webbrowser.open("interestpluscostpercent.pdf")
    plt.close()

# -------- final level -----------

start time = datetime.datetime.now()

database file name = 'database.db' # filname used for the database
export folder = './export/'
figure export format = '.pdf'
log file name = 'log.txt'
if os.path.exists(log file name):
    os.remove(log file name)
title = 'thesis'
optimization stoppingpercentage = 1.00002
optimization stoppingmaxtrials = 20


conn = sqlite3.connect(database file name)

#~ time test()

#~ for a in range(1,5+1):
    #~ title = 'Verification Trial %s - '%a
    #~ export folder = './exportverification%s/'%a
    #~ verificate()

#~ verificate()

#~ export folder = './exportvalidation/'
#~ validate()

Main window()

#~ sensitivity analysis()

#~ new database()
#~ import uptown projects()
#~ calculate("normal")
#~ optimize()
#~ export()


conn.close()

end time = datetime.datetime.now()

log("Start Time was " + str(start time))
log("End Time was " + str(end time))
log("Difference is " + str(end time - start time))
```