

A. M. ABDULSATTAR

A META-HEURISTIC FOR THE DISCRETE TIME-COST-QUALITY TRADE-OFF PROBLEM WITH GENERALIZED PRECEDENCE RELATIONSHIPS

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ATILIM UNIVERSITY

ABDULRAHMAN M. ABDULSATTAR

A MASTER OF SCIENCE THESIS
IN
THE DEPARTMENT OF CIVIL ENGINEERING

ATILIM UNIVERSITY 2021

JULY 2021

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A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ATILIM UNIVERSITY

BY

ABDULRAHMAN M. ABDULSATTAR

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF CIVIL ENGINEERING

JULY 2021

Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

Prof. Dr. Ender Keskinliç
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Civil Engineering, Atilim University.

Prof. Dr. Hasan Umur Akay
Head of Department

This is to certify that we have read the thesis “A Meta-Heuristic for The Discrete Time-Cost-Quality Trade-Off Problem with Generalized Precedence Relationships” submitted by Abdulrahman M. Abdulsattar and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Asst. Prof. Dr. Saman Aminbakhsh
Supervisor

Examining Committee Members:

Asst. Prof. Dr. Emre Caner Akçay
Civil Engineering, Atilim University

Asst. Prof. Dr. Saman Aminbakhsh
Civil Engineering, Atilim University

Asst. Prof. Dr. Güzde Bilgin
Civil Engineering, Başkent University

Date: 08.07.2021

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Abdulrahman M. Abdulsattar

Signature:

ABSTRACT

A META-HEURISTIC FOR THE DISCRETE TIME-COST-QUALITY TRADE-OFF PROBLEM WITH GENERALIZED PRECEDENCE RELATIONSHIPS

Abdulsattar, Abdulrahman M.

M.S., Department of Civil Engineering

Supervisor: Asst. Prof. Dr. Saman Aminbakhsh

July 2021, 119 pages

Building projects can certainly be considered as one of the most crucial elements that contributes greatly to economic growth of a nation. They facilitate developments in other industries too by providing appropriate working spaces and the means for mobilization of resources (e.g., office building, hospitals, schools, highways). Through unique public or private bids, the governments and stakeholders aim to achieve reasonable prices for such projects with minimum possible makespans and the best quality. Evidently, weighing the available offers and coming up with an optimal decision can pose challenges for the decision-makers. In this regard, generation of a tool that helps decision-makers strike a proper balance among the conflicting project objectives (i.e., time, cost, and quality) is imperative. To this end, this study proposes a method which assists in selection of the best compromise choices among the options available for each of the project activities. In addition to time and cost, the proposed method is designed to bring the quality aspect into the equation as well. To quantify the quality, a value referring to the weighted importance and performance of each activity is used. The proposed method is based on a slightly modified Genetic Algorithm (GA) that incorporates the domination concept for selection of the best solutions out of the potential candidates. The GA-based method is capable of handling unlimited number of precedence relationships for each activity and above all, it is able to capture and unravel any type of logical relationship. This very feature significantly

improves the practical relevance of this research as parallelization of activities is a common practice in real-life projects. Planners by benefitting from the various types of relationships (i.e., Start-to-Start, Start-to-Finish, Finish-to-Start, and Finish-to-Finish) and the concept of lag time frequently introduce parallelization into the network. Overlapped activities, in turn, help reduce the unwanted idle times and speed up the project significantly.

In order to demonstrate the application and to evaluate the effectiveness of the proposed model, it is used for solution of three different Time-Cost-Quality (TCQ) tradeoff problems, two of which are generated within the context of this thesis. The practiced instances include a small benchmark TCQ problem with 18 activities taken from the literature in addition to more complex 29- and 63-activity TCQ problems produced herein based on existing 29- and 63-activity time-cost tradeoff problems, respectively. The obtained results reveal both the effectiveness of the proposed model and the possibility to be used by the planners amidst making arduous decisions.

Keywords: Time-Cost-Quality Trade-off Problem, Genetic Algorithm, Optimization, Generalized Precedence Relationships.

ÖZ

GENEL ÖNCÜLLÜK İLİŞKİLİ KESİKLİ ZAMAN-MALİYET-KALİTE ÖDÜNLEŞİM PROBLEMİ İÇİN BİR META-SEZGİSEL YÖNTEM

Abdulsattar, Abdulrahman M.

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Tez Yöneticisi: Dr. Öğr. Üyesi. Saman Aminbakhsh

Temmuz 2021, 119 sayfa

İnşaat projeleri kesinlikle bir ülkenin ekonomik büyümesine büyük katkı sağlayan en önemli unsurlardan biri olarak kabul edilebilir. Uygun çalışma alanları ve kaynakların mobilizasyonu için araçlar (örneğin ofis binaları, hastaneler, okullar, otoyollar) sağlayarak diğer endüstrilerdeki gelişmeleri de kolaylaştırırlar. Eşsiz kamu veya özel teklifler yoluyla, hükümetler ve paydaşlar, bu tür projeler için mümkün olan en kısa sürede ve en iyi kalitede makul fiyatlara ulaşmayı amaçlar. Açıkçası, mevcut teklifleri tartmak ve en uygun kararı bulmak karar vericiler için zorluklar doğurabilir. Bu bağlamda, karar vericilerin çatışan proje hedefleri (yani zaman, maliyet ve kalite) arasında uygun bir denge kurmalarına yardımcı olacak bir aracın oluşturulması zorunludur. Bu amaçla, bu çalışma, proje faaliyetlerinin her biri için mevcut seçenekler arasından en iyi uzlaşma seçeneklerinin seçilmesine yardımcı olan bir yöntem önermektedir. Önerilen yöntem, zaman ve maliyetin yanı sıra kalite boyutunu da denkleme dahil etmek için tasarlanmıştır. Kaliteyi ölçmek için, her bir faaliyetin ağırlıklı önemine ve performansına atıfta bulunan bir değer kullanılır. Önerilen yöntem, potansiyel adaylardan en iyi çözümlerin seçilmesi için hakimiyet kavramını içeren biraz değiştirilmiş bir Genetik Algoritmaya (GA) dayanmaktadır. GA tabanlı yöntem, her bir aktivite için sınırsız sayıda öncelik ilişkisini yönetebilir ve hepsinden önemlisi, her türlü mantıksal ilişkiyi yakalayabilir ve çözebilir. Bu özellik,

faaliyetlerin paralelleştirilmesi gerçek yaşam projelerinde yaygın bir uygulama olduğundan, bu araştırmanın pratik alaka düzeyini önemli ölçüde artırır. Planlayıcılar, çeşitli ilişki türlerinden (yani, Başlangıç-Başlangıç, Başlangıç-Bitiş, Bitiş-Başlangıç ve Bitiş-Bitiş) ve gecikme süresi kavramından yararlanarak ağa sıklıkla paralelleştirme getirir. Örtüşen faaliyetler, istenmeyen boşa kalma sürelerini azaltmaya ve projeyi önemli ölçüde hızlandırmaya yardımcı olur.

Uygulamayı göstermek ve önerilen modelin etkinliğini değerlendirmek için, ikisi bu tez kapsamında oluşturulan üç farklı Zaman-Maliyet-Kalite (TCQ) deęiş tokuş probleminin çözümü için kullanılmıştır. Uygulanan örnekler, sırasıyla mevcut 29-ve 63-etkinlik zaman-maliyet takas problemlerine dayalı olarak burada üretilen daha karmaşık 29-ve 63-aktivite TCQ problemlerine ek olarak literatürden alınan 18 aktivite ile küçük bir kıyaslama TCQ problemini içerir. Elde edilen sonuçlar, hem önerilen modelin etkinliğini hem de planlamacılar tarafından zorlu kararlar alırken kullanılabilme olasılığını ortaya koymaktadır.

Anahtar Kelimeler: Zaman-Maliyet-Kalite Ödünleşim Problemi, Genetik Algoritması, Optimizasyon, Genelleştirilmiş Öncüllük İlişkileri.

To My parents

ACKNOWLEDGEMENTS

I would like to express my gratitude and thanks to my advisor, Asst. Prof. Dr. Saman Aminbakhsh, for his assistance and guidance in writing this thesis. Without his support and motivation, I would not have been able to write this thesis;

Furthermore, I would like express my appreciation to my father, Mohammed Abdulsattar Mohammed, who encouraged and supported me to continue my study.

Finally, a special thanks to all my family for believing in me and supporting me through my study journey. I would also like to appreciate the effort of everyone that helped me, even with a word and the effort of all my teachers in Civil Engineering department of Atilim University.

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LIST OF SYMBOLS/ABBREVIATIONS

CPM	Critical Path Method
PERT	Program Evaluation and Review Technique
CPS	Critical Path Segments
W/C	Water-Cement ratio
FS	Finish to Start
SS	Start to Start
FF	Finish to Finish
SF	Start to Finish
CTCQTP	Continuous Time Cost Quality Trade-off Problem
DTCQTP	Discrete Time Cost Quality Trade-off Problem
TCQSTP	Time Cost Quality Security Trade-off Problem
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
ANP	Analytic Network Process
GP	Goal Programming
NSGAI	Non-dominated Sorting Genetic Algorithm II
TOPSIS	Technique Order of Preference by Similarity to Ideal Solution
LWS	Linear Weighted Sum
LP	Linear Programming
IP	Integer Programming
DP	Dynamic Programming
EA	Evolutionary Algorithms
ACO	Ant-Colony Optimization
FastPGA	Fast Pareto Genetic Algorithm
FCGA	Fuzzy Clustering Genetic Algorithm
TCQET	Time Cost Quality Environment Trade-off Problem
MOICA	Multi-Objective Imperialist Competitive Algorithm

PESAI	Pareto Envelope-based Selection Algorithm-clustering
SPEA2	Strength Pareto Evolutionary Algorithm
QPI	Quality Performance Index
IGPSO	Immune Genetic Particle Swarm Optimization
IHS	Improved Harmony Search
MCDM	Multi-Criteria Decision-Making
ER	Evidential Reasoning
TOPSIS	Technique for Order of Preference Similarity to Ideal Solution
MOABCDE	Multiple Objective Artificial Bee Colony Differential Evolution
DE	Differential Evolution
ABC	Artificial Bee Colony
MOPSO	Multiple Objective Particle Swarm Optimization
MODE	Multiple Objective Differential Evolution
MOABC	Multiple Objective Artificial Bee Colony
DSAMOPSO	Dynamic Self-Multi-Objective Particle Swarm Optimization
PDBO	Problem Data-Based Optimization Algorithm
EVO	Egyptian Vulture Optimization Method
MAWA	Modified Adaptive Weight Approach
OMODE	Opposition-based Multiple Objective Differential Evolution
OMOSOS	Opposition Multiple Objective Symbiotic Organisms Searches
C	Total Project Cost
DC	Direct Cost
IC	Daily Indirect Cost
D	Duration of the Project
GenNum	Number of Generations
Popsiz	Population Size
CRO	Crossover Probability
Mut	Mutation Probability
NGASol	Non-dominated Genetic Algorithm Solutions

CHAPTER 1

INTRODUCTION

Construction projects are always very expensive and important to develop the economic system of any country as the new buildings contribute to providing opportunities as well as the economic growth of the country if they are implemented with high quality and an appropriate time and cost. Therefore, the process of selecting the appropriate contractor for the project to achieve the best possible quality after implementing the project in an appropriate time and cost is considered a difficult and important process for the project owners. Using unique public or private bids that depend on imposing a warranty period in the contract. In this period, the contractor will be responsible for fixing any construction errors in the structure within this period (one year, for instance). The interested contractors will propose their offers to construct the project. Although most contractors seek to minimize their profit as much as possible to win the contract, the problem is in some contractors who will minimize some qualities of the activities to achieve less project price with the same profit and time. This minimizing will lead to reduce the project lifespan or even cause failure in some cases. Therefore, the model's primary objective is to select the best offers among the available ones after comparing them to accomplish the project objectives. However, this study presents an extended introduction to the primary project requirements in the following subsections.

1.1 Project

The project is a temporary endeavor to create a unique project, product, or service [1]. The word "temporary" means that any project has a well-known start and end dates, and for "endeavor," which means human resources (workers, engineers, personal, and others). Furthermore, non-human resources (materials, money, machines, and others)

are organized uniquely for the project to accomplish the scope of the project under some constraints such as time, cost, and quality [1]–[3], as shown in Figure 1.2.

1.1.1. Project Characteristics

Each project has its properties that are different from any other projects, but all projects have some common properties, which are as follows [1]–[3]:

- a. Every project has its own goals to achieve, and it is necessary to invest in them.
- b. Projects have their constraints related to time, cost, and quality.
- c. Projects are a temporary organization (it will start and end at some time).
- d. The project contains activities; each has its start and end dates; all activities are called schedules.
- e. Each project is unique from all other projects (even if the projects were precisely similar, but they will be different in many aspects such as environmental conditions, personals of the project, and others).

1.2 Time

Time is the amount of time that the contractor needs to complete the project, or in some cases, it is specific data specified by the owner of the project. In this case, the contractors will compete according to the project's final cost and quality. The project's duration can be calculated by adding the durations of all activities in the critical path. Eventually, the calculated duration will be the least duration of the project to be completed. To estimate the project duration, It is required an expert team from different engineering specialties such as civil, electrical, mechanics, and others to estimate each activity's duration alone. Alternatively, it can depend on the expert's judgment by comparing similar projects by taking the effect of environmental conditions and the workers' productivity into considerations.

The following methods are generally used for estimating an activity's duration:

- a. Expert judgments guided by historical data for similar projects
- b. Parametric estimating algorithm to estimate the time and cost by using the historical data

- c. Three-point estimating to estimate the time by using three points (pessimistic, optimistic, expected)

After defining the activities duration, the project team will use the schedule to calculate the critical activities, the critical paths, and the project duration. It will then be decided to minimize the project duration to meet the client's time objectives.

1.3 Schedule

Scheduling is an essential tool in construction management; according to Project Management Institute [1], scheduling can be used to control the activities, check whether it is completed on the assigned date, and delay the project. Scheduling works include the following:

- 1) Define activities
- 2) Sequence of activities
- 3) Estimate activities' resources
- 4) Estimate activities' duration
- 5) Develop a schedule that includes all the above information.
- 6) Control and observe the progress of the project and make changes according to that.

There are several ways and techniques to control the schedule, and below are some of them:

- 1) Bar chart
- 2) Critical path method (CPM): this method was used in the proposed model, and it will be explained in the following subsection.
- 3) Program evaluation and review technique (PERT)
- 4) Critical path segments (CPS).

1.3.1 Critical Path Method (CPM)

It is an essential tool for scheduling and calculating the least time for the project to be completed, early start and finish time of activities (ES, EF), late start and finish time of activities (LS, LF), total float, and free float (TF, ff), and the critical activities and paths in the project are identified using this method. The activities are represented in

two ways: activity on arrow diagram (AOA) and activity on node (AON), which is more preferred in practice. Table 1.1 shows the advantages and disadvantages of this method. All activities are controlled by general precedence relationships (FS, FF, SS, and SF); these relationships are essential for calculating the total project duration and critical activities. Along with the principle of lag.

The following points contain a review for all general precedence relationships:

- a. Finish to Start (FS): it means that the activity can only be started after its predecessor's finish.
- b. Finish to Finish (FF): it means that the activity's finish date will be at the same time as its predecessor.
- c. Start to Start (SS): it means that the activity's start date will be the same as its predecessor's start date.
- d. Start to Finish (SF): It is the least used relationship among all relationships; it is rarely used in constructions, which means the activity's finish date will be the same as the start of its predecessor.

Table 1.1 Advantages and disadvantages of CPM

Advantages	Disadvantages
Generalized precedence relationships are available.	Hard to correct due to its structure
Multiple critical paths are possible.	Continuity of work is not guaranteed.
Multiple activities can be started at the same time.	Progress is difficult to calculate

1.4 Cost

The cost represents the amount of money required to complete the project; it is essential in constructing the project and selecting the most appropriate contractor for the project. Since it is an essential factor, it is crucial to carefully plan the estimating process and calculate the project's life span expenses and earnings.

The price of the project is the total cost of the project, adding to it the markup, as shown in Figure 1.1, and the cost can be classified into three main types, which are:

- a. **Fixed costs:** costs spent once at a time, **for example**, the cost of purchasing equipment.
- b. **Time-related costs:** costs spent along with the activity's duration, **for example**, the cost of labor.
- c. **Quantity- proportional costs:** costs change according to the quantity, **for example**, cost of the material.

Therefore, the cost of estimating plays an essential role in determining the budget of the project and bid cost.

Inaccurate cost estimating may lead to:

- Unrealistic budgets for the owner of the project
- Less than expected in earning
- Lost other works opportunities for the contractor

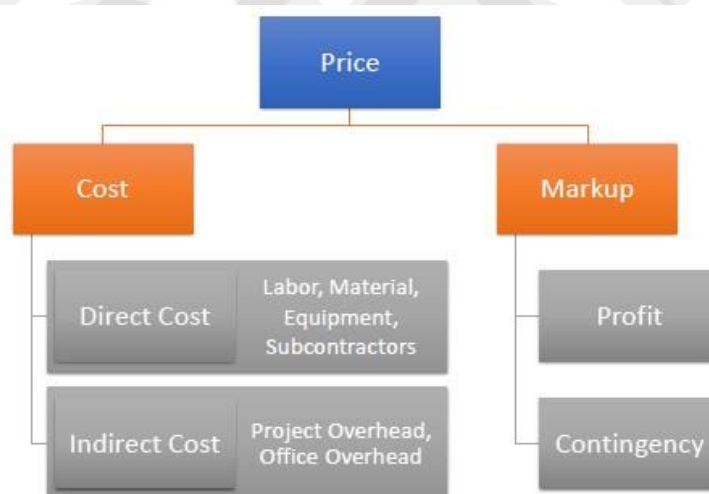


Figure 1.1 Price Components [1]

1.5 Quality

Quality represents the specifications that need to be committed to in order to achieve the best possible durability. It is mentioned in [1] as one of the three main elements that influence the project. Therefore, governments always seek to achieve the best

possible quality at the lowest time and cost. Quality of activity is calculated by assuming a weight for each quality indicator within the activity; this weight represents the importance of the activity's quality indicator. Adding all weights together should give us the overall activity's quality performance. Then, assigning a weight for each activity represents the importance of the activity to the overall project's quality. Finally, by summing all activities' weights, the overall project quality is calculated [4].

Below some examples related to highway quality indicators are provided [4]:

- a. Concrete pavement: Water–cement ratio (W/C), consolidation/density, air content, thickness, compressive strength, flexural strength.
- b. Bituminous pavement: Compaction density, asphalt content, gradation, surface smoothness, thickness, aggregate quality, void ratio, skid resistance
- c. Embankment: Compaction/density, moisture content, material quality, drainage

In the proposed model, the quality performance was calculated using excel sheets then has been used directly in the input file; this value reveals the General performance of the contractor's quality in constructing that activity. The project's quality is calculated by summing the quality performances of all activities.

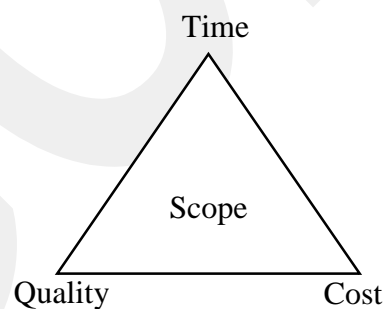


Figure 1.2 Project iron triangle [1]

1.6 General Overview of Time-Cost-Quality Trade-off Problem

Time cost and quality trade-off problems are considered one of the engineering management problems. It includes several options (offers) for constructing the project.

In general, the three main components of our problem (time, cost, and quality) are conflicting with each other, which means any change in a single component will lead to change at least another component or more; therefore, there is no one optimum solution but a group of optimum solutions. The decision-makers can select the best compromise solution that achieves their objectives even though all solutions are optimum, but they differ.

1.7 Continuous Time-Cost-Quality Trade-off Problem

Continuous means the relationship between the main three variables (Time, Cost, and Quality) is linear. The first person who considered the quality in his consideration was Babu and Suresh [5]; the traditional time–cost trade-off was upgraded into a three-dimensional time-cost-quality trade-off. Moreover, a linear relationship between the three variables was assumed, but this is not always applicable in real-world projects because the relationship is discrete in most cases. In this thesis, it has been assumed a discrete relationship between the activities [5]–[13].

1.8 Discrete Time-Cost-Quality Trade-off Problem

Discrete-time cost quality trade-off problem is one of the project scheduling problems. Discrete means that the objectives are separated from each other, and there is no relationship bind them; it is more realistic and applicable in real-world projects since each activity is expressed by a single node and has multiple execution modes to execute it. Each option contains a different time, cost, and quality value [4], [14]–[46].

1.9 Contributions of this Study

The main contribution of this study can be highlighted as the consideration of the general precedence relationships among the activities in the project network calculations. According to our research, there are no or few studies [16] considered solving this issue using the generalized precedence relationships along with the quality aspect and with different study cases, which makes the model more realistic and applicable in real-world project since in real-world projects, all the types of precedence relations are used. The user-friendliness of the algorithm is considered as one of the contributions.

1.10 Aims and Scopes

This study aims to improve and facilitate selecting the contractor to improve the scheduling process and strike a balance between the main objectives by introducing the general relations between the activities and using the genetic algorithm. The algorithm will be applied in a transportation case to study the effectiveness of the proposed algorithm. This study has been used in several studies, and it is taken from El-Rayes and Kandil [4].

1.11 Limitations

The proposed algorithm's limitations are the process of quantification of the quality which is a cumbersome process that has a certain degree of subjectivity, and the offers' details has to be specified by a constant number proposed by the contractors. These offers may not be necessarily accurate since, in real practice, numerous factors cannot be calculated, such as weather. Consequently, the author suggests incorporating the fuzzy set theory in future studies to calculate the uncertainties in the problem's main objectives.

1.12 Thesis Structure

The rest of the thesis is organized as follows; chapter two presents an extensive review of the continuous and discrete time cost quality trade-off (TCQT) problem, chapter three presents an overview of the methodology of preparing the proposed model, chapter four presents the validation and the results of the proposed model after applying it in a literature example, chapter five presents the conclusion and the recommendations for the future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

In this thesis, extensive literature reviews have supported the proposed thesis with a strong starting point by reviewing all the relevant thesis and articles from the best sources. This extensive literature review's primary goal is to analyze and investigate related articles and theses, and it is focused on the methodology, the method of development, limitations of the research, and their suggestions. Furthermore, this study mentioned the advantages and disadvantages of each reviewed research.

The literature review is categorized into two main parts:

- (1) Continuous Time-Cost-Quality Trade-off Problem
- (2) Discrete Time-Cost-Quality Trade-off Problem

2.2 Continuous Time-Cost-Quality Trade-off Problem

Continuous means there will always be a surface in the solution space that reflects the relation among the main objectives of time, cost, and quality. This relationship can be linear [5] or non-linear [43]. The first researcher who introduced the quality into the traditional TCTP was Babu and Suresh [5], who assumed that the quality would be affected when the project schedule is optimized; therefore, the author developed three models by using linear programming and assumed a linear relationship to study the influence of the trade-off on time, cost, and quality. These models are based on assigning the desired level for two variables and optimizing the third one. A scale between 0 and 1 was used to measure the quality. To verify the model's effectiveness, an example consisted of fourteen activities and two dummy activities; the results were satisfactory and promising. Then in 1999, [6] applied the models of [5] in a real cement factory in Thailand; the results showed the applicability of the model in real-life projects, but it was time-consuming and challenging to assess the quality in addition

to the linear relationship which it was not always applicable. The disadvantages of both Babu and Suresh; and Khang and Mon Myint [5], [6] were not considering incentive cost, reward cost, and the general precedence relationships among the activities.

After that, Babu and Suresh [5], Liu et al., [7] has been able to consider the security into the TCQTP to become Time Cost Quality Security Trade-off Problem (TCQSTP). The author used Particle Swarm Method (PSO) to optimize the problem's entities by assuming a continuous linear relationship between the problem's entities. For validating the efficiency of the proposed method, it was applied in a test example. Although the method proved its effectiveness, it has several drawbacks; for instance, using the linear relationships, large-scale examples, the general precedence relationships among the activities, and the indirect cost were not considered in the proposed model.

In 2009, Shi et al. [8] introduced a new model for the Quality Reliability-Cost Optimization problem. The Genetic algorithm (GA) was used to optimize the issue. The model was applied in a test example, and the model's effectiveness was validated. Even though the model contained several weak points, such as using the linear relationships is not practical in real projects, large-scale examples, the general precedence relationships among the activities, and the indirect cost was not considered in the proposed model.

Rong et al. [9] have developed an ANP method (Analytic network process) to evaluate the project by tabulating the data to study Time, Cost, and Quality.

Mokhtari et al. [10] suggested a stochastic model optimize TCQTP by adapting the statistical robust solution method to minimize the variance between the activities and take their bond into considerations. The model was applied in a nine activities example to illustrate its effectiveness; despite the satisfactory results, the model contained some weak points such as large-scale examples, the general precedence relationships among the activities, and the indirect cost was not considered in the proposed model.

In 2014, Razavi Hajiagha et al. [11] developed a fuzzy goal programming model to optimize TCQT problems using grey numbers. The method was applied in an example

consists of ten activities, each activity has two options (modes) to be executed; The results of the method proved the efficiency and strength of the proposed model despite the following; 1) the research used the continuous relationship between the entities although it is not the case in real projects, 2) there are just two options for each activity, 3) the general precedence relationships among the activities were not considered, 4) The method was not applied in a large-scale example, 5) the indirect cost was not included in the model.

Using stochastic optimization, Golpîra [12] optimized TCQTP by implementing it with the goal programming approach and applying the produced model in a real case to study its results. The real case was in Kurdistan and consisting of three activities with three modes each. Although the results showed the model's satisfaction and applicability, the model missed some points, such as it did not include the general precedence relationships among the activities and the indirect cost.

Zhong et al., [13] research, a dynamic TCQT model was used to optimize the same problem and use an improved NSGAI as an optimization tool and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as an evaluation tool to evaluate the solutions and choose the best compromise. A real-life rock fill dam located in china has been used as a case study to evaluate the proposed method. The results of applying the model in the study case revealed the method's applicability. The results were compared with NSGAI and LWS; the comparison showed the superiority of the proposed method; however, it did not include the general precedence relationships among the activities.

2.3 Discrete Time-Cost-Quality Trade-off Problem

The discrete-time cost quality trade-off problem is one of the project scheduling problems; it is more realistic and applicable in real-world projects since each activity is expressed by a single node and has multiple execution modes. Each option contains a different time, cost, and quality value.

Three different methods can solve this problem can be categorized as follows:

- I. **Exact methods:** Exact methods are mathematical methods such as linear programming (LP), integer programming (IP), and dynamic programming (DP); it is computed, robust, and accurate in calculating the problems; it gives eventually a globally optimal solution
- II. **Heuristic methods:** A non-computerized method depends on the thumb rule to find the global optimum or a near-optimum solution [47]. However, it is simple to use, it cannot be applied in computer programming, and it can be applied only to the problems their variables have a linear relationship; such as Simulation and Lagrangean relaxation.
- III. **Meta-heuristic methods (evolutionary methods):** It includes the methods that search for an optimum or near-optimum solutions for complicated problems. It is inspired by nature by mimic the living creatures and the evolution system of nature (Natural selection) [48]. This exploration method in a vast space of solutions gives an optimum or near-optimum solution in the least time and effort; the most common types of this methods are the genetic algorithm, the Mimic algorithm, Ant-Colony optimization (ACO), and Particle swarm optimization (PSO) and Figure 2.1 is showing the idea of the most common algorithms.

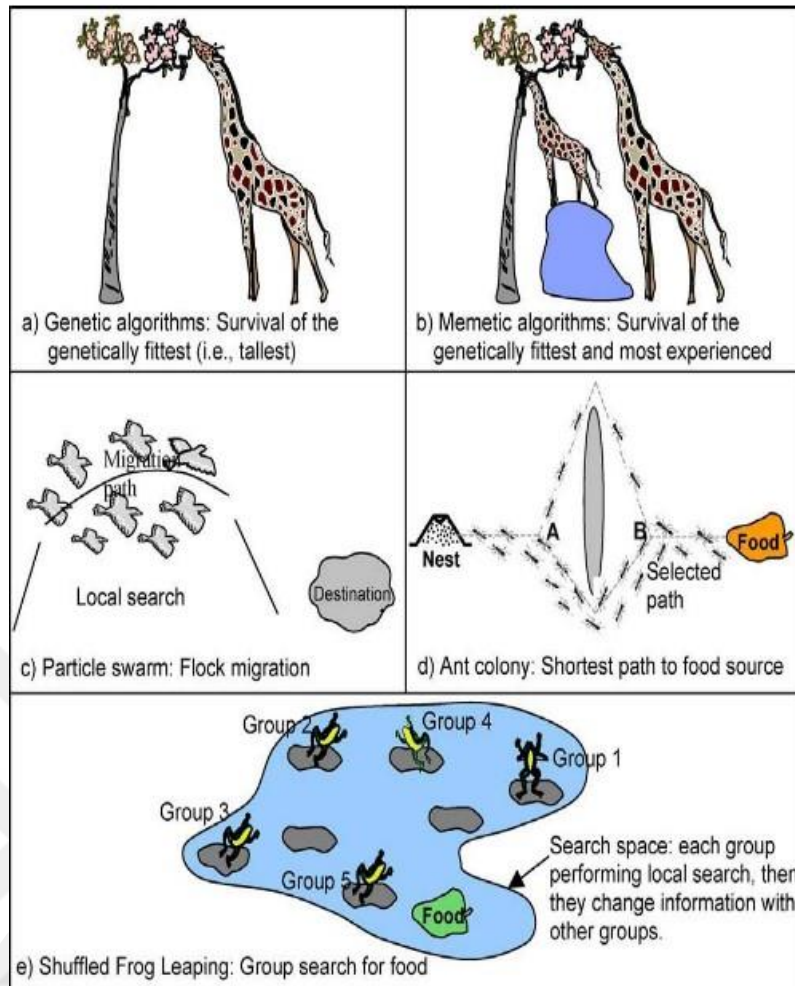


Figure 2.1 Natural evolutionary algorithms [1]

The first researcher who introduced The quality concept into TCTP using a non-linear relationship between the variables was El-Rayes and Kandil [4], proposed a multi-objective optimization model to solve the issue using a genetic algorithm as an optimization algorithm and used a transportation example to validate the model's effectiveness. As for quality quantification, it was measured by using quality indicators. Each activity in the project has been given several quality indicators; each indicator has a weight indicating its importance. The results validate the model's effectiveness, but the model did not consider the indirect cost and the general precedence relationships among the activities.

In 2006, Tareghian and Taheri [14] utilized interrelated programming to develop his three models to optimize the TCQT problem. The models were capable of optimizing one entity by assigning the desired level to other entities, assumed that cost and quality

are discrete points with a discrete non-increasing function of the project's duration. The effectiveness of the proposed model was proved by utilizing several examples. The proposed model has some drawbacks. For instance, large-scale examples, the general precedence relationships among the activities, and the indirect cost were not considered in the proposed model.

Using multi-objective Ant Colony Optimization by Afshar and Kaveh [25] analyzed and optimized the TCQT problem, was able to minimize time and cost and maximize the quality simultaneously. For measuring the proposed model's effectiveness and strength, it was applied in numerous examples. Despite considering the indirect cost, the model contains two drawbacks; 1) the model was not applied in large-scale examples. 2) The model did not include the general precedence relationships among the activities; the model's effectiveness and strength were proved.

Rahimi and Iranmanesh [36], the researcher applied one of the Meta-heuristic algorithms: Particle Swarm Optimization Algorithm for discrete-time-cost-quality trade-off problem (TCQTP) to minimize the total cost of the project and maximize the overall quality along with meeting a specific deadline. The proposed model's efficiency was validated using small- and large-scale instances, but the model contains some drawbacks. For example, the general precedence relationships among the activities and the indirect cost were not considered.

Iranmanesh et al. [41] tried to solve the same TCQT problem by utilizing a new algorithm modified from the genetic algorithm, and it is called the Fast Pareto Genetic algorithm (Fast PGA). The method has been applied in a simple project that consists of 30 activities; the method's effectiveness was proved; however, the method has some disadvantages. For example, large-scale examples, the general precedence relationships among the activities, and the indirect cost were not considered in the proposed model.

San Cristóbal [42] suggested a model that can optimize the owner's requirements; the proposed model is zero to one integer programming model and two other secondary models. The proposed model was applied in the road constructed between Mansores and Arouca in Portugal to demonstrate the robustness and effectiveness; despite that, the model was able to come out with a solution that satisfies all owner requirements,

but the model depended on the single approach optimization which eventually gives us a single optimum solution. The not considering extensive examples and the generalized precedence relationships were among the disadvantages of the proposed model.

Some researchers considered time as a non-renewable resource and the rest of the entities as renewable. Shankar et al. [43] introduced the quality into the traditional TCT problem to become Discrete Resource Quality Constrained Time Cost Trade-off. It has been used integer linear programming to form two models. The results showed that the cost would increase with steady quality. Along with all of this, the models have some weak points; such as each activity has only five options to implement, using the linear relationships among the entities is not practical in real projects, large-scale examples, the general precedence relationships among the activities, and the indirect costs were not considered in the proposed model.

In 2010, Assadipour and Iranmanesh [44] proposed a new model to optimize the TCQT problem using a Multi-objective Hybrid Cellular Genetic Algorithm. This method produces non-dominated solutions to help decision-makers choose the best solution among the top ones. Although the results showed the efficiency and superiority over the method, there were some drawbacks, such as large-scale examples, the general precedence relationships among the activities, and the indirect costs not considered in the proposed model.

Zheng and Mao [45] developed a model to optimize TCQTP by assuming each one of time, cost, and quality have a constant number that cannot be crossed. The model used the genetic algorithm as an optimization tool for the optimization process, the model was applied in a seven activities example, and the results were satisfactory. The model has some drawbacks, such as large-scale examples, the general precedence relationships among the activities, and the indirect costs that were not considered in the proposed model.

In Shankar et al., [46], the researcher analyzed Time Cost Quality Trade-off problem; then evaluations have been done for the project's resource allocation to choose the best alternative among the available solutions. Shankar et al. [46] have used computer simulation and interactive procedures to approach his model. After applying the

approach in a numerical example, the results showed the applicability of the proposed approach; however, the approach has some drawbacks, such as large-scale examples, the general precedence relationships among the activities, and the indirect costs proposed model.

A robust multi-response method has been used by Salmasnia et al. [15] to optimize the TCQT problem. The applicability of the proposed method was proved by applying it in a nine-activity example. This research's contribution can be summarized in; using a new method, assume an assumption that creates a balance between the deterministic assumptions and stochastic assumptions. Despite the above contributions, the method is missing some points such as large-scale examples, general precedence relationships among the activities, and the indirect costs that were not considered in the proposed model.

In 2013, Sorrentino [18] used the genetic algorithm to optimize the TCQT problem in a part of the real transportation project consisting of ten activities, used MATLAB to program the genetic algorithm, and the results the application were satisfactory. However, the method is missing considering many activities, general precedence relationships, and the proposed model's indirect costs.

Amiri et al. [16] proposed in their research the general precedence relationships among the activities and solving TCQT problem, which makes his model more comprehensive. It has been used the non-dominated sorting genetic algorithm as an optimization tool to optimize the problem discretely. The results were promising after applying it in several test examples (large-medium-small). The model comprises some drawbacks, such as the indirect cost was not considered, and the uncertainty approach in collecting the project's data was not considered.

A novel approach to optimize the TCQT problem called the Fuzzy clustering genetic algorithm (FCGA) has been proposed by Mungle et al. [17] and applied in a highway example to observe its capabilities effectiveness. The results were promising and satisfactory. Because of the lack of test examples in TCQT problems, the method has also been applied in TCT problems, and the results were compared with other approaches. The comparisons showed the superiority of FCGA over other methods. Despite the superiority of FCGA, it is missing some points; such as the indirect costs,

penalty costs, and incentive costs were not considered, which is not applicable in real projects in addition to not considering the general precedence relationships among the activities.

Some researchers inserted the environment as a new entity into the TCQT problem to upgrade the problem to be the Time Cost Quality Environment Trade-off problem (TCQET).

Zheng [19] used the uncertainty principle to measure quality and environment to develop a fuzzy multi-objective model and used an adaptive hybrid genetic algorithm as an optimization tool for the proposed problem. The results of applying the model in a real project ((Jinping-II) in china were satisfactory and promising; but, The proposed model contains some weak points; such as the model can be applied just in an electrical project or in the projects mentioned in Zheng, [19] research in addition to not considering the general precedence relationships among the activities and the indirect cost.

Hu and He [20] suggested a new approach in dealing with the TCQT problem; It has been used the project break down structure method and the genetic algorithm as an optimization tool. The model was applied in an example of a construction house with three-story contains 20 activities; the results were satisfactory and proved the effectiveness of the proposed model, but the model cannot be applied in large projects with a large number of activities because of the vast number of inputs besides the method did not consider the indirect cost and the general precedence relationships among the activities.

Two methods have been proposed to optimize the TCQT problem by Tavana et al., [21], namely non-dominated sorting genetic algorithm and efficient ϵ -constraint and considering the general precedence relationships among the activities and using the preemption principle to the activities. The methods have been applied in numerous generated examples for comparison between them. Using the reference set principle, the comparison results indicated that the non-dominated sorting genetic algorithm outperformed the efficient ϵ -constraint. However, the two methods contain some drawbacks, such as large-scale examples and indirect costs were not considered in addition to the preemption principle is not always applicable to the activities.

Some researchers were interested in identifying the subset for activities, especially since the same subset's activities cannot be performed in different modes. One of those researchers was Nabipoor Afruzi et al., [22]; used the multi-objective imperialist competitive algorithm to optimize the proposed model. The results of the proposed model were compared with four different approaches, namely, non-dominated sorting genetic algorithm (NSGAI), Pareto Envelope-based Selection Algorithm-clustering (PESAI), and Strength Pareto Evolutionary Algorithm (SP EA2). The results of the comparison showed the effectiveness of the proposed model. Despite that, the proposed model contains some drawbacks, such as; there are only two to three options available for each activity, the indirect cost was not considered, and the general precedence relationships among the activities were not considered.

Zhang et al. [23] proposed a new approach in calculating the quality, which is quality performance index (QPI), which was able to upgrade the particle swarm optimization by combining it with the genetic algorithm to form a new algorithm called Immune genetic particle swarm optimization (IGPSO). The proposed model was applied in a test example of a three-floor hybrid-structured office consisting of 19 activities; the results were satisfactory.

In 2015, Monghasemi [24] proposed two models under multi-objective optimization, namely genetic algorithm model (GA) and improved harmony search model (IHS). It has been used three evaluation methods within the multi-criteria decision-making (MCDM) approach for choosing the best solution from the produced solutions; by using three methods within MCDM; Evidential reasoning (ER), PROMETHEE, and TOPSIS. A comparison has been made to show which models give bettered results; the results showed that IHS gives better results when applying it in complex examples and ER's superiority on the other evaluation methods. As for the disadvantages of the proposed model, the indirect cost was not considered, and the general precedence relationships among the activities were not considered.

A new algorithm under the name of multiple objective artificial bee colony differential evolution (MOABCDE) was suggested to solve TCQTP; the algorithm is formed by combining differential evolution (DE) with the original artificial bee colony (ABC). For demonstrating the proposed algorithm's effectiveness, it was applied in a

generated example with 60 activities. The results were compared with four different algorithms; the non-dominated sorting genetic algorithm (NSGAI), multiple objective particle swarm optimization (MOPSO), multiple objective differential evolution (MODE), and multiple objective artificial bee colony (MOABC). The comparison results showed the superiority of the proposed algorithm over the other algorithms regarding the degree of satisfaction [26].

Razavi Hajiagha et al. [27] suggested optimizing the TCQT problem using grey numbers using two approaches; goal programming and genetic algorithm. The proposed methods were applied in two generated examples to realize their applicability; the results were promising and satisfactory despite the methods having some drawbacks: considering a large number of activities, general precedence relationships among the activities, and the indirect costs.

Monghasemi et al., [28] was the first researcher who used the ER approach as multi-criteria decision-making (MCDM) to choose the best Pareto optimal solution among the available solutions the optimization of TCQT problem. The simple genetic algorithm (GA) with the non-dominated sorting genetic algorithm was utilized as an optimization tool to optimize the TCQT problem and assign weights for each objective by using Shannon's entropy. Although the proposed model's effectiveness was proved by applying the model in a benchmark case study consisting of 18 activities, the model contains some weak points, such as considering many activities, general precedence relationships among the activities, and the indirect costs.

Khalili-Damghani et al. [29] introduced a new model to optimize the TCQT problem under the generalized relationships between the activities using the mixed-integer mathematical method in the optimization process. Four approaches were proposed to solve the model by using several generated examples. A comparison between the four approaches has been made, the results of the comparison showed the superiority of dynamic self-adaptive multi-objective particle swarm optimization (DSAMOPSO) over the rest. Not considering the uncertainties was one of the disadvantages of the proposed method.

Some researchers introduced new algorithms under Meta-heuristic algorithms; Saif et al. [30] introduced the problem data-based optimization algorithm (PDBO) to optimize

the TCQT problem. Eventually, the proposed algorithm will give a single optimal/near-optimal solution opposite to the rest of multi-objective algorithms, giving optimal solutions. The quality objective in this research was quantified in terms of its defects. An example consisted of nine activities that have been analyzed and solved using numerous methods. Using the proposed method (PDBO) to show the proposed method's applicability and efficiency, the results showed the superiority of the Egyptian vulture optimization method (EVO) over the rest. Not considering the uncertainties and the general precedence relationships among the activities were the disadvantages of the proposed model.

Cheng et al. [31] investigated a novel optimization model proposed under Chaotic Initialized Multiple Objective Differential Evolution with Adaptive Mutation Strategy (CA-MODE) to optimize the TCQT problem. A case of study submitted by [4] had been analyzed and solved by the proposed model. The results are compared with the previous research results for the same case study; the comparison results showed the relative superiority of the proposed model. Despite the comparative advantage of the proposed model, the general precedence relationships among activities were not considered, and a limited number of modes (e.g., only five-mode for each activity).

Mohamed and Bassuony [32] suggested three paradigms to optimize the TCQT problem; the first one is a simplified model with a genetic algorithm based on Excel add as an optimization tool, the second one is a stochastic model with using The PERT approach instead of critical path method to incorporate the uncertainty concept in the calculations, The last one is an advanced model with using three different approaches: 1) Goal programming (GP), 2) the modified adaptive weight approach (MAWA), and 3) the non-dominated sorting genetic algorithm (NSGAI) along with considering the general relationships among the activities and unlimited modes for each activity.

Yadaiah and Haragopal [33] used a new algorithm called the Hungarian algorithm to optimize the TCQT problem. A generated specific example has been used to validate the effectiveness and strength of the proposed model. The results showed the efficiency and superiority of the proposed model after comparing it with different approaches. However, the process contained some weak points, such as considering

many activities, general precedence relationships among the activities were not considered.

Kazaz et al. [34] suggested that using different construction materials will affect the time, cost, and quality of the project, especially in building construction. The first one introduced an approach that consisted of two main steps: the impact of construction material on the time, cost, and quality of the project compared with the active labor's stability and policy. The second one is to adjust the project's time and cost with consistent quality if the decision-makers are willing to change that.

Khan et al. [49] suggested a model that optimizes time-cost-quality- environment trade-off problem (TCQET). The model consisted of two stages; the first stage is about using the weight-sum procedure to calculate the main objectives' weights; the second stage is about solving the main problem (TCQET) by using the proposed approach (EBS-based) [35]. A case study was developed to ensure the proposed method's strength and efficiency, and the results were promising. Although the model was developed for large-scale projects, a large-scale example was not used in the research and the general precedence relationships among the activities.

Luong et al. [37] suggested a new novel approach to optimize the TCQT problem using opposition-based multiple objective differential evolution (OMODE) as an optimization tool. The proposed approach is using an opposition-based learning technique in the operations within the generation. An example was used for observing the efficiency of the proposed method, and the method was able to extract the optimum solution. The results were compared with several different approaches in different comparisons; the results of comparisons indicated the superiority of OMODE. Despite all the above, the proposed model is missing some points, such as considering many activities, general precedence relationships among the activities, and the indirect costs.

In repetitive projects such as transportation projects, the construction materials are repeatedly used in almost all activities; therefore, many researchers attempted to develop a unique model for such projects. One of these researchers was Tran et al., [38] proposed a novel approach under the name of Opposition multiple objective symbiotic organisms searches (OMOSOS). This method uses an opposition-based learning technique to explore and exploit the searching process within the population.

After applying this approach in two examples, the results were compared with several methods such as NSGAI and MOPSO. The comparison showed the superiority of OMOSOS. The OMOSOS has many advantages; however, the model did not consider many activities and general precedence relationships among the activities.

As for quality, Orm and Jeunet [39] have surveyed for the quantification of quality; the results indicated a direct relationship between quality and the activity's material and lack of quality measurement methods. The survey results can be summarized as follows:

- I. For each activity, there is a quality indicator that indicates the quality of performing the activity; its value is from zero to one.
- II. If the duration is constant, then by spending more money, the quality will increase.
- III. Each activity has to have a weight that indicates its importance to the project.
- IV. There is a relationship between the quality and the labors and night shifts.
- V. The multi-objective approaches are less used in comparison with single objective methods.
- VI. There is a lack of real examples, especially in actual large-scale instances (only one example with 52 activities of a pre-heater tower of a cement factory).

Hamta et al. [40] proposed a goal programming model to optimize the TCQT problem using the critical path method. The model was developed by utilizing the Lingo language. A real test example consists of 99 activities performed by an Iranian company implemented in the proposed model. The results were promising and satisfactory; however, the general precedence relationships among the activities and the indirect costs were not considered.

2.4 Summary

A summary has been provided for the types of TCQT problems according to the problem's assumption for the relationship between the objectives: continuous TCQT problem and discrete TCQT problem. Tables 2.1 and 2.2 summarize the review by the research priority according to years.

Table 2.1 A summary of studies on the continuous TCQ problem.

Continuous-Time Cost Quality Trade-off Problem			
Number in reference	Author	Year	Used method
[5]	A.J.G. Babu, Nalina Suresh	1996	Linear programming
[6]	Do Ba Khang, Yin Mon Myint	1999	Linear programming
[7]	Jin-peng Liu, Dong-xiao NIU, Yi-zhou Zhang	2009	Particle Swarm optimization
[8]	Shi Yu-fang, Li Hui-min, LU Ning	2009	Genetic Algorithm
[9]	Rong Xian, MU Lingling, Liu Ping	2009	Analytic network process
[10]	Mokhtari, Hadi Salmasnia, Ali Bastan, Mahdi	2012	statistically robust solution method
[11]	Razavi Hajiagha, S.H., Mahdiraji, H.A., Hashemi, S.S	2014	Stochastical model
[12]	Heris Golpira	2016	Fuzzy goal and grey linear programming
[13]	Deng-Hua ZHONG, Wei Hu, Bin-ping Wu, Zheng Li, Jun Zhang	2017	Genetic algorithm

Table 2.2 A summary of studies on the discrete TCQ problem

Discrete Time Cost Quality Trade-off Problem			
Number in reference	Author	Year	Used method
[4]	El-Rayes, Khaled Kandil, Amr	2005	Genetic algorithm
[14]	Tareghian, Hamed R.	2006	Integer programming

Table 2.2 A summary of studies on the discrete TCQ problem

Discrete Time Cost Quality Trade-off Problem			
Number in reference	Author	Year	Used method
	Taheri, Seyyed Hassan		
[25]	A. Afshar, A. Kaveh and O.R. Shoghli	2007	Multi-colony ant algorithm
[36]	Maryam Rahimi and Hossein Iranmanesh	2008	Particle Swarm Optimization
[41]	H. Iranmanesh, M. R. Skandari, and M. Allahverdilo	2009	Genetic algorithm
[42]	San Cristóbal, José Ramón	2009	Integer Programming
[43]	N. Shankar, M.M.K. Raju and P. Hima Bindu.	2010	Integer linear programming
[44]	Gh. Assadipour and H. Iranmanesh	2010	Genetic algorithm
[45]	Zheng, Xiao Mao, Qingyun	2010	Genetic Algorithm
[46]	N. Shankar, M. M. K. Raju, G. Srikanth and P. Bindu	2011	Computer simulation and interactive procedure
[15]	Ali Salmasnia, Hadi Mokhtari, Isa Nakhai Kamal Abadi	2012	Robust multi-response
[18]	Mariarosa Sorrentino	2013	Genetic Algorithm
[16]	Maghsoud Amiri, Amir Abtahi and Kaveh Damghani	2013	Genetic Algorithm
[17]	Santosh Mungle, Lyes Benyoucef, Young Son, M.K. Tiwari	2013	Genetic Algorithm
[19]	Huan Zheng	2014	Genetic Algorithm

Table 2.2 A summary of studies on the discrete TCQ problem

Discrete Time Cost Quality Trade-off Problem			
Number in reference	Author	Year	Used method
[20]	Wenfa Hu and Xinhua He	2014	Genetic Algorithm
[21]	Madjid Tavana, Amir Abtahi, Kaveh Damghani	2014	Genetic Algorithm
[22]	Elham Afruzi, Amir Najafi, Emad Roghanian, Mostafa Mazinani	2014	Imperialist competitive algorithm
[23]	Zhang, Lianying Du, Jingjing Zhang, Shushan	2014	Immune Genetic Particle Swarm Optimization
[24]	Shahryar Monghasemi	2015	Genetic Algorithm
[26]	Tran, Duc Hoc Cheng, Min Yuan Cao, Minh Tu	2015	multiple objective artificial bee colony with differential evolution
[27]	Seyed Hajiagha, Hadi Akrami, Shide Hashemi, Hannan Mahdiraji	2015	Integer Grey Goal Programming
[28]	Shahryar Monghasemi, Mohammad Nikoo, Mohammad Fasaee, Jan Adamowski	2015	Genetic Algorithm
[29]	Kaveh Damghani, Madjid Tavanab, Amir Abtahid and Francisco Arteaga	2015	Four approaches
[30]	Abdulelah Saif, Safia Abbas, Zaki Fayed	2015	Problem data-based optimization
[31]	Min-Yuan Cheng, Duc-Hoc Tran and Minh-Tu Cao	2016	CA-MODE

Table 2.2 A summary of studies on the discrete TCQ problem

Discrete Time Cost Quality Trade-off Problem			
Number in reference	Author	Year	Used method
[32]	Mahmoud Mohamed El Bassuony	2016	Three approaches
[33]	Ventepaka Yadaiah, V. V. Haragopal	2016	Hungarian Algorithm
[34]	Aynur Kazaz, Serdar Ulubeyl, Bayram ER, Turgut Acikara	2016	An approach consists of two steps
[35]	Huan Zheng	2017	EBS-based
[37]	Duc-Long Luong, Duc-Hoc Tran and Phong Thanh Nguyen	2018	OMODE
[38]	Duc-Hoc Tran, Long Luong-Duc, Minh-Tin Duong, Trong-Nhan Le, Anh-Duc Pham	2018	OMOSOS
[39]	Mayassa Bou Orma, Jully Jeunet	2018	A survey
[40]	Nima Hamta, Mohammad Ehsanifar and Javad Sarikhani	2018	Goal programming

As shown in the foregoing tables and to the best of the author's knowledge, only two studies [16], [29] have been able to incorporate the general precedence relationships along with the quality aspect in the literature. The proposed model is distinguished from all previous models not only due to the speed of the model in finding non-dominated solutions by the dynamic elimination of the dominated ones and keeping only the non-dominated solutions, but also because of the diversity and the complexity of the practiced test examples. Three different TCQ trade-off problems, two of which

are generated within the context of this thesis are used which will provide a database of examples for future studies in this field for comparisons purposes as this knowledge area lacks large benchmark examples along with their solutions.



CHAPTER 3

METHODOLOGY

3.1 Chapter Overview

The primary purpose of this chapter is to elaborate the development of the proposed model. The developed model's main objective is to select an appropriate execution option for each activity to achieve the primary considerations, such as completing the project with the proper time, convenient cost, and the best possible quality. Meaning the model will provide a set of solutions for the same projects; each contains a chain of selected executions options for the project's activities. The proposed model was implemented using the C# language by benefiting from its capabilities and ease of use.

3.2 Modified Genetic Algorithm for Time-Cost-Quality Problem with Generic Relationships

3.2.1 Decision Variables

The decision variables are the changeable variables that affect the project elements (i.e. time, cost, and quality of the project) directly and indirectly, for instance, the number of working hours, the productivity of labor, construction method, and quality of the used materials, etc. All these variables have been combined into a single variable called "Offer". Each activity has several executions options "offers", and each offer contains a particular time, cost, and quality for executing the activity. These details are calculated depending on the construction method, the type of the used material, and the mentioned above variables, all of them are within the acceptable methods to execute the project (The specifications). Meaning each offer has an expected direct cost for executing a specific unit within the activity, the expected duration for executing the activity by depending on the bill of quantity table, and the anticipated

quality, which can be calculated by observing the previous projects in the same field and also by using the weights method which was explained in section 1.6.

The time, cost, and quality of the project will be calculated depending on selected offers; therefore, selecting the offers is vital for the project's success; consequently, the model was implemented. The model will have the capability of selecting the best possible offer for each activity to strike a balance between the main project's elements.

3.2.2 Optimization Constraints

Fixed boundaries have to be satisfied with the suggested solution to be acceptable.

The suggested constraints of the proposed model are: -

- a. Maximum acceptable time for the project (Deadline)
- b. Maximum allowable cost for the project (Budget)
- c. Minimum acceptable quality for the project (Specifications)

3.2.3 Project Total Cost

As mentioned earlier in section 1.4, the total project cost involves the project's direct and indirect costs. The direct cost includes the direct cost of all executed activities in the project, the indirect cost is a specific value for all the project's indirect costs within a single day, and it can be calculated by multiplying this value with the total duration of the project. Equation 3.1 has been used in the proposed model to calculate the total project cost.

$$C = \sum DC + IC \times D \quad (3.1)$$

where C represents the total project cost, $\sum DC$ is the summation of the direct cost of all activities, $IC * D$ represents the total indirect cost of the project, and it is equal to the multiplication of the value of the indirect cost of the project for a single day by the duration of the project.

3.2.4 Project Duration

The total project duration was calculated in the proposed model using the critical path method, explained in section 1.4.1. A forward path is applied to calculate the project duration. It is assumed that the first activity's earliest start time is equal to one (The first day of the project). The earliest finish time of the same or any activity can be calculated by using equation 3.2. The earliest start time of the succeeding activity is equal to its predecessor's most significant earliest finish time. The biggest earliest finish time of the last activities is considered as the total project duration. A backward path is applied to recognize the critical activities by calculating the total float for each activity. The last activity's latest finish time is considered equal to the earliest finish time of the same activity. The latest finish time of any succeeding activity is equal to the fewest latest start time of its predecessors, and its latest start time (same or any other activity) can be calculated using equation 3.3. The critical activity is an activity with zero total floats, and using equation 3.4, the total float is calculated for each activity.

$$\text{Earliest Finish Time (EFT)} = \text{Earliest Start Time (EST)} + \text{Duration} \quad (3.2)$$

$$\text{Late Start Time (LST)} = \text{Late Finish Time (LFT)} - \text{Duration} \quad (3.3)$$

$$\text{Total Float (TF)} = \text{LST} - \text{EST} = \text{LFT} - \text{EFT} \quad (3.4)$$

3.2.5 Project Quality

The proposed model assumes that the quality is precalculated depending on the approach [4]. The overall project's quality value will be between 0 and 100; this value reveals the general quality of executing the selected modes. The project quality is calculated by summing all activities' performance indicators; each activity has a specific weight value that indicates its importance to the whole project. There are too many methods of calculating the project quality, and they were mentioned earlier in section 1.6, and the experts' judgment can be taken into considerations in calculating the activity's quality.

3.2.6 Optimization Objective

The working method of the proposed model is as follows:

- I. Minimizing total project duration within the project's boundaries, such as the project's cost and quality.
- II. Minimizing the total cost with an acceptable rate without affecting deadline and the acceptable quality.
- III. Maximizing the quality of the project by depending on the allowable constraints of time and cost.
- IV. They simultaneously optimized the project's time, cost, and quality using the non-dominated concept to find the optimum or near optimum solutions.

3.2.7 Optimization Approach

To achieve the objective goals, optimizing the time, cost, and quality of the project, a customized genetic algorithm has been proposed. The proposed algorithm is a tool to optimize and search for the best solutions in potential solutions. The algorithm uses the non-dominated concept to evaluate the produced solutions and selecting the best solutions among the available ones. The proposed algorithm depends on the survival of the fittest.

The model was implemented in three main phases: 1) initialization phase: in this phase, X solutions are generated randomly; 2) Fitness evaluation phase: in this phase, the solutions are evaluated by using the non-dominated concept and classified into dominated and non-dominated solutions; 3) Population Optimization phase: this phase seeks through the generations to find the Pareto optimal solutions, and the general process is shown in Figure 3.6.

The details of these phases are explained in the following sections and its flowchart is demonstrated in Figure 3.1.

3.2.7.1 Initialization Phase

This phase is subcategorized into two main categories:

- I. Project information and genetic algorithm parameters
 - a) Project preliminary information: reading the preliminary project information such as the number of activities, the indirect cost of project per day, the upper limit of the total cost for the project (Budget), the lower limit of acceptable quality for the project (Specifications), the upper limit of allowable time of the project to be accepted (Deadline).
 - b) The precedence relationships: reading the precedence relationships among the activities with the type of relationship and the number of days as a lag (positive or negative days) as shown in Figure 3.7.
 - c) The available offers: reading the available offers for each activity with its details (the anticipated time, the expected direct cost, the calculated quality) shown in Figure 3.8.
 - d) The genetic algorithm (GA) elements: the GA elements will be adjusted inside the model, and they are 1) Number of generations (*GenNum*). 2) Population size (*Popsize*). 3) Cross over probability from zero to one (CRO). 4) Mutation probability from zero to one (Mut). These elements can be only adjusted inside the model for two reasons 1) to separate the project information from GA elements. 2) The adjustment process is not as crucial as the project information for the stakeholders; therefore, it can be adjusted only by the designer or the executor of the optimization process. As for the chromosomes size (the solution), the model will take the number of activities as the chromosome size, and each gene (bit) in the chromosome represents a specific activity, and its value indicates the selected offer for that activity.

- II. Generate random solutions: for the first generation ($GenNum = 1$), each random solution represents a different way of executing the project. These **Popsize** solutions will be used in the next phase of the optimization process to find the best combinations that give the best time, cost, and quality of the project from the activities' available offers.

3.2.7.2 Fitness Evaluation Phase

The primary purpose of this phase is to evaluate the solution(s) in each generation (g) in the perspective of time (the less, the better), cost (the less, the better), and quality (the more, the better). From the evaluation process, the possibility of appearing in the next generation (s) for the solution(s) is calculated, and it is done as follows:

- I. Calculating the project duration from using the selected modes from solution (s) in the generation (g) by summing all critical path activities' durations, as shown in Equation 3-5.

$$\text{Minimize project duration} = \sum_{i=1}^I T_i^n \quad (3.5)$$

where T_i^n is the duration of activity (i) in the critical path using the selected mode (n) [4].

- II. Calculating the total project cost from using the selected modes from solution (s) in the generation (g) by summing the costs of all activities and with adding the total indirect cost, which can be calculated from knowing the total duration of the project and the whole process is shown in Equation 3-6.

$$\text{Minimize project cost} = \sum_{i=1}^I DC_i^n + IC * D \quad (3.6)$$

where $\sum_{i=1}^I DC_i^n$ Represents the summation of all activities' direct cost in the selected modes, $IC * D$ represents the total indirect cost of the project, and it is equal to the multiplication of the value of the indirect cost for a single day the duration of the project.

- III. Calculating the project quality from using the proposed modes from solution (s) in the generation (g) by summing all activities' quality performance, as shown in Equation 3-7.

$$\text{Maximize project quality} = \sum_{i=1}^I Q_i^n \quad (3.7)$$

where:

Q_i^n is the final quality performance for activity (i) using the mode (n) in solution (s) within a generation (g).

- IV. Using the non-dominated concept, the solutions will be organized into dominated and non-dominated solutions; the non-dominated solutions will be given a specific weight that gives them a better chance to be selected in the next generation (s), and the rest will have another weight less than the non-dominated weight.
- V. The non-dominated solutions will be added to a unique set of non-dominated genetic algorithm solutions (NGASol); the NGASol will work as an archive to store the non-dominated solutions edited along with the upcoming generations.
- VI. Using the Roulette wheel will select for us **Popsiz**e solutions, and it can be used as a parent population in the next phase.

3.2.7.3 Population Optimization Phase

The purpose of this phase is to generate two kinds of populations in each generation as i) Parent population and ii) Child population.

In each generation, the parent population is used to generate a child population using the crossover and mutation of the GA concepts to reform the parent population's selected offers into the child population within each generation.

- I. Identify Pareto optimal solutions by comparing the solutions with each other and extract the optimal ones; for instance, solution **a** dominates solution **b** if and only if solution **a** has better values in all objectives than the solution **b** or the solution **a** is better than the solution **b** in at least one objective and equal with other objectives (better quality and less time and cost)
- II. Create a child population (C_g) from the parent population (P_g) using GA operators like selection, crossover, and mutation. The selection process will select the solutions to the possibility of crossover and mutation or pass to the next generation ($g+1$) without any changes. The possibility of the non-dominated solution to be selected is higher than all other dominated solutions because of the assigned weight. On the other hand, the crossover operation between two selected pairs (solutions) will be done by depending on the selected crossover point by switching the genes between this points to produce a new pair of chromosomes (solutions) that hold new features. As the mutation, it is done for each chromosome separately (after the crossover operation), in order to that, a random point is selected, and its

value (gene's value) is flipped into a random value from the available values (available offers of this activity). This operation ensures the diversity in the produced solutions and prevents sticking the searching process in a local optimal. The new child population (C_g) is evaluated in the same way as in the fitness evaluation phase.

- III. After the evaluation operation, the resulting chromosomes will be compared to the NGASol list to add the non-dominated solutions and remove or replace the dominated ones; thus, the NGASol will always be updated and kept with just optimal global solutions. The child population (C_g) will be considered as a parent population (P_{g+1}) for the next generation, and this phase will be reapplied to the new parent population (P_{g+1}) to generate a new child population (C_{g+1}), this iterative operation will continue until the predefined number of generations is reached.

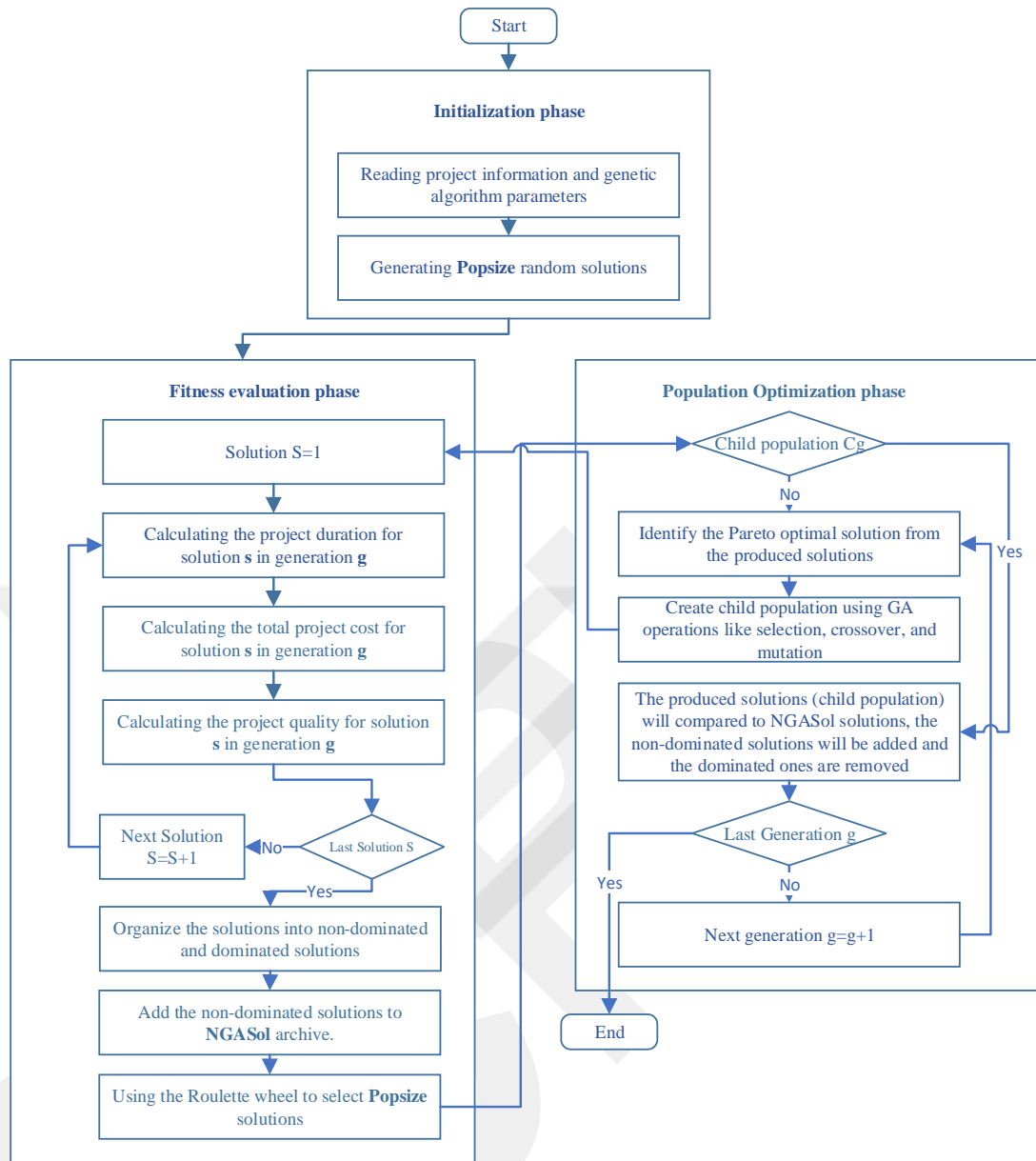


Figure 3.1 Optimization Process.

3.2.8 Optimization model

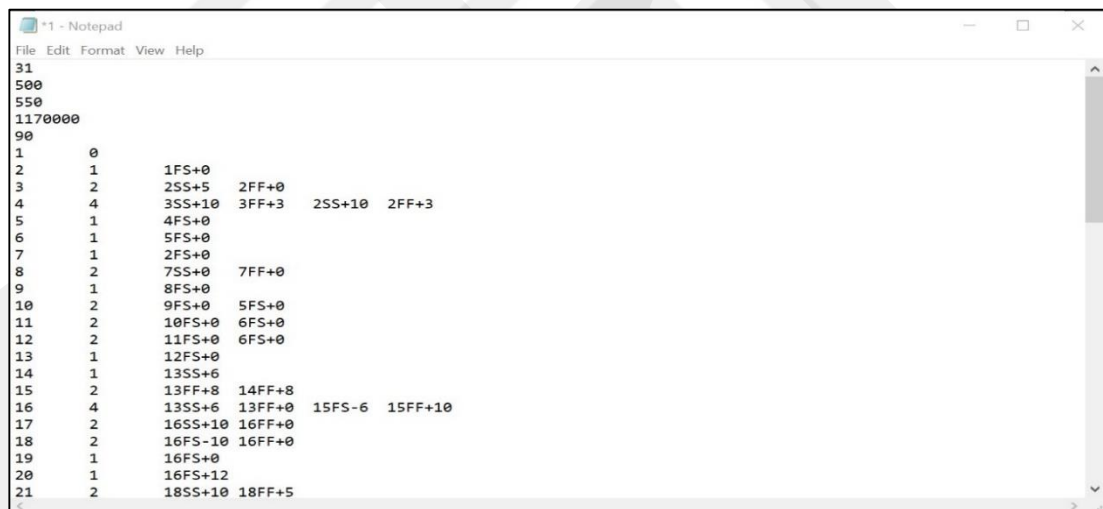
Visual studio 2019 has been used as a platform to write and develop the proposed model, C sharp language was used as a coding language due to its popularity, success, power, and it is considered less complicated than some other languages.

As for the proposed method, its characteristics were as follows:

- I. Easy to prepare, a prepared text file has been used as an input file to the model, making the errors' chance appear less.
- II. It is easy to consider any number of variables.
- III. Less time of entering data due to the preparation process consumes less time than other methods.

Figures 3.2 and 3.3 demonstrate sample input data holding various information about the test problem organized as follows:

- a. The number of activities.
- b. The indirect cost of the project per day.
- c. Deadline (Maximum project duration).
- d. Budget (Maximum project total cost).
- e. Minimum acceptable quality (Specifications).
- f. The general relationships between the activities (FS, FF, SS, SF)
- g. The available offers for each activity and its details.



```

*1 - Notepad
File Edit Format View Help
31
500
550
1170000
90
1      0
2      1      1FS+0
3      2      2SS+5  2FF+0
4      4      3SS+10  3FF+3  2SS+10  2FF+3
5      1      4FS+0
6      1      5FS+0
7      1      2FS+0
8      2      7SS+0  7FF+0
9      1      8FS+0
10     2      9FS+0  5FS+0
11     2      10FS+0 6FS+0
12     2      11FS+0 6FS+0
13     1      12FS+0
14     1      13SS+6
15     2      13FF+8 14FF+8
16     4      13SS+6 13FF+0 15FS-6 15FF+10
17     2      16SS+10 16FF+0
18     2      16FS-10 16FF+0
19     1      16FS+0
20     1      16FS+12
21     2      18SS+10 18FF+5

```

Figure 3.2 The input text file (part a).

```

*1 - Notepad
File Edit Format View Help
20      1      16FS+12
21      2      18SS+10 18FF+5
22      4      21SS+12 21FF+2 17FS-10 17FF+0
23      2      22SS+15 22FF+2
24      2      23FS-15 23FF+0
25      2      24SS+15 24FF+5
26      2      24FS-10 24FF+0
27      2      26FS-10 26FF+0
28      2      27FS-10 27FF+0
29      2      28FS-10 28FF+0
30      4      19FS+0  20FS+0  25FS+0  29FS+0
31      1
0      0
1      2      15      60000  90      12      68000  98
2      3      25      30000  91      20      38000  92      15      44000  92
3      3      25      50000  93      20      54000  95      15      60000  92
4      2      12      17000  92      9       21000  96
5      1      6       3000   98
6      2      12      27000  95      9       32000  99
7      1      6       8000   99
8      3      20      44000  94      15      48000  94      12      54000  96
9      2      12      15000  95      9       22000  97
10     1      6       3000   99
11     1      1       500    100
12     3      25      95000  100     20      105000 100     15      109000 94
13     3      15      34000  94      12      41000  92      9       51000  95

```

Figure 3.3 The input text file (part b).

3.2.9 Input Variables

The input file must cover some variables in order for the model to be able to provide the best outcomes.

In case of unavailability of some variables, it should be put as zero.

- a. Number of activities
- b. The indirect cost of the project for one day
- c. Minimum acceptable duration (Deadline)
- d. Maximum acceptable cost (Budget)
- e. Minimum acceptable quality (Specifications)
- f. The general relationships among the activities.
- g. The number of offers for each activity and its details.

The input text file should be prepared as follows:

- a. The first line represents the number of activities.
- b. The second line represents the indirect cost for a single working day for the whole project.
- c. The third line shows the upper limit for the acceptable duration of the project (Deadline)
- d. The fourth line shows the upper limit for the total project cost (Budget)

- e. The fifth line shows the minimum acceptable average quality of the project (Specifications)
 - f. The following lines will be about the precedence relationships between the activities and the type of relationship between them (FS, FF, SS, SF), and it is done as follows (Figure 3.4).
 - i) The name of the activity
 - ii) The number of connected predecessors.
 - iii) Each predecessor's name with its relationship and a positive or negative lag (if there is no lag, it has to be written as zero).
- 1) Upon completion of all precedence relations, two zeros shall be written, indicating that defining the precedence relations between the activities is ended.
 - 2) Upon completion of the previous part, the available offer for each activity is written as follows (Figure 3.5)
 - i) The name of the activity
 - ii) The number of available offers for it.
 - iii) The details of each offer

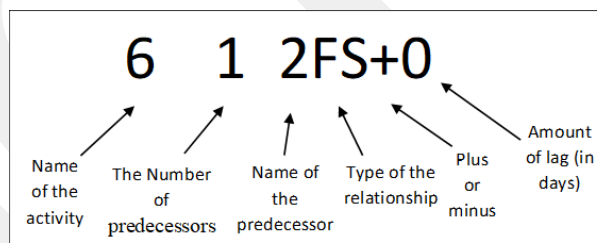


Figure 3.4 An example of the precedence relationship between the activities.

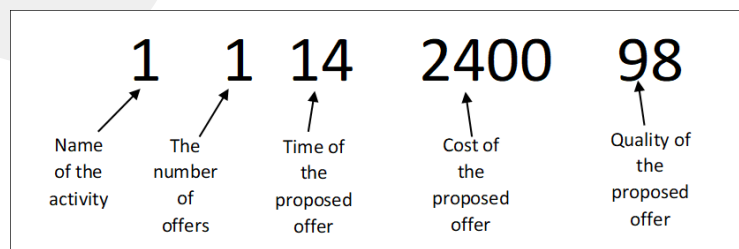


Figure 3.5 An example of available offers for an activity.

3.2.10 Output File

The proposed method will be able to create a file with the following information, as shown in Figures 3.6 and 3.7:

- I. A set of non-dominated solutions in the form of group format, each element represents the selected execution option for the same activity in the same rank.
- II. Project information by mentioning the total duration, total cost, and the quality of the project.

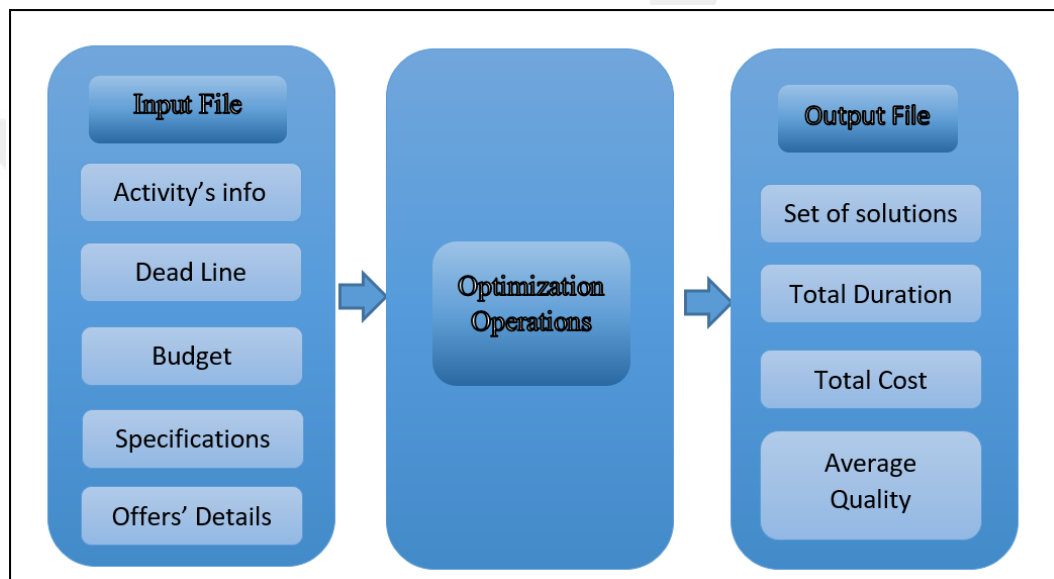


Figure 3.6 Model Description.

```
NSGA List.txt - Notepad
File Edit Format View Help
The Selected Modes For All Activities : - 1 - 5 - 2 - 1 - 1 - 2 - 3 - 2 - 5 - 5 - 3 - 2 - 4 - 3 - 3 - 1 - 5 - 3 - 3 -
Total duration : 104 Working Days
Total Cost : 139920 $
Average Quality : 84.194/100

The Selected Modes For All Activities : - 1 - 5 - 5 - 1 - 1 - 4 - 3 - 3 - 3 - 5 - 3 - 1 - 4 - 3 - 3 - 1 - 3 - 3 - 3 -
Total duration : 104 Working Days
Total Cost : 151100 $
Average Quality : 89.309/100

The Selected Modes For All Activities : - 1 - 5 - 3 - 1 - 3 - 4 - 3 - 3 - 3 - 5 - 3 - 3 - 4 - 3 - 3 - 1 - 5 - 3 - 3 -
Total duration : 104 Working Days
Total Cost : 167600 $
Average Quality : 96.909/100
```

Figure 3.7 Model's results.

The model contains some restrictions to improve the produced solutions through the optimization process; the first constraint is to restrict the produced solutions to be within the acceptable limits of the duration, cost, and quality, and the optimization process will simultaneously optimize the time, cost, and quality by using the non-dominated concept.

CHAPTER 4

MODEL VALIDATION AND RESULTS

In order to demonstrate the application and to evaluate the effectiveness of the proposed model, three Time-Cost-Quality (TCQ) tradeoff problems are fed into the model under various conditions regarding the rate of the daily indirect cost. Details of parameter configuration, practiced test instances, as well as the obtained results are elaborated in this chapter.

4.1 Parameter Configuration

The model's parameters were analyzed in three different study cases, through this process; the parameters were adjusted and tuned to get the best quality solutions. The values of the used parameters for each study case is listed below:

- The population size

The population size was configured based on 500 percent of the number of activities, this percentage was adjusted and tuned to get the best quality solutions.

- Population size of 9000 was used for 18-activity study case.
- Population size between 14,500 was used for 29-activity study case.
- Population size between 31,500 was used for 63-activity study case with note that increasing the population size for this study case will increase the quality of the produced solutions but more CPU time will be required.
- The crossover probability (CRO) was assigned to be 0.80 for all study cases.
- The mutation probability (Mut) was assigned to be 0.01 for all study cases.
- The generation number

The generation number was configured based on 25 percent of the number of activities, this percentage was adjusted and tuned to get the best quality solutions.

- Generation number was set to be 450 for 18-activity study case.
- Generation number between 725 was used for 29-activity study case.
- Generation number between 1,575 was used for 63-activity study case.

It is worth mentioning the meta-heuristic algorithms do not guarantee the optimality of the produced solutions but it will give the decision makers with the confidence with their decision since the produced solutions will be near optimum solutions.

4.2 Description of the Test Instances

To exemplify the use and demonstrate the model's effectiveness, it was applied in three different study cases with 18, 29, and 63 activities; the first one is a literature example as a small-size example contains 18 activities with only a finish to start precedence relationships, The medium-size example is the second one which contains 29 activities with general precedence relationships, and the last one is the large size example contains 63 activities with an only finish to start precedence relationship. However, it contains two different indirect costs to be solved separately. Details of the instances will be given in the following sections.

4.2.1 18-Activity Problem

The first study case was applied to validate and examine the proposed model's effectiveness and strength. The study is created by Feng et al. [50], and many researchers have used it to study TCTP. This example has been modified and upgraded later to include the quality element by El-Rayes and Kandil [4]. The study example consists of 18 activities; each has a different number of available offers to execute it. On average, each activity has about 3.4 modes to be executed with; this creates a searching space of $3.4^{18} = 3.6$ billion solution to search in which considered a challenging task to do. The proposed model will search for the optimum solution (non-

dominated) depending on the domination concept. The dominated solutions will be precluded. The precedence relationships between the activities are shown in Figure 4.1. The details of the available offers for the activities are shown in table 4.1. The indirect cost is assumed to be \$0 per day, the minimum acceptable project quality and the deadline are set to be 70 and 147 days, respectively, for the budget, it was assumed to be freely chosen.

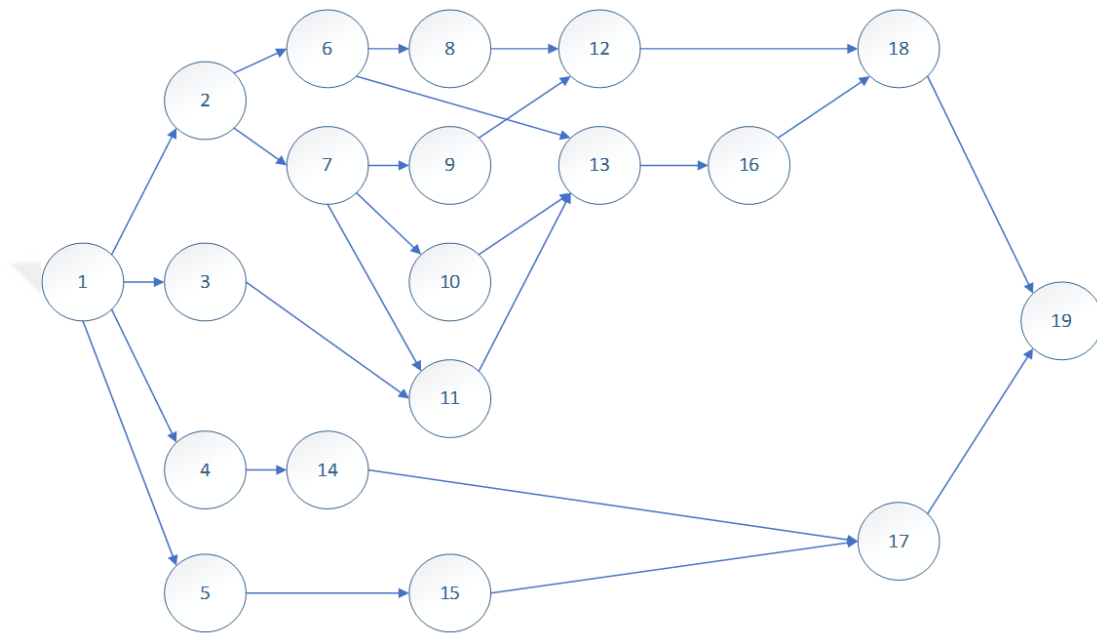


Figure 4.1 Project network for 18-activity problem.

Table 4.1 The original data of 18-activity problem [4].

Activity	Offers	Duration	Cost	Activity weight	Quality indicator K=1		Quality indicator K=2		Quality indicator K=3	
					IW*	QP*	IW	QP	IW	QP
1	1	14	2400	3	50	100	30	20	96	98
	2	15	2150			90			89	
	3	16	1900			86			77	84
	4	21	1500			75			72	73
	5	24	1200			63			60	65
2	1	15	3000	5	40	98	40	94	20	99

Table 4.1 The original data of 18-activity problem [4].

Activity	Offers	Duration	Cost	Activity weight	Quality indicator K=1		Quality indicator K=2		Quality indicator K=3	
					IW*	QP*	IW	QP	IW	QP
	2	18	2400			87		94		95
	3	20	1800			81		92		85
	4	23	1500			77		72		70
	5	25	1000			60		66		59
3	1	15	4500	8	70	100	15	97	15	98
	2	22	4000			80		82		81
	3	33	3200			62		60		63
4	1	12	45000	11	50	99	35	95	15	94
	2	16	35000			74		71		76
	3	20	30000			59		63		64
5	1	22	20000	10	60	100	20	97	20	99
	2	24	17500			93		89		89
	3	28	15000			77		71		72
	4	30	10000			61		64		61
6	1	14	40000	11	50	95	25	95	25	100
	2	18	32000			76		74		79
	3	24	18000			59		62		68
7	1	9	30000	10	30	97	30	99	40	93
	2	15	24000			70		73		71
	3	18	22000			61		62		67
8	1	14	220	1	100	95	0		0	
	2	15	215			83				
	3	16	200			75				
	4	21	208			68				
	5	24	120			61				
9	1	15	300	1	50	100	50	99	0	
	2	18	240			97		92		
	3	20	180			81		88		
	4	23	150			71		75		

Table 4.1 The original data of 18-activity problem [4].

Activity	Offers	Duration	Cost	Activity weight	Quality indicator K=1		Quality indicator K=2		Quality indicator K=3	
					IW*	QP*	IW	QP	IW	QP
	5	25	100			63		64		
10	1	15	450	1	60	94	40	97	0	
	2	22	400			79		83		
	3	33	320			63		69		
11	1	12	450	2	70	96	30	95	0	
	2	16	350			72		75		
	3	20	300			61		66		
12	1	22	2000	3	50	99	35	98	15	95
	2	24	1750			89		85		87
	3	28	1500			70		71		79
	4	30	1000			62		61		63
13	1	14	4000	7	40	99	40	96	20	97
	2	18	3200			73		71		76
	3	24	1800			60		62		63
14	1	9	3000	6	80	100	10	95	10	98
	2	15	2400			79		82		81
	3	18	2200			63		67		66
15	1	16	3500	7	70	100	30	98	0	
16	1	20	3000	3	30	97	30	96	40	98
	2	22	2000			89		85		87
	3	24	1750			81		79		78
	4	28	1500			72		73		74
	5	30	1000			67		60		62
17	1	14	4000	6	70	98	20	97	10	99
	2	18	3200			73		75		72
	3	24	1800			62		65		61
18	1	9	3000	5	30	98	45	99	25	94
	2	15	2400			75		77		71
	3	18	2200			63		66		67

* QP = Quality Performance; IW = Indicator Weight

The original data was rearranged and organized to fit the proposed model's input text file, and Figures 4.2 and 4.3 illustrate the modified case example.

```

4.txt - Notepad
File Edit Format View Help
0
19
0
1 0
2 1 1FS+0
3 1 1FS+0
4 1 1FS+0
5 1 1FS+0
6 1 2FS+0
7 1 2FS+0
8 1 6FS+0
9 1 7FS+0
10 1 7FS+0
11 2 7FS+0 3FS+0
12 2 8FS+0 9FS+0
13 3 6FS+0 10FS+0 11FS+0
14 1 4FS+0
15 1 5FS+0
16 1 13FS+0
17 2 14FS+0 15FS+0
18 3 12FS+0 15FS+0 16FS+0
19 2 17FS+0 18FS+0
0
0
1 1 0 0 0
2 5 24 1200 1.875 21 1500 2.211 16 1900 2.487 15 2150 2.685 14 2400 2.952
3 5 25 1000 3.11 23 1500 3.68 20 1800 4.31 18 2400 4.57 15 3000 4.83

```

Figure 4.2 18-activity problem after modifications (part a).

```

4.txt - Notepad
File Edit Format View Help
15 1 5FS+0
16 1 13FS+0
17 2 14FS+0 15FS+0
18 3 12FS+0 15FS+0 16FS+0
19 2 17FS+0 18FS+0
0
0
1 1 0 0 0
2 5 24 1200 1.875 21 1500 2.211 16 1900 2.487 15 2150 2.685 14 2400 2.952
3 5 25 1000 3.11 23 1500 3.68 20 1800 4.31 18 2400 4.57 15 3000 4.83
4 3 33 3200 4.948 22 4000 6.436 15 4500 7.94
5 3 20 30000 6.7265 16 35000 8.0575 12 45000 10.6535
6 4 30 10000 6.16 28 15000 7.48 24 17500 9.14 22 20000 9.92
7 3 24 18000 6.82 18 32000 8.3875 14 40000 10.5875
8 3 18 22000 6.37 15 24000 7.13 9 30000 9.6
9 5 24 120 0.61 21 208 0.68 16 200 0.75 15 215 0.83 14 220 0.95
10 5 25 100 0.635 23 150 0.73 20 180 0.845 18 240 0.945 15 300 0.995
11 3 33 320 0.654 22 400 0.806 15 450 0.952
12 3 20 300 1.25 16 350 1.458 12 450 1.914
13 4 30 1000 1.854 28 1500 2.151 24 1750 2.619 22 2000 2.9415
14 3 24 1800 4.298 18 3200 5.096 14 4000 6.818
15 3 18 2200 3.822 15 2400 4.77 9 3000 5.958
16 1 16 3500 6.958
17 5 30 1000 1.887 28 1500 2.193 24 1750 2.376 22 2000 2.61 20 3000 2.913
18 3 24 1800 3.75 18 3200 4.398 14 4000 5.874
19 3 18 2200 3.2675 15 2400 3.745 9 3000 4.8725

```

Figure 4.3 18-activity problem after modifications (part b).

4.2.1.1 Results and Discussion of Findings for 18-Activity Problem

Results of the application of the proposed model in the first example are represented selectively in table 4.2 and the complete results can be found in Table A.1 of the

Appendix A chapter. For studying the produced results' quality and strength, it was compared with table 4.3, which is the results that have been obtained by El-Rayes and Kandil [4].

Table 4.2 Abridged List of results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
1	104	164820	93.061	5 5 1 3 3 3 3 1 5 3 2 4 3 3 1 5 3 3
10	105	157565	94.343	4 5 3 2 4 3 3 4 5 3 3 4 3 3 1 4 3 3
22	106	155700	92.459	3 2 3 2 4 3 3 3 5 3 2 4 3 3 1 4 3 3
32	107	152110	92.268	5 5 3 1 4 3 3 5 4 3 1 4 3 3 1 2 3 3
49	108	149670	91.866	5 5 3 2 4 2 3 5 5 3 1 4 3 3 1 4 3 3
66	109	145470	89.786	4 5 3 2 2 2 3 1 5 3 3 4 3 3 1 5 3 3
82	110	167048	96.1995	4 3 3 3 4 3 3 2 4 3 3 3 3 3 1 5 3 3
95	111	159655	94.5	5 5 3 3 4 2 3 4 4 3 2 4 3 3 1 4 3 3
111	112	151850	92.0855	4 5 3 1 4 3 3 1 3 3 3 3 3 3 1 3 3 3
122	113	157080	93.2385	5 3 3 2 4 3 3 3 3 2 2 3 3 3 1 5 3 3
132	114	151400	91.905	1 3 3 1 4 3 3 3 5 3 3 4 3 3 1 5 3 3
147	115	152880	92.4185	3 5 3 1 4 3 3 3 3 2 3 3 3 3 1 5 3 3
162	116	141570	91.099	5 5 3 3 2 1 3 5 5 3 3 3 3 3 1 5 3 3
175	117	138808	89.812	4 5 3 3 4 1 2 2 5 3 3 3 3 3 1 2 3 3
187	118	134390	89.2665	4 5 3 2 4 1 3 3 4 3 2 4 3 3 1 1 3 3
192	119	121700	86.0245	5 5 3 1 1 1 3 5 3 3 3 4 3 3 1 5 3 3
197	120	143595	91.1815	4 2 3 3 4 1 3 4 3 3 2 4 3 3 1 3 3 3
213	121	165505	95.21	1 5 3 3 4 3 3 4 4 2 3 4 3 3 1 1 3 3
238	122	143900	92.5185	4 5 3 3 3 1 3 5 3 2 3 4 3 3 1 5 3 3
263	123	145120	92.6465	4 5 3 3 4 1 3 5 2 2 3 4 3 3 1 3 3 3
287	124	143690	92.096	4 5 3 3 3 1 3 3 4 2 3 3 3 3 1 5 3 3
303	125	142195	91.358	3 3 3 3 3 1 3 4 3 2 3 3 3 3 1 5 3 3
310	126	109815	79.446	3 2 3 1 1 1 1 4 2 3 2 3 3 3 1 2 3 3
314	127	107560	77.369	3 2 3 1 1 1 1 5 4 3 3 1 1 3 1 4 3 3
315	128	141395	91.1275	2 4 3 3 3 1 3 4 3 2 3 4 3 3 1 3 3 3
321	129	108880	78.6215	1 1 3 1 1 1 1 3 3 3 2 4 3 3 1 2 3 3
322	130	143040	91.622	2 5 3 3 3 1 3 3 4 2 3 3 3 3 1 5 3 3

Table 4.2 Abridged List of results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
332	131	118115	83.6675	2 4 3 1 1 1 3 4 1 3 3 4 3 3 1 1 3 3
346	132	109870	80.0595	1 3 3 1 1 1 1 1 2 2 3 4 3 3 1 3 3 3
352	133	130840	89.1095	4 4 3 1 4 1 3 5 5 1 3 4 3 3 1 5 3 3
364	134	126740	87.2545	3 4 3 1 3 1 3 1 5 1 3 4 3 3 1 3 3 3
369	135	121065	85.017	4 5 3 1 1 1 3 4 3 1 3 3 3 3 1 5 3 3
374	136	107738	77.804	2 1 3 1 1 1 1 2 3 2 3 1 3 3 1 1 3 3
377	137	103255	71.7155	1 1 3 1 1 1 1 4 4 3 2 4 1 1 1 1 1 3
379	138	107130	76.933	2 4 3 1 1 1 1 3 3 3 3 3 3 2 1 1 1 3
381	139	105990	75.969	1 1 3 1 1 1 1 3 4 3 2 3 3 3 1 1 1 3
382	140	107708	78.101	2 3 3 1 1 1 1 2 5 2 3 3 3 3 1 2 1 3
386	141	107115	77.2205	1 1 3 1 1 1 1 4 5 2 3 4 3 3 1 3 1 3
392	142	106355	76.82	2 3 3 1 1 1 1 4 4 3 2 1 3 3 1 1 1 3
393	143	102880	71.067	1 1 3 1 1 1 1 3 3 2 2 3 1 1 1 1 1 3
396	144	107315	77.294	1 4 3 1 1 1 1 4 2 3 2 3 3 3 1 1 1 3
400	145	104315	74.062	2 2 3 1 1 1 1 4 2 2 3 2 1 3 1 1 1 3
401	146	102380	69.88	2 1 1 1 1 1 1 3 3 2 1 1 1 3 1 2 1 3
403	147	105230	74.658	1 3 3 1 1 1 1 3 3 2 2 2 1 3 1 4 1 3
405	148	101270	67.498	1 1 1 1 1 1 1 1 2 3 2 2 1 1 1 1 1 3
406	149	105515	74.9665	4 1 3 1 1 1 1 4 1 2 3 1 3 3 1 1 1 2
409	150	105600	75.087	1 1 3 1 1 1 1 3 2 3 1 1 3 3 1 2 1 3
411	152	100870	66.311	4 1 1 1 1 1 1 1 1 3 2 1 1 1 1 1 1 1
412	158	102225	69.8145	3 1 3 1 1 1 1 4 4 1 2 1 1 1 1 1 1 2
413	159	102150	70.438	1 1 3 1 1 1 1 3 2 3 3 1 1 2 1 2 1 1

Table 4.3 Comparison of results for 18-activity problem.

Results of El-Rayes and Kandil [4]				Results of the proposed model			
Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Sol. #	Dur (Day)	Cost (\$)	Quality (%)
1	104	166320	95	1	104	164820	93.061
2	114	105470	71	132	114	151400	91.905
3	115	141620	90	147	115	152880	92.4185
4	109	121350	77	66	109	145470	89.786
5	124	104620	72	287	124	143690	92.096

The outcomes of the proposed model for the first study case were 413 solutions produced in one minute and 23 seconds, they were compared with the results that have been obtained by El-Rayes and Kandil [4]. For instance, the 80th solution dominates the 4th solution; simultaneously, the proposed model's direct cost was 164820\$, which is lower than the direct cost of 166,320 for the same duration 104 with a slight decrease in the quality aspect 93.061% and 95%, respectively. Furthermore, the model was able to achieve better maximum and minimum quality and cost respectively, the maximum achievable quality of the proposed model was better than the quality in the literature 96.1995% and 95%, respectively, and the same for the cost aspect, the model was able to achieve better cost than the cost in the literature 100,870\$ and 104,620\$ respectively. The results can be further enhanced by introducing specific constraints to improve the produced solutions' quality for specific or multiple aspects. For instance, increasing the minimum acceptable quality will improve the quality aspect of the produced solutions.

Fig. 4.4 shows the typical Pareto optimal front located using the proposed model for this case example. This 3D illustration shows clearly the relationships among project duration, cost, and quality and may help decision-makers evaluate various potential project performance plans.

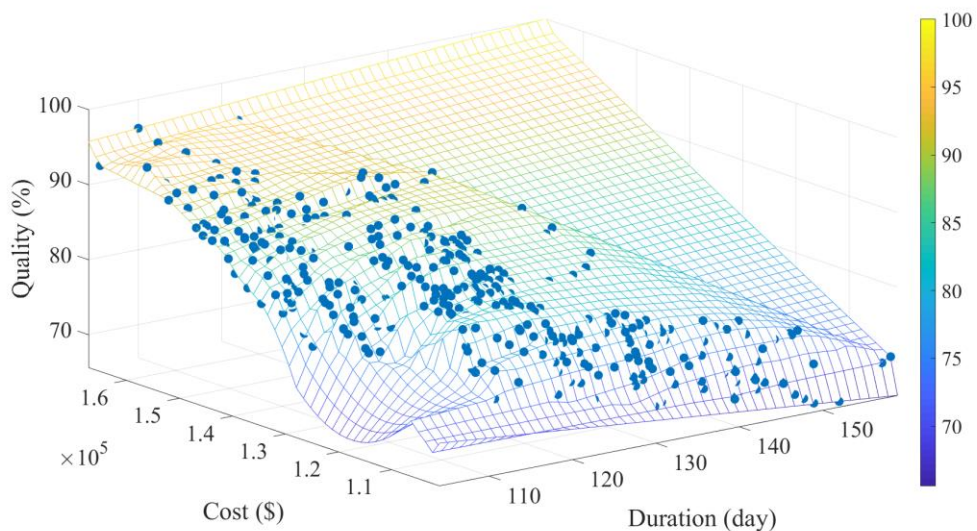


Figure 4.4 Time–Cost–Quality trade-off Pareto front for 18-activity problem.

4.2.2 29-Activity Problem

The second study case was applied to validate and examine the proposed model's capability in handling the general precedence relationships in addition to the model's effectiveness and strength. The study case is a self-generated example; it is generated to provide future studies with more examples to consider in their studies to study TCQTP. The study example consists of 29 activities and two dummy activities; each has a different number of available offers to execute it. On average, each activity has about 2.4 modes to be executed with; this creates a searching space of $2.4^{29} = 106$ billion solution to search in which considered a challenging task to do. The proposed model will search for optimum solutions (non-dominated ones) depending on the domination concept. The dominated solutions will be precluded. The precedence relationships between the activities are shown in Figure 4.4. The details of the available offers for the activities are shown in fig 4.5 and table 4.4. The indirect cost is assumed to be €1200/day with a delay penalty of € 1500/day and an incentive payment of €500/day; the produced solutions will be selected within these conditions.

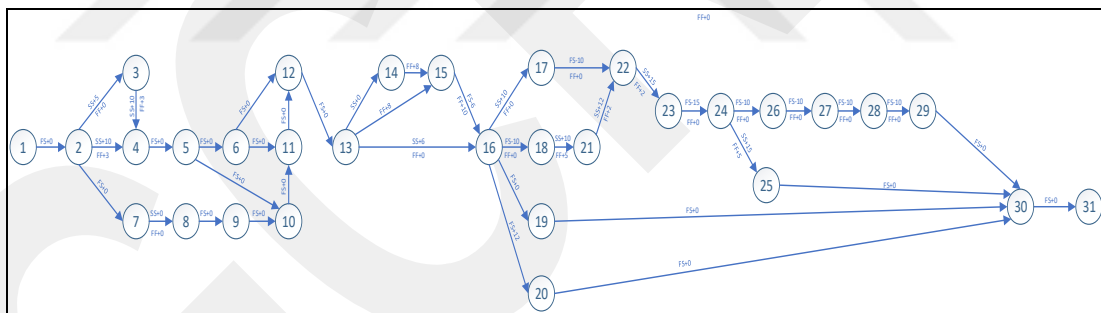


Figure 4.5 Project network for 29-activity problem.

Table 4.4 Data of 29-activity problem.

Activity	Predecessors	Relationships + Lag	Offers	Time	Direct Cost	Quality
1	0	-	1	0	0	0
2	1	FS+0	1	15	60000	1.262
			2	12	68000	1.882

Table 4.4 Data of 29-activity problem.

Activity	Predecessors	Relationships + Lag	Offers	Time	Direct Cost	Quality
3	2	SS+5	1	25	30000	2.628
			2	20	38000	3.388
	2	FF+0	3	15	44000	3.724
4	2	SS+10	1	25	50000	1.312
	2	FF+3	2	20	54000	1.692
	3	SS+10	3	15	60000	1.914
	3	FF+3				
5	4	FS+0	1	12	17000	4.305
			2	9	21000	6.615
6	5	FS+0	1	6	3000	0.976
7	2	FS+0	1	12	27000	1.25
			2	9	32000	1.87
8	7	SS+0	1	6	8000	6.972
	7	FF+0				
9	8	FS+0	1	20	44000	3.375
			2	15	48000	4.325
			3	12	54000	4.93
10	5	FS+0	1	12	15000	3.732
	9	FS+0	2	9	22000	5.592
11	6	FS+0	1	6	3000	4.965
	10	FS+0				
12	6	FS+0	1	1	500	2.97
	11	FS+0				
13	12	FS+0	1	25	95000	2.692
			2	20	105000	3.452
			3	15	109000	3.8
14	13	SS+6	1	15	34000	3.165
			2	12	41000	4.115

Table 4.4 Data of 29-activity problem.

Activity	Predecessors	Relationships + Lag	Offers	Time	Direct Cost	Quality
			3	9	51000	4.865
15	13	FF+8	1	12	9000	1.344
	14	FF+8	2	9	13000	1.964
16	13	SS+6	1	25	30000	3.768
	13	FF+0	2	15	38000	4.908
	15	FS-6	3	12	42000	5.832
	15	FF+10				
17	16	SS+10	1	40	78000	1.875
	16	FF+0	2	35	85000	2.445
			3	30	90000	2.784
18	16	FS-10	1	25	23000	1.242
	16	FF+0	2	20	26000	1.622
			3	12	35000	1.89
19	16	FS+0	1	20	14000	1.342
			2	15	18000	1.722
			3	12	24000	1.914
20	16	FS+12	1	25	14000	2.496
			2	20	19000	3.256
			3	15	24000	3.884
21	18	SS+10	1	20	38000	1.866
	18	FF+5	2	15	42000	2.796
22	17	FS-10	1	40	42000	1.857
	17	FF+0	2	35	50000	2.427
	21	SS+12	3	30	58000	2.766
	21	FF+2				
23	22	SS+15	1	40	36000	0.639
	22	FF+2	2	30	48000	0.829
			3	25	56000	0.919

Table 4.4 Data of 29-activity problem.

Activity	Predecessors	Relationships + Lag	Offers	Time	Direct Cost	Quality
24	23	FS-15	1	40	65000	1.962
	23	FF+0	2	35	74000	2.532
			3	25	79000	2.817
25	24	SS+15	1	9	7000	1.936
	24	FF+15				
26	24	FS-10	1	25	45000	2.5
	24	FF+0	2	20	51000	3.26
			3	15	59000	3.86
27	26	FS-10	1	25	50000	1.326
	26	FF+0	2	20	58000	1.706
			3	15	64000	1.87
28	27	FS-10	1	30	60000	3.702
	27	FF+0	2	25	72000	4.842
			3	20	78000	5.958
29	28	FS-10	1	12	9000	0.637
	28	FF+0	2	9	13000	0.827
			3	7	18000	0.917
30	19	FS+0	1	1	500	2.88
	20	FS+0				
	25	FS+0				
	29	FS+0				
31	30	FS+0	1	0	0	0

4.2.2.1 Results and Discussion of Findings for 29-Activity Problem

Results of the application of the proposed model in the second example are represented selectively in table 4.5, and the complete results can be found in Table A.2 of the Appendix A chapter.

Table 4.5 Abridged List of results of the proposed model for 29-activity problem.

Sol. #	Dur (Day)	Cost (€)	Quality (%)	Mode Selection
1	174	1290800	90.781	2 3 3 2 1 1 1 3 2 1 1 3 3 1 2 3 2 2 1 1 2 3 3 1 3 3 3 3 1
2	176	1282200	90.635	1 2 3 2 1 2 1 3 2 1 1 3 3 1 2 3 2 2 2 1 1 3 3 1 3 3 3 3 1
4	177	1292900	91.024	1 1 3 2 1 2 1 3 2 1 1 3 3 2 2 3 1 2 2 1 3 3 3 1 3 3 3 3 1
6	179	1317300	93.082	2 3 3 2 1 2 1 3 2 1 1 2 3 1 2 3 2 2 2 2 3 3 3 1 3 3 3 3 1
17	180	1307000	93.288	2 3 3 2 1 1 1 2 2 1 1 3 2 2 3 3 2 2 3 2 2 3 3 1 3 3 3 3 1
21	181	1285700	91.127	1 2 3 2 1 2 1 3 2 1 1 2 3 1 2 3 2 2 2 2 1 3 3 1 3 3 3 2 1
24	182	1296400	92.548	1 3 3 2 1 2 1 2 2 1 1 3 3 2 3 3 2 1 3 1 2 2 3 1 3 3 3 2 1
29	183	1270100	89.567	1 2 3 2 1 1 1 3 2 1 1 2 2 1 2 3 2 2 2 2 1 3 3 1 3 3 3 1 1
31	184	1321800	93.781	2 2 2 2 1 2 1 3 2 1 1 3 3 2 2 2 2 2 3 2 3 3 3 1 3 3 3 3 1
39	185	1295500	92.31	2 2 3 2 1 2 1 2 2 1 1 3 2 2 3 3 1 2 2 2 2 3 3 1 3 2 3 2 1
43	186	1321200	93.96	2 3 3 2 1 2 1 3 2 1 1 2 3 2 2 3 2 2 3 2 3 2 3 1 3 3 3 1 1
49	187	1305900	93.024	1 3 3 2 1 1 1 3 2 1 1 3 3 2 3 2 2 2 3 2 1 2 3 1 3 3 3 3 1
50	188	1249600	86.84	1 1 2 2 1 1 1 2 2 1 1 2 2 1 2 3 2 1 1 2 1 3 3 1 3 3 3 1 1
52	189	1273300	89.957	1 1 3 2 1 2 1 3 2 1 1 2 2 2 2 3 2 2 2 2 1 2 3 1 3 3 3 1 1
55	191	1268700	89.328	1 2 3 2 1 2 1 2 2 1 1 2 2 1 2 3 2 2 2 2 1 2 3 1 3 2 3 1 1

Table 4.5 Abridged List of results of the proposed model for 29-activity problem.

Sol. #	Dur (Day)	Cost (€)	Quality (%)	Mode Selection
57	192	1340400	94.025	2 3 2 2 1 2 1 3 2 1 1 3 3 1 3 3 3 2 2 2 3 3 2 1 3 3 3 2 1
60	194	1238800	82.06	1 1 2 1 1 1 1 1 2 1 1 1 1 1 2 3 2 1 1 2 1 3 3 1 3 3 3 2 1
61	195	1244500	85.826	1 1 2 2 1 1 1 2 2 1 1 2 1 1 2 3 2 1 1 2 1 2 3 1 3 2 3 2 1
63	196	1244200	85.47	1 1 2 2 1 2 1 1 2 1 1 1 1 1 2 3 2 1 2 2 1 2 3 1 3 3 3 1 1
64	197	1317900	93.546	2 3 3 2 1 2 1 3 2 1 1 3 3 2 3 2 2 1 2 2 2 1 3 1 3 3 3 2 1
66	198	1242600	83.563	1 1 3 2 1 2 1 2 2 1 1 1 1 1 1 1 1 1 2 1 1 3 3 1 3 3 3 2 1
68	202	1242400	83.87	1 1 1 2 1 1 1 1 2 1 1 2 1 1 2 3 2 1 1 2 1 2 3 1 2 3 3 1 1
70	204	1234800	80.391	1 1 1 2 1 1 1 1 1 1 2 1 1 1 2 1 2 1 1 1 2 3 1 3 3 3 2 1
71	208	1234600	82.031	1 1 2 2 1 1 1 2 2 1 1 1 1 1 1 1 2 2 1 1 1 2 3 1 2 3 3 2 1
72	212	1233400	78.051	1 1 2 1 1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 2 3 1 2 3 3 1 1
73	219	1234300	78.305	1 1 1 2 1 1 1 1 1 1 2 1 1 1 1 2 1 1 2 1 2 1 2 3 1 3 3 1 1 1

The outcomes of the proposed model were 73 non-dominated solutions in five minutes and 12 seconds; 26 solutions were chosen out of them by selecting the solutions with the highest quality within the same duration. The model achieved maximum, minimum quality and cost respectively, the maximum achievable quality of the proposed model was 94.025 in solution number 57, and the model's minimum cost was 123,3400\$ in solution number 72. The results can be further enhanced by introducing specific constraints to improve the produced solutions' quality for specific or multiple aspects. For instance, increasing the minimum acceptable quality will improve the quality aspect of the produced solutions.

Fig. 4.9 shows the typical Pareto optimal front located using the proposed model for this case example. This 3D illustration shows clearly the relationships among project duration, cost, and quality and may help decision-makers evaluate various potential project performance plans.

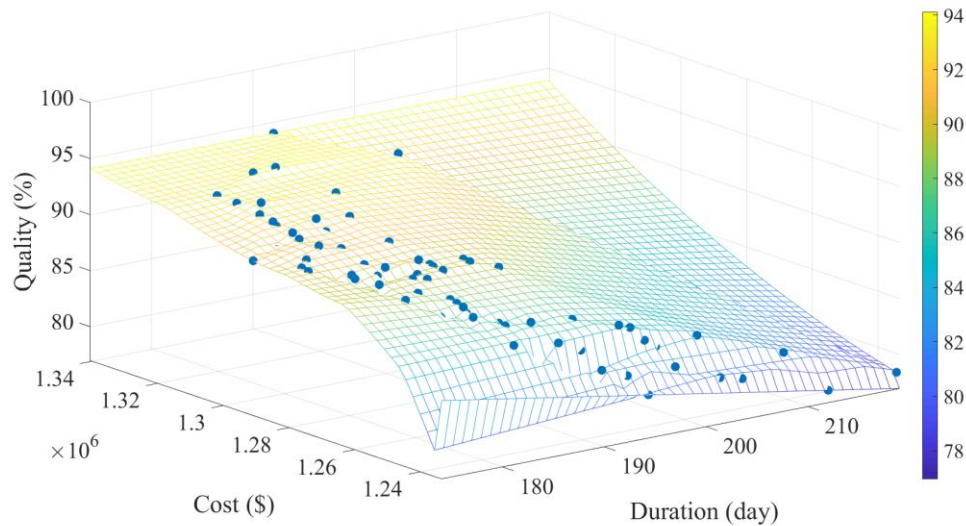


Figure 4.6 Time–Cost–Quality trade-off Pareto front for 29-activity problem.

4.2.3 63-Activity Problems

The third study case was applied to validate and examine the proposed model’s capability in handling a large number of activities. The study case is a self-generated example; it is generated to provide future studies with more large examples to consider in their studies to study TCQTP. The study example consists of 63 activities and two dummy activities; each has many available offers to execute it. On average, each activity has about 4.58 modes to be executed with; this creates a searching space of $4.58^{63} = 4.59$ octillion solutions to search in which considered a very challenging task to do. The proposed model will search for optimum solutions (non-dominated ones) depending on the domination concept. The dominated solutions will be precluded. The precedence relationships between the activities are shown in [Table 4.6](#). The details of the available offers for the activities are shown in [fig 4.9](#), [4.10](#), [4.11](#), [4.12](#), [4.13](#), and [4.14](#). Two indirect costs were assumed to study the indirect cost’s influence on the

project; the indirect costs are 2300\$ and 3500\$ per day. There are no boundaries assumed in the project's solutions, and the produced solutions will be selected freely.

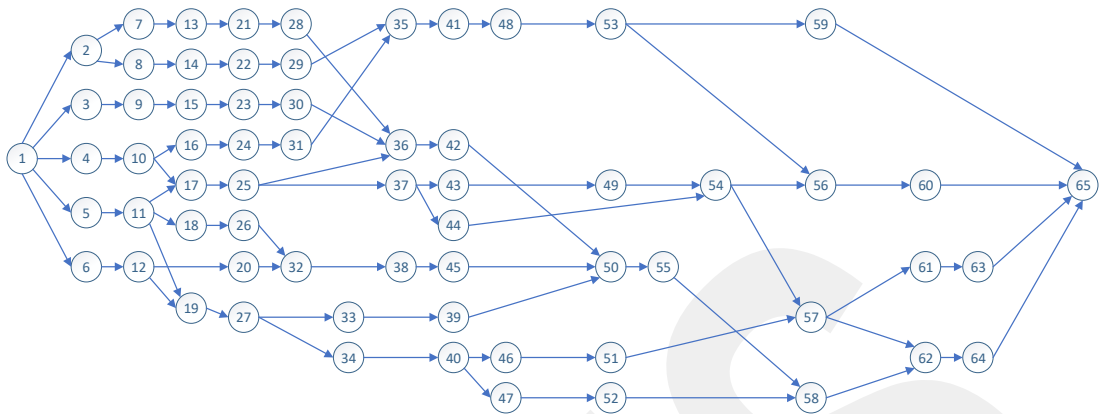


Figure 4.7 Project network for 63-activity problem.

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
1	0	-	1	0	0	0
2	1	FS+0	1	14	3750	1.356
			2	12	4250	1.516
			3	10	5400	1.756
			4	9	6250	1.976
3	1	FS+0	1	21	11250	1.869
			2	18	14800	2.109
			3	17	16200	2.469
			4	15	19650	2.799
4	1	FS+0	1	24	22450	0.619
			2	22	24900	0.699
			3	19	27950	0.819
			4	17	31650	0.929
5	1	FS+0	1	19	17800	1.938
			2	17	19400	2.508
			3	15	21600	2.838
6	1	FS+0	1	28	31180	1.24
			2	26	34200	1.4
			3	23	38250	1.64
			4	21	41400	1.86
7	2	FS+0	1	44	54260	0.646
			2	42	58450	0.726
			3	38	63225	0.846
			4	35	68150	0.956
8	2	FS+0	1	39	47600	1.266
			2	36	50750	1.426
			3	33	54800	1.666
			4	30	59750	1.886

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
9	3	FS+0	1	52	62140	0.637
			2	47	69700	0.717
			3	44	72600	0.837
			4	39	81750	0.947
10	4	FS+0	1	63	72750	0.645
			2	59	79450	0.725
			3	55	86250	0.805
			4	51	91500	0.885
			5	49	99500	0.955
11	5	FS+0	1	57	66500	1.27
			2	53	70250	1.43
			3	50	75800	1.59
			4	46	80750	1.75
			5	41	86450	1.89
12	6	FS+0	1	63	83100	0.618
			2	59	89450	0.698
			3	55	97800	0.778
			4	50	104250	0.858
			5	45	112400	0.928
13	7	FS+0	1	68	75500	0.615
			2	62	82000	0.695
			3	58	87500	0.775
			4	53	91800	0.855
			5	49	96550	0.925
14	8	FS+0	1	40	34250	1.358
			2	37	38500	1.518
			3	33	43950	1.758
			4	31	48750	1.998

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
15	9	FS+0	1	33	52750	2.464
			2	30	58450	2.784
			3	27	63400	3.264
			4	25	66250	3.744
16	10	FS+0	1	47	38140	1.286
			2	40	41500	1.446
			3	35	47650	1.686
			4	32	54100	1.926
17	10	FS+0	1	75	94600	0.625
			2	70	101250	0.705
	11	FS+0	3	66	112750	0.785
			4	61	124500	0.865
			5	57	132850	0.935
18	11	FS+0	1	60	78450	1.326
			2	55	84500	1.486
			3	49	91250	1.746
			4	47	94640	1.926
19	11	FS+0	1	81	127150	1.298
			2	73	143250	1.458
	12	FS+0	3	66	154600	1.718
			4	61	161900	1.898
20	12	FS+0	1	36	82500	1.989
			2	34	94800	2.559
			3	30	101700	2.889
21	13	FS+0	1	41	48350	1.266
			2	37	53250	1.426
			3	34	59450	1.706
			4	32	66800	1.886

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Realaionship + Lag	Offers	Time	Direct Cost	Quality
22	14	FS+0	1	64	85250	0.648
			2	60	92600	0.728
			3	57	99800	0.808
			4	53	107500	0.888
			5	49	113750	0.958
23	15	FS+0	1	58	74250	0.617
			2	53	79100	0.697
			3	50	86700	0.777
			4	47	91500	0.857
			5	42	97400	0.927
24	16	FS+0	1	43	66450	1.308
			2	41	69800	1.468
			3	37	75800	1.628
			4	33	81400	1.788
			5	30	88450	1.928
25	17	FS+0	1	66	72500	0.62
			2	62	78500	0.7
			3	58	83700	0.78
			4	53	89350	0.86
			5	49	96400	0.93
26	18	FS+0	1	54	66650	0.663
			2	50	70100	0.743
			3	47	74800	0.823
			4	43	79500	0.903
			5	40	86800	0.973
27	19	FS+0	1	84	93500	0.638
			2	79	102500	0.718
			3	73	111250	0.798

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
			4	68	119750	0.878
			5	62	128500	0.948
28	21	FS+0	1	67	78500	2.025
			2	60	86450	2.265
			3	57	89100	2.505
			4	56	91500	2.745
			5	53	94750	2.955
29	22	FS+0	1	66	85000	0.64
			2	63	89750	0.72
			3	60	92500	0.8
			4	58	96800	0.88
			5	54	100500	0.95
30	23	FS+0	1	76	92700	0.648
			2	71	98500	0.728
			3	67	104600	0.808
			4	64	109900	0.888
			5	60	115600	0.958
31	24	FS+0	1	34	27500	0.618
			2	32	29800	0.698
			3	29	31750	0.778
			4	27	33800	0.858
			5	26	36200	0.928
32	20	FS+0	1	96	145000	0.646
			2	89	154800	0.726
	26	FS+0	3	83	168650	0.806
			4	77	179500	0.886
			5	72	189100	0.956
33	27	FS+0	1	43	43150	0.668

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
			2	40	48300	0.748
			3	37	51450	0.828
			4	35	54600	0.908
			5	33	61450	0.978
34	27	FS+0	1	52	61250	0.674
			2	49	64350	0.754
			3	44	68750	0.834
			4	41	74500	0.914
			5	38	79500	0.984
35	29	FS+0	1	74	89250	1.318
			2	71	93800	1.478
	31	FS+0	3	66	99750	1.638
			4	62	105100	1.798
			5	57	114250	1.938
36	25	FS+0	1	138	183000	2.712
	28	FS+0	2	126	201500	3.032
			3	115	238000	3.352
	30	FS+0	4	103	283750	3.672
			5	98	297500	3.952
37	25	FS+0	1	138	183000	2.712
			2	126	201500	3.032
			3	115	238000	3.352
			4	103	283750	3.672
			5	98	297500	3.952
38	32	FS+0	1	34	22500	0.652
			2	32	24100	0.732
			3	29	26750	0.812
			4	27	29800	0.892

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
			5	24	31600	0.962
39	33	FS+0	1	51	61250	1.24
			2	47	65800	1.4
			3	44	71250	1.56
			4	41	76500	1.72
			5	38	80400	1.86
40	34	FS+0	1	67	81150	1.971
			2	61	87600	2.211
			3	57	92100	2.451
			4	52	97450	2.691
			5	49	102800	2.901
41	35	FS+0	1	41	45250	0.651
			2	39	48400	0.731
			3	36	51200	0.811
			4	33	54700	0.891
			5	31	58200	0.961
42	36	FS+0	1	37	17500	1.262
			2	31	21200	1.422
			3	27	26850	1.662
			4	23	32300	1.882
43	37	FS+0	1	44	36400	0.62
			2	41	39750	0.7
			3	38	42800	0.78
			4	32	48300	0.86
			5	30	50250	0.93
44	37	FS+0	1	75	66800	0.675
			2	69	71200	0.755
			3	63	76400	0.835

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
			4	59	81300	0.915
			5	54	86200	0.985
45	38	FS+0	1	82	102750	0.641
			2	76	109500	0.721
			3	70	127000	0.801
			4	66	136800	0.881
			5	63	146000	0.951
46	40	FS+0	1	59	84750	1.374
			2	55	91400	1.534
			3	51	101300	1.694
			4	47	126500	1.854
			5	43	142750	1.994
47	40	FS+0	1	66	94250	1.268
			2	63	99500	1.428
			3	59	108250	1.588
			4	55	118500	1.748
			5	50	136000	1.888
48	41	FS+0	1	54	73500	0.633
			2	51	78500	0.713
			3	47	83600	0.793
			4	44	88700	0.873
			5	41	93400	0.943
49	43	FS+0	1	41	36750	0.665
			2	39	39800	0.745
			3	37	43800	0.825
			4	34	48500	0.905
			5	31	53950	0.975
50	39	FS+0	1	173	267500	0.621

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reala ^s h ⁱ p + Lag	Offers	Time	Direct Cost	Quality
			2	159	289700	0.701
	42	FS+0	3	147	312000	0.781
	45	FS+0	4	138	352500	0.861
5			121	397750	0.931	
51	46	FS+0	1	101	47800	1.336
			2	74	61300	1.496
			3	63	76800	1.776
			4	49	91500	1.976
52	47	FS+0	1	83	84600	0.624
			2	77	93650	0.704
			3	72	98500	0.784
			4	65	104600	0.864
			5	61	113200	0.934
53	48	FS+0	1	31	23150	0.643
			2	28	27600	0.723
			3	26	29800	0.803
			4	24	32750	0.883
			5	21	35200	0.953
54	44	FS+0	1	39	31500	0.644
			2	36	34250	0.724
	49	FS+0	3	33	37800	0.804
			4	29	41250	0.884
			5	26	44600	0.954
55	50	FS+0	1	23	16500	2.034
			2	22	17800	2.274
			3	21	19750	2.514
			4	20	21200	2.754
			5	18	24300	2.964

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Realaationship + Lag	Offers	Time	Direct Cost	Quality
56	53	FS+0	1	29	23400	0.662
			2	27	25250	0.742
	54	FS+0	3	26	26900	0.822
			4	24	29400	0.902
			5	22	32500	0.972
57	51	FS+0	1	38	41250	0.632
			2	35	44650	0.712
	54	FS+0	3	33	47800	0.792
			4	31	51400	0.872
			5	29	55450	0.942
58	52	FS+0	1	41	37800	1.368
			2	38	41250	1.528
	55	FS+0	3	35	45600	1.688
			4	32	49750	1.848
			5	30	53400	1.988
59	53	FS+0	1	24	12500	0.65
			2	22	13600	0.73
			3	20	15250	0.81
			4	18	16800	0.89
			5	16	19450	0.96
60	56	FS+0	1	27	34600	0.667
			2	24	37500	0.747
			3	22	41250	0.827
			4	19	46750	0.907
			5	17	50750	0.977
61	57	FS+0	1	31	28500	0.676
			2	29	30500	0.756
			3	27	33250	0.836

Table 4.6 Data of 63-activity problem.

Activity	Predessors	Reaationship + Lag	Offers	Time	Direct Cost	Quality
			4	25	38000	0.916
			5	21	43800	0.986
62	57	FS+0	1	29	22500	0.671
			2	27	24750	0.751
	58	FS+0	3	25	27250	0.831
			4	22	29800	0.911
			5	20	33500	0.981
63	61	FS+0	1	25	38750	2.052
			2	23	41200	2.292
			3	21	44750	2.532
			4	19	49800	2.772
			5	17	51100	2.982
64	62	FS+0	1	27	9500	0.646
			2	26	9700	0.726
			3	25	10100	0.806
			4	24	10800	0.886
			5	22	12700	0.956
65	59	FS+0	1	0	0	0
	60	FS+0				
	63	FS+0				
	64	FS+0				

4.2.3.1 Results and Discussion of Findings for 63-Activity Problems

Results of the application of the proposed model on the first and second conditions of the third example are represented selectively in table 4.7, and 4.8 and the complete results can be found in Tables A.3 and A.4 of the Appendix A chapter.

Table 4.7 Abridged List of results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
1	534	6059140	83.151	1 1 4 1 2 1 1 4 5 5 1 4 1 1 1 2 4 2 3 4 5 5 3 2 5 3 3 3 3 3 3 3 2 5 3 4 3 1 2 4 4 2 4 4 4 3 1 5 4 5 5 5 5 4 5 5 5 4 5 5 5 5
2	536	6055290	83.001	1 1 4 1 2 1 1 4 5 5 1 4 1 1 1 2 4 2 3 4 5 5 3 2 5 3 3 3 3 3 3 3 2 5 3 4 3 1 2 4 4 2 4 4 4 3 1 5 4 5 5 5 5 4 5 5 5 5 3 5 5 4
3	537	6002025	82.351	4 3 1 1 3 3 1 4 4 5 2 3 1 2 3 3 3 4 1 2 1 3 2 4 5 1 3 2 5 4 3 1 4 2 5 3 4 5 2 4 4 3 2 5 3 4 4 5 5 4 4 5 1 2 3 2 5 5 3 5 5 2 5
4	538	6099505	87.191	4 4 2 2 4 3 2 4 5 5 1 2 4 1 1 3 4 2 3 3 4 3 2 4 5 3 5 3 4 3 4 3 4 5 5 2 3 5 5 1 4 5 3 4 4 2 4 4 5 3 2 3 2 5 2 5 5 5 5 4 3 5 5
6	539	6087635	85.751	2 4 4 3 1 3 2 4 5 5 5 4 1 1 2 4 1 1 2 2 4 2 1 2 3 5 3 3 1 3 3 1 3 5 3 3 3 5 4 4 4 5 5 4 4 4 5 5 4 3 5 3 5 3 5 5 5 5 5 5 5 5
10	540	5949530	84.651	4 1 3 3 4 4 2 2 1 4 1 4 4 4 1 2 4 4 1 1 2 2 2 4 5 3 4 3 5 3 4 3 3 2 5 3 3 4 4 1 4 2 2 4 1 3 4 4 5 2 2 5 5 5 5 1 5 5 4 2 5 5 4
11	541	6042355	85.341	4 2 1 3 4 3 3 4 4 4 1 4 2 4 1 4 4 2 2 3 5 5 3 2 2 3 3 4 1 4 3 4 3 2 5 5 5 1 3 4 4 4 4 5 2 3 1 4 5 4 5 2 1 4 5 4 5 2 2 4 5 4 5
12	542	6029550	85.781	4 4 3 2 3 1 4 2 5 5 2 3 1 4 3 2 4 4 2 3 3 3 4 2 3 4 2 5 5 3 5 2 3 3 4 1 4 2 5 4 4 3 4 2 5 3 1 5 5 2 4 5 1 5 3 2 5 1 3 2 5 3 5
15	544	6014830	85.661	1 3 3 2 3 4 4 3 5 5 3 2 2 4 1 1 4 2 2 1 3 3 5 2 4 3 5 5 3 5 3 4 3 5 5 5 3 5 4 1 4 3 2 4 3 3 3 1 5 2 2 5 1 5 4 4 3 3 5 1 4 5 5
17	545	6039740	86.001	1 3 1 3 4 1 1 1 4 5 1 5 4 4 2 2 4 2 2 2 2 4 2 4 4 3 3 3 3 3 3 3 4 3 5 3 5 3 5 1 4 4 2 2 4 5 4 5 5 2 2 5 5 5 5 4 3 5 5 5 5 5 5
19	546	6129740	87.221	4 4 1 3 4 1 1 4 1 4 1 1 2 1 1 2 4 4 3 4 2 2 5 5 3 5 3 5 3 5 5 4 3 5 5 5 3 3 4 4 3 5 4 4 4 2 4 4 5 4 1 4 5 5 5 5 5 3 4 5 5 5 5
24	547	6165720	87.571	4 2 4 3 1 4 2 2 3 5 3 3 4 4 1 5 3 3 3 3 2 4 4 2 5 3 3 3 5 3 3 5 3 4 5 2 2 4 4 4 1 5 3 4 3 5 4 3 5 4 3 5 5 5 5 5 4 5 5 5 4 4 5
27	548	6080710	86.721	4 1 3 3 1 4 1 1 4 5 1 1 4 4 2 2 4 3 3 4 2 4 3 2 4 5 3 3 3 5 3 4 3 3 5 3 4 3 3 4 3 4 4 2 4 2 4 4 5 4 5 3 3 5 5 4 5 4 5 5 5 5 5
30	549	6062965	86.601	3 4 1 3 4 3 4 4 4 5 1 1 2 4 1 2 3 1 3 4 1 2 3 5 2 4 3 3 4 2 5 4 3 5 5 3 3 2 2 5 2 4 3 4 3 4 3 5 5 3 4 5 4 5 5 5 5 5 3 4 4 4 4
37	550	5963880	84.901	1 4 2 3 2 2 4 3 3 5 2 4 4 4 1 2 4 4 1 1 2 3 3 3 3 3 3 3 2 3 2 4 3 2 4 5 3 5 4 5 4 4 4 4 1 2 5 4 5 1 1 5 5 5 5 3 4 2 4 4 5 5 5

Table 4.7 Abridged List of results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
39	551	5992665	85.261	4 3 3 3 3 3 1 3 3 5 4 5 1 4 2 4 4 4 3 4 3 2 2 1 5 1 5 3 2 2 4 4 2 3 5 4 3 3 3 3 4 1 4 1 5 2 1 3 5 2 1 3 2 5 1 3 4 4 5 1 2 5 5
40	552	5976565	85.641	3 4 4 3 4 3 3 4 1 3 3 3 4 4 2 4 4 4 2 3 1 3 2 1 2 5 5 2 1 3 5 3 1 3 4 4 2 4 5 2 2 4 5 3 1 3 2 3 5 1 2 2 3 5 5 2 5 5 2 1 5 5 5
43	553	5901240	83.621	1 3 4 2 4 1 4 4 4 1 1 4 3 4 1 2 4 2 3 2 2 1 2 4 3 2 4 3 5 1 4 3 3 3 3 3 2 4 4 4 2 1 4 1 2 2 4 5 4 1 5 1 5 5 3 5 1 5 2 5 5 5
45	554	6162665	87.401	3 2 4 2 3 3 4 4 3 1 5 5 3 4 4 1 4 4 2 4 1 2 2 2 2 2 4 5 5 4 5 5 3 5 5 4 5 3 4 5 4 5 4 4 1 3 5 5 5 4 5 5 3 5 4 4 4 1 5 3 3 5
48	555	6126670	87.241	1 3 1 3 1 1 4 1 1 5 1 5 4 4 1 2 2 2 2 3 2 2 4 2 5 3 5 4 5 3 3 4 3 4 5 3 2 3 5 5 3 4 5 4 4 4 3 5 5 4 5 5 5 5 4 5 5 5 3 5 5 5 5
51	556	5911060	83.751	1 4 1 3 4 1 4 4 1 4 1 1 1 4 2 2 3 2 1 2 2 2 4 2 4 1 3 3 5 3 3 3 3 3 5 3 2 5 4 4 3 2 4 2 2 2 1 1 5 4 4 4 5 5 1 4 5 4 1 4 5 5 5
53	557	6185040	87.701	2 4 1 3 4 1 3 1 5 4 3 5 3 3 1 2 3 4 3 3 4 4 2 4 5 3 5 4 1 5 1 4 4 5 5 3 4 5 4 4 4 4 4 4 5 5 5 5 4 3 3 5 5 3 5 4 3 3 5 3 1 5
55	558	5971995	85.291	4 4 2 3 1 3 4 1 2 5 2 2 3 4 4 2 3 2 2 2 1 4 5 5 5 1 5 2 4 2 5 2 4 3 3 2 4 4 1 4 3 1 1 5 3 2 2 5 5 4 4 3 3 5 3 4 5 5 2 1 4 5 5
60	559	5938300	84.461	1 4 3 2 4 4 4 3 1 5 2 2 4 4 2 2 3 1 3 2 1 2 1 5 2 1 3 3 3 2 3 5 5 3 3 3 1 3 4 1 4 4 4 4 4 1 1 3 5 3 4 5 4 5 4 3 3 4 4 2 5 5 5
62	560	6170530	87.741	4 4 1 2 3 4 4 1 5 5 5 1 1 3 4 2 4 4 3 3 3 2 5 3 5 1 4 1 4 3 5 4 1 4 5 5 3 4 5 1 3 4 4 4 4 4 4 5 4 2 4 5 4 2 3 2 5 4 3 5 5 3
64	561	6072075	86.761	1 4 4 2 2 3 4 3 1 5 5 3 4 4 4 4 1 3 3 2 2 1 4 2 4 1 5 5 5 3 5 3 2 5 3 4 2 3 4 3 4 4 4 4 2 4 4 5 5 4 1 2 2 5 4 3 5 5 5 2 3 5 2
68	562	5898360	83.421	2 4 1 3 1 4 3 2 4 2 1 5 1 4 1 2 4 3 3 3 1 5 3 5 5 1 5 1 5 5 1 1 1 2 3 2 4 5 2 1 3 5 1 4 2 4 4 2 5 3 4 2 1 5 3 4 5 2 1 2 2 5 5
74	563	5823890	80.771	1 4 1 2 4 4 2 4 4 5 1 3 1 3 1 1 1 1 3 1 2 2 1 2 2 2 3 2 1 1 3 3 4 3 3 1 4 4 4 2 4 3 2 3 3 2 4 4 5 2 2 2 4 5 5 5 4 5 1 2 5 2 5
75	564	6059730	86.821	4 4 1 2 3 4 4 1 5 5 5 1 1 3 4 2 4 4 3 3 3 2 5 3 5 1 4 1 4 3 5 4 1 4 5 5 5 2 5 4 3 2 2 4 4 4 4 1 4 1 3 4 2 5 2 1 5 4 1 4 5 5 5
78	565	6065915	87.961	3 4 2 3 4 3 2 2 4 4 1 4 4 4 4 2 4 3 3 2 4 1 1 5 4 3 5 4 3 3 3 2 4 3 5 4 5 5 5 4 4 2 4 5 3 5 4 4 4 1 1 4 3 5 2 4 5 4 3 2 4 5 4
83	566	5972530	86.021	4 4 3 3 1 1 3 1 4 5 1 2 3 4 4 2 3 4 1 3 2 3 4 2 4 1 5 3 3 2 3 4 3 3 5 3 3 3 5 4 4 2 4 4 1 2 2 4 4 3 2 1 5 5 4 5 2 5 5 5 5 5 5

Table 4.7 Abridged List of results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
87	567	5955740	85.571	4 4 2 3 3 2 1 4 1 3 1 3 3 4 1 1 3 1 3 4 3 4 3 4 2 2 4 1 5 2 1 5 3 4 3 2 5 3 5 4 4 1 3 4 3 4 4 4 5 3 2 2 4 5 3 3 5 5 3 5 4 5 3
90	568	5947440	84.601	3 2 4 3 3 2 4 2 2 4 1 2 1 4 4 4 4 1 2 4 2 2 3 1 4 1 5 3 1 3 1 2 2 5 5 3 3 5 5 3 3 4 1 2 3 5 4 2 5 2 3 4 1 4 2 2 5 4 1 3 5 4 3
95	569	6028650	86.671	2 1 1 3 3 4 4 2 3 4 1 1 4 4 4 2 3 3 3 2 2 5 2 2 5 3 4 5 3 2 3 1 3 2 5 3 3 4 4 3 4 4 4 4 1 4 3 4 3 4 4 5 2 5 5 4 5 5 5 5 5 5 5
98	570	6056580	86.821	3 3 1 3 4 4 3 1 5 5 1 1 4 3 2 1 4 4 2 2 2 4 5 2 2 3 3 3 5 2 3 5 3 2 5 3 4 3 4 4 4 4 5 3 5 4 4 5 3 1 4 5 5 5 1 5 5 5 2 5 5 5 5
104	571	5941350	85.131	1 2 3 3 4 4 1 3 1 5 1 1 3 4 4 4 2 1 3 2 2 4 4 1 2 1 3 1 1 3 3 3 3 4 5 3 5 5 3 5 4 3 4 4 2 4 5 2 3 3 2 5 3 5 5 3 5 3 5 3 5 5 5
107	572	5973550	86.111	4 3 4 3 3 1 3 3 1 5 1 2 1 4 4 2 4 1 2 3 5 2 2 5 4 3 4 3 2 3 3 4 5 3 5 3 3 5 5 4 3 3 3 3 2 3 4 2 3 2 5 5 5 5 4 2 5 5 5 5 5 2 5
113	573	5908155	84.721	4 4 4 3 4 3 3 1 1 5 1 5 3 4 4 1 4 2 1 2 2 5 2 2 1 1 3 3 3 5 3 1 1 3 3 4 5 2 5 2 3 4 3 1 3 3 4 2 5 3 2 5 4 5 4 3 5 4 3 2 5 5 3
118	574	5930020	84.751	4 4 3 3 4 4 4 1 1 3 2 1 4 4 1 3 4 1 3 2 1 3 1 5 4 1 5 5 3 3 1 1 3 2 4 4 5 3 1 4 3 3 4 4 4 4 4 4 2 1 4 1 4 3 2 5 4 5 2 5 5 3
120	575	5846890	82.281	3 4 3 2 2 1 2 1 2 5 1 3 2 4 4 2 4 1 2 2 2 3 5 3 4 1 3 3 3 1 3 1 2 2 3 1 2 5 4 4 2 3 4 1 2 1 1 1 5 4 4 5 3 5 5 3 5 1 2 1 2 5 4
124	576	5942850	85.331	4 4 1 3 3 4 4 3 4 3 3 4 3 4 4 1 2 4 2 2 2 2 5 3 1 3 3 4 3 3 1 3 4 3 3 2 2 5 1 4 5 2 4 2 3 4 4 4 1 4 4 1 5 5 5 5 1 5 1 5 5 5
129	577	5850940	83.621	4 4 3 3 2 2 3 3 3 2 2 5 1 4 4 2 4 2 1 4 4 2 5 3 3 1 4 4 4 2 3 1 3 3 3 3 2 1 2 3 4 3 1 5 3 1 4 4 3 1 1 2 1 5 4 5 5 5 3 5 5 5 5
132	578	6015980	86.361	4 4 1 3 4 1 1 1 4 5 2 1 1 4 1 3 4 2 3 3 3 2 5 2 2 3 3 5 4 3 2 4 3 3 3 3 3 2 4 4 4 3 4 2 4 4 3 5 4 4 4 5 5 5 1 5 5 4 5 5 5 5 5
134	579	5884180	83.941	3 2 2 3 1 2 4 3 2 5 1 4 3 4 4 2 3 2 3 1 4 2 2 2 5 3 5 3 3 1 2 1 2 3 3 3 3 3 4 2 4 4 1 1 1 3 1 4 4 4 3 2 1 5 3 3 5 5 5 3 5 5 5
136	580	5972055	85.671	4 3 3 3 1 3 4 4 1 5 2 2 3 4 4 2 3 2 2 2 1 4 5 5 5 1 5 5 3 3 2 5 5 2 5 3 4 5 4 2 3 5 5 4 1 2 4 1 2 1 4 4 1 2 4 5 5 3 5 5 5 4 5
143	581	5894150	84.331	3 3 2 2 4 2 4 4 2 5 1 3 2 4 4 2 3 4 3 3 1 1 1 4 5 1 4 3 3 1 3 5 3 4 5 2 3 1 4 2 4 2 4 2 1 3 2 1 3 1 4 5 5 5 3 1 5 4 4 2 3 4 2
145	582	6116850	88.161	1 4 1 3 4 1 4 2 1 5 1 5 4 3 4 2 4 3 3 4 2 1 2 5 4 3 5 3 3 1 2 3 5 3 3 3 3 3 5 4 4 2 4 5 5 4 4 4 4 4 2 5 5 5 5 3 5 5 5 5 5 5 4

Table 4.7 Abridged List of results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
148	583	5942540	85.291	3 4 2 3 1 1 4 2 1 5 1 1 4 3 4 2 3 2 3 2 2 4 2 2 2 3 5 3 1 3 3 3 1 3 3 3 3 3 4 4 4 4 4 2 3 4 2 1 4 4 4 1 5 5 5 2 5 5 5 5 5 5 5
152	584	6049930	86.821	1 3 3 3 1 1 2 1 1 5 1 2 4 4 3 4 3 2 3 4 3 3 4 1 3 2 5 5 5 3 3 4 3 5 3 3 4 4 5 5 4 4 4 4 4 4 3 3 4 2 3 2 5 3 3 5 5 4 5 5 4 5
155	585	5929030	84.761	1 4 1 3 3 1 3 1 1 4 1 2 3 3 1 2 4 2 3 4 2 2 2 2 2 3 4 3 3 3 3 3 3 3 3 3 4 5 4 4 4 4 4 2 2 2 5 1 4 4 1 5 2 5 5 5 5 5 5 5 5 5 5
159	586	6064550	86.951	4 4 1 3 4 1 3 1 5 4 3 4 1 3 3 2 2 3 3 3 2 4 5 4 2 2 5 5 4 2 3 4 2 3 3 3 2 4 4 4 3 2 4 4 4 4 4 4 3 4 4 5 5 4 2 5 5 3 4 5 5 5 5
163	587	5953950	85.421	4 4 1 3 3 2 4 2 3 5 1 2 3 4 3 5 2 3 3 3 1 1 4 3 2 1 5 3 5 3 2 4 2 1 4 3 4 3 4 4 1 4 1 4 3 3 4 4 3 2 1 5 3 5 5 3 5 3 3 5 5 5 1
169	588	5967780	85.971	1 3 3 3 4 1 4 1 5 5 5 2 3 4 1 2 4 4 3 4 2 4 4 4 5 1 4 3 3 3 2 1 1 2 3 1 3 3 5 5 4 4 4 4 3 4 4 4 3 1 2 5 5 5 4 1 5 2 1 5 3 5 5
174	589	5808170	81.251	3 2 4 2 2 4 3 1 2 5 3 1 2 4 1 2 4 1 1 3 2 2 2 2 2 2 5 3 3 4 1 4 3 1 3 3 2 2 3 3 3 3 4 3 3 2 4 1 4 1 2 3 3 5 5 3 5 5 3 3 5 5 2
175	591	5950590	86.571	4 4 4 3 4 2 3 2 1 5 1 5 2 4 4 2 4 2 3 3 1 2 2 2 2 4 5 4 4 3 2 2 3 2 3 3 5 5 5 3 3 4 3 4 1 5 4 5 3 1 1 4 5 5 5 4 5 3 2 5 5 4 5
182	592	6018040	87.041	4 4 1 3 4 1 3 1 4 2 3 3 4 4 4 5 4 2 3 4 4 5 2 1 3 1 4 4 4 5 3 5 5 3 1 1 4 5 5 4 3 4 3 2 4 4 4 4 4 1 4 4 1 5 3 5 5 4 3 3 5 5 5
185	593	5775430	81.041	1 3 4 3 4 4 1 1 1 1 1 1 4 4 4 2 4 2 1 3 3 4 2 4 2 1 3 4 3 5 3 4 2 2 3 1 3 2 1 1 4 1 1 4 3 1 2 2 3 1 1 1 2 5 5 5 5 5 3 5 1 5 5
187	594	5817640	82.031	4 3 1 2 3 1 3 1 3 2 1 1 4 4 1 2 3 2 3 2 4 5 2 1 2 1 3 1 2 3 2 5 2 5 3 2 3 3 1 1 4 2 4 3 1 1 3 4 3 4 1 3 2 5 3 4 5 5 5 1 5 5 5
189	595	5749135	79.201	1 1 1 3 1 3 2 3 1 4 3 1 2 4 1 1 4 2 2 1 1 2 1 4 2 3 3 2 2 2 3 1 4 3 3 2 3 2 2 4 4 5 2 1 1 1 1 4 3 2 1 5 4 5 5 5 5 3 1 5 5 3 4
190	596	5929980	85.211	4 4 2 3 4 4 3 1 5 5 3 1 1 4 4 1 4 2 3 4 2 2 3 2 1 2 2 3 1 5 3 3 5 3 5 1 5 1 4 4 4 3 4 2 1 4 4 4 2 1 3 1 5 3 5 4 4 4 2 4 5 5 5
193	597	5772465	80.801	4 4 2 3 3 3 2 2 1 4 1 2 3 2 1 1 3 1 1 3 2 3 1 5 1 1 4 1 4 5 2 3 3 5 2 2 3 4 4 2 3 1 1 1 1 3 3 2 4 1 4 3 4 3 5 4 5 5 1 5 5 5 4
195	598	5912540	84.831	4 3 1 2 4 1 1 1 5 4 1 4 2 4 4 2 4 2 3 4 3 4 2 2 2 3 5 5 4 2 3 3 1 2 2 2 2 3 4 4 4 5 3 1 3 2 4 5 3 3 4 1 5 5 3 5 4 5 5 1 4 5 5
196	599	5808640	82.121	4 4 1 3 3 2 3 1 2 4 1 3 4 3 4 3 3 1 2 1 4 3 1 3 4 4 4 1 4 3 1 3 1 2 3 1 3 3 4 1 1 5 4 1 2 2 4 4 3 1 1 1 5 5 5 3 5 3 5 3 4 3 5

Table 4.7 Abridged List of results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
198	600	5796200	81.601	4 3 4 3 3 1 3 3 1 5 1 2 1 4 4 2 4 1 1 2 1 2 3 3 1 3 4 1 1 4 2 2 1 2 2 2 1 3 5 4 2 4 4 3 4 1 3 3 4 1 1 2 5 5 1 5 5 2 2 1 5 5 5
199	601	5817810	82.411	4 4 4 3 1 4 1 1 4 5 1 2 4 4 2 2 4 3 1 2 2 5 4 1 3 1 3 5 3 2 1 1 2 3 3 1 4 1 4 1 2 3 1 4 2 3 1 4 2 2 2 2 1 5 5 4 4 4 5 4 5 5 5
201	602	5793690	81.521	4 2 1 3 2 1 3 1 5 3 1 4 3 4 1 2 3 1 3 4 2 2 1 1 5 1 3 3 3 4 2 1 4 4 3 4 3 4 3 4 2 2 3 2 1 3 3 1 1 2 2 5 4 3 2 5 3 4 5 3 5
202	603	5904050	84.731	4 4 1 3 4 1 1 3 4 1 1 1 4 4 3 2 4 3 2 4 4 1 1 2 2 2 4 4 4 4 5 2 1 5 3 5 2 5 5 1 4 5 4 2 2 1 1 1 2 3 1 4 5 5 5 5 3 5 2 1 5 4 5
205	604	5896965	84.621	4 4 1 2 3 3 4 4 5 5 1 2 3 4 4 1 4 3 3 3 2 1 4 4 5 2 4 5 1 3 1 1 3 2 4 4 5 2 4 4 4 2 4 2 1 4 1 2 1 1 2 4 1 5 5 1 5 2 5 3 5 1 5
207	605	6144315	88.541	4 4 1 3 4 3 3 4 2 4 3 2 4 4 4 3 4 3 3 3 4 3 4 4 4 4 3 2 5 3 3 3 4 5 3 3 4 3 5 3 4 2 3 5 5 3 5 4 1 4 4 5 1 4 4 3 5 2 2 5 5 4 5
209	606	5819480	82.511	2 4 2 3 1 1 3 1 1 5 1 1 4 4 3 2 3 2 1 2 4 2 2 2 2 1 4 4 3 3 2 3 5 3 3 3 3 3 3 2 4 4 1 1 1 3 2 4 2 3 4 3 4 5 2 5 5 5 4 1 4 5 5
213	608	6106540	88.101	3 4 4 3 4 4 4 3 1 3 1 3 1 4 3 5 4 1 3 4 3 3 4 2 3 4 5 1 4 5 5 2 3 5 5 5 5 4 5 2 4 5 3 2 4 4 1 2 1 3 4 3 4 4 5 4 3 5 3 4 3 5 4
216	609	5792950	81.671	4 4 4 3 4 1 3 1 1 1 2 4 4 4 2 3 3 3 2 3 3 2 1 2 3 2 5 3 3 1 2 2 3 3 2 3 3 3 1 4 3 3 2 1 2 4 1 4 3 1 3 1 4 5 3 5 5 2 1 4 5 1 2
217	610	6143015	88.521	4 4 1 3 4 3 3 4 2 4 3 2 4 4 4 3 4 3 3 3 4 3 4 4 4 4 3 2 5 3 3 3 4 5 3 3 4 3 5 3 4 2 3 5 5 3 5 4 1 4 4 5 1 5 2 2 4 5 2 4 4 5 3
219	613	5704490	76.821	4 4 1 2 2 1 1 3 3 4 1 2 1 2 1 2 4 1 1 4 1 4 2 4 2 1 3 2 5 4 2 1 2 2 2 3 1 1 2 4 4 1 1 1 1 5 1 2 3 1 4 1 2 2 5 4 4 3 4 1 4 1 3
220	614	5761640	79.811	1 4 1 2 3 2 3 1 1 3 1 1 1 4 2 2 3 1 1 2 2 2 2 1 4 1 1 1 3 2 1 4 2 3 2 3 3 3 4 3 4 4 2 2 2 4 4 5 3 3 3 5 5 5 1 3 5 4 1 5 5 2 5
222	622	5724140	78.781	2 4 3 2 2 2 2 2 3 1 2 3 1 4 1 1 2 2 2 1 1 1 1 4 1 2 5 1 5 1 2 1 5 2 1 1 3 2 5 2 2 3 1 1 2 4 2 5 3 1 3 1 1 5 1 3 5 5 3 2 4 5 5

Table 4.8 Abridged List of results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
1	532	6687815	85.251	2 4 4 1 4 3 1 3 3 5 5 5 1 4 1 4 3 1 2 4 2 3 3 2 5 1 2 4 5 5 5 3 3 3 5 2 3 3 4 5 4 3 5 4 4 4 3 1 5 2 3 3 5 5 4 4 5 5 2 4 5 5 1

Table 4.8 Abridged List of results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
2	535	6676115	84.611	2 4 4 1 4 3 1 3 3 5 5 5 1 4 1 4 3 1 2 4 2 3 3 2 5 1 2 4 5 5 5 3 3 3 5 2 3 3 4 5 4 3 5 4 4 4 3 1 5 2 3 3 5 5 1 1 2 5 1 5 5 5 5
3	536	6647650	84.291	1 4 4 1 3 1 4 4 2 4 5 5 4 3 4 5 4 2 2 2 2 2 4 1 2 1 5 5 4 3 5 5 4 5 5 1 5 5 3 4 4 5 1 5 1 2 2 1 5 3 3 5 2 4 1 2 5 3 1 1 5 1 4
4	537	6705860	86.051	3 3 4 2 2 1 4 2 1 3 1 5 4 3 3 4 3 3 3 4 4 5 2 4 4 4 3 3 3 2 5 1 3 3 5 5 4 4 4 4 4 4 4 2 5 1 2 5 2 3 3 1 5 1 5 5 3 3 4 5 5 4
6	538	6643175	84.091	3 1 3 2 2 3 4 2 4 5 3 5 1 4 2 3 2 3 2 4 1 4 2 2 5 4 4 2 5 4 4 4 3 1 5 1 2 3 3 4 3 5 2 5 1 3 1 2 5 4 4 5 4 5 1 2 4 3 3 3 5 5 5
7	539	6702490	85.341	3 4 1 1 1 1 4 2 1 3 1 5 4 3 3 4 3 3 3 4 4 5 2 4 4 4 3 3 3 2 5 1 3 3 5 5 4 4 4 4 4 4 4 2 5 1 2 5 2 3 3 1 5 1 5 5 3 3 4 5 5 4
8	540	6634605	84.431	4 2 3 3 3 3 3 3 5 1 3 4 1 1 2 4 2 2 2 1 4 1 2 3 2 5 3 4 1 4 5 2 3 5 3 4 4 5 1 4 2 1 4 4 4 4 3 5 3 4 5 4 5 2 4 5 5 1 3 4 3 5
10	541	6611085	83.321	2 4 4 2 1 3 1 3 1 5 1 5 4 2 1 5 4 4 1 4 2 4 2 2 4 1 3 5 3 2 4 4 3 3 5 2 3 1 4 4 3 4 1 3 1 3 1 4 5 4 3 1 5 5 5 3 4 3 1 5 5 5 5
12	542	6669500	85.081	2 4 1 3 2 4 3 4 2 5 2 5 1 4 3 4 2 2 1 3 2 2 3 3 3 4 5 5 4 1 5 2 3 1 5 2 4 5 5 5 3 4 5 5 1 1 3 5 5 3 3 3 5 5 4 2 5 2 3 1 4 5 4
14	543	6623540	83.791	1 4 4 2 4 4 3 3 5 5 1 1 3 1 1 2 2 2 3 2 1 2 4 2 2 5 5 2 4 3 5 1 3 5 5 3 4 3 2 4 4 4 5 4 3 3 2 4 5 2 3 2 3 5 1 1 4 5 1 3 5 5 5
16	544	6726940	86.661	2 3 3 2 4 4 4 4 1 5 4 5 4 4 3 4 4 4 1 3 1 1 1 4 3 3 4 3 5 4 4 4 3 4 4 5 5 5 2 1 3 4 4 3 3 1 4 4 5 4 1 5 4 5 5 2 4 3 4 5 5 5 4
20	545	6824250	87.601	2 4 3 2 2 2 4 4 3 4 3 2 4 3 3 3 2 4 3 4 1 5 4 4 5 5 5 2 3 1 5 5 4 3 4 4 4 1 5 2 4 5 3 3 5 4 5 4 5 4 4 3 4 5 4 4 4 3 1 1 3 5 5
22	546	6743405	86.931	2 4 3 3 4 3 1 2 2 4 3 5 1 4 1 4 4 4 3 4 4 5 2 3 5 1 4 5 5 4 5 3 2 4 5 2 5 4 5 5 4 2 4 1 3 4 4 5 5 3 2 4 4 5 4 4 5 3 1 5 1 1 5
28	547	6684970	86.131	2 4 4 3 1 4 4 4 2 4 3 3 2 4 4 3 4 4 3 4 3 3 3 3 4 3 4 4 2 3 4 2 1 1 4 4 4 3 5 4 3 1 1 3 3 2 5 1 5 2 4 4 5 5 5 4 4 1 3 4 5 4 2
30	548	6506810	81.831	1 4 4 3 1 4 2 1 2 4 2 2 4 4 1 1 3 4 1 1 2 3 1 5 5 2 5 1 5 2 2 1 1 1 4 5 4 4 4 3 3 4 3 4 2 1 1 1 5 2 2 1 5 5 1 2 5 1 2 2 4 5 5
31	549	6809165	87.851	3 4 3 2 3 3 4 3 5 5 3 4 3 4 4 3 4 4 3 4 3 5 2 4 1 4 5 1 2 2 4 2 4 4 4 2 4 5 4 5 4 1 5 4 3 4 1 5 5 4 4 5 5 2 4 5 5 2 4 1 5 3 1
35	550	6683820	86.151	2 4 3 3 1 4 4 3 3 4 1 2 3 4 4 5 4 4 1 4 2 4 2 2 3 3 5 4 5 1 3 4 3 3 3 1 3 5 4 4 3 4 3 4 3 3 4 1 5 4 4 1 5 5 5 1 5 5 4 4 5 3 3

Table 4.8 Abridged List of results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
37	551	6633900	84.831	4 4 4 2 2 1 4 2 2 3 5 5 4 3 2 1 4 3 2 3 2 4 3 5 2 1 5 4 4 5 5 1 5 3 3 4 4 3 5 3 4 1 5 3 3 3 5 1 5 2 4 4 3 5 3 3 5 1 2 1 5 1 4
38	552	6729560	86.811	4 4 3 3 3 1 3 3 2 2 1 5 3 4 4 3 3 4 3 2 2 4 5 4 1 2 4 5 5 2 5 4 2 2 5 3 4 5 1 5 3 2 5 4 1 3 4 4 5 3 2 3 5 5 4 4 4 3 3 5 5 4 5
43	553	6608510	84.081	2 3 4 2 4 1 4 4 5 3 3 3 3 4 4 2 2 4 2 4 2 2 1 3 3 3 4 1 3 4 5 5 2 2 3 1 3 4 1 1 4 4 1 3 1 4 4 1 5 4 1 2 2 5 1 4 5 2 3 5 4 5 5
45	554	6779350	87.171	3 4 2 3 4 4 3 2 2 5 4 5 2 3 4 1 1 4 3 1 3 5 3 4 5 1 5 2 3 3 5 4 5 3 5 3 4 2 5 5 2 3 3 4 3 4 4 3 5 4 4 5 3 5 3 3 5 5 3 2 3 4 5
49	555	6764480	87.041	3 4 1 3 1 1 3 1 2 1 4 4 4 4 3 4 3 2 2 2 4 5 5 2 5 3 5 2 3 4 2 3 3 3 3 4 5 3 2 4 4 5 2 5 3 5 5 4 5 4 4 5 5 5 5 5 5 3 5 5 5 5 5
55	557	6636715	85.621	4 4 4 2 4 3 3 4 1 5 5 1 4 4 3 2 4 4 3 4 2 1 4 1 5 4 1 3 2 5 1 3 2 2 4 2 5 1 5 4 4 1 3 3 1 2 4 4 5 2 3 4 1 4 4 4 5 1 3 5 4 4 5
60	558	6676965	85.651	4 3 4 3 3 3 3 3 2 5 3 1 1 4 4 2 4 4 1 1 4 1 5 3 2 3 5 5 1 3 3 5 3 3 5 1 4 5 2 4 3 3 1 3 3 5 2 3 5 1 2 4 5 4 3 5 5 5 1 4 5 5 5
61	559	6534115	81.851	3 3 3 2 4 3 3 4 1 5 1 1 3 3 2 2 4 1 2 4 2 5 2 2 5 4 3 1 2 5 1 1 3 1 5 3 5 3 2 1 4 1 3 2 3 3 3 3 5 3 1 1 4 3 3 2 4 4 3 1 4 2 5
62	560	6605680	84.121	2 4 4 3 4 2 3 4 1 5 4 3 4 4 1 4 4 2 1 4 1 2 2 2 5 3 3 3 5 3 2 3 2 3 5 3 4 2 3 2 3 5 2 4 1 1 4 1 4 4 1 1 4 4 1 3 4 5 3 3 5 5 5
64	561	6526025	82.191	1 2 3 3 1 3 1 1 2 4 2 5 3 4 1 2 4 2 1 1 2 2 2 2 3 3 5 5 4 3 2 1 4 3 3 2 3 4 5 4 4 1 4 4 2 1 2 5 5 1 1 1 4 5 5 5 5 5 3 4 5 5 5
67	562	6764190	87.551	3 1 1 3 4 1 4 1 2 5 1 2 4 4 3 1 4 4 3 2 1 4 4 4 4 4 3 4 3 1 4 5 3 3 5 3 3 3 4 5 4 4 4 1 4 5 3 4 4 4 5 5 5 5 5 1 5 5 1 4 5 5 5
70	563	6801385	87.641	4 4 2 3 1 3 2 1 1 4 2 5 4 4 3 5 4 4 2 4 3 5 4 2 2 4 5 5 4 3 3 3 4 4 5 3 2 3 5 1 4 1 4 2 4 2 1 3 5 4 4 5 2 3 3 3 5 4 5 4 5 5 5
72	564	6554475	82.871	3 3 2 3 4 3 4 3 2 3 1 4 3 4 2 1 2 3 1 2 1 2 4 3 5 1 3 5 1 5 2 1 4 3 3 2 3 2 5 1 4 1 2 5 4 1 2 1 5 1 4 3 4 5 5 4 5 2 3 5 5 3 5
75	566	6602425	84.031	1 2 3 3 3 3 3 4 3 3 1 1 1 3 4 2 3 4 3 4 2 1 2 4 5 2 5 2 2 3 2 3 3 4 3 3 3 2 4 4 3 2 4 1 1 2 3 2 5 4 3 1 5 5 5 5 5 2 4 3 5 5 5
78	567	6594170	84.171	4 4 4 3 1 1 1 1 2 3 1 1 4 4 4 1 4 1 2 4 4 4 2 3 5 4 2 5 3 2 3 3 5 4 3 3 1 3 3 4 4 4 2 1 3 2 2 4 5 3 3 2 2 5 5 3 3 5 3 1 5 5 5
82	568	6529890	82.621	3 4 1 3 4 4 2 2 2 4 1 3 1 4 4 2 4 2 2 4 2 2 4 5 3 5 1 5 5 2 3 1 3 1 2 3 2 4 3 3 3 5 2 1 1 2 2 1 5 1 1 5 5 5 2 5 4 1 5 4 5 3 5

Table 4.8 Abridged List of results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
85	570	6496730	80.111	3 1 1 3 3 4 2 2 1 3 1 1 4 1 1 2 4 2 1 2 2 4 2 3 2 2 3 3 4 3 3 1 3 3 3 3 5 2 3 1 4 2 2 1 3 4 1 4 5 1 2 4 2 5 2 2 5 5 5 5 4 5 5
87	571	6701160	86.161	1 4 4 3 4 1 4 4 3 4 1 1 3 3 4 2 3 2 1 4 4 2 4 2 2 1 5 5 4 4 3 4 3 2 5 3 4 3 4 4 4 4 4 3 1 3 2 1 4 4 4 1 5 5 5 3 5 5 5 4 5 5 3
94	572	6493000	80.221	4 1 4 3 4 1 2 2 1 2 2 1 1 1 4 2 4 1 1 4 1 4 2 2 1 1 5 2 5 3 2 1 3 3 3 4 1 3 4 1 2 4 2 4 2 4 1 5 5 1 1 5 2 3 1 4 5 2 5 4 5 5 5
95	573	6481880	79.651	3 1 1 3 3 4 2 2 1 3 1 1 4 1 1 2 4 2 1 2 2 4 2 3 2 2 3 3 4 3 3 1 3 3 3 3 5 2 3 1 4 2 2 1 3 4 1 4 5 1 2 4 2 5 2 2 5 5 3 2 3 5 5
97	574	6488115	79.961	1 4 1 3 4 3 1 4 1 1 3 1 1 4 1 2 3 1 3 2 2 2 5 4 3 3 4 4 3 1 2 1 3 3 3 2 3 4 3 3 3 3 1 4 1 3 1 1 5 2 1 1 5 3 2 3 3 1 2 2 5 2 5
98	575	6539690	82.621	2 4 1 3 1 1 2 2 1 4 3 4 3 4 4 2 3 4 2 3 3 5 2 5 3 1 5 1 1 3 2 1 5 4 2 2 2 4 5 3 4 2 2 4 3 2 1 1 5 1 1 1 3 5 4 5 5 2 2 4 3 2 2
100	576	6602430	84.851	4 4 2 3 4 2 2 3 2 2 1 4 1 4 1 2 4 3 3 3 2 2 4 3 4 1 4 3 1 5 3 1 4 3 5 2 4 3 3 4 4 2 2 4 3 2 4 2 3 3 3 5 3 3 5 2 5 1 3 5 4 5 5
101	577	6723980	86.711	2 4 1 3 3 2 4 3 3 4 3 4 2 4 1 2 4 3 3 3 1 1 2 2 5 1 5 3 3 2 2 4 3 2 3 3 5 4 4 4 4 5 4 4 4 4 3 3 4 4 5 4 1 5 5 5 5 5 5 3 5 4 5
102	578	6558460	83.061	4 4 4 2 3 1 1 3 2 3 1 4 4 3 3 2 2 2 2 3 1 1 1 1 4 2 3 1 4 3 3 1 3 3 3 1 3 2 4 5 4 4 4 4 1 3 4 4 4 1 4 1 5 5 5 3 5 4 5 4 5 5 5
103	579	6599200	84.401	4 4 1 3 4 2 4 4 2 3 1 3 2 4 3 3 3 1 1 3 3 1 4 2 4 3 1 3 3 5 3 1 5 2 3 3 3 3 5 5 4 4 1 2 3 3 4 5 4 2 2 1 5 5 2 3 5 5 4 4 5 5 4
108	580	6730715	86.851	4 4 1 3 4 3 3 1 3 4 5 1 4 4 3 1 1 4 3 4 5 3 4 4 5 5 3 5 4 3 3 4 3 3 3 3 2 3 5 5 3 4 5 4 1 3 3 1 4 1 2 4 3 5 3 5 5 4 4 3 5 5 3
111	581	6553275	83.251	4 4 1 3 4 3 4 3 2 2 2 2 2 3 4 2 2 2 1 2 2 2 2 2 5 2 4 3 1 4 1 2 3 3 3 3 3 2 4 4 4 1 4 5 1 4 3 3 4 1 1 5 3 5 5 5 5 2 5 4 5 5 5
114	582	6543660	82.711	1 1 1 3 1 2 3 4 3 4 1 3 1 4 1 2 4 2 2 3 2 2 4 4 3 1 5 3 3 5 1 3 5 2 2 1 5 3 4 2 4 5 5 2 1 5 4 4 4 1 1 1 2 5 5 4 5 2 5 5 5 5 5
116	583	6496540	81.691	3 3 3 3 4 2 2 2 1 4 1 1 1 4 3 2 4 2 2 1 4 1 1 2 2 1 5 2 4 3 2 1 5 2 3 3 5 5 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 4 5 5 5 2 5 5 2 3
119	584	6496215	80.941	4 1 1 2 3 3 2 3 4 4 2 1 4 3 3 2 4 1 3 2 3 2 1 2 3 3 3 5 4 4 3 4 1 1 4 2 3 2 2 2 3 4 2 2 1 1 3 1 3 2 1 5 2 5 5 1 5 5 2 1 4 5 5
120	585	6536080	82.781	4 4 3 2 3 1 4 1 1 4 1 1 2 4 1 1 4 1 3 2 1 5 2 2 2 3 3 2 2 1 4 1 1 2 3 3 4 2 5 2 4 4 4 1 4 1 1 5 4 1 3 5 5 5 2 3 5 2 3 5 5 5 5

Table 4.8 Abridged List of results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
122	587	6618625	85.461	4 4 3 3 4 3 2 3 1 5 1 3 4 4 4 2 2 3 3 4 1 3 4 2 5 3 4 1 1 5 3 1 2 1 4 2 3 1 5 5 3 3 5 1 3 1 1 5 3 1 4 5 5 5 3 4 5 2 3 4 5 5 1
123	588	6539690	83.001	3 3 2 3 3 4 3 1 2 3 3 2 4 4 4 2 3 1 2 4 1 4 2 3 5 1 1 1 4 2 2 1 2 4 3 4 4 3 4 3 4 1 3 3 2 3 5 3 3 2 1 1 5 4 1 5 4 2 3 4 5 4 5
125	590	6505740	81.701	3 3 3 3 4 2 2 2 1 4 1 1 1 4 3 2 4 2 2 1 4 1 1 2 2 1 5 2 4 3 2 1 5 2 3 3 5 5 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 5 1 4 3 2 5 3 5 3
127	591	6492030	80.851	2 4 4 1 4 2 1 1 3 5 2 2 1 4 1 3 3 1 2 1 1 2 2 1 3 1 4 3 2 3 1 4 3 4 3 1 3 2 4 1 3 4 4 2 2 1 2 3 4 1 4 4 2 5 5 5 5 2 5 3 3 5 5
130	592	6491640	80.401	4 2 4 2 4 1 1 1 2 2 4 1 4 4 1 2 2 1 1 4 1 4 5 1 3 1 2 4 3 4 3 1 1 3 3 2 5 3 1 4 2 4 5 2 1 2 2 3 4 1 1 3 2 5 5 5 5 5 1 4 3 5 5
131	593	6427390	76.931	3 1 2 1 1 1 1 3 1 1 1 5 1 3 3 2 1 2 1 4 1 2 1 2 2 2 5 1 3 5 2 3 3 2 2 2 4 2 4 4 3 1 1 2 2 1 4 4 5 1 1 4 2 4 1 2 4 2 3 1 5 5 5
132	596	6491990	80.471	3 4 1 3 4 2 4 4 1 4 1 1 1 3 1 2 2 2 1 1 2 1 4 2 4 1 5 3 2 5 3 4 3 1 2 4 3 1 1 3 4 2 5 3 1 1 5 2 4 1 1 1 4 5 4 5 5 5 2 4 5 4 5
134	597	6496530	80.991	4 1 4 3 1 1 3 2 1 3 2 1 2 3 3 2 4 2 1 3 1 1 2 2 5 1 5 2 3 1 1 3 4 2 3 2 4 4 2 1 4 5 4 2 1 4 3 2 3 2 1 1 5 5 4 4 4 1 5 5 5 5 5
137	598	6485580	80.591	1 4 3 3 3 4 1 1 1 2 1 3 3 4 1 4 3 1 2 2 2 3 2 1 2 1 5 3 2 3 2 3 3 3 2 5 1 3 3 4 2 1 1 2 2 1 4 2 4 1 4 3 2 5 1 5 5 2 1 5 5 5 5
138	602	6420700	76.251	2 4 1 3 4 1 2 3 1 1 1 1 1 1 1 2 1 1 1 2 1 2 1 2 3 2 2 3 3 1 4 3 1 4 3 1 3 2 4 2 3 5 1 1 1 1 4 4 4 1 1 2 4 4 5 1 5 2 3 5 3 1 5
139	603	6468420	79.771	4 2 1 2 1 1 4 1 1 1 1 1 1 4 1 1 3 1 1 4 4 1 2 2 2 1 4 4 2 2 3 4 4 3 3 1 4 4 5 3 3 4 4 1 2 4 4 2 3 1 1 4 4 5 3 1 5 4 3 2 5 1 5
140	604	6417440	76.801	1 3 3 1 3 2 3 3 1 5 2 1 4 3 1 3 2 1 1 4 1 2 1 2 2 3 4 1 2 1 3 1 2 1 2 2 3 3 1 4 4 3 2 2 1 3 4 2 3 1 4 1 3 2 2 5 5 3 2 2 5 1 4
141	607	6443460	78.501	1 3 2 1 1 2 4 4 1 2 1 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 5 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5
142	609	6434960	76.981	1 1 1 1 1 4 1 4 1 2 1 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 3 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5
144	610	6433510	77.091	1 1 3 1 1 1 1 1 1 1 4 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 5 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5

The outcomes of the proposed model in the first and second case were 222 and 144 non-dominated solutions, in 40.19 and 66.34 minutes in the first and second case respectively; 73 and 64 solutions were chosen out of them, by choosing the solutions of the highest quality within the same duration. The model was able to achieve maximum, minimum quality and cost in the first and second case, the maximum achievable quality of the proposed model was 88.541 and 87.851 in the solutions number 207 and 31, respectively, and the same for the cost aspect, the model's minimum cost was 569,1760 and 641,7440 \$ in solutions number 215 and 140 respectively. The results can be further enhanced by introducing specific constraints to improve the produced solutions' quality for specific or multiple aspects. For instance, increasing the minimum acceptable quality will improve the quality aspect of the produced solutions.

Figs. 4.17 and 4.18 show the typical Pareto optimal fronts located using the proposed model for this case example with IC = \$2300/day and IC = \$3500/day, respectively. These 3D illustrations show clearly the relationships among project duration, cost, and quality and could help decision-makers evaluate various potential project performance plans.

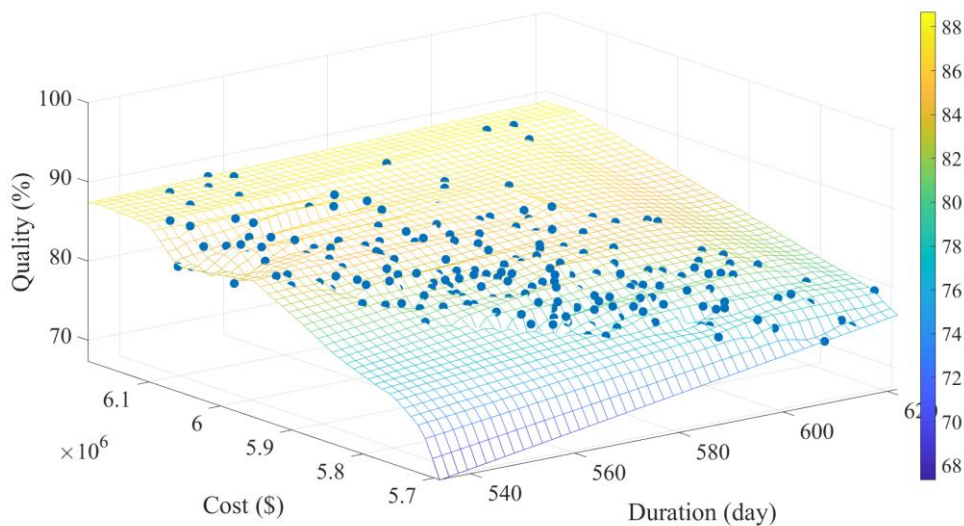


Figure 4.8 Time–Cost–Quality trade-off Pareto front for 63-activity problem with IC = \$2300/day.

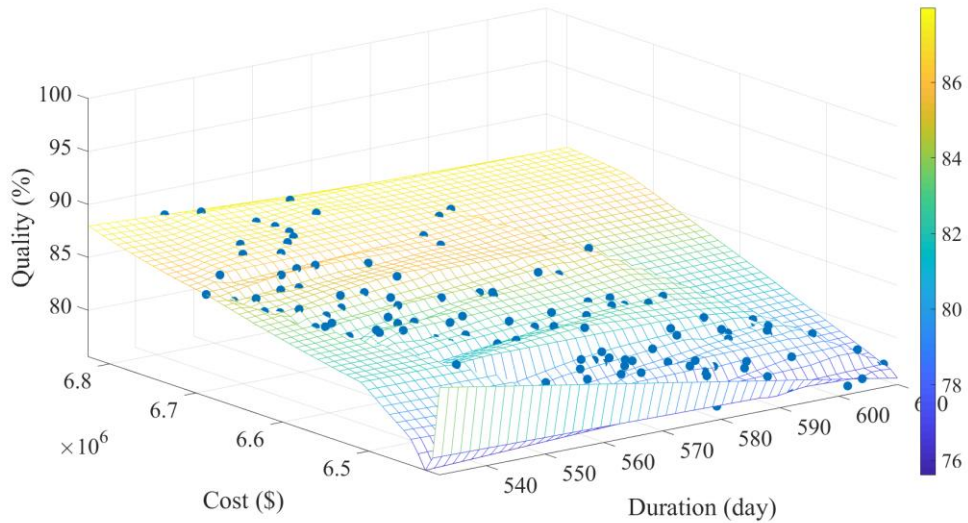


Figure 4.9 Time–Cost–Quality trade-off Pareto front for 63-activity problem with IC = \$3500/day.

4.3 Proposed Model’s Advantages and Disadvantages

Table 4.9 summarizes the advantages and disadvantages of the proposed model.

Table 4.9 The advantages and disadvantages of the proposed model.

Advantages	Disadvantages
<ul style="list-style-type: none"> -Easy to use -The input file can be prepared earlier -General precedence relationships are considered -The direct and indirect cost are considered -Unlimited number of predecessors and successors is possible 	<ul style="list-style-type: none"> -The uncertainty concept was not considered -Multi-criteria decision making was not considered

4.4 Summary

A model has been developed to improve the construction process by improving the three main aspects of the construction: time, cost, and quality. The model’s main objective is to select the best offer out of the available ones to balance the three objectives. By the end of the optimization process, each activity will have one selected offer. The unlimited number of predecessors and successors and the general

precedence relationships were considered in the developed model, making the model more reliable and realistic to real-world projects. The results of applying the model in the literature examples were satisfactory.



CHAPTER 5

CONCLUSIONS

Building projects can certainly be considered as one of the most crucial elements that contributes greatly to economic growth of a nation. They facilitate developments in other industries too by providing appropriate working spaces and the means for mobilization of resources (e.g., office building, hospitals, schools, highways). Through unique public or private bids, the governments and stakeholders aim to achieve reasonable prices for such projects with minimum possible makespans and the best quality. Evidently, weighing the available offers and coming up with an optimal decision can pose challenges for the decision-makers. That is, the process of selecting the right contractor is a vital and difficult process for the project success, as this process eventually will determine the total cost of the project, the required time to implement it, and the average quality of the project. In this regard, generation of a tool that helps decision-makers strike a proper balance among the conflicting project objectives (i.e., time, cost, and quality) is imperative. To this end, this study aims to propose a method which will assist in selection of the best compromise choices among the options available for each of the project activities.

A method is presented herein to solve the challenging multi-objective Time-Cost-Quality (TCQ) trade-off optimization problem. The developed model is coded in C# programming language which aims at concurrent minimization of time and cost while maximizing the project's quality. Basically, in addition to time and cost, the proposed method is designed to bring the quality aspect into the equation as well. To quantify the quality, a value referring to the weighted importance and performance of each activity is used. To the best of author's knowledge, there are few, if not null, studies that have dealt with medium- to large-scale Time-Cost-Quality trade-off problems incorporating the generalized precedence relationships. There exist numerous studies though that have attempted optimization of the trade-offs among the project objectives.

The various proposed approaches can be categorized according to the nature of the algorithms used; namely, exact and metaheuristics. Of metaheuristic approaches, the evolutionary algorithms (EA) are generally preferred over other algorithms due to their ability in optimizing more than a single objective, and since they require less computational time and effort to locate either the optimum or near-optimum solutions. As the optimization algorithm for the proposed model, Genetic Algorithm (GA) – one of the most well-established evolutionary algorithms – is adopted with some modifications in this study. In the modified version, the non-dominated solutions out of the parent solutions are identified and stored in an updatable archive. Members of the dynamic archive are compared to offspring solutions at each generation, as a result of which the dominated solutions are replaced with the non-dominated ones. By the end of all generations, the archive only contains the set of non-dominated solutions produced over all the generations. In the proposed technique, the Roulette Wheel is implemented as the selection method to determine and choose the fitter solutions for reproduction purposes, and to provide diversity by avoiding the local optima at the same time.

The proposed GA-based method is capable of handling unlimited number of precedence relationships for each activity and above all, it is able to capture and unravel any type of logical relationship. This very feature significantly improves the practical relevance of this research as parallelization of activities is a common practice in real-life projects. Planners by benefitting from the various types of relationships (i.e., Start-to-Start, Start-to-Finish, Finish-to-Start, and Finish-to-Finish) and the concept of lag time frequently introduce parallelization into the network. Overlapped activities, in turn, help reduce the unwanted idle times and speed up the project significantly. The proposed model is distinguished from all the previous models not only due to the speed of the model in finding non-dominated solutions by the dynamic elimination of the dominated ones and keeping only the non-dominated solutions, but also because of the diversity and the complexity of the practiced test examples. In order to demonstrate the application and evaluate the effectiveness of the proposed model, it is used for solution of three different TCQ trade-off problems, two of which are generated within the context of this thesis. The practiced instances include a small benchmark TCQ problem with 18 activities taken from the literature in addition to

more complex 29- and 63-activity TCQ problems produced herein based on existing 29- and 63-activity time-cost tradeoff problems, respectively. The results obtained reveal both the effectiveness of the proposed model and the possibility to be used by the planners amidst making arduous decisions. It is also reckoned that the newly introduced complex projects would provide a basis for future studies in this field for comparisons purposes as this knowledge area is still in dearth of large benchmark examples.

5.2. Research Contributions

Contributions of this research can be summarized as follows:

- Improves the process of construction in general and helps select the best offers in particular;
- Provides an inclusive review of TCQ algorithms extant in the literature;
- Incorporates the generalized precedence relationships among the activities.

5.3. Recommendations for Future Studies

Despite the strength and effectiveness of the proposed model, several aspects can be improved in future studies, and these aspects can be summarized as follows:

- Incorporating the uncertainty concept in the construction of the project to study the TCQ trade-off problem more effectively;
- Incorporating another objective to TCQ trade-off problems such as environment or safety;
- Creating a user interface to guide the users on entering, preparing, and understanding the input and output files;
- Incorporating the multi-criteria decision-making (MCDM) model that helps the decision-makers select a solution out of the produced solutions by ranking them according to their importance to the owner.

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APPENDIX A

COMPLETE SETS OF RESULTS OBTAINED BY THE PROPOSED MODEL

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
1	104	164820	93.061	5 5 1 3 3 3 3 1 5 3 2 4 3 3 1 5 3 3
2	104	151920	91.538	5 3 3 1 4 3 3 5 5 3 2 4 3 2 1 5 3 3
3	104	146720	89.086	5 1 3 1 2 3 3 5 5 3 2 4 3 3 1 5 3 3
4	104	145450	88.349	5 1 3 1 2 3 3 3 5 3 2 4 3 3 1 3 3 3
5	104	143700	88.096	5 1 3 1 4 3 1 3 5 3 2 4 3 3 1 5 3 3
6	104	140670	86.408	5 1 3 1 2 3 2 5 5 3 1 4 3 3 1 5 3 3
7	104	139400	84.735	5 3 3 1 2 3 2 3 5 3 1 4 3 1 1 3 3 3
8	104	137020	83.376	5 1 3 1 2 3 2 5 5 3 2 4 1 3 1 2 3 3
9	104	134450	81.902	5 1 3 1 2 3 1 3 5 3 1 4 1 3 1 1 3 3
10	105	157565	94.343	4 5 3 2 4 3 3 4 5 3 3 4 3 3 1 4 3 3
11	105	151970	92.259	4 5 3 1 4 3 3 5 5 3 2 4 3 3 1 2 3 3
12	105	149870	90.72	4 5 3 2 3 3 2 1 5 3 2 4 3 3 1 5 3 3
13	105	146908	89.341	4 5 3 1 2 3 3 2 5 3 1 4 3 3 1 2 3 3
14	105	146315	89.199	4 5 3 2 2 3 2 4 5 3 3 4 3 3 1 3 3 3
15	105	144850	89.023	4 4 3 1 4 3 2 3 5 3 2 4 3 3 1 1 3 3
16	105	142970	88.009	4 1 3 1 3 3 2 5 5 3 2 4 3 3 1 5 3 3
17	105	142870	87.391	4 2 3 1 3 3 2 5 5 3 2 4 3 2 1 5 3 3
18	105	137665	86.688	5 5 3 1 1 3 2 4 5 3 1 4 3 3 1 5 3 3
19	105	134808	85.332	5 2 3 1 1 3 2 2 5 3 3 4 3 3 1 2 3 3
20	105	133350	83.108	5 4 3 1 1 3 2 3 5 3 1 4 1 3 1 2 3 3
21	105	131958	81.009	5 4 1 1 1 3 1 2 5 3 2 4 3 2 1 3 3 3
22	106	155700	92.459	3 2 3 2 4 3 3 3 5 3 2 4 3 3 1 4 3 3
23	106	151600	91.182	3 4 3 2 4 3 2 3 5 3 2 4 3 3 1 5 3 3
24	106	148415	89.5265	5 2 3 2 3 3 2 4 5 3 1 3 3 3 1 5 3 3
25	106	134600	83.561	4 4 3 1 1 3 2 3 5 3 1 4 1 3 1 5 3 3
26	106	132700	83.254	4 3 2 1 1 3 1 3 5 3 1 4 3 3 1 4 3 3
27	106	132600	82.535	4 4 3 1 1 3 2 3 5 3 1 4 1 3 1 1 3 3
28	106	131920	82.166	4 2 3 1 1 3 1 5 5 3 2 4 3 1 1 3 3 3
29	106	131750	81.589	4 1 3 1 1 3 2 3 5 3 2 4 1 3 1 2 3 3
30	106	129500	78.655	4 1 1 1 1 3 1 3 5 3 1 4 3 2 1 1 3 3
31	106	127900	77.323	4 1 1 1 1 3 1 3 5 3 1 4 1 3 1 1 3 3
32	107	152110	92.268	5 5 3 1 4 3 3 5 4 3 1 4 3 3 1 2 3 3
33	107	146715	90.2625	4 4 3 1 4 3 2 4 5 3 3 3 3 3 1 5 3 3
34	107	146615	89.8065	4 4 3 1 4 3 2 4 5 3 2 3 3 3 1 5 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
35	107	145465	89.7255	4 4 3 1 4 3 2 4 5 3 3 3 3 3 1 3 3 3
36	107	143465	88.7495	4 5 3 1 3 3 2 4 5 3 2 3 3 3 1 3 3 3
37	107	142320	88.2025	4 5 3 1 2 3 2 5 5 3 3 3 3 3 1 5 3 3
38	107	142300	88.0025	4 5 3 1 2 3 2 3 5 3 3 3 3 3 1 5 3 3
39	107	140700	87.4205	4 5 3 1 3 3 1 3 5 3 2 3 3 3 1 1 3 3
40	107	140450	87.2055	4 4 3 1 2 3 2 3 5 3 3 3 3 3 1 3 3 3
41	107	140200	87.0225	4 4 3 1 2 3 2 3 5 3 3 3 3 3 1 2 3 3
42	107	137400	86.2855	5 5 3 1 1 3 2 3 5 3 1 3 3 3 1 5 3 3
43	107	137055	85.658	5 5 3 1 1 3 2 4 4 3 2 4 3 2 1 5 3 3
44	107	134465	84.5505	5 1 3 1 1 3 2 4 5 3 2 3 3 3 1 4 3 3
45	107	134215	84.3165	5 1 3 1 1 3 2 4 5 3 2 3 3 3 1 3 3 3
46	107	133665	83.783	3 1 3 1 1 3 2 4 5 3 1 4 3 3 1 2 3 3
47	107	133165	83.477	3 1 3 1 1 3 2 4 5 3 1 4 3 3 1 1 3 3
48	107	132150	83.36	3 1 3 1 1 3 1 3 5 3 1 4 3 3 1 4 3 3
49	108	149670	91.866	5 5 3 2 4 2 3 5 5 3 1 4 3 3 1 4 3 3
50	108	147800	90.349	5 5 2 2 3 2 3 3 5 3 3 4 3 3 1 5 3 3
51	108	142098	88.154	4 5 3 1 1 3 3 2 4 3 1 4 3 3 1 3 3 3
52	108	140650	87.713	5 5 3 2 4 2 1 3 5 3 1 4 3 3 1 1 3 3
53	108	140108	87.591	5 4 3 2 4 2 1 2 5 3 2 4 3 3 1 1 3 3
54	108	137120	87.556	5 4 3 1 4 2 1 5 5 3 2 4 3 3 1 5 3 3
55	108	136615	86.523	5 3 3 2 2 2 1 4 5 3 3 4 3 3 1 5 3 3
56	108	136520	86.268	5 5 3 1 3 2 2 1 5 3 2 4 3 2 1 5 3 3
57	108	132700	85.383	5 2 3 1 3 2 1 3 5 3 2 4 3 3 1 4 3 3
58	108	132050	84.708	5 4 3 1 2 2 1 3 5 3 1 4 3 3 1 5 3 3
59	108	129150	82.904	5 5 2 1 1 2 2 3 5 3 1 4 3 3 1 5 3 3
60	108	128715	82.51	5 1 3 1 2 2 1 4 5 3 2 4 3 3 1 1 3 3
61	108	127900	82.367	5 5 2 1 1 2 2 3 5 3 1 4 3 3 1 3 3 3
62	108	127165	81.264	5 1 2 1 1 2 2 4 5 3 1 4 3 3 1 5 3 3
63	108	125265	79.903	5 1 1 1 1 2 2 4 5 3 3 4 3 3 1 3 3 3
64	108	125250	79.823	5 1 1 1 1 2 2 3 5 3 3 4 3 3 1 3 3 3
65	108	124420	79.344	5 1 1 1 1 2 1 5 5 3 2 4 3 3 1 5 3 3
66	109	145470	89.786	4 5 3 2 2 2 3 1 5 3 3 4 3 3 1 5 3 3
67	109	143148	88.491	3 5 3 1 3 3 2 2 4 3 2 4 3 3 1 2 3 3
68	109	142950	88.386	4 4 3 1 4 2 3 3 5 3 1 4 3 2 1 3 3 3
69	109	136965	87.625	4 4 3 1 4 2 1 4 5 3 3 4 3 3 1 5 3 3
70	109	134450	85.669	4 5 3 1 2 2 2 3 5 3 2 4 3 3 1 5 3 3
71	109	129550	84.805	4 5 3 1 1 2 2 3 5 3 3 4 3 3 1 5 3 3
72	109	129415	84.221	4 5 3 1 1 2 2 4 5 3 1 4 3 3 1 5 3 3
73	109	127920	83.621	4 5 3 1 1 2 2 5 5 3 1 4 3 3 1 2 3 3
74	109	125565	82.405	4 1 3 1 1 2 1 4 5 3 3 4 3 3 1 5 3 3
75	109	124958	81.326	4 4 3 1 1 2 1 2 5 3 1 4 3 2 1 3 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
76	109	124850	80.681	4 1 3 1 1 2 1 3 5 3 2 4 3 2 1 5 3 3
77	109	124170	79.077	4 1 1 1 1 2 1 5 5 3 2 4 3 3 1 5 3 3
78	109	123365	79.068	4 1 3 1 1 2 1 4 5 3 1 4 3 1 1 3 3 3
79	109	122700	77.637	4 1 2 1 1 2 1 3 5 3 1 4 1 3 1 5 3 3
80	109	122070	77.169	4 1 1 1 1 2 1 5 5 3 2 4 3 2 1 2 3 3
81	109	122050	76.547	4 1 1 1 1 2 2 3 5 3 3 4 1 3 1 1 3 3
82	110	167048	96.1995	4 3 3 3 4 3 3 2 4 3 3 3 3 3 1 5 3 3
83	110	163350	95.146	4 4 3 3 3 3 3 5 3 3 3 4 3 3 1 1 3 3
84	110	153295	92.501	4 5 3 1 4 3 3 4 3 3 1 4 3 3 1 5 3 3
85	110	144945	89.242	4 2 3 1 4 3 2 4 3 3 3 4 3 3 1 4 3 3
86	110	143058	88.6205	5 2 3 2 4 2 2 2 5 3 3 3 3 3 1 5 3 3
87	110	142015	88.415	3 5 3 1 3 2 3 4 5 3 3 4 2 3 1 5 3 3
88	110	140450	88.0835	5 5 3 1 2 2 3 3 5 3 2 3 3 3 1 5 3 3
89	110	138070	87.9895	5 5 3 1 4 2 2 5 5 3 3 3 3 3 1 2 3 3
90	110	136370	87.2135	5 4 3 1 3 2 2 5 5 3 2 3 3 3 1 5 3 3
91	110	134065	86.7465	5 5 3 1 3 2 1 4 5 3 3 3 3 3 1 4 3 3
92	110	129300	84.607	3 5 3 1 1 2 2 3 5 3 3 4 3 3 1 5 3 3
93	110	121500	77.2525	5 1 2 1 1 2 1 3 5 3 2 3 1 3 1 3 3 3
94	110	120700	75.7645	5 1 1 1 1 2 1 3 5 3 2 3 1 3 1 3 3 3
95	111	159655	94.5	5 5 3 3 4 2 3 4 4 3 2 4 3 3 1 4 3 3
96	111	153300	92.5655	5 5 3 1 4 3 3 5 3 3 1 3 3 3 1 5 3 3
97	111	149120	91.7235	4 3 3 2 4 2 3 5 5 3 3 3 3 3 1 5 3 3
98	111	148550	90.51	5 5 3 1 2 3 3 5 3 2 2 4 3 3 1 5 3 3
99	111	147188	90.347	3 5 3 1 4 3 2 2 3 3 3 4 3 3 1 5 3 3
100	111	144590	90.285	5 5 3 1 4 2 3 3 4 3 1 4 3 3 1 4 3 3
101	111	143660	89.392	5 1 3 1 4 2 3 1 4 3 3 4 3 3 1 5 3 3
102	111	142110	88.612	5 2 3 1 4 2 3 5 4 3 1 4 3 3 1 1 3 3
103	111	136115	86.8265	4 4 3 1 3 2 2 4 5 3 2 3 3 3 1 5 3 3
104	111	132315	85.1225	4 5 3 1 2 2 1 4 5 3 3 3 3 3 1 5 3 3
105	111	127800	83.7625	4 5 3 1 1 2 2 3 5 3 3 3 3 3 1 2 3 3
106	111	126550	82.7985	4 4 3 1 1 2 1 3 5 3 1 3 3 3 1 5 3 3
107	111	124015	80.8725	4 4 3 1 1 2 1 4 5 3 2 3 3 2 1 1 3 3
108	111	123550	79.9615	4 1 2 1 1 2 1 3 5 3 3 3 3 3 1 3 3 3
109	111	123308	79.1585	4 3 3 1 1 2 2 2 5 3 3 3 1 2 1 1 3 3
110	111	120165	75.1865	4 1 1 1 1 2 1 4 5 3 1 3 1 3 1 2 3 3
111	112	151850	92.0855	4 5 3 1 4 3 3 1 3 3 3 3 3 3 1 3 3 3
112	112	148608	90.581	5 5 3 1 2 3 3 2 2 2 3 4 3 3 1 5 3 3
113	112	147960	90.56	4 5 3 2 3 3 1 5 4 2 3 4 3 3 1 5 3 3
114	112	144160	90.308	4 5 3 1 4 2 3 1 4 3 3 4 3 3 1 3 3 3
115	112	140390	88.089	4 5 3 1 2 2 3 3 4 3 2 4 3 3 1 5 3 3
116	112	128905	84.575	4 4 3 1 1 2 2 4 4 3 3 4 3 3 1 5 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
117	112	126320	82.8005	3 4 3 1 1 2 1 5 5 3 1 3 3 3 1 5 3 3
118	112	124900	81.1405	3 1 3 1 1 2 1 3 5 3 1 3 3 3 1 5 3 3
119	112	122605	79.813	4 4 3 1 1 2 1 4 4 3 2 4 1 3 1 1 3 3
120	112	122300	78.9265	3 1 3 1 1 2 1 3 5 3 1 3 3 2 1 1 3 3
121	112	121500	78.2915	3 1 3 1 1 2 1 3 5 3 2 3 1 3 1 3 3 3
122	113	157080	93.2385	5 3 3 2 4 3 3 3 3 2 2 3 3 3 1 5 3 3
123	113	153270	93.091	3 5 3 1 4 3 3 5 5 2 3 4 3 3 1 5 3 3
124	113	145580	90.696	5 5 3 1 4 2 3 3 3 3 2 4 3 3 1 5 3 3
125	113	142910	89.8935	5 5 3 1 3 2 3 5 4 3 2 3 3 3 1 5 3 3
126	113	142600	88.997	5 5 3 2 4 2 1 5 3 3 2 4 3 3 1 5 3 3
127	113	140600	88.456	5 5 3 1 2 2 3 5 3 3 2 4 3 3 1 5 3 3
128	113	134000	85.726	5 4 3 1 2 2 2 5 3 3 2 4 3 3 1 5 3 3
129	113	133680	85.672	5 1 3 1 1 2 3 3 3 3 3 4 3 3 1 5 3 3
130	113	125195	82.789	5 2 3 1 1 2 1 4 3 3 3 4 3 3 1 4 3 3
131	113	120400	76.639	4 1 3 1 1 2 1 3 5 3 1 4 1 3 1 1 2 3
132	114	151400	91.905	1 3 3 1 4 3 3 3 5 3 3 4 3 3 1 5 3 3
133	114	141650	90.5575	5 5 3 3 2 1 3 3 5 3 1 4 3 3 1 5 3 3
134	114	141570	89.3945	5 5 3 1 3 2 3 5 5 3 3 2 3 3 1 3 3 3
135	114	140345	88.069	4 5 3 1 2 2 3 4 3 3 2 4 3 3 1 5 3 3
136	114	133708	87.5055	5 2 3 3 1 1 3 2 5 3 2 4 3 3 1 2 3 3
137	114	128950	86.7435	5 3 2 1 4 1 3 3 5 3 1 4 3 3 1 4 3 3
138	114	126650	86.6305	5 5 3 1 2 1 3 3 5 3 1 4 3 3 1 5 3 3
139	114	123708	84.6035	5 5 3 2 2 1 2 2 5 3 2 4 3 3 1 1 3 3
140	114	119500	82.9315	5 4 3 2 1 1 2 3 5 3 2 4 3 2 1 5 3 3
141	114	112200	81.5685	5 5 3 1 1 1 1 3 5 3 2 4 3 3 1 2 3 3
142	114	111600	79.4205	5 1 3 1 1 1 2 3 5 3 2 4 3 2 1 2 3 3
143	114	111270	78.8835	5 4 2 1 1 1 2 5 5 3 3 4 1 3 1 3 3 3
144	114	110415	76.7205	5 3 1 1 1 1 1 4 5 3 2 4 3 1 1 5 3 3
145	114	109800	76.3885	5 1 1 1 1 1 1 3 5 3 2 4 3 2 1 5 3 3
146	114	106158	73.7525	5 1 1 1 1 1 1 2 5 3 1 4 1 3 1 1 3 3
147	115	152880	92.4185	3 5 3 1 4 3 3 3 3 2 3 3 3 3 1 5 3 3
148	115	144470	91.4185	4 1 3 3 4 1 3 5 5 3 2 4 3 3 1 5 3 3
149	115	141550	89.25	5 5 3 1 3 2 3 5 3 2 2 4 3 3 1 2 3 3
150	115	130870	88.9515	4 4 3 1 4 1 3 5 5 3 2 4 3 3 1 5 3 3
151	115	129358	88.5745	4 3 3 1 4 1 3 2 5 3 3 4 3 3 1 4 3 3
152	115	128870	86.9975	4 5 3 1 4 1 3 5 5 3 2 4 3 2 1 1 3 3
153	115	127815	86.7215	4 2 3 2 4 1 2 4 5 3 3 4 3 3 1 3 3 3
154	115	123450	85.7815	4 5 3 1 4 1 1 3 5 3 2 4 3 3 1 5 3 3
155	115	121815	85.7605	4 5 3 1 3 1 2 4 5 3 3 4 3 3 1 3 3 3
156	115	120820	84.9835	4 4 3 1 1 1 3 5 5 3 1 4 3 3 1 5 3 3
157	115	119200	83.5645	4 5 3 1 2 1 2 3 5 3 2 4 3 3 1 3 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
158	115	118370	82.2415	4 1 3 1 2 1 2 1 5 3 2 4 3 3 1 5 3 3
159	115	111365	81.7345	4 3 3 1 1 1 1 4 5 3 3 4 3 3 1 4 3 3
160	115	110165	77.3895	4 1 1 1 1 1 1 4 5 3 2 4 3 3 1 5 3 3
161	115	107715	76.9335	4 1 3 1 1 1 1 4 5 3 1 4 1 3 1 2 3 3
162	116	141570	91.099	5 5 3 3 2 1 3 5 5 3 3 3 3 3 1 5 3 3
163	116	141365	89.275	5 1 3 3 3 1 3 4 5 3 2 3 3 2 1 5 3 3
164	116	141315	89.17	4 4 3 1 3 2 3 4 5 2 2 4 3 3 1 4 3 3
165	116	131220	89.0135	3 5 3 1 4 1 3 5 5 3 2 4 3 3 1 5 3 3
166	116	126550	86.972	5 5 3 1 2 1 3 3 5 3 3 3 3 3 1 5 3 3
167	116	125620	86.4405	3 4 3 2 1 1 3 1 5 3 3 4 3 3 1 5 3 3
168	116	120565	84.582	5 5 3 1 2 1 2 4 5 3 3 3 3 3 1 5 3 3
169	116	120400	83.849	5 5 3 2 1 1 2 3 5 3 1 3 3 3 1 5 3 3
170	116	118970	83.642	5 5 3 1 2 1 2 1 5 3 3 3 3 3 1 2 3 3
171	116	118965	82.976	5 2 3 1 2 1 2 4 5 3 2 3 3 3 1 5 3 3
172	116	118008	82.919	5 3 3 1 2 1 2 2 5 3 2 3 3 3 1 3 3 3
173	116	117720	82.0465	3 2 2 1 3 1 1 5 5 3 2 4 3 3 1 4 3 3
174	116	117370	81.879	5 5 3 1 2 1 2 5 5 3 3 3 1 3 1 4 3 3
175	117	138808	89.812	4 5 3 3 4 1 2 2 5 3 3 3 3 3 1 2 3 3
176	117	134215	89.074	4 5 3 2 4 1 3 4 5 3 2 3 3 3 1 1 3 3
177	117	125600	85.989	4 4 3 1 2 1 3 3 5 3 2 3 3 3 1 5 3 3
178	117	120558	84.391	4 4 3 1 1 1 3 2 5 3 1 3 3 3 1 5 3 3
179	117	120220	83.979	4 5 3 1 2 1 2 5 5 3 2 3 3 3 1 5 3 3
180	117	119700	83.975	4 4 3 1 2 1 2 3 5 3 3 3 3 3 1 5 3 3
181	117	119410	83.7905	5 3 3 1 2 1 2 5 4 3 1 4 3 3 1 5 3 3
182	117	119100	83.715	4 3 3 1 2 1 2 3 5 3 3 3 3 3 1 5 3 3
183	117	117608	82.423	4 4 3 1 2 1 2 2 5 3 2 3 3 3 1 1 3 3
184	117	116300	81.755	4 1 3 1 2 1 1 3 5 3 3 3 3 3 1 5 3 3
185	117	110410	80.1815	5 1 3 1 1 1 1 5 4 3 2 4 3 3 1 3 3 3
186	117	106400	75.245	4 1 3 1 1 1 1 3 5 3 2 3 1 2 1 1 3 3
187	118	134390	89.2665	4 5 3 2 4 1 3 3 4 3 2 4 3 3 1 1 3 3
188	118	130805	88.7815	4 4 3 1 4 1 3 4 4 3 2 4 3 3 1 5 3 3
189	118	123998	86.1575	4 5 3 1 4 1 2 2 4 3 3 4 3 3 1 2 3 3
190	118	119460	84.2645	4 4 3 1 1 1 3 1 4 3 2 4 3 3 1 3 3 3
191	118	109700	79.244	3 1 3 1 1 1 1 3 5 3 2 3 3 3 1 3 3 3
192	119	121700	86.0245	5 5 3 1 1 1 3 5 3 3 3 4 3 3 1 5 3 3
193	119	119810	84.3265	3 5 3 1 1 1 3 1 4 3 2 4 3 3 1 3 3 3
194	119	117700	83.0155	5 2 3 2 1 1 2 5 3 3 3 4 3 3 1 2 3 3
195	119	117160	82.9905	3 5 3 1 2 1 1 5 4 3 2 4 3 3 1 4 3 3
196	119	108510	78.356	5 3 3 1 1 1 1 5 4 3 2 3 1 3 1 2 3 3
197	120	143595	91.1815	4 2 3 3 4 1 3 4 3 3 2 4 3 3 1 3 3 3
198	120	134390	89.629	4 4 3 2 4 1 3 3 4 3 3 3 3 3 1 3 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
199	120	131430	89.3175	4 5 3 1 4 1 3 3 3 3 3 4 3 3 1 5 3 3
200	120	128880	87.8045	4 3 3 1 4 1 3 3 3 3 2 4 3 3 1 3 3 3
201	120	127838	87.0885	4 4 3 2 4 1 1 2 3 3 3 4 3 3 1 5 3 3
202	120	125180	86.3405	4 5 3 1 2 1 3 3 3 3 3 4 3 3 1 3 3 3
203	120	124750	86.3315	4 4 3 1 4 1 2 5 3 3 2 4 3 3 1 5 3 3
204	120	119430	84.1045	4 5 3 1 2 1 2 3 3 3 3 4 3 3 1 4 3 3
205	120	119100	83.7825	4 5 3 1 3 1 1 5 3 3 3 4 3 2 1 3 3 3
206	120	118230	83.5845	4 3 3 1 2 1 2 3 3 3 3 4 3 3 1 4 3 3
207	120	118100	83.0445	4 1 3 1 1 1 3 5 3 3 2 4 3 3 1 3 3 3
208	120	115345	82.7115	4 5 3 1 1 1 2 4 3 3 2 4 3 3 1 5 3 3
209	120	111008	80.605	5 3 3 1 1 1 1 2 5 3 2 2 3 3 1 4 3 3
210	120	110800	80.4105	4 2 3 1 1 1 1 5 3 3 1 4 3 3 1 4 3 3
211	120	107488	75.9765	4 1 2 1 1 1 1 2 3 3 3 4 1 3 1 3 3 3
212	120	106160	73.897	4 1 1 1 1 1 1 5 4 3 2 3 1 3 1 2 3 3
213	121	165505	95.21	1 5 3 3 4 3 3 4 4 2 3 4 3 3 1 1 3 3
214	121	144870	91.824	4 5 3 3 4 1 3 1 5 3 3 4 3 3 1 4 3 2
215	121	140750	91.0455	5 5 3 3 4 1 2 3 5 2 3 4 3 3 1 5 3 3
216	121	140150	90.7855	5 4 3 3 4 1 2 3 5 2 3 4 3 3 1 5 3 3
217	121	139830	90.459	5 4 3 3 4 1 2 3 3 3 3 3 3 3 1 5 3 3
218	121	130500	88.6035	3 4 3 1 4 1 3 5 3 3 2 4 3 3 1 5 3 3
219	121	129150	88.3525	5 5 3 1 3 1 3 3 5 2 2 4 3 3 1 5 3 3
220	121	126430	86.822	5 5 3 1 2 1 3 3 3 3 3 3 3 3 1 5 3 3
221	121	125605	86.6925	5 5 3 1 4 1 2 4 4 2 2 4 3 3 1 5 3 3
222	121	121500	85.2145	5 5 3 1 1 1 3 5 3 2 1 4 3 3 1 5 3 3
223	121	121300	85.038	5 5 3 1 1 1 3 5 3 3 1 3 3 3 1 5 3 3
224	121	120645	84.6195	5 5 3 2 1 1 2 4 3 2 3 4 3 3 1 5 3 3
225	121	120430	84.352	5 5 3 1 2 1 2 3 3 3 3 3 3 3 1 5 3 3
226	121	119145	83.8995	5 5 3 2 1 1 2 4 3 2 3 4 3 3 1 2 3 3
227	121	118030	83.5085	5 4 3 1 2 1 1 3 3 2 3 4 3 3 1 5 3 3
228	121	115545	82.8325	5 5 3 1 1 1 2 4 3 2 2 4 3 3 1 5 3 3
229	121	115530	82.7525	5 5 3 1 1 1 2 3 3 2 2 4 3 3 1 5 3 3
230	121	115330	82.576	5 5 3 1 1 1 2 3 3 3 2 3 3 3 1 5 3 3
231	121	114530	82.4495	5 5 3 1 1 1 2 3 3 2 2 4 3 3 1 4 3 3
232	121	114450	82.3095	5 5 3 1 1 1 2 1 3 2 2 4 3 3 1 4 3 3
233	121	114080	82.039	5 5 3 1 1 1 2 3 3 3 2 3 3 3 1 3 3 3
234	121	111005	80.961	3 5 3 1 1 1 1 4 4 3 3 3 3 3 1 1 3 3
235	121	109830	79.64	5 2 3 1 1 1 1 3 3 3 2 3 3 3 1 1 3 3
236	121	108160	77.6315	5 1 3 1 1 1 1 1 4 2 3 4 1 3 1 3 3 3
237	121	105258	73.0115	2 1 1 1 1 1 1 2 5 3 1 4 1 3 1 1 3 3
238	122	143900	92.5185	4 5 3 3 3 1 3 5 3 2 3 4 3 3 1 5 3 3
239	122	139780	90.3685	4 4 3 3 4 1 2 3 3 2 3 4 3 3 1 5 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
240	122	131300	89.0315	4 5 3 1 4 1 3 1 3 2 3 4 3 3 1 5 3 3
241	122	128745	87.8075	4 5 3 1 3 1 3 4 3 2 1 4 3 3 1 5 3 3
242	122	128195	87.7555	4 4 3 1 3 1 3 4 3 2 2 4 3 3 1 5 3 3
243	122	127930	87.291	4 4 3 1 3 1 3 3 3 3 1 3 3 3 1 5 3 3
244	122	125380	86.7015	4 5 3 1 4 1 2 3 3 2 3 4 3 3 1 5 3 3
245	122	124780	86.4415	4 4 3 1 4 1 2 3 3 2 3 4 3 3 1 5 3 3
246	122	124130	86.1645	4 5 3 1 4 1 2 3 3 2 3 4 3 3 1 3 3 3
247	122	121408	85.0415	4 4 3 1 4 1 1 2 5 2 3 4 3 3 1 2 3 3
248	122	121295	85.0355	4 5 3 1 1 1 3 4 3 2 2 4 3 3 1 5 3 3
249	122	120695	84.7755	4 4 3 1 1 1 3 4 3 2 2 4 3 3 1 5 3 3
250	122	119800	84.5425	4 4 3 1 1 1 3 3 5 2 2 4 3 3 1 4 3 3
251	122	118595	84.029	4 4 3 1 1 1 3 4 3 3 3 3 3 3 1 1 3 3
252	122	118280	83.8755	4 4 3 1 3 1 1 3 3 2 3 4 3 3 1 1 3 3
253	122	117780	83.2415	4 4 3 1 2 1 1 3 3 2 3 4 3 3 1 5 3 3
254	122	115380	82.9415	4 5 3 1 1 1 2 3 3 2 3 4 3 3 1 5 3 3
255	122	114800	82.8815	4 4 3 1 1 1 2 5 3 2 3 4 3 3 1 5 3 3
256	122	114180	82.462	4 5 3 1 1 1 2 3 3 3 3 3 3 3 1 4 3 3
257	122	114000	82.445	4 3 3 1 1 1 2 5 3 3 3 3 3 3 1 5 3 3
258	122	113550	81.8385	4 4 3 1 1 1 2 3 5 2 2 4 3 3 1 3 3 3
259	122	109500	78.969	4 1 3 1 1 1 1 1 3 3 2 3 3 3 1 2 3 3
260	122	107380	76.589	4 1 3 1 1 1 1 3 3 3 2 3 1 3 1 2 3 3
261	122	107238	75.654	4 1 2 1 1 1 1 2 3 3 3 3 1 3 1 3 3 3
262	122	106795	75.481	4 1 3 1 1 1 1 4 3 3 2 3 1 2 1 2 3 3
263	123	145120	92.6465	4 5 3 3 4 1 3 5 2 2 3 4 3 3 1 3 3 3
264	123	139800	90.513	5 4 3 3 4 1 2 5 3 2 3 3 3 3 1 5 3 3
265	123	139365	90.2905	4 5 3 3 4 1 2 4 2 2 3 4 3 3 1 4 3 3
266	123	135130	90.0015	3 5 3 2 4 1 3 3 3 2 3 4 3 3 1 4 3 3
267	123	128170	87.7605	4 4 3 1 3 1 3 5 2 2 2 4 3 3 1 5 3 3
268	123	127400	87.386	5 2 3 1 3 1 3 5 3 2 3 3 3 3 1 5 3 3
269	123	126920	87.2235	4 4 3 1 3 1 3 5 2 2 2 4 3 3 1 3 3 3
270	123	126400	86.876	5 5 3 1 2 1 3 5 3 2 3 3 3 3 1 5 3 3
271	123	121210	85.5135	3 5 3 1 1 1 3 5 4 2 3 4 3 3 1 5 3 3
272	123	121110	85.0575	3 5 3 1 1 1 3 5 4 2 2 4 3 3 1 5 3 3
273	123	119465	84.471	2 3 3 1 1 1 3 4 5 3 3 3 3 3 1 5 3 3
274	123	117380	83.143	5 5 3 1 2 1 1 3 3 2 3 3 3 3 1 4 3 3
275	123	113515	82.356	5 5 3 1 1 1 1 4 5 2 3 3 3 3 1 5 3 3
276	123	113395	82.206	5 5 3 1 1 1 1 4 3 2 3 3 3 3 1 5 3 3
277	123	113388	82.056	5 5 3 1 1 1 1 2 3 2 3 3 3 3 1 5 3 3
278	123	112780	81.866	5 4 3 1 1 1 1 3 3 2 3 3 3 3 1 5 3 3
279	123	110710	80.71	5 3 3 1 1 1 1 5 4 3 3 4 3 3 1 3 3 2
280	123	110050	79.937	4 2 3 1 1 1 1 3 5 3 3 1 3 3 1 4 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
281	123	109380	79.38	5 1 3 1 1 1 1 3 3 2 3 3 3 3 1 1 3 3
282	123	109280	78.924	5 1 3 1 1 1 1 3 3 2 2 3 3 3 1 1 3 3
283	123	109030	78.7815	3 1 3 1 1 1 1 3 3 2 2 4 3 3 1 1 3 3
284	123	107660	77.1665	3 1 3 1 1 1 1 1 4 2 3 4 1 3 1 3 3 3
285	123	106730	76.541	3 1 3 1 1 1 1 3 3 3 3 3 1 3 1 1 3 3
286	123	106015	74.098	5 1 1 1 1 1 1 4 5 2 3 3 1 3 1 1 3 3
287	124	143690	92.096	4 5 3 3 3 1 3 3 4 2 3 3 3 3 1 5 3 3
288	124	142315	91.1095	3 3 3 3 3 1 3 4 2 2 2 4 3 3 1 5 3 3
289	124	128170	88.159	4 4 3 1 3 1 3 5 5 2 3 3 3 3 1 5 3 3
290	124	128050	88.009	4 4 3 1 3 1 3 5 3 2 3 3 3 3 1 5 3 3
291	124	127050	87.706	4 4 3 1 3 1 3 5 3 2 3 3 3 3 1 4 3 3
292	124	125145	86.459	4 5 3 1 4 1 2 4 3 2 3 3 3 3 1 5 3 3
293	124	121145	85.169	4 5 3 1 1 1 3 4 3 2 3 3 3 3 1 5 3 3
294	124	121130	85.089	4 5 3 1 1 1 3 3 3 2 3 3 3 3 1 5 3 3
295	124	120145	84.866	4 5 3 1 1 1 3 4 3 2 3 3 3 3 1 4 3 3
296	124	119030	84.109	4 4 3 1 1 1 3 3 3 2 3 3 3 3 1 2 3 3
297	124	119020	84.0885	1 5 3 1 3 1 1 5 5 3 2 4 3 3 1 4 3 3
298	124	113358	81.941	5 5 3 1 1 1 1 2 2 2 3 3 3 3 1 5 3 3
299	124	109270	79.009	5 1 3 1 1 1 1 5 2 2 2 3 3 3 1 1 3 3
300	124	108988	78.379	4 1 3 1 1 1 1 2 3 2 1 3 3 3 1 1 3 3
301	124	105650	73.801	4 1 1 1 1 1 1 5 3 2 3 3 1 3 1 1 3 3
302	124	104750	71.209	4 1 1 1 1 1 1 5 3 2 2 3 1 1 1 1 3 3
303	125	142195	91.358	3 3 3 3 3 1 3 4 3 2 3 3 3 3 1 5 3 3
304	125	109020	78.742	4 1 3 1 1 1 1 5 2 2 2 3 3 3 1 1 3 3
305	125	108750	78.451	3 1 3 1 1 1 1 5 3 2 1 3 3 3 1 1 3 3
306	125	107600	77.16	4 3 3 1 1 1 1 3 2 3 1 3 1 3 1 1 3 3
307	125	106550	75.931	3 1 3 1 1 1 1 5 3 2 1 3 1 3 1 1 3 3
308	125	105770	75.6915	4 3 3 1 1 1 1 5 3 2 4 1 3 1 1 1 3
309	125	104645	71.631	3 1 1 1 1 1 1 4 3 2 1 3 1 2 1 1 3 3
310	126	109815	79.446	3 2 3 1 1 1 1 4 2 3 2 3 3 3 1 2 3 3
311	126	109180	78.9575	2 1 3 1 1 1 1 3 3 3 2 4 3 3 1 2 3 3
312	126	105450	74.435	1 1 3 1 1 1 1 3 5 3 2 3 1 2 1 1 3 3
313	126	104350	70.7955	4 1 1 1 1 1 1 5 3 2 1 4 1 2 1 1 2 3
314	127	107560	77.369	3 2 3 1 1 1 1 5 4 3 3 1 1 3 1 4 3 3
315	128	141395	91.1275	2 4 3 3 3 1 3 4 3 2 3 4 3 3 1 3 3 3
316	128	117945	83.555	2 4 3 1 1 1 3 4 3 3 3 3 3 3 1 1 3 3
317	128	110530	80.2715	2 4 3 1 1 1 1 3 3 2 2 4 3 3 1 2 3 3
318	128	105570	75.034	3 1 3 1 1 1 1 5 5 3 2 3 1 3 1 4 1 3
319	128	105238	71.9975	5 1 1 1 1 1 1 2 3 3 1 4 1 3 1 1 3 1
320	128	104550	71.144	4 1 1 1 1 1 1 5 3 2 1 4 1 2 1 1 3 2
321	129	108880	78.6215	1 1 3 1 1 1 1 3 3 3 2 4 3 3 1 2 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
322	130	143040	91.622	2 5 3 3 3 1 3 3 4 2 3 3 3 3 1 5 3 3
323	130	110195	80.186	2 3 3 1 1 1 1 4 3 2 2 3 3 3 1 4 3 3
324	130	109820	79.914	1 3 3 1 1 1 1 1 5 3 3 2 3 3 1 4 3 3
325	130	109200	79.583	2 3 3 1 1 1 1 5 3 2 2 3 3 3 1 1 3 3
326	130	108090	77.42	4 3 2 1 1 1 1 3 4 3 3 3 3 3 1 3 1 3
327	130	106010	75.757	4 3 3 1 1 1 1 5 4 3 1 3 1 3 1 2 1 3
328	130	105190	73.423	4 2 2 1 1 1 1 3 4 3 1 3 1 3 1 2 1 3
329	130	105150	72.913	2 1 2 1 1 1 1 3 5 2 1 3 1 2 1 1 3 3
330	130	104700	72.3175	4 2 2 1 1 1 1 1 3 3 1 4 1 2 1 2 1 3
331	130	104458	71.4065	2 1 1 1 1 1 1 2 5 3 1 4 1 3 1 1 3 1
332	131	118115	83.6675	2 4 3 1 1 1 3 4 1 3 3 4 3 3 1 1 3 3
333	131	110100	80.4645	1 3 3 1 1 1 1 3 5 2 3 4 3 3 1 3 3 3
334	131	109100	78.8585	1 1 3 1 1 1 1 5 3 2 2 4 3 3 1 3 3 3
335	131	108830	78.4755	1 1 3 1 1 1 1 3 3 2 2 4 3 3 1 2 3 3
336	131	108230	78.449	1 1 3 1 1 1 1 3 3 3 3 3 3 3 1 1 3 3
337	131	107730	77.708	5 1 3 1 1 1 1 3 3 3 3 3 3 3 1 2 1 3
338	131	107365	77.2115	1 2 3 1 1 1 1 4 5 2 3 4 1 3 1 2 3 3
339	131	106350	76.2555	1 1 3 1 1 1 1 3 5 2 3 4 1 3 1 1 3 3
340	131	106150	75.8495	1 1 3 1 1 1 1 5 3 2 2 4 1 3 1 1 3 3
341	131	105760	75.17	3 2 3 1 1 1 1 5 4 3 3 1 1 3 1 1 2 3
342	131	105250	73.5545	5 1 2 1 1 1 1 3 5 2 2 4 1 3 1 2 1 3
343	131	104950	72.876	4 2 2 1 1 1 1 3 5 3 2 4 1 3 1 2 1 2
344	131	104920	72.868	4 2 2 1 1 1 1 5 5 3 1 4 1 3 1 2 1 2
345	131	102670	69.861	4 1 1 1 1 1 1 5 5 3 2 2 1 2 1 1 1 3
346	132	109870	80.0595	1 3 3 1 1 1 1 1 2 2 3 4 3 3 1 3 3 3
347	132	108420	78.7105	1 1 3 1 1 1 1 5 2 2 3 4 3 3 1 1 3 3
348	132	105400	74.9575	4 1 3 1 1 1 1 1 3 2 3 4 1 3 1 2 1 3
349	132	105188	74.395	4 1 3 1 1 1 1 2 3 3 2 3 1 3 1 2 1 3
350	132	104680	74.159	4 1 3 1 1 1 1 3 3 3 2 3 1 3 1 1 1 3
351	132	102950	70.1475	4 1 1 1 1 1 1 5 3 2 1 4 1 2 1 1 1 3
352	133	130840	89.1095	4 4 3 1 4 1 3 5 5 1 3 4 3 3 1 5 3 3
353	133	126315	86.769	1 5 3 1 3 1 3 4 5 2 3 3 3 3 1 2 3 3
354	133	118820	84.076	1 5 3 1 3 1 1 5 5 2 3 3 3 3 1 4 3 3
355	133	108950	78.992	1 1 3 1 1 1 1 5 3 2 3 3 3 3 1 3 3 3
356	133	108700	78.809	1 1 3 1 1 1 1 5 3 2 3 3 3 3 1 2 3 3
357	133	108165	77.869	1 1 3 1 1 1 1 4 5 2 1 3 3 3 1 1 3 3
358	133	108150	77.789	1 1 3 1 1 1 1 3 5 2 1 3 3 3 1 1 3 3
359	133	108045	77.719	1 1 3 1 1 1 1 4 3 2 1 3 3 3 1 1 3 3
360	133	106830	76.6575	3 1 3 1 1 1 1 3 3 2 2 4 3 3 1 1 1 3
361	133	104640	72.435	1 1 1 1 1 1 1 3 4 2 2 3 1 3 1 1 3 3
362	133	104300	70.969	1 2 1 1 1 1 1 5 3 2 2 3 1 1 1 1 3 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
363	133	103950	70.598	5 1 2 1 1 1 1 1 3 2 1 3 1 1 1 2 1 3
364	134	126740	87.2545	3 4 3 1 3 1 3 1 5 1 3 4 3 3 1 3 3 3
365	134	109100	79.138	4 4 3 1 1 1 1 5 3 2 3 3 3 3 1 3 1 3
366	134	107330	76.839	4 1 3 1 1 1 1 3 3 2 2 3 3 3 1 2 1 3
367	134	104470	73.3965	3 2 3 1 1 1 1 5 2 2 1 4 1 2 1 1 1 3
368	134	103670	71.9075	1 2 3 1 1 1 1 1 5 3 1 4 1 1 1 1 1 3
369	135	121065	85.017	4 5 3 1 1 1 3 4 3 1 3 3 3 3 1 5 3 3
370	135	108205	78.076	5 3 3 1 1 1 1 4 4 3 1 1 3 3 1 4 1 3
371	135	107615	77.698	4 3 3 1 1 1 1 4 2 2 2 3 3 3 1 1 1 3
372	135	107300	76.816	3 1 3 1 1 1 1 5 3 2 1 3 3 3 1 3 1 3
373	135	107095	76.721	3 1 3 1 1 1 1 4 3 2 2 3 3 3 1 2 1 3
374	136	107738	77.804	2 1 3 1 1 1 1 2 3 2 3 1 3 3 1 1 3 3
375	136	105020	74.657	1 3 3 1 1 1 1 1 5 3 1 3 1 3 1 2 1 3
376	136	104070	73.827	1 3 3 1 1 1 1 1 5 3 3 3 1 2 1 1 1 3
377	137	103255	71.7155	1 1 3 1 1 1 1 4 4 3 2 4 1 1 1 1 1 3
378	137	102900	70.82	3 1 1 1 1 1 1 5 3 3 3 4 1 3 1 1 1 2
379	138	107130	76.933	2 4 3 1 1 1 1 3 3 3 3 3 3 2 1 1 1 3
380	138	104850	74.5815	2 2 3 1 1 1 1 3 5 2 2 4 1 3 1 1 1 3
381	139	105990	75.969	1 1 3 1 1 1 1 3 4 3 2 3 3 3 1 1 1 3
382	140	107708	78.101	2 3 3 1 1 1 1 2 5 2 3 3 3 3 1 2 1 3
383	140	103770	72.034	1 2 3 1 1 1 1 1 5 3 1 4 1 2 1 2 1 2
384	140	102258	69.2825	2 1 1 1 1 1 1 2 5 3 1 4 1 3 1 1 1 1
385	140	101720	69.051	1 1 1 1 1 1 1 5 5 3 2 2 1 2 1 1 1 3
386	141	107115	77.2205	1 1 3 1 1 1 1 4 5 2 3 4 3 3 1 3 1 3
387	141	104430	73.8315	1 1 3 1 1 1 1 3 3 2 2 4 1 3 1 2 1 3
388	141	103570	72.3715	1 1 2 1 1 1 1 5 5 2 2 4 1 3 1 1 1 3
389	141	103130	72.161	1 1 3 1 1 1 1 3 3 3 2 3 1 2 1 1 1 3
390	141	103100	70.8315	1 1 1 1 1 1 1 5 3 2 1 4 1 3 1 2 1 3
391	141	102650	69.4865	1 1 1 1 1 1 1 1 3 2 1 4 1 2 1 3 1 3
392	142	106355	76.82	2 3 3 1 1 1 1 4 4 3 2 1 3 3 1 1 1 3
393	143	102880	71.067	1 1 3 1 1 1 1 3 3 2 2 3 1 1 1 1 1 3
394	143	102540	70.767	1 1 1 1 1 1 1 3 4 2 3 3 1 3 1 1 1 3
395	143	102380	69.563	1 1 2 1 1 1 1 3 3 2 2 3 1 1 1 1 1 3
396	144	107315	77.294	1 4 3 1 1 1 1 4 2 3 2 3 3 3 1 1 1 3
397	144	105915	75.834	1 1 3 1 1 1 1 4 2 3 2 3 3 3 1 1 1 3
398	144	103800	72.735	2 3 3 1 1 1 1 1 3 2 1 2 1 2 1 1 1 3
399	144	102400	70.242	1 1 1 1 1 1 1 3 2 3 2 3 1 3 1 1 1 3
400	145	104315	74.062	2 2 3 1 1 1 1 4 2 2 3 2 1 3 1 1 1 3
401	146	102380	69.88	2 1 1 1 1 1 1 3 3 2 1 1 1 3 1 2 1 3
402	146	101955	69.754	2 1 1 1 1 1 1 4 4 2 1 1 1 3 1 1 1 3
403	147	105230	74.658	1 3 3 1 1 1 1 3 3 2 2 2 1 3 1 4 1 3

Table A.1 Results of the proposed model for 18-activity problem.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
404	147	101400	68.21	1 1 1 1 1 1 1 5 3 2 1 4 1 2 1 1 1 2
405	148	101270	67.498	1 1 1 1 1 1 1 1 2 3 2 2 1 1 1 1 1 3
406	149	105515	74.9665	4 1 3 1 1 1 1 4 1 2 3 1 3 3 1 1 1 2
407	149	105095	74.83	1 1 3 1 1 1 1 4 3 2 1 1 3 3 1 1 1 3
408	149	100930	66.7395	1 1 1 1 1 1 1 3 3 2 1 3 1 1 1 1 1 2
409	150	105600	75.087	1 1 3 1 1 1 1 3 2 3 1 1 3 3 1 2 1 3
410	150	102558	71.351	1 1 2 1 1 1 1 2 2 3 3 1 1 3 1 1 1 3
411	152	100870	66.311	4 1 1 1 1 1 1 1 1 3 2 1 1 1 1 1 1 1
412	158	102225	69.8145	3 1 3 1 1 1 1 4 4 1 2 1 1 1 1 1 1 2
413	159	102150	70.438	1 1 3 1 1 1 1 3 2 3 3 1 1 2 1 2 1 1

Table A.2 Results of the proposed model for 29-activity problem.

Sol. #	Dur (Day)	Cost (€)	Quality (%)	Mode Selection
1	174	1290800	90.781	2 3 3 2 1 1 1 3 2 1 1 3 3 1 2 3 2 2 1 1 2 3 3 1 3 3 3 3 1
2	176	1282200	90.635	1 2 3 2 1 2 1 3 2 1 1 3 3 1 2 3 2 2 2 1 1 3 3 1 3 3 3 3 1
3	176	1280200	90.519	1 2 3 2 1 2 1 2 2 1 1 3 3 2 2 3 1 1 2 1 3 3 3 1 3 3 3 1 1
4	177	1292900	91.024	1 1 3 2 1 2 1 3 2 1 1 3 3 2 2 3 1 2 2 1 3 3 3 1 3 3 3 3 1
5	177	1283900	91.014	1 2 3 2 1 1 1 3 2 1 1 3 2 1 2 3 2 2 2 2 3 3 3 1 3 3 3 2 1
6	179	1317300	93.082	2 3 3 2 1 2 1 3 2 1 1 2 3 1 2 3 2 2 2 2 3 3 3 1 3 3 3 3 1
7	179	1311300	93.007	1 3 3 2 1 2 1 3 2 1 1 3 3 2 2 3 3 1 3 2 2 3 3 1 2 3 3 3 1
8	179	1304300	92.665	2 2 3 2 1 1 1 3 2 1 1 3 3 2 2 2 2 2 2 2 3 3 3 1 3 3 3 2 1
9	179	1300300	92.425	2 3 3 2 1 2 1 3 2 1 1 3 3 1 3 3 2 1 2 1 2 3 3 1 3 3 3 1 1
10	179	1299300	92.135	2 1 2 2 1 1 1 2 2 1 1 3 3 2 2 3 2 2 3 2 3 3 3 1 3 3 3 3 1
11	179	1294300	92.045	2 1 2 2 1 1 1 2 2 1 1 3 3 2 2 3 2 2 3 2 3 3 3 1 3 3 3 2 1
12	179	1292300	91.657	2 2 3 2 1 1 1 3 2 1 1 2 2 2 2 3 2 2 2 2 2 3 3 1 3 3 3 3 1
13	179	1286300	91.654	2 2 3 2 1 1 1 2 2 1 1 3 3 2 3 3 2 2 1 2 1 3 3 1 3 3 3 2 1
14	179	1276300	90.037	1 1 2 2 1 1 1 2 2 1 1 3 3 2 2 3 2 2 1 2 3 3 3 1 3 3 3 2 1
15	179	1275300	89.8	2 1 3 2 1 1 1 2 2 1 1 3 3 2 2 3 2 2 2 1 1 3 3 1 3 3 3 2 1
16	179	1274300	88.917	1 1 2 2 1 2 1 1 2 1 1 3 3 1 2 3 2 2 2 1 3 3 3 1 3 3 3 2 1
17	180	1307000	93.288	2 3 3 2 1 1 1 2 2 1 1 3 2 2 3 3 2 2 3 2 2 3 3 1 3 3 3 3 1
18	180	1294000	91.734	2 1 3 2 1 2 1 3 2 1 1 3 2 2 2 3 2 1 2 2 3 3 3 1 3 3 3 2 1
19	180	1271000	89.525	1 2 3 2 1 1 1 3 2 1 1 3 3 1 2 3 1 2 1 2 1 3 3 1 3 3 3 1 1
20	180	1263000	88.93	1 1 3 2 1 1 1 2 2 1 1 3 2 1 2 3 2 1 2 2 2 3 3 1 3 3 3 2 1
21	181	1285700	91.127	1 2 3 2 1 2 1 3 2 1 1 2 3 1 2 3 2 2 2 2 1 3 3 1 3 3 3 2 1
22	181	1278700	90.377	2 2 3 2 1 1 1 3 2 1 1 2 2 1 2 3 2 2 2 2 1 3 3 1 3 3 3 2 1
23	181	1274700	89.75	1 2 3 2 1 1 1 2 2 1 1 3 3 2 2 3 2 2 2 1 1 3 3 1 3 3 3 1 1
24	182	1296400	92.548	1 3 3 2 1 2 1 2 2 1 1 3 3 2 3 3 2 1 3 1 2 2 3 1 3 3 3 2 1

Table A.2 Results of the proposed model for 29-activity problem.

Sol. #	Dur (Day)	Cost (€)	Quality (%)	Mode Selection
25	182	1293400	91.674	1 2 3 2 1 1 1 3 2 1 1 3 2 2 2 2 2 2 3 2 2 3 3 1 3 3 3 3 1
26	182	1275400	90.274	1 1 3 2 1 1 1 2 2 1 1 3 3 2 3 3 2 2 1 2 1 3 3 1 3 3 3 2 1
27	182	1265400	88.96	2 2 3 2 1 1 1 2 2 1 1 3 2 2 2 3 2 2 1 1 1 2 3 1 3 3 3 2 1
28	182	1258400	87.488	1 1 2 2 1 1 1 2 2 1 1 3 2 1 2 3 1 1 2 1 2 3 3 1 3 3 3 3 1
29	183	1270100	89.567	1 2 3 2 1 1 1 3 2 1 1 2 2 1 2 3 2 2 2 2 1 3 3 1 3 3 3 1 1
30	183	1257100	86.962	1 1 3 2 1 1 1 2 2 1 1 2 1 1 2 3 2 1 1 2 2 3 3 1 3 3 3 3 1
31	184	1321800	93.781	2 2 2 2 1 2 1 3 2 1 1 3 3 2 2 2 2 2 3 2 3 3 3 1 3 3 3 3 1
32	184	1271800	89.64	1 1 3 2 1 2 1 2 2 1 1 2 2 1 2 3 2 2 3 2 1 3 3 1 3 3 3 2 1
33	184	1268800	89.518	1 1 2 2 1 2 1 2 2 1 1 3 2 1 2 3 2 2 2 2 2 3 3 1 3 3 3 1 1
34	184	1261800	88.392	1 1 3 2 1 1 1 2 2 1 1 2 2 1 2 3 2 2 2 2 1 3 3 1 3 3 3 2 1
35	184	1259800	88.252	1 2 3 2 1 2 1 2 2 1 1 2 1 1 2 3 2 1 2 2 1 3 3 1 3 3 3 1 1
36	184	1257800	88.108	1 1 2 2 1 2 1 2 2 1 1 3 3 1 2 3 2 2 1 1 1 2 3 1 3 3 3 2 1
37	184	1256800	87.632	1 1 3 2 1 1 1 2 2 1 1 2 2 1 2 3 2 2 1 2 1 3 3 1 3 3 3 2 1
38	184	1254800	87.492	1 2 3 2 1 2 1 2 2 1 1 2 1 1 2 3 2 1 1 2 1 3 3 1 3 3 3 1 1
39	185	1295500	92.31	2 2 3 2 1 2 1 2 2 1 1 3 2 2 3 3 1 2 2 2 2 3 3 1 3 2 3 2 1
40	185	1283500	91.228	1 3 3 2 1 2 1 2 2 1 1 3 2 2 3 3 2 1 3 1 1 2 3 1 3 3 3 2 1
41	185	1274500	90.495	1 1 3 2 1 2 1 3 2 1 1 3 2 2 2 3 2 2 2 2 1 2 3 1 3 3 3 2 1
42	185	1245500	85.72	1 1 2 2 1 1 1 2 2 1 1 2 1 1 2 3 2 1 1 1 2 3 3 1 3 3 3 2 1
43	186	1321200	93.96	2 3 3 2 1 2 1 3 2 1 1 2 3 2 2 3 2 2 3 2 3 2 3 1 3 3 3 1 1
44	186	1274200	89.944	1 3 2 2 1 1 1 2 2 1 1 3 3 2 2 3 2 2 1 2 1 2 3 1 3 3 3 1 1
45	186	1273200	89.862	1 1 2 2 1 2 1 2 2 1 1 3 3 1 3 3 2 2 1 2 1 3 3 1 3 3 3 1 1
46	186	1270200	89.793	1 1 2 2 1 2 1 3 2 1 1 3 2 2 2 3 2 1 2 2 1 3 3 1 3 3 3 1 1
47	186	1253200	86.77	1 1 2 2 1 2 1 1 2 1 1 2 2 2 2 3 1 1 2 1 1 3 3 1 3 3 3 2 1
48	186	1251200	86.72	1 1 2 2 1 1 1 2 2 1 1 2 2 2 2 3 1 2 1 1 1 3 3 1 3 3 3 2 1

Table A.2 Results of the proposed model for 29-activity problem.

Sol. #	Dur (Day)	Cost (€)	Quality (%)	Mode Selection
49	187	1305900	93.024	1 3 3 2 1 1 1 3 2 1 1 3 3 2 3 2 2 2 3 2 1 2 3 1 3 3 3 3 1
50	188	1249600	86.84	1 1 2 2 1 1 1 2 2 1 1 2 2 1 2 3 2 1 1 2 1 3 3 1 3 3 3 1 1
51	188	1243600	81.518	1 1 2 1 1 1 1 1 1 1 1 3 2 1 2 3 1 1 1 1 2 3 3 1 3 3 3 2 1
52	189	1273300	89.957	1 1 3 2 1 2 1 3 2 1 1 2 2 2 2 3 2 2 2 2 1 2 3 1 3 3 3 1 1
53	189	1271300	89.933	1 1 2 2 1 1 1 3 2 1 1 2 2 2 2 3 2 2 3 2 1 2 3 1 3 3 3 2 1
54	189	1244300	85.34	1 1 2 2 1 1 1 2 2 1 1 2 1 1 2 3 2 2 1 1 1 3 3 1 3 3 3 1 1
55	191	1268700	89.328	1 2 3 2 1 2 1 2 2 1 1 2 2 1 2 3 2 2 2 2 1 2 3 1 3 2 3 1 1
56	191	1243700	84.39	1 1 1 2 1 1 1 1 2 1 1 2 2 1 2 3 1 1 1 1 1 3 3 1 3 3 3 2 1
57	192	1340400	94.025	2 3 2 2 1 2 1 3 2 1 1 3 3 1 3 3 3 2 2 2 3 3 2 1 3 3 3 2 1
58	192	1249400	86.402	1 1 3 2 1 1 1 2 2 1 1 2 1 1 2 3 1 1 2 2 1 2 3 1 3 3 3 1 1
59	192	1240400	82.75	1 1 2 1 1 1 1 1 2 1 1 2 2 1 2 3 2 1 1 1 1 2 3 1 3 3 3 2 1
60	194	1238800	82.06	1 1 2 1 1 1 1 1 2 1 1 1 1 1 2 3 2 1 1 2 1 3 3 1 3 3 3 2 1
61	195	1244500	85.826	1 1 2 2 1 1 1 2 2 1 1 2 1 1 2 3 2 1 1 2 1 2 3 1 3 2 3 2 1
62	195	1235500	80.51	1 1 2 1 1 1 1 1 1 1 1 2 2 1 2 3 1 1 1 1 1 2 3 1 3 3 3 2 1
63	196	1244200	85.47	1 1 2 2 1 2 1 1 2 1 1 1 1 1 2 3 2 1 2 2 1 2 3 1 3 3 3 1 1
64	197	1317900	93.546	2 3 3 2 1 2 1 3 2 1 1 3 3 2 3 2 2 1 2 2 2 1 3 1 3 3 3 2 1
65	197	1242900	84.28	1 1 1 2 1 1 1 1 2 1 1 2 1 1 2 3 1 1 1 2 1 2 3 1 3 3 3 2 1
66	198	1242600	83.563	1 1 3 2 1 2 1 2 2 1 1 1 1 1 1 1 1 1 2 1 1 3 3 1 3 3 3 2 1
67	198	1236600	82.361	1 1 2 2 1 2 1 1 2 1 1 2 1 1 1 2 1 1 1 1 1 3 3 1 2 3 3 2 1
68	202	1242400	83.87	1 1 1 2 1 1 1 1 2 1 1 2 1 1 2 3 2 1 1 2 1 2 3 1 2 3 3 1 1
69	202	1235400	80.771	1 1 2 2 1 1 1 1 1 1 1 2 1 1 1 2 1 2 1 1 1 2 3 1 3 3 3 2 1
70	204	1234800	80.391	1 1 1 2 1 1 1 1 1 1 1 2 1 1 1 2 1 2 1 1 1 2 3 1 3 3 3 2 1
71	208	1234600	82.031	1 1 2 2 1 1 1 2 2 1 1 1 1 1 1 1 2 2 1 1 1 2 3 1 2 3 3 2 1
72	212	1233400	78.051	1 1 2 1 1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 2 3 1 2 3 3 1 1

Table A.2 Results of the proposed model for 29-activity problem.

Sol. #	Dur (Day)	Cost (€)	Quality (%)	Mode Selection
73	219	1234300	78.305	1 1 1 2 1 1 1 1 1 1 1 2 1 1 1 1 2 1 1 2 1 2 3 1 3 3 1 1 1

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
1	534	6059140	83.151	1 1 4 1 2 1 1 4 5 5 1 4 1 1 1 2 4 2 3 4 5 5 3 2 5 3 3 3 3 3 3 3 3 2 5 3 4 3 1 2 4 4 2 4 4 4 3 1 5 4 5 5 5 5 4 5 5 5 4 5 5 5 5
2	536	6055290	83.001	1 1 4 1 2 1 1 4 5 5 1 4 1 1 1 2 4 2 3 4 5 5 3 2 5 3 3 3 3 3 3 3 3 2 5 3 4 3 1 2 4 4 2 4 4 4 3 1 5 4 5 5 5 5 4 5 5 5 5 3 5 5 4
3	537	6002025	82.351	4 3 1 1 3 3 1 4 4 5 2 3 1 2 3 3 3 4 1 2 1 3 2 4 5 1 3 2 5 4 3 1 4 2 5 3 4 5 2 4 4 3 2 5 3 4 4 5 5 4 4 5 1 2 3 2 5 5 3 5 5 2 5
4	538	6099505	87.191	4 4 2 2 4 3 2 4 5 5 1 2 4 1 1 3 4 2 3 3 4 3 2 4 5 3 5 3 4 3 4 3 4 5 5 2 3 5 5 1 4 5 3 4 4 2 4 4 5 3 2 3 2 5 2 5 5 5 5 4 3 5 5
5	538	5950430	84.721	4 1 3 3 4 4 2 2 1 4 1 4 4 4 1 2 4 4 1 1 2 2 2 4 5 3 4 3 5 3 4 3 3 2 5 3 3 4 4 1 4 2 2 4 1 3 4 4 5 2 2 5 5 5 5 1 5 3 3 5 5 5 5
6	539	6087635	85.751	2 4 4 3 1 3 2 4 5 5 5 5 4 1 1 2 4 1 1 2 2 4 2 1 2 3 5 3 3 1 3 3 1 3 5 3 3 3 5 4 4 4 5 5 4 4 4 5 5 4 3 5 3 5 3 5 5 5 5 5 5 5 5
7	539	6059690	85.011	1 3 3 3 4 2 1 4 5 3 5 3 4 3 4 5 4 2 3 4 2 5 2 1 3 1 4 2 1 2 5 2 3 5 5 1 4 1 4 3 4 4 4 4 4 3 4 5 5 4 1 3 2 2 5 1 5 3 2 1 5 3 5
8	539	5936780	83.791	4 1 3 3 4 4 2 2 1 4 1 4 4 4 1 2 4 4 1 1 2 2 2 4 5 3 4 3 5 3 4 3 3 2 5 3 3 4 4 1 4 2 2 4 1 3 4 4 5 2 2 5 5 5 5 1 5 5 4 2 5 1 5
9	540	6085905	86.671	4 4 2 2 4 3 2 4 5 5 1 2 4 1 1 3 4 2 3 3 4 3 2 4 5 3 5 3 4 3 4 3 4 5 5 2 3 5 5 1 4 5 3 4 4 2 4 4 5 3 2 3 2 5 2 2 4 5 3 5 4 5 3
10	540	5949530	84.651	4 1 3 3 4 4 2 2 1 4 1 4 4 4 1 2 4 4 1 1 2 2 2 4 5 3 4 3 5 3 4 3 3 2 5 3 3 4 4 1 4 2 2 4 1 3 4 4 5 2 2 5 5 5 5 1 5 5 4 2 5 5 4
11	541	6042355	85.341	4 2 1 3 4 3 3 4 4 4 1 4 2 4 1 4 4 2 2 3 5 5 3 2 2 3 3 4 1 4 3 4 3 2 5 5 5 1 3 4 4 4 4 5 2 3 1 4 5 4 5 2 1 4 5 4 5 2 2 4 5 4 5
12	542	6029550	85.781	4 4 3 2 3 1 4 2 5 5 2 3 1 4 3 2 4 4 2 3 3 3 4 2 3 4 2 5 5 3 5 2 3 3 4 1 4 2 5 4 4 3 4 2 5 3 1 5 5 2 4 5 1 5 3 2 5 1 3 2 5 3 5
13	542	6019830	84.761	4 4 3 3 1 4 1 2 5 5 1 1 2 2 4 4 2 2 2 3 3 1 4 3 2 5 3 3 5 3 4 5 3 2 5 3 4 1 5 4 4 4 4 4 3 1 1 4 5 1 5 3 1 5 2 5 5 5 5 5 5 5 5
14	542	5995190	84.731	4 3 2 3 4 2 2 1 4 5 5 5 3 3 3 3 2 1 2 1 4 3 1 5 3 4 4 1 4 4 3 1 3 4 5 1 5 3 4 3 4 4 4 5 3 1 4 3 5 1 4 4 2 5 1 5 5 5 1 5 5 4 5
15	544	6014830	85.661	1 3 3 2 3 4 4 3 5 5 3 2 2 4 1 1 4 2 2 1 3 3 5 2 4 3 5 5 3 5 3 4 3 5 5 5 3 5 4 1 4 3 2 4 3 3 3 1 5 2 2 5 1 5 4 4 3 3 5 1 4 5 5
16	544	5933840	83.621	3 4 4 3 3 1 2 4 3 4 2 4 3 4 1 3 4 2 2 4 1 4 3 2 1 3 3 3 5 3 5 1 4 2 4 2 4 1 3 1 4 3 4 3 3 1 3 4 5 2 3 5 5 5 2 2 4 4 1 4 5 2 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
17	545	6039740	86.001	1 3 1 3 4 1 1 1 4 5 1 5 4 4 2 2 4 2 2 2 2 4 2 4 4 3 3 3 3 3 3 3 4 3 5 3 5 3 5 1 4 4 2 2 4 5 4 5 5 2 2 5 5 5 5 4 3 5 5 5 5 5 5
18	545	5924440	82.901	2 2 1 3 4 4 4 4 4 5 1 1 2 4 1 2 2 2 1 3 2 5 3 3 2 3 5 3 3 3 3 1 3 2 5 1 5 1 3 4 2 3 2 4 1 2 3 5 5 3 2 5 5 5 3 3 5 4 5 5 5 2 5
19	546	6129740	87.221	4 4 1 3 4 1 1 4 1 4 1 1 2 1 1 2 4 4 3 4 2 2 5 5 3 5 3 5 3 5 5 4 3 5 5 5 3 3 4 4 3 5 4 4 4 2 4 4 5 4 1 4 5 5 5 5 5 3 4 5 5 5 5
20	546	6016400	86.581	2 4 4 3 3 1 2 3 1 4 4 2 4 4 3 2 4 4 3 3 2 2 4 4 5 3 5 3 5 4 5 3 1 5 5 2 3 1 4 5 4 5 1 3 2 2 3 3 5 3 2 2 2 5 1 3 4 4 5 3 4 5 1
21	546	5999430	84.771	1 4 2 3 1 4 1 3 5 5 1 3 4 4 4 3 3 1 2 2 2 1 2 5 4 4 2 5 4 2 3 4 3 1 5 3 3 3 3 4 4 5 4 3 1 3 5 2 5 3 3 1 4 5 5 5 5 3 5 1 5 5 4
22	546	5948690	84.251	4 3 4 2 3 4 3 4 4 3 5 1 3 3 3 1 4 3 1 3 2 5 1 4 3 1 4 1 1 1 4 1 5 3 4 4 5 5 5 1 4 5 1 4 1 4 2 1 5 1 1 5 5 4 4 3 5 5 5 2 5 5 1
23	546	5887870	82.111	4 1 1 2 1 1 2 1 3 5 5 5 1 3 4 3 4 2 3 2 1 4 2 1 2 1 1 1 3 1 3 4 3 3 5 1 4 3 4 4 4 1 2 3 1 2 3 1 5 2 4 5 4 5 5 3 5 3 3 5 5 5 5
24	547	6165720	87.571	4 2 4 3 1 4 2 2 3 5 3 3 4 4 1 5 3 3 3 3 2 4 4 2 5 3 3 3 5 3 3 5 3 4 5 2 2 4 4 4 1 5 3 4 3 5 4 3 5 4 3 5 5 5 5 5 4 5 5 5 4 4 5
25	547	5932515	84.081	1 4 1 3 4 3 1 1 3 5 2 1 2 4 2 2 2 2 3 2 2 3 4 3 2 3 5 5 2 3 3 3 2 1 5 3 3 3 3 4 4 5 1 5 1 4 1 1 5 4 4 3 1 5 3 3 5 3 3 2 5 5 5
26	547	5924890	83.001	2 2 1 3 4 4 4 4 4 5 1 1 2 4 1 2 2 2 1 3 2 5 3 3 2 3 5 3 3 3 3 1 3 2 5 1 5 1 3 4 2 3 2 4 1 2 3 5 5 3 2 5 5 5 3 3 5 4 5 4 5 3 4
27	548	6080710	86.721	4 1 3 3 1 4 1 1 4 5 1 1 4 4 2 2 4 3 3 4 2 4 3 2 4 5 3 3 3 5 3 4 3 3 5 3 4 3 3 4 3 4 4 2 4 2 4 4 5 4 5 3 3 5 5 4 5 4 5 5 5 5 5
28	548	6008860	85.191	3 3 3 2 3 1 3 3 3 5 3 3 4 3 2 2 2 1 3 3 1 5 3 4 2 2 5 3 2 3 5 3 3 2 5 4 2 4 5 4 3 3 2 5 3 4 5 4 5 4 1 5 5 5 5 1 5 2 1 2 2 3 5
29	548	5911160	82.321	2 4 1 1 1 4 2 1 3 5 5 5 1 3 4 3 4 2 3 2 1 4 2 1 2 1 1 1 3 1 3 4 3 3 5 1 4 3 4 4 4 1 2 3 1 2 3 1 5 2 4 5 4 5 5 3 5 3 3 5 5 5 5
30	549	6062965	86.601	3 4 1 3 4 3 4 4 4 5 1 1 2 4 1 2 3 1 3 4 1 2 3 5 2 4 3 3 4 2 5 4 3 5 5 3 3 2 2 5 2 4 3 4 3 4 3 5 5 3 4 5 4 5 5 5 5 5 3 4 4 4 4
31	549	6004815	86.191	1 4 3 3 4 3 1 4 5 5 3 3 4 4 4 5 4 2 3 4 4 5 2 1 3 1 4 4 4 3 1 3 2 1 3 2 3 3 4 4 4 3 3 5 2 4 3 4 5 2 4 1 3 5 5 3 5 2 5 5 5 3 5
32	549	5989200	84.781	4 2 1 2 3 4 2 2 5 4 4 2 3 4 4 3 2 1 2 3 5 5 2 3 5 5 4 3 4 2 2 2 2 5 3 3 5 3 5 2 4 2 5 5 3 2 1 2 5 4 1 2 5 5 2 5 5 1 1 1 5 5 3

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
33	549	5986130	84.751	4 1 2 3 2 2 1 2 1 5 3 1 1 4 1 2 4 1 3 2 2 4 2 2 4 3 3 3 3 3 3 3 3 5 3 4 2 4 4 4 4 1 4 3 4 4 5 4 2 5 5 5 5 3 5 5 5 5 5 5
34	549	5916940	83.841	4 4 2 3 3 4 3 2 5 5 2 3 1 2 1 2 3 3 3 2 3 2 2 2 3 1 3 3 3 4 2 5 3 1 5 1 4 3 4 4 4 1 2 3 1 2 3 1 5 2 4 5 4 5 5 3 5 3 3 5 5 5 5
35	549	5904590	83.581	4 4 1 3 3 4 2 4 1 4 4 5 3 3 3 2 4 2 1 4 3 2 2 5 4 2 4 5 4 2 2 2 3 2 4 1 4 4 5 4 3 4 3 4 3 1 2 2 5 1 1 1 2 5 1 2 5 2 1 4 5 4 4
36	549	5877555	81.841	2 4 3 1 3 3 1 1 1 5 1 1 1 3 4 2 4 4 2 2 5 2 2 2 5 1 4 3 3 3 1 3 4 1 5 1 3 3 4 2 4 3 4 4 2 4 3 3 5 2 1 1 2 5 1 5 5 5 4 1 5 1 5
37	550	5963880	84.901	1 4 2 3 2 2 4 3 3 5 2 4 4 4 1 2 4 4 1 1 2 3 3 3 3 3 3 3 2 3 2 4 3 2 4 5 3 5 4 5 4 4 4 4 1 2 5 4 5 1 1 5 5 5 5 3 4 2 4 4 5 5 5
38	550	5945790	84.381	4 4 4 2 4 4 1 3 4 5 1 1 4 4 3 2 4 3 2 2 2 2 2 4 1 3 4 3 1 1 4 2 1 5 3 5 5 1 4 4 4 3 4 1 2 1 4 5 4 4 4 1 4 3 4 5 5 5 5 5 1 5
39	551	5992665	85.261	4 3 3 3 3 3 1 3 3 5 4 5 1 4 2 4 4 4 3 4 3 2 2 1 5 1 5 3 2 2 4 4 2 3 5 4 3 3 3 3 4 1 4 1 5 2 1 3 5 2 1 3 2 5 1 3 4 4 5 1 2 5 5
40	552	5976565	85.641	3 4 4 3 4 3 3 4 1 3 3 3 4 4 2 4 4 4 2 3 1 3 2 1 2 5 5 2 1 3 5 3 1 3 4 4 2 4 5 2 2 4 5 3 1 3 2 3 5 1 2 2 3 5 5 2 5 5 2 1 5 5 5
41	552	5876665	81.681	2 4 4 1 4 3 4 1 4 5 3 1 1 1 2 1 3 1 2 2 1 4 4 2 5 4 5 1 4 1 1 3 2 3 4 2 5 2 4 4 4 4 2 4 1 2 1 2 5 4 1 1 1 4 4 2 4 3 4 5 5 4 5
42	552	5843450	80.331	1 2 3 2 4 1 1 2 1 5 1 5 2 2 1 2 3 2 2 3 2 2 1 2 5 3 5 1 3 1 3 1 2 2 5 4 5 4 4 5 4 4 1 2 2 2 1 1 5 2 2 3 1 5 1 5 3 2 5 4 5 2 5
43	553	5901240	83.621	1 3 4 2 4 1 4 4 4 1 1 4 3 4 1 2 4 2 3 2 2 1 2 4 3 2 4 3 5 1 4 3 3 3 3 3 2 4 4 4 2 1 4 1 2 2 4 5 4 1 5 1 5 5 3 5 1 5 2 5 5 5
44	553	5875960	80.451	1 2 3 1 1 1 1 1 1 5 1 1 1 3 1 2 4 2 1 2 2 2 2 2 3 5 1 3 3 3 3 1 3 5 3 2 3 4 2 3 4 4 4 1 2 4 4 5 2 4 3 5 5 5 3 5 5 5 5 5 5 5
45	554	6162665	87.401	3 2 4 2 3 3 4 4 3 1 5 5 3 4 4 1 4 4 2 4 1 2 2 2 2 2 4 5 5 4 5 5 3 5 5 4 5 3 4 5 4 5 4 4 1 3 5 5 5 4 5 5 3 5 4 4 4 1 5 3 3 5
46	554	5895860	82.691	3 1 3 3 4 1 1 2 1 4 1 4 1 4 4 2 2 3 3 2 2 2 2 4 4 4 3 1 4 3 4 3 2 3 5 1 3 1 4 4 2 4 4 3 1 2 3 3 5 1 1 4 2 5 5 5 5 5 3 2 5 5 3
47	554	5865430	81.111	1 4 1 3 1 1 1 3 3 4 1 2 1 1 2 2 4 3 3 3 2 1 2 5 1 1 3 2 5 4 3 1 5 3 4 1 3 2 4 2 3 4 1 4 1 4 4 1 5 2 1 1 5 5 2 5 4 2 3 4 5 5 5
48	555	6126670	87.241	1 3 1 3 1 1 4 1 1 5 1 5 4 4 1 2 2 2 2 3 2 2 4 2 5 3 5 4 5 3 3 4 3 4 5 3 2 3 5 5 3 4 5 4 4 4 3 5 5 4 5 5 5 5 4 5 5 5 3 5 5 5 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
49	555	5987090	85.821	4 4 3 3 4 2 2 1 2 5 4 2 3 4 4 3 2 1 2 3 5 5 2 3 5 5 4 3 4 2 2 2 2 5 3 3 5 3 5 2 4 2 5 5 3 2 1 2 5 4 1 2 5 5 2 5 5 1 1 1 5 5 3
50	555	5919390	84.371	4 3 4 2 4 4 3 1 2 4 1 1 2 4 3 2 2 2 3 3 3 2 2 2 4 3 4 1 4 2 2 1 3 1 4 4 5 3 4 3 4 5 3 5 2 3 1 4 5 2 3 5 4 5 5 1 4 4 4 2 4 5 3
51	556	5911060	83.751	1 4 1 3 4 1 4 4 1 4 1 1 1 4 2 2 3 2 1 2 2 2 4 2 4 1 3 3 5 3 3 3 3 3 5 3 2 5 4 4 3 2 4 2 2 2 1 1 5 4 4 4 5 5 1 4 5 4 1 4 5 5 5
52	556	5874400	82.211	4 4 2 3 3 1 1 4 1 3 1 3 3 1 1 2 2 1 1 3 3 2 5 5 5 2 4 2 3 2 3 4 3 3 3 3 3 1 4 4 4 5 1 5 1 3 1 4 5 3 4 1 5 5 3 1 5 5 4 2 5 5 5
53	557	6185040	87.701	2 4 1 3 4 1 3 1 5 4 3 5 3 3 1 2 3 4 3 3 4 4 2 4 5 3 5 4 1 5 1 4 4 5 5 3 4 5 4 4 4 4 4 4 5 5 5 5 4 3 3 5 5 3 5 4 3 3 5 3 1 5
54	557	5854760	81.271	2 1 4 3 3 1 4 4 1 4 1 1 3 3 3 1 3 2 1 3 2 2 1 1 2 3 3 3 2 3 3 3 1 3 5 1 4 2 3 1 3 2 4 2 1 2 1 5 5 3 4 4 4 5 5 3 5 2 3 5 5 3 5
55	558	5971995	85.291	4 4 2 3 1 3 4 1 2 5 2 2 3 4 4 2 3 2 2 2 1 4 5 5 5 1 5 2 4 2 5 2 4 3 3 2 4 4 1 4 3 1 1 5 3 2 2 5 5 4 4 3 3 5 3 4 5 5 2 1 4 5 5
56	558	5955875	85.061	4 3 4 3 3 3 2 4 4 5 1 1 2 4 4 2 3 3 1 2 5 1 1 2 5 4 5 3 4 5 2 4 3 3 3 2 4 3 4 3 3 3 1 3 2 4 1 2 5 4 2 5 4 5 2 5 5 3 1 5 5 5 5
57	558	5952130	84.931	4 4 4 3 3 2 1 1 5 2 1 1 3 4 1 2 3 3 1 4 2 2 2 1 2 3 5 3 5 3 3 4 4 2 3 3 3 3 5 1 3 4 4 4 2 2 4 4 5 4 4 2 4 5 5 5 5 5 5 2 5 5 5
58	558	5948630	84.571	4 4 4 3 3 2 1 1 5 2 1 1 3 4 1 2 3 3 1 4 2 2 2 1 2 3 5 3 5 3 3 4 4 2 3 3 3 3 4 1 3 4 4 4 2 2 4 4 5 4 4 2 4 5 3 5 5 2 5 5 5 5 5
59	558	5899660	84.001	4 4 4 3 4 1 1 4 1 5 2 5 4 4 2 2 2 1 3 3 3 1 3 1 3 1 2 3 1 3 1 3 1 1 4 1 4 3 4 4 3 4 3 4 3 3 1 2 5 4 4 3 1 5 4 3 5 5 5 1 5 3 5
60	559	5938300	84.461	1 4 3 2 4 4 4 3 1 5 2 2 4 4 2 2 3 1 3 2 1 2 1 5 2 1 3 3 3 2 3 5 5 3 3 3 1 3 4 1 4 4 4 4 4 1 1 3 5 3 4 5 4 5 4 3 3 4 4 2 5 5 5
61	559	5885780	82.411	2 3 1 3 1 1 1 1 1 5 1 1 2 4 4 2 1 4 3 1 2 2 2 5 2 1 3 5 3 3 2 2 4 1 4 3 3 1 4 4 4 5 1 5 1 3 1 4 5 3 4 1 5 5 3 1 5 5 4 2 5 5 5
62	560	6170530	87.741	4 4 1 2 3 4 4 1 5 5 5 1 1 3 4 2 4 4 3 3 3 2 5 3 5 1 4 1 4 3 5 4 1 4 5 5 3 4 5 1 3 4 4 4 4 4 4 4 5 4 2 4 5 4 2 3 2 5 4 3 5 5 3
63	560	5890700	82.791	4 3 2 3 3 1 1 4 4 3 5 1 3 3 3 1 4 3 1 3 2 5 1 4 3 1 4 1 1 1 4 1 5 3 4 4 5 5 5 1 4 5 1 1 1 4 2 1 5 1 1 3 2 5 5 5 5 3 1 1 3 4 4
64	561	6072075	86.761	1 4 4 2 2 3 4 3 1 5 5 3 4 4 4 4 1 3 3 2 2 1 4 2 4 1 5 5 5 3 5 3 2 5 3 4 2 3 4 3 4 4 4 4 2 4 4 5 5 4 1 2 2 5 4 3 5 5 5 2 3 5 2

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
65	561	5973610	85.391	1 4 1 3 2 1 4 3 5 3 5 3 4 3 4 1 3 1 3 4 3 4 3 4 2 2 4 1 5 2 1 5 3 4 3 2 5 3 5 4 4 1 3 4 3 4 4 4 5 1 1 4 5 5 1 5 5 5 1 5 5 3 5
66	561	5873850	81.691	1 3 3 1 3 2 2 4 5 5 1 3 1 4 2 1 3 1 3 3 2 2 2 2 2 3 2 2 5 3 3 3 3 3 3 3 2 3 4 4 3 4 4 2 2 4 3 3 5 2 2 1 4 5 2 4 5 3 3 4 5 3 5
67	561	5849940	81.211	1 4 1 2 4 4 2 4 4 5 1 3 1 3 1 1 1 1 3 1 2 2 1 2 2 2 3 2 1 1 3 3 4 3 3 1 4 4 4 2 4 3 2 3 3 2 4 4 5 2 2 2 4 5 5 5 5 5 5 5 5 1 5
68	562	5898360	83.421	2 4 1 3 1 4 3 2 4 2 1 5 1 4 1 2 4 3 3 3 1 5 3 5 5 1 5 1 5 5 1 1 1 2 3 2 4 5 2 1 3 5 1 4 2 4 4 2 5 3 4 2 1 5 3 4 5 2 1 2 2 5 5
69	562	5888390	82.971	4 4 4 3 1 1 2 2 1 5 1 4 1 3 4 1 2 4 3 1 1 2 4 3 4 2 2 5 5 2 3 2 4 1 3 3 4 3 4 1 4 1 5 2 1 3 3 5 5 3 2 1 2 5 5 5 5 3 1 5 5 3 5
70	562	5883200	82.341	4 2 2 3 2 1 3 4 1 5 2 2 1 3 1 5 2 2 3 2 2 1 2 2 4 4 5 3 5 4 2 5 2 2 3 4 3 2 4 4 2 3 1 3 2 4 1 2 5 2 3 5 2 5 3 3 5 5 2 2 5 5 5
71	562	5872900	81.701	2 3 1 3 4 1 1 3 1 2 1 5 1 1 1 1 3 1 3 2 2 4 2 5 2 2 3 3 3 3 2 4 3 3 3 1 3 3 4 4 4 5 1 4 2 4 2 4 5 3 4 5 1 5 1 5 5 1 5 5 5 5 5
72	562	5863815	81.511	4 2 1 3 4 3 1 1 3 3 1 2 1 2 3 2 2 2 3 2 2 2 3 2 2 1 3 4 5 3 3 1 3 3 3 5 3 5 4 4 4 3 2 4 1 4 1 2 5 3 2 3 3 5 4 2 5 5 4 3 5 1 5
73	562	5848330	81.091	4 1 2 3 1 1 1 2 5 1 1 1 2 3 4 1 4 1 2 3 2 5 1 1 5 1 3 2 1 1 3 3 4 3 3 1 4 4 4 2 4 3 2 3 3 2 4 4 5 2 2 2 4 5 5 5 5 5 5 5 5 1 5
74	563	5823890	80.771	1 4 1 2 4 4 2 4 4 5 1 3 1 3 1 1 1 1 3 1 2 2 1 2 2 2 3 2 1 1 3 3 4 3 3 1 4 4 4 2 4 3 2 3 3 2 4 4 5 2 2 2 4 5 5 5 4 5 1 2 5 2 5
75	564	6059730	86.821	4 4 1 2 3 4 4 1 5 5 5 1 1 3 4 2 4 4 3 3 3 2 5 3 5 1 4 1 4 3 5 4 1 4 5 5 2 5 4 3 2 2 4 4 4 4 1 4 1 3 4 2 5 2 1 5 4 1 4 5 5 5
76	564	5997115	86.231	4 3 4 3 3 3 2 4 4 5 1 1 2 4 4 3 4 1 3 3 2 2 5 1 2 2 5 3 1 3 2 3 3 1 3 3 3 3 4 5 4 2 3 3 4 4 4 4 5 4 4 5 2 5 5 4 5 2 5 1 5 5 1
77	564	5883440	83.051	4 4 4 3 1 1 2 2 1 5 1 4 1 3 4 1 2 4 3 1 1 2 4 3 4 2 2 5 5 2 3 2 4 1 3 3 4 3 4 1 4 1 5 2 1 3 3 5 5 3 2 1 2 5 3 2 5 4 5 1 5 5 4
78	565	6065915	87.961	3 4 2 3 4 3 2 2 4 4 1 4 4 4 4 2 4 3 3 2 4 1 1 5 4 3 5 4 3 3 3 2 4 3 5 4 5 5 5 4 4 2 4 5 3 5 4 4 4 1 1 4 3 5 2 4 5 4 3 2 4 5 4
79	565	5909550	84.541	4 4 1 2 3 1 2 2 1 3 1 3 3 4 4 2 4 3 3 3 4 2 5 4 2 3 5 5 3 1 2 5 3 3 3 3 3 4 4 4 4 4 1 4 2 2 5 2 5 1 1 3 2 5 1 1 4 4 4 2 5 3 5
80	565	5894390	83.551	4 4 2 2 4 1 3 1 1 3 1 1 1 4 4 3 4 2 1 3 2 5 3 3 2 3 5 1 1 3 3 2 5 3 3 2 3 3 4 4 3 2 4 4 2 4 4 4 5 2 1 2 3 5 3 4 4 5 5 3 5 3 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
81	565	5859775	82.621	4 3 4 3 2 3 2 3 3 4 2 2 2 4 4 1 3 1 3 3 2 1 1 2 5 2 3 2 4 2 1 2 3 2 3 5 3 4 2 4 4 2 4 4 1 4 1 4 5 2 1 1 2 5 1 5 4 4 4 5 5 3 3
82	565	5817400	79.571	1 1 3 3 2 1 3 4 1 2 2 1 2 2 1 3 2 1 1 2 1 2 2 2 2 1 5 4 5 3 4 4 3 1 3 3 3 1 4 4 4 2 4 4 1 4 4 2 5 3 1 4 2 5 5 3 5 2 2 1 5 5 5
83	566	5972530	86.021	4 4 3 3 1 1 3 1 4 5 1 2 3 4 4 2 3 4 1 3 2 3 4 2 4 1 5 3 3 2 3 4 3 3 5 3 3 3 5 4 4 2 4 4 1 2 2 4 4 3 2 1 5 5 4 5 2 5 5 5 5 5 5
84	566	5960180	85.091	4 4 3 3 1 1 3 1 4 5 1 2 3 4 4 2 3 4 1 3 2 3 4 2 4 1 5 3 3 2 3 4 3 3 5 3 3 3 5 4 4 2 4 4 1 2 2 4 4 3 2 1 5 5 4 5 2 5 5 5 5 1 5
85	566	5850930	81.241	3 4 3 3 1 1 3 2 1 4 1 2 1 4 1 2 3 2 1 3 2 2 2 3 2 2 3 3 3 1 3 1 3 1 4 3 3 3 3 4 4 4 4 5 3 2 2 1 4 4 2 5 2 5 5 5 4 3 3 1 5 1 5
86	566	5810795	80.471	1 4 3 3 3 3 1 1 1 5 1 1 1 4 1 2 4 2 1 2 3 1 1 2 2 4 3 4 3 4 3 3 3 2 3 1 2 1 3 2 4 2 1 3 2 1 1 5 5 1 4 5 5 5 1 4 5 5 5 5 3 5
87	567	5955740	85.571	4 4 2 3 3 2 1 4 1 3 1 3 3 4 1 1 3 1 3 4 3 4 3 4 2 2 4 1 5 2 1 5 3 4 3 2 5 3 5 4 4 1 3 4 3 4 4 4 5 3 2 2 4 5 3 3 5 5 3 5 4 5 3
88	567	5884850	83.081	1 1 1 3 2 1 1 1 2 5 1 4 3 4 4 2 3 2 3 1 4 2 2 2 5 3 5 3 3 1 2 1 2 3 3 3 3 3 4 2 4 4 1 1 1 3 1 4 5 4 1 5 5 5 3 5 5 5 5 3 5 5 5
89	567	5804580	79.291	1 2 4 1 1 1 1 4 2 5 1 5 2 3 1 1 1 1 1 1 2 2 5 2 2 3 5 3 1 1 3 1 1 2 3 1 4 3 4 1 4 4 2 2 1 4 4 4 5 3 2 3 2 5 4 1 5 5 1 5 5 5 5
90	568	5947440	84.601	3 2 4 3 3 2 4 2 2 4 1 2 1 4 4 4 4 1 2 4 2 2 3 1 4 1 5 3 1 3 1 2 2 5 5 3 3 5 5 3 3 4 1 2 3 5 4 2 5 2 3 4 1 4 2 2 5 4 1 3 5 4 3
91	568	5890960	83.331	1 3 1 1 1 2 4 1 1 3 1 3 1 4 4 2 4 1 3 2 2 2 4 5 3 4 3 5 3 4 3 3 2 5 3 3 4 4 1 4 2 2 4 1 3 4 4 3 3 1 5 1 5 3 4 5 5 5 3 5 5 5
92	568	5843140	81.261	1 3 1 3 3 1 1 1 1 5 1 3 4 4 1 2 3 2 1 2 2 1 4 1 3 3 5 1 3 2 3 3 3 1 4 3 4 4 5 5 3 2 4 1 3 1 4 2 5 1 4 2 3 4 1 1 5 1 3 2 5 5 4
93	568	5838055	81.071	1 2 1 3 3 3 1 1 1 2 3 1 1 3 3 2 4 1 2 2 1 2 2 2 2 1 5 4 5 3 4 4 3 1 3 3 3 1 4 4 4 2 4 4 1 4 4 2 5 3 1 4 2 5 5 3 5 2 2 1 5 5 5
94	568	5798795	77.111	2 1 4 1 1 3 1 4 1 2 5 1 1 2 1 1 3 3 2 1 2 2 2 2 2 3 3 1 4 3 3 5 3 2 3 3 5 2 1 4 4 1 1 4 1 1 4 1 5 1 3 5 3 5 3 4 5 2 3 1 5 2 5
95	569	6028650	86.671	2 1 1 3 3 4 4 2 3 4 1 1 4 4 4 2 3 3 3 2 2 5 2 2 5 3 4 5 3 2 3 1 3 2 5 3 3 4 4 3 4 4 4 4 1 4 3 4 3 4 4 5 2 5 5 4 5 5 5 5 5 5 5
96	569	5882015	82.981	3 4 4 2 4 3 1 1 5 4 2 5 4 4 3 1 3 1 1 2 2 3 2 2 4 3 5 2 2 5 3 1 1 2 3 2 1 3 2 2 4 4 1 2 2 5 5 1 5 2 3 5 4 5 4 4 5 2 1 4 3 5 4

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
97	569	5803940	78.161	2 4 1 3 3 4 1 2 2 4 1 5 1 2 1 2 1 2 1 2 1 2 3 2 2 3 2 3 4 2 5 4 4 2 4 2 4 2 1 4 4 3 1 2 1 2 1 3 5 2 1 1 1 5 5 1 1 3 5 1 5 4 5
98	570	6056580	86.821	3 3 1 3 4 4 3 1 5 5 1 1 4 3 2 1 4 4 2 2 2 4 5 2 2 3 3 3 5 2 3 5 3 2 5 3 4 3 4 4 4 4 5 3 5 4 4 5 3 1 4 5 5 5 1 5 5 5 2 5 5 5 5
99	570	5873420	82.721	3 4 4 3 1 4 1 2 1 2 3 4 3 4 3 1 4 3 1 3 3 2 2 2 2 2 3 2 3 2 3 1 1 2 3 1 3 3 4 4 3 4 4 1 2 4 3 4 5 2 3 3 4 5 5 2 5 1 5 2 5 5 5
100	570	5859000	82.681	4 4 1 3 3 4 2 4 5 2 1 2 3 4 3 3 3 3 3 2 2 2 3 1 4 3 3 2 2 1 3 1 1 5 2 3 3 2 1 3 4 5 2 2 1 3 5 1 5 3 4 1 4 5 2 1 4 2 2 2 5 5 3
101	570	5834540	81.831	3 4 1 3 3 4 2 1 1 5 1 1 3 2 2 2 2 4 3 3 2 5 2 5 4 2 5 5 1 3 2 1 5 1 3 2 2 1 1 5 3 3 4 3 1 3 1 5 5 1 1 1 1 5 5 2 5 5 2 4 4 5 5
102	570	5815990	81.311	1 1 1 3 2 4 3 2 2 2 1 1 1 4 1 2 2 2 3 3 1 2 3 2 5 3 5 1 5 3 2 2 3 2 3 4 4 5 4 2 3 3 4 2 1 1 1 4 5 2 1 4 2 5 5 5 4 2 2 3 5 5 5
103	570	5795565	79.121	4 4 1 2 2 3 1 2 3 4 1 1 3 2 1 1 1 3 2 4 2 4 2 5 4 1 5 1 5 3 5 1 2 3 3 2 3 1 3 2 2 4 2 2 1 1 1 1 5 3 3 2 2 5 1 3 3 4 3 2 3 1 5
104	571	5941350	85.131	1 2 3 3 4 4 1 3 1 5 1 1 3 4 4 4 2 1 3 2 2 4 4 1 2 1 3 1 1 3 3 3 3 4 5 3 5 5 3 5 4 3 4 4 2 4 5 2 3 3 2 5 3 5 5 3 5 3 5 3 5 5 5
105	571	5875450	83.191	4 4 1 2 4 4 3 4 3 4 1 2 4 3 2 2 2 1 3 3 1 5 3 4 2 2 5 2 1 5 2 3 1 1 2 3 4 4 4 2 3 3 2 4 4 3 3 1 5 1 3 2 5 3 3 5 5 5 1 4 5 3 5
106	571	5801760	79.671	3 3 1 3 1 1 1 1 2 1 1 1 1 3 1 2 4 2 1 2 2 2 2 2 1 1 3 3 3 5 3 3 3 3 3 3 2 5 3 4 3 1 1 3 1 4 4 1 5 2 4 5 1 5 2 5 5 1 5 5 4 5 5
107	572	5973550	86.111	4 3 4 3 3 1 3 3 1 5 1 2 1 4 4 2 4 1 2 3 5 2 2 5 4 3 4 3 2 3 3 4 5 3 5 3 3 5 5 4 3 3 3 3 2 3 4 2 3 2 5 5 5 5 4 2 5 5 5 5 2 5
108	572	5954990	85.371	4 4 3 3 2 2 4 1 4 4 5 3 2 4 4 4 3 2 2 3 2 5 5 2 2 3 4 4 4 1 1 4 2 3 2 3 3 5 4 1 3 4 4 2 3 2 3 4 5 1 5 3 1 5 2 3 5 2 5 4 5 5 5
109	572	5867950	83.101	3 4 2 3 3 1 3 4 2 4 2 5 4 4 2 4 4 4 2 1 2 2 5 1 3 3 1 5 1 3 1 3 3 3 3 1 5 5 3 2 3 3 4 1 2 1 1 1 5 1 5 1 1 4 4 2 5 3 3 4 4 5 5
110	572	5810170	80.471	3 4 4 1 1 1 3 1 2 5 1 5 2 3 1 1 1 1 1 1 2 2 5 2 2 3 5 3 1 1 3 1 1 2 3 1 4 3 4 1 4 4 2 2 1 4 4 4 5 3 2 3 2 5 4 1 5 5 1 5 5 5 5
111	572	5792030	79.981	4 2 1 3 1 1 3 3 4 1 1 1 1 1 4 1 4 2 1 4 3 4 2 3 4 1 2 2 2 3 2 5 3 4 3 2 4 3 3 4 4 2 2 2 1 1 1 4 5 2 1 4 2 5 5 5 4 2 2 3 5 5 5
112	572	5789530	79.361	1 2 1 3 1 1 3 3 4 1 1 1 1 1 4 1 4 2 1 4 3 4 2 3 4 1 2 2 2 3 2 5 3 4 3 2 4 3 3 4 4 2 2 2 1 1 1 4 5 2 1 4 2 5 5 5 4 2 2 3 5 5 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
113	573	5908155	84.721	4 4 4 3 4 3 3 1 1 5 1 5 3 4 4 1 4 2 1 2 2 5 2 2 1 1 3 3 3 5 3 1 1 3 3 4 5 2 5 2 3 4 3 1 3 3 4 2 5 3 2 5 4 5 4 3 5 4 3 2 5 5 3
114	573	5886060	83.541	1 4 1 3 1 4 2 1 2 5 3 1 3 4 4 3 4 1 1 3 2 2 2 2 2 3 4 3 3 3 1 3 3 3 5 3 5 4 4 4 3 4 2 4 2 2 2 4 4 1 1 5 5 5 5 1 4 5 4 3 5 5 2
115	573	5846940	81.931	1 4 4 3 4 4 1 4 1 4 1 1 1 4 1 5 1 2 3 4 2 4 1 4 4 5 3 5 1 3 1 1 3 4 2 3 5 3 3 2 3 5 2 2 2 1 1 1 5 2 2 5 3 5 5 3 5 5 3 2 5 2 4
116	573	5810750	81.131	4 4 2 3 2 2 1 3 3 1 1 3 3 3 4 2 2 3 1 3 2 1 2 2 2 1 5 3 4 1 3 5 3 3 2 1 4 3 1 3 3 2 1 3 1 4 3 4 5 3 2 1 1 5 5 2 5 2 3 2 5 5 5
117	573	5768250	78.151	3 2 2 2 4 1 1 4 1 2 1 1 1 2 2 2 4 4 1 2 4 2 2 3 5 2 5 3 1 3 3 1 2 1 3 3 1 2 4 4 3 2 3 1 3 1 1 1 5 1 4 5 1 5 2 1 5 4 1 5 5 1 2
118	574	5930020	84.751	4 4 3 3 4 4 4 1 1 3 2 1 4 4 1 3 4 1 3 2 1 3 1 5 4 1 5 5 3 3 1 1 3 2 4 4 5 3 1 4 3 3 4 4 4 4 4 4 2 1 4 1 4 3 2 5 4 5 2 5 5 3
119	574	5854430	82.081	1 4 3 2 3 1 1 1 1 2 3 1 1 4 1 2 4 2 3 4 2 2 2 1 1 1 4 3 1 4 3 3 2 3 3 3 2 3 4 4 4 2 4 4 1 4 3 3 5 1 4 1 5 4 5 4 5 2 2 5 5 5 4
120	575	5846890	82.281	3 4 3 2 2 1 2 1 2 5 1 3 2 4 4 2 4 1 2 2 2 3 5 3 4 1 3 3 3 1 3 1 2 2 3 1 2 5 4 4 2 3 4 1 2 1 1 1 5 4 4 5 3 5 5 3 5 1 2 1 2 5 4
121	575	5827470	82.201	4 4 3 3 1 2 4 3 1 2 2 3 4 3 1 5 3 1 3 1 2 4 3 1 2 2 2 3 1 3 3 4 2 1 2 1 3 4 5 5 4 3 4 1 1 2 4 2 5 2 2 4 5 3 5 3 5 4 2 2 5 5 5
122	575	5778230	78.821	1 3 1 3 4 1 3 1 1 3 1 5 2 4 1 2 4 1 1 2 2 2 2 3 2 4 5 2 4 1 3 3 4 1 3 3 4 1 1 5 3 1 2 2 1 2 2 4 5 2 3 2 1 2 5 5 5 5 2 2 5 2 3
123	575	5757790	78.181	3 4 1 3 4 1 2 3 4 2 4 3 1 2 1 2 4 2 1 2 1 1 4 4 5 3 4 1 3 1 5 1 1 1 3 1 3 2 1 4 4 2 1 1 1 1 1 1 5 1 1 2 1 4 5 5 4 5 2 2 5 3 2
124	576	5942850	85.331	4 4 1 3 3 4 4 3 4 3 3 4 3 4 4 1 2 4 2 2 2 2 2 5 3 1 3 3 4 3 3 1 3 4 3 3 2 2 5 1 4 5 2 4 2 3 4 4 4 1 4 4 1 5 5 5 5 1 5 1 5 5 5
125	576	5892190	83.611	4 2 2 3 3 2 2 2 2 5 1 1 1 4 1 2 2 3 3 3 2 4 1 3 2 2 3 3 3 3 2 3 3 3 3 3 5 3 4 3 4 4 4 4 1 2 5 4 4 2 2 5 5 5 5 1 5 4 5 5 5 5 5
126	576	5883945	83.471	1 1 1 3 1 3 4 2 4 5 1 3 1 4 1 2 3 2 3 4 2 3 5 2 2 2 5 1 3 1 3 1 3 4 3 3 3 3 5 4 4 4 1 2 2 2 4 4 4 1 3 2 4 5 3 5 5 2 5 5 5 5 5
127	576	5837490	82.521	4 4 4 3 3 2 3 3 1 1 1 2 2 4 3 2 4 1 1 3 1 4 3 2 4 1 3 1 1 3 3 1 1 3 3 1 1 5 5 4 3 3 4 2 3 2 4 4 5 3 4 2 4 5 1 4 5 2 2 1 3 5 1
128	576	5805930	80.181	4 4 2 1 1 4 3 4 4 1 1 3 2 2 4 2 3 2 1 1 2 4 1 2 1 1 5 1 1 4 1 1 3 3 2 3 5 5 3 2 3 3 1 4 1 2 5 2 5 3 4 1 1 5 2 3 5 5 2 4 5 5 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
129	577	5850940	83.621	4 4 3 3 2 2 3 3 3 2 2 5 1 4 4 2 4 2 1 4 4 2 5 3 3 1 4 4 4 2 3 1 3 3 3 3 2 1 2 3 4 3 1 5 3 1 4 4 3 1 1 2 1 5 4 5 5 5 3 5 5 5 5
130	577	5843920	83.021	1 2 2 3 1 4 2 2 4 5 1 5 1 4 3 2 4 4 3 3 2 4 2 5 3 1 3 1 5 3 3 2 1 5 2 1 4 2 4 3 4 5 1 1 2 2 2 4 4 1 1 5 2 5 5 3 5 5 3 5 5 5 3
131	577	5788655	80.301	1 1 4 3 4 3 1 1 2 4 1 3 1 4 1 1 2 2 3 1 3 2 2 5 2 2 4 3 5 3 3 3 3 5 3 1 1 4 4 4 4 1 4 4 1 1 1 1 4 1 1 1 3 5 3 2 5 3 3 3 5 2 5
132	578	6015980	86.361	4 4 1 3 4 1 1 1 4 5 2 1 1 4 1 3 4 2 3 3 3 2 5 2 2 3 3 5 4 3 2 4 3 3 3 3 3 2 4 4 4 3 4 2 4 4 3 5 4 4 4 5 5 5 1 5 5 4 5 5 5 5 5
133	578	5764290	78.651	2 3 3 1 2 1 2 1 1 1 1 1 1 4 1 2 3 1 2 2 2 1 4 1 2 3 4 2 3 2 4 3 3 1 3 2 3 2 1 3 2 4 1 2 1 4 1 1 5 3 1 3 5 5 3 5 5 3 3 4 5 5 4
134	579	5884180	83.941	3 2 2 3 1 2 4 3 2 5 1 4 3 4 4 2 3 2 3 1 4 2 2 2 5 3 5 3 3 1 2 1 2 3 3 3 3 3 4 2 4 4 1 1 1 3 1 4 4 4 3 2 1 5 3 3 5 5 5 3 5 5 5
135	579	5825750	81.461	4 4 1 2 4 1 1 4 1 5 1 2 1 4 1 2 2 4 1 2 3 2 2 5 1 3 5 3 3 3 3 1 2 4 3 3 2 3 4 4 4 2 1 5 2 1 3 2 4 1 1 5 5 5 5 3 4 5 2 2 5 2 2
136	580	5972055	85.671	4 3 3 3 1 3 4 4 1 5 2 2 3 4 4 2 3 2 2 2 1 4 5 5 5 1 5 5 3 3 2 5 5 2 5 3 4 5 4 2 3 5 5 4 1 2 4 1 2 1 4 4 1 2 4 5 5 3 5 5 5 4 5
137	580	5858640	83.691	3 3 3 3 4 4 4 1 5 5 1 1 2 4 3 2 2 1 3 2 5 2 2 5 3 1 2 4 4 4 2 4 2 3 3 1 3 5 3 2 4 3 2 2 1 4 3 2 4 2 2 3 5 5 3 4 5 2 1 2 5 5 5
138	580	5843455	82.541	4 3 2 3 3 3 4 1 3 5 1 1 1 4 1 2 3 3 2 2 2 5 5 2 2 2 4 2 2 1 2 3 3 2 3 3 5 1 1 3 4 1 4 1 1 4 5 4 4 1 4 3 2 5 1 5 5 5 5 5 5 3 4
139	580	5810410	81.021	4 4 2 2 2 1 3 4 1 3 1 3 2 1 3 3 3 2 3 2 2 2 4 2 4 2 3 3 3 4 1 3 3 3 2 4 3 3 4 2 4 5 2 2 2 2 2 2 5 1 4 3 1 4 3 1 3 5 4 3 5 4 5
140	580	5804210	80.511	4 4 2 2 2 1 3 4 1 3 1 3 2 1 3 3 3 2 3 2 2 2 4 2 4 2 3 3 3 4 1 3 3 3 2 4 3 3 4 2 4 5 2 2 2 2 2 2 5 1 4 3 3 5 3 3 5 5 2 2 4 1 1
141	580	5784760	80.441	4 3 1 2 4 1 4 2 2 5 3 4 4 3 4 2 3 3 1 2 3 3 4 4 5 1 4 2 3 3 2 1 3 2 3 3 4 1 1 1 4 1 2 1 1 1 1 5 4 1 1 2 1 2 5 5 5 5 3 1 5 2 5
142	580	5774950	79.281	3 4 3 3 3 1 3 3 3 5 2 3 1 1 1 2 3 2 2 2 2 5 2 2 1 3 3 1 3 1 4 1 3 2 4 3 5 3 4 2 3 4 1 2 1 2 2 4 3 1 1 3 1 4 1 5 3 2 1 5 5 1 5
143	581	5894150	84.331	3 3 2 2 4 2 4 4 2 5 1 3 2 4 4 2 3 4 3 3 1 1 1 4 5 1 4 3 3 1 3 5 3 4 5 2 3 1 4 2 4 2 4 2 1 3 2 1 3 1 4 5 5 5 3 1 5 4 4 2 3 4 2
144	581	5796440	81.151	4 4 2 2 3 4 1 4 3 3 2 2 4 3 1 1 3 2 2 2 2 1 2 4 2 1 5 2 4 4 1 2 4 3 2 2 4 3 1 2 4 4 2 2 4 1 2 1 5 1 1 5 3 5 2 1 5 3 3 1 5 5 4

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
145	582	6116850	88.161	1 4 1 3 4 1 4 2 1 5 1 5 4 3 4 2 4 3 3 4 2 1 2 5 4 3 5 3 3 1 2 3 5 3 3 3 3 3 5 4 4 2 4 5 5 4 4 4 4 4 2 5 5 5 5 3 5 5 5 5 5 4
146	582	5971965	85.801	2 4 4 2 3 3 4 3 4 3 3 3 4 4 3 3 4 2 2 3 2 2 2 4 4 1 5 5 2 1 3 2 2 2 5 4 3 4 4 4 2 3 4 2 1 3 4 4 3 1 5 4 4 5 5 5 5 3 1 5 5 5 5
147	582	5902110	84.421	4 4 1 3 2 1 3 2 5 4 2 2 2 4 4 3 3 3 3 3 1 5 1 2 1 2 5 5 3 4 4 5 1 3 3 2 5 4 4 2 4 4 5 3 2 1 1 2 3 3 4 1 2 3 5 2 5 2 2 4 4 4 5
148	583	5942540	85.291	3 4 2 3 1 1 4 2 1 5 1 1 4 3 4 2 3 2 3 2 2 4 2 2 2 3 5 3 1 3 3 3 1 3 3 3 3 3 4 4 4 4 4 2 3 4 2 1 4 4 4 1 5 5 5 2 5 5 5 5 5 5 5
149	583	5777415	80.251	3 4 3 3 2 3 2 1 1 1 2 1 3 4 3 2 3 2 3 2 2 1 1 2 5 2 4 4 4 1 1 3 3 4 2 3 3 1 1 4 3 4 4 1 1 1 1 4 5 2 5 2 4 5 3 3 5 4 3 1 4 1 4
150	583	5764100	80.011	1 3 1 3 3 1 2 1 1 1 1 4 3 4 2 3 1 2 2 2 1 3 2 2 3 2 5 1 3 1 2 4 3 1 2 4 5 5 5 5 2 3 1 2 2 2 1 4 5 1 1 4 2 5 5 3 5 4 2 5 5 1 5
151	583	5759615	78.821	3 2 2 2 2 3 1 3 5 5 1 2 4 2 1 1 3 3 1 2 2 2 2 1 2 1 4 3 1 1 1 4 3 3 2 1 3 1 5 4 4 3 3 1 3 3 4 4 5 1 1 1 5 5 3 5 5 1 1 2 5 1 4
152	584	6049930	86.821	1 3 3 3 1 1 2 1 1 5 1 2 4 4 3 4 3 2 3 4 3 3 4 1 3 2 5 5 5 3 3 4 3 5 3 3 4 4 5 5 4 4 4 4 4 4 3 3 4 2 3 2 5 3 3 5 5 4 5 5 4 5
153	584	5836845	82.481	2 4 4 3 1 3 3 1 4 5 1 2 2 4 2 2 2 4 3 4 2 4 2 1 5 3 3 3 3 3 2 1 3 3 3 1 3 5 3 4 3 2 4 1 1 2 3 4 4 1 1 5 5 3 4 1 4 1 3 1 5 5 5
154	584	5754400	78.821	3 2 1 3 2 1 1 2 3 2 2 2 1 2 3 1 4 4 1 3 1 3 1 4 5 1 2 1 3 2 1 1 3 3 3 3 5 4 4 3 3 3 4 3 1 2 1 1 4 1 1 1 5 5 4 1 5 4 1 5 5 3 4
155	585	5929030	84.761	1 4 1 3 3 1 3 1 1 4 1 2 3 3 1 2 4 2 3 4 2 2 2 2 2 3 4 3 3 3 3 3 3 3 3 3 4 5 4 4 4 4 4 2 2 2 5 1 4 4 1 5 2 5 5 5 5 5 5 5 5 5 5
156	585	5890590	84.081	4 4 1 2 3 2 4 1 1 1 1 1 1 4 4 2 2 2 2 3 2 2 2 2 4 2 4 4 3 5 2 3 3 4 3 2 4 3 4 4 4 5 2 4 2 4 3 1 4 3 4 5 1 5 1 4 5 5 5 1 5 5 5
157	585	5823890	81.381	4 4 3 2 3 1 4 1 2 5 2 5 2 3 1 2 2 3 3 3 2 4 1 4 3 1 4 3 2 3 1 5 3 4 2 3 5 3 1 5 4 3 1 1 1 2 1 1 5 4 2 2 1 4 4 1 3 3 2 4 3 3 5
158	585	5782665	80.911	1 3 2 3 2 3 1 2 4 2 1 1 1 4 4 2 4 1 1 2 3 2 2 1 3 1 5 2 5 2 1 3 3 3 3 3 3 3 4 1 3 5 4 3 1 2 5 2 4 2 1 1 2 5 4 2 5 5 4 1 5 5 5
159	586	6064550	86.951	4 4 1 3 4 1 3 1 5 4 3 4 1 3 3 2 2 3 3 3 2 4 5 4 2 2 5 5 4 2 3 4 2 3 3 3 2 4 4 4 3 2 4 4 4 4 4 4 3 4 4 5 5 4 2 5 5 3 4 5 5 5 5
160	586	5869630	83.791	4 4 3 3 4 4 1 1 5 5 2 1 1 4 4 1 4 1 2 2 5 1 5 1 3 1 4 3 4 4 3 2 1 3 5 1 4 3 4 1 1 1 2 2 3 2 3 1 3 3 1 4 2 5 3 5 5 2 4 4 5 3 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
161	586	5821480	81.531	3 4 3 2 1 1 2 1 1 4 1 3 4 4 4 1 2 2 1 2 1 3 2 5 4 1 4 5 1 5 3 3 1 3 2 1 1 3 4 2 4 2 3 2 3 4 5 2 5 1 3 4 2 5 2 4 5 1 1 4 3 5 3
162	586	5753970	75.541	1 2 1 3 1 2 1 2 1 1 2 1 1 1 1 3 1 3 1 2 3 2 4 2 2 1 3 1 1 1 3 3 4 1 3 3 4 1 1 5 3 1 2 2 1 2 2 4 5 2 3 2 1 2 5 5 5 5 4 2 4 4 5
163	587	5953950	85.421	4 4 1 3 3 2 4 2 3 5 1 2 3 4 3 5 2 3 3 3 1 1 4 3 2 1 5 3 5 3 2 4 2 1 4 3 4 3 4 4 1 4 1 4 3 3 4 4 3 2 1 5 3 5 5 3 5 3 3 5 5 5 1
164	587	5920990	85.111	4 1 4 3 2 1 4 1 1 5 1 1 4 4 2 2 4 2 3 3 5 2 4 2 2 1 3 3 5 3 3 3 3 3 3 3 3 4 3 4 4 5 2 4 2 4 4 3 1 5 5 5 5 3 3 5 5 1 5 5 5 5
165	587	5825280	82.401	4 4 2 3 4 4 1 2 1 1 1 1 1 1 1 2 4 1 1 3 1 2 5 5 4 1 5 4 4 2 3 3 3 5 3 3 3 2 4 3 4 4 1 2 1 2 2 2 3 4 4 1 5 5 5 1 5 4 5 5 5 5 5
166	587	5811240	81.161	3 3 2 2 4 1 1 1 4 1 1 1 3 3 4 2 4 1 3 2 2 2 4 1 4 1 4 2 3 4 4 3 3 5 3 3 2 2 4 4 4 1 2 3 1 1 3 2 4 2 3 1 1 5 1 3 5 2 2 5 3 3 5
167	587	5780915	80.771	1 3 2 3 2 3 1 2 4 2 1 1 1 4 4 2 4 1 1 2 3 2 2 1 3 1 5 2 5 2 1 3 3 3 3 3 3 3 4 1 3 5 4 3 1 2 5 2 4 2 1 1 2 5 4 2 5 4 4 1 4 5 5
168	587	5764600	80.401	2 4 4 3 4 1 1 1 2 3 1 1 4 3 2 1 1 2 3 2 2 2 4 3 4 1 3 3 2 2 1 3 3 4 2 3 5 3 3 2 3 5 2 2 2 1 1 1 5 2 2 5 3 5 5 3 5 5 2 1 3 1 5
169	588	5967780	85.971	1 3 3 3 4 1 4 1 5 5 5 2 3 4 1 2 4 4 3 4 2 4 4 4 5 1 4 3 3 3 2 1 1 2 3 1 3 3 5 5 4 4 4 4 3 4 4 4 3 1 2 5 5 5 4 1 5 2 1 5 3 5 5
170	588	5966780	85.591	3 4 2 3 3 4 3 1 3 4 3 2 4 4 3 3 4 1 3 4 3 4 3 2 1 3 5 1 3 1 4 3 3 3 3 2 5 4 4 2 4 5 4 5 2 4 3 5 3 2 4 5 2 3 2 5 5 2 1 1 5 5 2
171	588	5841115	83.101	4 1 3 3 4 3 4 4 2 4 1 5 1 4 4 3 4 4 3 1 1 2 3 4 1 1 3 3 4 2 5 1 3 2 2 2 2 1 4 2 4 4 2 1 2 3 1 1 3 4 2 1 3 5 2 5 5 5 4 4 5 2 5
172	588	5814105	81.291	1 4 1 2 3 3 2 1 5 5 1 2 1 4 1 5 2 1 1 4 1 5 2 3 5 1 5 2 4 4 3 4 3 3 3 2 2 3 5 4 1 2 2 1 1 4 4 3 3 1 1 2 2 5 1 5 5 2 5 2 5 4 5
173	588	5753400	77.101	1 1 1 1 3 1 1 4 1 3 1 1 2 1 1 2 3 1 1 2 2 3 1 2 4 3 4 3 1 1 3 1 1 2 3 1 4 3 4 1 4 4 2 2 1 4 1 5 4 3 1 5 5 3 5 2 5 2 3 1 5 5 5
174	589	5808170	81.251	3 2 4 2 2 4 3 1 2 5 3 1 2 4 1 2 4 1 1 3 2 2 2 2 2 2 5 3 3 4 1 4 3 1 3 3 2 2 3 3 3 3 4 3 3 2 4 1 4 1 2 3 3 5 5 3 5 5 3 3 5 5 2
175	591	5950590	86.571	4 4 4 3 4 2 3 2 1 5 1 5 2 4 4 2 4 2 3 3 1 2 2 2 2 4 5 4 4 3 2 2 3 2 3 3 5 5 5 3 3 4 3 4 1 5 4 5 3 1 1 4 5 5 5 4 5 3 2 5 5 4 5
176	591	5906680	84.631	4 4 2 3 4 4 3 1 5 5 3 1 1 4 4 1 4 2 3 4 2 2 3 2 1 2 2 3 1 5 3 3 5 3 5 1 5 1 4 4 4 3 4 2 1 4 4 4 2 1 4 5 2 5 5 1 5 3 3 2 5 1 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
177	591	5863910	84.011	4 4 4 3 4 1 4 3 3 4 1 1 1 2 4 2 3 4 3 4 2 2 1 1 4 4 5 1 5 3 2 5 3 2 3 3 3 3 3 2 3 4 2 3 1 4 4 2 3 1 1 2 1 5 4 5 5 5 2 3 4 5 4
178	591	5799190	81.161	1 4 4 2 3 4 1 1 1 5 2 1 1 3 3 2 2 2 1 1 1 2 2 2 2 5 1 3 1 3 3 3 5 3 3 2 3 4 5 4 2 1 2 2 2 4 1 3 4 4 3 1 5 3 5 5 5 1 1 5 5 5
179	591	5740660	77.861	4 4 2 2 4 1 1 2 1 1 1 1 2 2 4 2 1 1 1 1 3 2 2 2 2 1 3 3 4 3 3 3 5 2 2 1 5 1 3 5 3 2 1 1 2 1 3 4 5 1 5 1 3 5 5 5 5 3 2 5 2 1 5
180	591	5737710	77.561	1 2 3 1 1 2 1 2 2 1 1 3 1 3 1 2 4 1 2 2 1 2 2 2 3 3 4 3 3 3 3 3 3 2 1 3 3 4 5 4 4 4 2 3 1 4 1 4 1 2 5 1 5 3 5 5 4 1 2 4 1 5
181	591	5716580	77.181	1 4 2 2 3 4 3 1 4 4 2 2 2 2 1 1 3 1 1 1 1 2 2 2 3 3 3 3 1 2 3 3 1 2 3 2 1 1 4 4 4 1 1 1 2 2 4 5 2 2 3 3 5 4 1 3 5 1 2 2 4 4
182	592	6018040	87.041	4 4 1 3 4 1 3 1 4 2 3 3 4 4 4 5 4 2 3 4 4 5 2 1 3 1 4 4 4 5 3 5 5 3 1 1 4 5 5 4 3 4 3 2 4 4 4 4 4 1 4 4 1 5 3 5 5 4 3 3 5 5 5
183	592	5822680	82.281	2 4 2 3 2 4 1 3 1 4 1 1 1 4 1 5 4 2 1 2 2 1 1 2 2 1 5 5 3 3 2 3 2 3 3 3 3 5 5 4 2 3 4 2 2 3 2 4 3 1 4 3 5 5 5 5 5 1 1 5 5 5 5
184	592	5736430	77.881	4 1 1 1 1 1 1 2 2 1 1 1 1 3 1 2 3 4 2 4 2 2 2 2 2 1 3 3 3 3 3 5 3 1 2 1 5 3 4 4 4 4 4 1 1 3 4 2 4 1 2 1 5 5 1 1 5 5 3 1 5 1 5
185	593	5775430	81.041	1 3 4 3 4 4 1 1 1 1 1 1 4 4 4 2 4 2 1 3 3 4 2 4 2 1 3 4 3 5 3 4 2 2 3 1 3 2 1 1 4 1 1 4 3 1 2 2 3 1 1 1 2 5 5 5 5 5 3 5 1 5 5
186	593	5752785	79.721	1 1 1 3 1 3 2 3 1 4 3 1 2 4 1 1 4 2 2 1 1 2 1 4 2 3 3 2 2 2 3 1 4 3 3 2 3 2 2 4 4 5 2 1 1 1 1 4 3 2 1 5 4 5 5 5 5 3 1 5 5 5 5
187	594	5817640	82.031	4 3 1 2 3 1 3 1 3 2 1 1 4 4 1 2 3 2 3 2 4 5 2 1 2 1 3 1 2 3 2 5 2 5 3 2 3 3 1 1 4 2 4 3 1 1 3 4 3 4 1 3 2 5 3 4 5 5 5 1 5 5 5
188	594	5752330	78.161	1 1 2 2 2 4 1 2 2 1 1 3 1 3 1 2 4 1 2 2 1 2 2 2 3 3 4 3 3 3 3 3 3 2 1 3 3 4 5 4 4 4 2 3 1 4 1 4 1 2 5 1 5 3 5 5 4 1 2 4 1 5
189	595	5749135	79.201	1 1 1 3 1 3 2 3 1 4 3 1 2 4 1 1 4 2 2 1 1 2 1 4 2 3 3 2 2 2 3 1 4 3 3 2 3 2 2 4 4 5 2 1 1 1 1 4 3 2 1 5 4 5 5 5 5 3 1 5 5 3 4
190	596	5929980	85.211	4 4 2 3 4 4 3 1 5 5 3 1 1 4 4 1 4 2 3 4 2 2 3 2 1 2 2 3 1 5 3 3 5 3 5 1 5 1 4 4 4 3 4 2 1 4 4 4 2 1 3 1 5 3 5 4 4 4 2 4 5 5 5
191	596	5805170	81.521	1 4 4 3 1 2 4 3 2 5 2 4 3 4 1 3 2 1 1 4 2 2 2 1 2 3 5 2 2 1 1 4 3 3 2 1 4 3 4 4 4 3 4 2 3 4 1 3 4 2 1 3 1 5 1 3 2 3 4 4 5 3 5
192	596	5744535	79.351	2 1 3 3 1 3 2 3 1 4 3 1 2 4 1 1 4 2 2 1 1 2 1 4 2 3 3 2 2 3 3 1 4 3 3 2 3 2 2 4 4 5 2 1 1 1 1 4 3 2 1 5 5 5 3 5 4 3 1 2 5 4 3

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
193	597	5772465	80.801	4 4 2 3 3 3 2 2 1 4 1 2 3 2 1 1 3 1 1 3 2 3 1 5 1 1 4 1 4 5 2 3 3 5 2 2 3 4 4 2 3 1 1 1 1 3 3 2 4 1 4 3 4 3 5 4 5 5 1 5 5 5 4
194	597	5751915	79.781	3 4 2 3 2 3 1 3 3 2 2 3 2 3 1 4 3 1 2 1 2 1 1 2 2 3 4 1 5 5 2 1 2 4 1 2 3 2 2 1 3 3 5 2 3 2 3 1 4 1 1 1 5 5 4 3 5 3 2 4 5 5 5
195	598	5912540	84.831	4 3 1 2 4 1 1 1 5 4 1 4 2 4 4 2 4 2 3 4 3 4 2 2 2 3 5 5 4 2 3 3 1 2 2 2 2 3 4 4 4 5 3 1 3 2 4 5 3 3 4 1 5 5 3 5 4 5 5 1 4 5 5
196	599	5808640	82.121	4 4 1 3 3 2 3 1 2 4 1 3 4 3 4 3 3 1 2 1 4 3 1 3 4 4 4 1 4 3 1 3 1 2 3 1 3 3 4 1 1 5 4 1 2 2 4 4 3 1 1 1 5 5 5 3 5 3 5 3 4 3 5
197	599	5719965	78.221	3 4 2 3 2 3 1 3 3 2 2 3 2 3 1 4 3 1 2 1 2 1 1 2 2 3 4 1 5 5 2 1 2 4 1 2 3 2 2 1 3 3 5 2 3 2 3 1 4 1 1 1 5 5 1 1 5 4 2 1 4 1 5
198	600	5796200	81.601	4 3 4 3 3 1 3 3 1 5 1 2 1 4 4 2 4 1 1 2 1 2 3 3 1 3 4 1 1 4 2 2 1 2 2 2 1 3 5 4 2 4 4 3 4 1 3 3 4 1 1 2 5 5 1 5 5 2 2 1 5 5 5
199	601	5817810	82.411	4 4 4 3 1 4 1 1 4 5 1 2 4 4 2 2 4 3 1 2 2 5 4 1 3 1 3 5 3 2 1 1 2 3 3 1 4 1 4 1 2 3 1 4 2 3 1 4 2 2 2 2 1 5 5 4 4 4 5 4 5 5 5
200	601	5710830	77.181	1 1 1 3 1 1 2 1 1 2 1 1 2 2 2 2 2 2 1 2 1 2 1 4 2 1 1 2 3 3 1 2 3 1 2 3 3 5 1 4 4 3 2 4 2 2 2 1 4 4 1 2 1 5 5 1 4 5 4 4 3 5 5 3
201	602	5793690	81.521	4 2 1 3 2 1 3 1 5 3 1 4 3 4 1 2 3 1 3 4 2 2 1 1 5 1 3 3 3 4 2 1 4 4 3 4 3 4 3 4 3 4 2 2 3 2 1 3 3 1 1 2 2 5 4 3 2 5 3 4 5 3 5
202	603	5904050	84.731	4 4 1 3 4 1 1 3 4 1 1 1 4 4 3 2 4 3 2 4 4 1 1 2 2 2 4 4 4 4 5 2 1 5 3 5 2 5 5 1 4 5 4 2 2 1 1 1 2 3 1 4 5 5 5 5 3 5 2 1 5 4 5
203	603	5783870	81.451	3 4 1 3 4 4 2 1 3 1 1 1 1 4 1 2 4 4 1 2 2 2 2 2 2 3 2 5 1 3 3 2 2 2 3 3 5 3 1 3 2 4 1 2 1 4 4 3 1 2 5 5 5 5 5 5 3 3 5 4 5 5
204	603	5743200	78.781	4 2 2 3 2 1 3 4 2 3 1 3 4 2 1 2 3 1 1 2 1 1 2 4 2 1 2 4 5 4 3 4 2 2 2 1 4 1 2 2 4 4 2 2 2 4 5 3 3 2 2 3 3 5 3 5 4 1 2 3 2 3 5
205	604	5896965	84.621	4 4 1 2 3 3 4 4 5 5 1 2 3 4 4 1 4 3 3 3 2 1 4 4 5 2 4 5 1 3 1 1 3 2 4 4 5 2 4 4 4 2 4 2 1 4 1 2 1 1 2 4 1 5 5 1 5 2 5 3 5 1 5
206	604	5835080	82.811	2 4 2 3 1 1 3 1 1 5 1 1 4 4 3 2 3 2 1 2 4 2 2 2 2 1 4 4 3 3 2 3 5 3 3 3 3 3 3 2 4 4 1 1 1 3 2 4 2 3 4 3 4 5 4 5 5 1 5 5 5 5 5
207	605	6144315	88.541	4 4 1 3 4 3 3 4 2 4 3 2 4 4 4 3 4 3 3 3 4 3 4 4 4 4 3 2 5 3 3 3 4 5 3 3 4 3 5 3 4 2 3 5 5 3 5 4 1 4 4 5 1 4 4 3 5 2 2 5 5 4 5
208	605	5802935	82.021	3 3 2 3 1 3 4 1 2 2 1 1 2 4 3 3 4 3 3 2 2 5 2 2 2 2 3 5 1 4 1 1 2 5 3 4 4 2 4 4 2 1 2 2 1 2 2 4 3 1 1 1 5 4 2 3 5 5 4 4 4 5 5

Table A.3 Results of the proposed model for 63-activity problem with IC = \$2300/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
209	606	5819480	82.511	2 4 2 3 1 1 3 1 1 5 1 1 4 4 3 2 3 2 1 2 4 2 2 2 1 4 4 3 3 2 3 5 3 3 3 3 3 2 4 4 1 1 1 3 2 4 2 3 4 3 4 5 2 5 5 5 4 1 4 5 5
210	606	5742740	79.361	3 3 2 2 4 1 1 1 3 3 1 2 2 3 2 1 4 2 3 3 1 2 2 3 1 1 2 5 1 2 2 1 3 1 3 1 1 4 1 5 3 4 1 2 3 2 1 4 3 2 1 1 5 5 2 5 5 5 4 4 4 2 5
211	606	5739190	78.681	1 4 3 3 2 1 3 1 1 1 3 1 1 4 1 2 1 2 1 4 2 1 2 1 3 3 3 3 3 4 3 5 1 2 2 1 3 5 1 3 4 5 4 3 2 1 2 1 3 1 5 3 1 4 4 1 5 4 3 4 5 2 5
212	606	5704330	75.291	1 2 2 1 2 4 2 1 2 3 1 1 1 3 1 1 1 1 1 1 2 2 5 1 1 1 1 2 1 3 1 3 5 1 1 3 3 3 4 4 3 4 2 4 1 1 2 1 5 1 3 1 4 5 2 1 4 1 1 5 5 5 4
213	608	6106540	88.101	3 4 4 3 4 4 4 3 1 3 1 3 1 4 3 5 4 1 3 4 3 3 4 2 3 4 5 1 4 5 5 2 3 5 5 5 5 4 5 2 4 5 3 2 4 4 1 2 1 3 4 3 4 4 5 4 3 5 3 4 3 5 4
214	608	5738940	79.711	4 4 4 3 2 2 4 3 1 2 1 2 1 1 2 1 4 1 2 2 2 4 3 2 2 2 4 3 3 4 3 4 3 2 3 3 1 1 4 2 3 1 1 1 1 3 3 2 3 1 1 1 1 5 5 2 3 2 5 4 5 4 4
215	608	5691760	75.191	3 2 1 1 1 4 2 1 1 3 1 1 3 1 1 2 3 1 1 4 1 3 1 3 3 1 2 3 2 4 3 3 3 2 3 3 1 5 1 1 3 4 1 2 2 2 4 4 3 1 1 4 1 2 3 4 5 2 1 2 5 1 5
216	609	5792950	81.671	4 4 4 3 4 1 3 1 1 1 2 4 4 4 2 3 3 3 2 3 3 2 1 2 3 2 5 3 3 1 2 2 3 3 2 3 3 3 1 4 3 3 2 1 2 4 1 4 3 1 3 1 4 5 3 5 5 2 1 4 5 1 2
217	610	6143015	88.521	4 4 1 3 4 3 3 4 2 4 3 2 4 4 4 3 4 3 3 3 4 3 4 4 4 4 3 2 5 3 3 3 4 5 3 3 4 3 5 3 4 2 3 5 5 3 5 4 1 4 4 5 1 5 2 2 4 5 2 4 4 5 3
218	610	5726980	78.701	4 3 3 2 1 1 4 3 1 2 1 2 1 1 2 1 4 1 2 2 2 4 3 2 2 2 4 3 3 4 3 4 3 2 3 3 1 1 4 2 3 1 1 1 1 3 3 2 3 1 1 1 1 5 5 2 3 2 5 4 5 4 4
219	613	5704490	76.821	4 4 1 2 2 1 1 3 3 4 1 2 1 2 1 2 4 1 1 4 1 4 2 4 2 1 3 2 5 4 2 1 2 2 2 3 1 1 2 4 4 1 1 1 1 5 1 2 3 1 4 1 2 2 5 4 4 3 4 1 4 1 3
220	614	5761640	79.811	1 4 1 2 3 2 3 1 1 3 1 1 1 4 2 2 3 1 1 2 2 2 2 1 4 1 1 1 3 2 1 4 2 3 2 3 3 3 4 3 4 4 2 2 2 4 4 5 3 3 3 5 5 5 1 3 5 4 1 5 5 2 5
221	614	5697880	76.081	1 1 3 1 1 1 1 3 1 4 1 1 2 2 1 2 1 1 1 2 3 1 2 2 2 3 2 2 4 3 2 3 1 2 2 2 5 3 4 4 4 1 1 1 3 1 4 4 3 1 4 1 2 5 1 2 5 3 5 5 3 5 5
222	622	5724140	78.781	2 4 3 2 2 2 2 3 1 2 3 1 4 1 1 2 2 2 1 1 1 1 4 1 2 5 1 5 1 2 1 5 2 1 1 3 2 5 2 2 3 1 1 2 4 2 5 3 1 3 1 1 5 1 3 5 5 3 2 4 5 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
1	532	6687815	85.251	2 4 4 1 4 3 1 3 3 5 5 5 1 4 1 4 3 1 2 4 2 3 3 2 5 1 2 4 5 5 5 3 3 3 5 2 3 3 4 5 4 3 5 4 4 4 3 1 5 2 3 3 5 5 4 4 5 5 2 4 5 5 1
2	535	6676115	84.611	2 4 4 1 4 3 1 3 3 5 5 5 1 4 1 4 3 1 2 4 2 3 3 2 5 1 2 4 5 5 5 3 3 3 5 2 3 3 4 5 4 3 5 4 4 4 3 1 5 2 3 3 5 5 1 1 2 5 1 5 5 5 5
3	536	6647650	84.291	1 4 4 1 3 1 4 4 2 4 5 5 4 3 4 5 4 2 2 2 2 2 4 1 2 1 5 5 4 3 5 5 4 5 5 1 5 5 3 4 4 5 1 5 1 2 2 1 5 3 3 5 2 4 1 2 5 3 1 1 5 1 4
4	537	6705860	86.051	3 3 4 2 2 1 4 2 1 3 1 5 4 3 3 4 3 3 3 4 4 5 2 4 4 4 3 3 3 2 5 1 3 3 5 5 4 4 4 4 4 4 4 2 5 1 2 5 2 3 3 1 5 1 5 5 3 3 4 5 5 4
5	537	6664025	84.971	2 4 2 3 2 3 4 4 5 4 4 2 4 4 3 2 2 2 1 2 4 1 2 3 4 3 4 3 5 3 5 3 4 5 5 2 5 1 1 3 4 5 2 4 2 2 5 3 5 3 4 2 5 5 5 4 5 2 3 5 5 3 5
6	538	6643175	84.091	3 1 3 2 2 3 4 2 4 5 3 5 1 4 2 3 2 3 2 4 1 4 2 2 5 4 4 2 5 4 4 4 3 1 5 1 2 3 3 4 3 5 2 5 1 3 1 2 5 4 4 5 4 5 1 2 4 3 3 3 5 5 5
7	539	6702490	85.341	3 4 1 1 1 1 4 2 1 3 1 5 4 3 3 4 3 3 3 4 4 5 2 4 4 4 3 3 3 2 5 1 3 3 5 5 4 4 4 4 4 4 4 2 5 1 2 5 2 3 3 1 5 1 5 5 3 3 4 5 5 4
8	540	6634605	84.431	4 2 3 3 3 3 3 3 5 1 3 4 1 1 2 4 2 2 2 1 4 1 2 3 2 5 3 4 1 4 5 2 3 5 3 4 4 5 1 4 2 1 4 4 4 4 3 5 3 4 5 4 5 2 4 5 5 1 3 4 3 5
9	540	6615670	83.251	3 3 1 3 1 2 1 4 4 3 2 3 3 3 4 3 4 3 1 4 3 5 2 3 4 2 5 3 3 1 5 4 3 5 4 3 3 4 4 3 3 4 3 4 2 1 1 1 5 2 3 2 5 5 1 2 5 2 5 5 5 1 5
10	541	6611085	83.321	2 4 4 2 1 3 1 3 1 5 1 5 4 2 1 5 4 4 1 4 2 4 2 2 4 1 3 5 3 2 4 4 3 3 5 2 3 1 4 4 3 4 1 3 1 3 1 4 5 4 3 1 5 5 5 3 4 3 1 5 5 5 5
11	541	6586460	81.921	4 4 1 1 1 2 1 1 2 5 5 3 1 3 1 5 2 1 2 3 1 5 1 4 5 2 4 5 4 2 4 3 5 3 4 1 2 4 5 4 4 3 3 4 3 1 1 2 5 4 1 5 3 5 1 1 5 4 4 3 5 1 5
12	542	6669500	85.081	2 4 1 3 2 4 3 4 2 5 2 5 1 4 3 4 2 2 1 3 2 2 3 3 3 4 5 5 4 1 5 2 3 1 5 2 4 5 5 5 3 4 5 5 1 1 3 5 5 3 3 3 5 5 4 2 5 2 3 1 4 5 4
13	542	6610270	83.581	3 4 1 3 1 4 3 3 4 5 3 1 1 3 1 3 2 2 2 2 2 2 2 2 3 2 5 2 4 2 3 4 3 3 5 3 5 1 1 5 3 4 5 4 1 3 2 4 5 4 4 1 5 5 5 3 5 1 5 5 5 5 5
14	543	6623540	83.791	1 4 4 2 4 4 3 3 5 5 1 1 3 1 1 2 2 2 3 2 1 2 4 2 2 5 5 2 4 3 5 1 3 5 5 3 4 3 2 4 4 4 5 4 3 3 2 4 5 2 3 2 3 5 1 1 4 5 1 3 5 5 5
15	543	6597000	82.571	4 3 1 1 4 1 4 4 2 5 4 3 1 2 1 4 3 2 1 3 2 1 3 2 5 1 4 5 3 1 2 3 5 3 5 1 4 3 3 2 4 1 3 4 1 1 5 4 5 4 4 1 4 5 1 3 5 2 5 4 5 5 5
16	544	6726940	86.661	2 3 3 2 4 4 4 4 1 5 4 5 4 4 3 4 4 4 1 3 1 1 1 4 3 3 4 3 5 4 4 4 3 4 4 5 5 5 2 1 3 4 4 3 3 1 4 4 5 4 1 5 4 5 5 2 4 3 4 5 5 5 4

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
17	544	6682450	85.921	3 4 4 2 2 1 1 3 1 5 2 5 2 3 1 2 2 1 3 3 2 2 5 3 2 3 3 3 4 5 4 4 3 3 5 3 4 5 4 3 4 4 5 4 1 4 4 4 5 4 3 4 3 5 5 4 5 5 3 5 5 5 5
18	544	6590965	82.171	3 2 2 2 2 3 4 4 1 4 5 4 1 4 1 4 3 2 1 2 5 3 5 5 2 1 2 5 1 1 5 1 4 2 5 4 4 1 3 4 3 4 1 3 2 2 2 1 5 2 1 5 3 5 2 1 5 5 3 5 5 5 5
19	544	6560970	81.931	3 1 4 3 1 4 1 4 4 2 1 1 3 4 1 1 3 4 1 2 2 2 2 2 4 1 2 4 5 4 5 3 4 2 5 3 3 2 4 1 4 2 4 4 2 2 2 4 5 2 4 5 3 5 5 3 5 5 3 3 5 2 4
20	545	6824250	87.601	2 4 3 2 2 2 4 4 3 4 3 2 4 3 3 3 2 4 3 4 1 5 4 4 5 5 5 2 3 1 5 5 4 3 4 4 4 1 5 2 4 5 3 3 5 4 5 4 5 4 4 3 4 5 4 4 4 3 1 1 3 5 5
21	545	6668700	84.981	1 4 3 3 4 2 4 2 3 2 1 5 1 4 3 3 3 2 2 1 4 5 2 4 4 5 4 5 1 1 4 1 3 4 5 1 4 3 4 3 4 4 4 5 2 3 1 1 5 3 5 4 4 4 3 4 5 2 3 2 4 5 3
22	546	6743405	86.931	2 4 3 3 4 3 1 2 2 4 3 5 1 4 1 4 4 4 3 4 4 5 2 3 5 1 4 5 5 4 5 3 2 4 5 2 5 4 5 5 4 2 4 1 3 4 4 5 5 3 2 4 4 5 4 4 5 3 1 5 1 1 5
23	546	6626615	84.121	4 4 4 2 2 3 3 4 4 3 2 4 4 2 2 3 4 4 3 4 1 5 2 2 4 3 3 3 3 1 5 3 1 3 4 4 5 1 5 2 2 3 5 3 1 4 1 1 5 2 1 5 5 5 1 2 5 3 4 2 3 4 5
24	546	6585965	83.151	2 3 1 3 2 3 1 2 4 5 1 1 1 4 4 2 4 1 1 4 2 3 2 5 4 3 3 5 5 3 3 2 4 1 5 3 5 1 2 2 3 5 2 1 1 5 1 5 5 3 4 1 4 5 2 4 5 5 2 5 5 5 5
25	546	6582315	82.991	2 4 1 3 3 3 1 3 3 5 4 4 4 4 2 4 4 3 2 3 3 5 2 4 2 4 4 4 2 1 4 1 2 3 4 2 1 5 1 4 2 3 1 4 1 1 3 1 5 2 1 1 4 5 1 2 5 2 2 5 4 4 5
26	546	6548540	81.481	4 1 2 3 3 2 4 3 2 3 2 5 1 4 1 4 3 4 1 2 2 5 1 1 2 3 2 5 2 2 5 2 5 4 5 2 3 2 4 5 3 1 1 4 1 1 3 1 5 2 1 1 4 5 1 2 5 2 2 5 4 4 5
27	546	6546800	80.411	1 4 3 1 2 2 3 2 1 5 4 4 4 3 2 2 1 3 1 1 1 3 4 5 2 1 3 2 4 4 5 2 3 3 5 3 4 3 3 4 3 1 2 5 1 1 1 2 5 2 2 4 3 3 5 5 5 1 3 3 5 2 5
28	547	6684970	86.131	2 4 4 3 1 4 4 4 2 4 3 3 2 4 4 3 4 4 3 4 3 3 3 3 4 3 4 4 2 3 4 2 1 1 4 4 4 3 5 4 3 1 1 3 3 2 5 1 5 2 4 4 5 5 5 4 4 1 3 4 5 4 2
29	547	6634335	84.981	3 3 4 3 1 3 1 1 1 4 1 1 3 4 1 2 3 4 2 2 2 5 5 4 5 5 4 4 2 1 2 3 2 4 5 3 4 3 3 5 4 4 2 4 3 3 5 5 5 1 1 5 3 5 2 5 5 5 1 5 5 5 2
30	548	6506810	81.831	1 4 4 3 1 4 2 1 2 4 2 2 4 4 1 1 3 4 1 1 2 3 1 5 5 2 5 1 5 2 2 1 1 1 4 5 4 4 4 3 3 4 3 4 2 1 1 1 5 2 2 1 5 5 1 2 5 1 2 2 4 5 5
31	549	6809165	87.851	3 4 3 2 3 3 4 3 5 5 3 4 3 4 4 3 4 4 3 4 3 5 2 4 1 4 5 1 2 2 4 2 4 4 4 2 4 5 4 5 4 1 5 4 3 4 1 5 5 4 4 5 5 2 4 5 5 2 4 1 5 3 1
32	549	6716805	86.481	4 4 1 3 4 3 3 1 4 5 2 3 4 4 1 4 3 3 2 4 2 5 5 2 5 3 4 5 4 2 2 2 5 2 5 1 5 3 4 5 3 4 4 3 1 4 4 1 5 3 4 1 5 3 3 2 3 5 5 5 4 3 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
33	549	6592760	83.851	3 3 3 3 1 2 2 3 4 1 2 1 2 3 2 3 4 3 3 1 5 3 2 4 2 5 5 1 4 4 2 3 1 5 1 3 2 3 5 4 3 3 3 1 1 5 4 5 2 2 3 3 5 3 5 5 5 5 3 5 5
34	549	6575170	83.081	3 4 4 2 1 2 1 2 1 4 1 1 1 4 1 1 2 1 2 3 1 2 2 3 1 3 4 4 4 1 5 3 3 3 5 3 4 2 4 2 3 4 4 4 1 3 4 3 5 4 4 5 5 5 5 1 5 2 1 5 5 5 5
35	550	6683820	86.151	2 4 3 3 1 4 4 3 3 4 1 2 3 4 4 5 4 4 1 4 2 4 2 2 3 3 5 4 5 1 3 4 3 3 3 1 3 5 4 4 3 4 3 4 3 3 4 1 5 4 4 1 5 5 5 1 5 5 4 4 5 3 3
36	550	6588430	83.271	3 3 2 2 4 1 2 1 3 2 1 2 4 4 1 2 4 2 1 2 4 4 3 2 5 1 4 5 3 1 2 3 5 3 5 1 4 3 3 2 4 1 3 4 1 1 5 4 5 4 4 1 4 5 1 3 5 2 5 4 5 5 5
37	551	6633900	84.831	4 4 4 2 2 1 4 2 2 3 5 5 4 3 2 1 4 3 2 3 2 4 3 5 2 1 5 4 4 5 5 1 5 3 3 4 4 3 5 3 4 1 5 3 3 3 5 1 5 2 4 4 3 5 3 3 5 1 2 1 5 1 4
38	552	6729560	86.811	4 4 3 3 3 1 3 3 2 2 1 5 3 4 4 3 3 4 3 2 2 4 5 4 1 2 4 5 5 2 5 4 2 2 5 3 4 5 1 5 3 2 5 4 1 3 4 4 5 3 2 3 5 5 4 4 4 3 3 5 5 4 5
39	552	6610140	84.891	4 2 4 3 4 2 3 2 5 4 2 1 1 4 3 2 4 4 3 4 1 4 2 1 5 3 5 3 4 5 2 1 3 2 4 1 1 4 4 2 3 1 2 4 3 1 1 5 5 3 2 4 5 5 5 4 4 3 2 3 5 3 4
40	552	6583040	83.341	3 4 1 2 4 4 4 3 2 5 1 1 2 1 1 4 3 4 3 4 2 4 2 3 2 3 3 3 4 4 3 1 2 2 3 3 2 2 2 1 4 2 5 4 1 2 4 5 5 4 1 2 3 5 5 3 5 5 3 3 5 5 5
41	552	6565040	81.951	4 1 1 3 4 1 3 2 3 4 1 5 4 4 1 2 4 2 1 4 3 4 2 5 2 4 4 3 4 5 5 1 2 1 4 3 2 2 2 2 2 4 2 2 1 3 1 4 5 2 4 2 1 3 1 2 5 5 5 4 5 4 5
42	552	6497940	78.751	2 4 4 1 3 1 2 2 4 5 1 4 1 1 1 2 4 2 1 2 2 2 2 2 3 1 2 3 1 2 4 3 1 4 2 3 4 4 1 4 1 4 5 2 2 4 3 5 3 1 5 3 5 2 1 5 1 5 3 5 1 5
43	553	6608510	84.081	2 3 4 2 4 1 4 4 5 3 3 3 3 4 4 2 2 4 2 2 1 3 3 3 4 1 3 4 5 5 2 2 3 1 3 4 1 1 4 4 1 3 1 4 4 1 5 4 1 2 2 5 1 4 5 2 3 5 4 5 5
44	553	6565480	82.131	1 3 2 3 1 1 1 3 2 5 1 1 2 1 4 2 4 2 2 2 1 3 2 1 4 3 5 4 3 3 3 3 3 3 5 3 3 3 2 2 4 1 4 4 2 2 4 2 5 2 4 5 5 5 4 1 5 5 4 3 4 5 5
45	554	6779350	87.171	3 4 2 3 4 4 3 2 2 5 4 5 2 3 4 1 1 4 3 1 3 5 3 4 5 1 5 2 3 3 5 4 5 3 5 3 4 2 5 5 2 3 3 4 3 4 4 3 5 4 4 5 3 5 3 3 5 5 3 2 3 4 5
46	554	6736300	86.941	4 4 3 3 2 4 3 2 5 1 4 1 4 4 4 5 3 3 2 3 3 4 5 5 5 1 5 4 5 5 4 2 3 1 3 3 3 4 3 4 3 3 3 4 4 1 4 1 5 2 5 5 4 5 5 1 5 5 3 3 4 5 5
47	554	6554505	81.871	3 4 4 3 2 3 3 3 2 3 1 3 3 3 1 2 4 4 1 2 1 2 1 3 4 3 2 2 4 4 2 3 3 3 5 3 3 5 2 2 3 5 1 4 1 3 4 1 5 3 1 1 4 5 4 3 4 5 2 4 4 1 5
48	554	6493150	78.251	2 1 3 1 3 1 2 1 1 1 1 1 1 1 1 3 3 2 2 1 2 1 5 2 2 3 3 5 3 3 3 5 1 2 1 5 3 4 2 3 4 3 4 1 4 1 2 4 2 5 3 2 1 3 5 5 1 5 2 1 4 5 5 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
49	555	6764480	87.041	3 4 1 3 1 1 3 1 2 1 4 4 4 4 3 4 3 2 2 2 4 5 5 2 5 3 5 2 3 4 2 3 3 3 3 4 5 3 2 4 4 5 2 5 3 5 5 4 5 4 4 5 5 5 5 5 5 3 5 5 5 5 5
50	555	6747890	86.991	4 2 1 2 4 4 1 4 3 1 2 4 3 4 3 5 4 4 3 4 5 1 4 3 4 3 5 5 5 4 2 3 3 3 3 2 5 5 5 5 4 5 4 5 4 4 3 1 5 1 2 2 1 5 5 3 5 1 4 5 5 5 2
51	555	6561790	83.531	4 2 4 3 4 2 3 2 5 4 2 1 1 4 3 2 4 4 3 4 1 4 3 1 5 1 3 2 2 3 1 5 4 5 5 1 3 2 5 5 2 1 1 4 1 1 3 1 5 2 1 1 4 5 1 4 4 3 3 2 5 3 3
52	555	6561260	81.931	1 1 3 3 1 2 2 2 1 5 2 1 4 4 1 2 4 1 1 2 1 3 2 2 1 4 3 3 1 3 5 2 3 2 5 3 2 3 4 4 3 1 4 1 1 1 4 4 5 4 4 5 5 5 2 5 5 5 2 5 5 5 5
53	555	6489210	78.391	3 1 1 3 1 2 3 3 4 3 1 4 1 1 1 2 4 2 1 2 2 2 2 2 3 1 2 3 1 2 4 3 1 4 2 3 4 4 1 4 1 4 5 2 2 4 3 5 3 1 5 3 5 2 1 5 1 5 3 5 1 5
54	555	6487560	77.991	1 1 1 3 1 2 3 3 4 3 1 4 1 1 1 2 4 2 1 2 2 2 2 2 3 1 2 3 1 2 4 3 1 4 2 3 4 4 1 4 1 4 5 2 2 4 3 5 3 1 5 3 5 2 1 5 1 5 3 5 1 5
55	557	6636715	85.621	4 4 4 2 4 3 3 4 1 5 5 1 4 4 3 2 4 4 3 4 2 1 4 1 5 4 1 3 2 5 1 3 2 2 4 2 5 1 5 4 4 1 3 3 1 2 4 4 5 2 3 4 1 4 4 4 5 1 3 5 4 4 5
56	557	6560910	83.941	3 3 4 2 3 1 4 3 4 4 4 3 1 4 3 2 3 3 3 1 1 1 4 2 5 1 5 4 4 2 3 4 3 1 3 3 4 2 5 3 4 3 1 2 2 5 2 3 5 3 1 1 1 5 4 5 5 2 2 1 5 3 5
57	557	6557350	82.271	4 4 1 3 3 2 3 3 4 1 2 5 3 4 3 1 2 1 2 1 1 1 4 5 5 1 2 3 3 1 4 2 2 1 5 3 5 4 5 1 2 4 4 3 3 1 2 2 5 2 4 2 3 4 4 2 4 2 3 1 5 4 2
58	557	6484640	78.311	3 2 1 3 3 1 1 3 3 2 1 4 1 1 1 2 4 2 1 2 2 2 2 2 3 1 2 3 1 2 4 3 1 4 2 3 4 4 1 4 1 4 5 2 2 4 3 5 3 1 5 3 5 2 1 5 1 5 3 5 1 5
59	557	6484590	77.741	1 1 4 3 2 1 1 3 3 2 1 4 1 1 1 2 4 2 1 2 2 2 2 2 3 1 2 3 1 2 4 3 1 4 2 3 4 4 1 4 1 4 5 2 2 4 3 5 3 1 5 3 5 2 1 5 1 5 3 5 1 5
60	558	6676965	85.651	4 3 4 3 3 3 3 3 2 5 3 1 1 4 4 2 4 4 1 1 4 1 5 3 2 3 5 5 1 3 3 5 3 3 5 1 4 5 2 4 3 3 1 3 3 5 2 3 5 1 2 4 5 4 3 5 5 5 1 4 5 5 5
61	559	6534115	81.851	3 3 3 2 4 3 3 4 1 5 1 1 3 3 2 2 4 1 2 4 2 5 2 2 5 4 3 1 2 5 1 1 3 1 5 3 5 3 2 1 4 1 3 2 3 3 3 3 5 3 1 1 4 3 3 2 4 4 3 1 4 2 5
62	560	6605680	84.121	2 4 4 3 4 2 3 4 1 5 4 3 4 4 1 4 4 2 1 4 1 2 2 2 5 3 3 3 5 3 2 3 2 3 5 3 4 2 3 2 3 5 2 4 1 1 4 1 4 4 1 1 4 4 1 3 4 5 3 3 5 5 5
63	560	6556560	81.971	4 4 1 3 1 2 1 1 1 5 1 1 1 3 1 2 2 2 2 2 2 2 2 2 3 3 3 4 2 3 3 2 3 4 1 1 5 4 4 4 2 2 4 3 2 4 1 5 3 4 5 4 5 5 5 5 2 2 2 5 5 2
64	561	6526025	82.191	1 2 3 3 1 3 1 1 2 4 2 5 3 4 1 2 4 2 1 1 2 2 2 2 3 3 5 5 4 3 2 1 4 3 3 2 3 4 5 4 4 1 4 4 2 1 2 5 5 1 1 1 4 5 5 5 5 5 3 4 5 5 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
65	561	6505205	79.911	2 2 1 3 3 3 3 3 5 2 3 4 2 2 1 2 4 2 2 1 3 5 1 3 3 4 1 1 2 3 2 1 4 3 3 5 3 4 4 4 4 3 1 3 1 2 2 4 5 1 1 2 1 5 1 1 5 4 5 3 5 3 5
66	561	6491755	79.131	3 1 3 1 2 3 1 4 1 5 3 4 2 2 1 2 4 2 2 1 3 5 1 3 3 4 1 1 2 3 2 1 4 3 3 5 3 4 4 4 4 3 1 3 1 2 2 4 5 1 1 2 1 5 1 1 5 4 5 2 4 5 5
67	562	6764190	87.551	3 1 1 3 4 1 4 1 2 5 1 2 4 4 3 1 4 4 3 2 1 4 4 4 4 4 3 4 3 1 4 5 3 3 5 3 3 3 4 5 4 4 4 1 4 5 3 4 4 4 5 5 5 5 5 1 5 5 1 4 5 5 5
68	562	6632040	85.041	4 4 4 3 4 1 4 1 5 5 1 3 4 4 1 4 3 2 1 4 2 3 2 1 5 1 5 3 3 3 5 3 3 3 3 2 2 1 4 2 3 2 3 3 3 1 5 3 5 4 1 2 5 5 2 1 5 4 5 4 5 5 5
69	562	6494930	79.241	3 4 1 1 1 2 2 2 1 1 1 1 1 3 3 2 2 2 1 4 2 4 2 4 5 1 2 3 2 5 3 3 3 1 3 2 3 5 4 1 4 1 4 5 2 2 4 3 5 3 1 5 3 5 2 1 5 1 5 3 5 1 5
70	563	6801385	87.641	4 4 2 3 1 3 2 1 1 4 2 5 4 4 3 5 4 4 2 4 3 5 4 2 2 4 5 5 4 3 3 3 4 4 5 3 2 3 5 1 4 1 4 2 4 2 1 3 5 4 4 5 2 3 3 3 5 4 5 4 5 5 5
71	563	6474820	77.661	4 1 4 1 1 1 1 1 1 1 1 1 3 1 1 2 1 1 2 2 1 5 2 3 5 3 2 2 1 4 3 1 2 1 5 3 4 2 3 4 3 4 1 4 1 2 4 2 5 3 2 1 3 5 5 1 5 2 1 4 5 5 5
72	564	6554475	82.871	3 3 2 3 4 3 4 3 2 3 1 4 3 4 2 1 2 3 1 2 1 2 4 3 5 1 3 5 1 5 2 1 4 3 3 2 3 2 5 1 4 1 2 5 4 1 2 1 5 1 4 3 4 5 5 4 5 2 3 5 5 3 5
73	564	6505035	80.111	2 4 2 2 1 3 1 4 1 5 3 4 2 2 1 2 4 2 2 1 3 5 1 3 3 4 1 1 2 3 2 1 4 3 3 5 3 4 4 4 4 3 1 3 1 2 2 4 5 1 1 2 1 5 1 1 5 4 5 2 4 5 5
74	564	6479900	77.981	2 2 3 3 4 1 4 3 1 3 1 5 1 3 3 1 4 2 1 2 1 5 1 5 5 2 3 2 2 3 2 1 5 2 4 4 2 2 1 4 1 1 1 5 2 1 1 1 5 2 1 3 1 2 1 2 5 3 1 4 5 2 4
75	566	6602425	84.031	1 2 3 3 3 3 3 4 3 3 1 1 1 3 4 2 3 4 3 4 2 1 2 4 5 2 5 2 2 3 2 3 3 4 3 3 3 2 4 4 3 2 4 1 1 2 3 2 5 4 3 1 5 5 5 5 5 2 4 3 5 5 5
76	566	6477450	79.291	2 4 3 1 2 4 1 3 1 1 1 1 2 4 3 5 3 1 1 1 1 2 3 2 2 3 4 1 1 3 5 5 2 1 3 2 1 2 4 2 3 2 4 3 1 3 4 4 5 2 1 3 1 5 2 4 5 4 3 2 5 3 5
77	566	6452415	77.751	2 2 2 1 4 3 3 4 2 5 3 4 1 3 1 2 1 1 1 1 2 2 1 5 5 2 5 4 4 5 2 4 3 2 3 2 4 1 1 2 2 1 1 2 2 1 1 5 5 2 2 4 2 3 1 2 5 5 1 5 5 3 5
78	567	6594170	84.171	4 4 4 3 1 1 1 1 2 3 1 1 4 4 4 1 4 1 2 4 4 4 2 3 5 4 2 5 3 2 3 3 5 4 3 3 1 3 3 4 4 4 2 1 3 2 2 4 5 3 3 2 2 5 5 3 3 5 3 1 5 5 5
79	567	6592870	83.961	4 4 4 3 1 1 1 1 2 3 1 1 4 4 4 1 4 1 2 4 4 4 2 3 5 4 2 5 3 2 3 3 5 4 3 3 1 3 3 4 4 4 2 1 3 2 2 4 5 3 3 2 2 5 5 3 3 5 3 1 5 4 5
80	567	6545320	82.251	4 3 3 1 1 1 4 1 1 1 1 3 1 4 1 2 2 4 3 3 2 2 1 1 2 1 5 3 2 3 5 1 3 1 3 2 3 3 4 3 4 1 4 4 3 4 4 4 5 1 2 3 4 5 4 4 5 5 2 5 5 5 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
81	567	6492580	79.721	1 1 2 3 1 1 4 4 3 1 2 2 4 2 1 2 3 1 1 2 2 2 3 2 3 3 5 3 3 2 3 1 3 3 3 2 3 1 4 4 4 5 2 2 1 1 4 2 5 2 4 5 5 5 5 5 5 5 1 2 5 2 5
82	568	6529890	82.621	3 4 1 3 4 4 2 2 2 4 1 3 1 4 4 2 4 2 2 4 2 2 4 5 3 5 1 5 5 2 3 1 3 1 2 3 2 4 3 3 3 5 2 1 1 2 2 1 5 1 1 5 5 5 2 5 4 1 5 4 5 3 5
83	568	6506045	80.641	4 4 1 2 1 3 3 4 1 3 5 1 1 3 1 1 3 1 1 2 2 2 2 5 2 4 3 3 5 1 2 2 5 3 3 3 5 3 4 5 3 2 1 2 1 1 4 4 5 1 1 3 5 5 3 5 4 3 5 3 5 3 5
84	568	6498345	80.351	4 4 1 2 1 3 3 4 1 3 5 1 1 3 1 1 3 1 1 2 2 2 2 5 2 4 3 3 5 1 2 2 5 3 3 3 5 3 4 5 3 2 1 2 1 1 4 4 5 1 3 4 1 4 2 1 5 4 5 2 5 4 5
85	570	6496730	80.111	3 1 1 3 3 4 2 2 1 3 1 1 4 1 1 2 4 2 1 2 2 4 2 3 2 2 3 3 4 3 3 1 3 3 3 3 5 2 3 1 4 2 2 1 3 4 1 4 5 1 2 4 2 5 2 2 5 5 5 5 4 5 5
86	570	6472940	77.781	2 1 2 1 2 2 1 3 4 1 2 1 1 2 1 2 2 1 1 4 4 2 4 2 5 2 3 1 3 2 3 4 2 3 3 1 4 3 3 2 4 1 3 2 2 4 1 4 5 2 1 1 1 5 2 3 5 1 4 5 4 5 5
87	571	6701160	86.161	1 4 4 3 4 1 4 4 3 4 1 1 3 3 4 2 3 2 1 4 4 2 4 2 2 1 5 5 4 4 3 4 3 2 5 3 4 3 4 4 4 4 4 3 1 3 2 1 4 4 4 1 5 5 5 3 5 5 5 4 5 5 3
88	571	6681400	85.811	2 3 2 2 3 2 2 4 1 5 1 4 4 4 4 2 3 2 3 3 1 2 4 3 1 4 5 5 4 5 3 4 3 1 4 2 3 3 4 3 3 2 2 4 3 3 3 4 4 2 4 5 4 5 5 5 5 4 1 5 5 5 5
89	571	6552990	82.971	3 4 2 3 4 1 1 3 5 5 2 1 4 4 1 1 4 2 3 2 2 2 1 1 2 2 5 4 1 5 1 1 4 3 5 1 1 2 2 3 3 2 4 3 1 3 1 2 5 1 3 5 5 4 3 5 4 5 2 1 4 5 5
90	571	6514600	82.581	4 4 1 2 3 4 2 2 2 3 2 1 4 4 4 1 2 1 2 4 3 2 4 2 3 4 1 1 2 3 2 1 4 3 3 5 3 4 4 4 4 3 1 3 1 2 2 4 5 1 1 2 1 5 1 1 5 4 5 2 4 5 5
91	571	6494765	80.851	3 4 2 3 2 3 3 4 1 1 3 1 1 4 1 2 3 1 3 2 2 2 5 4 3 3 4 4 3 1 2 1 3 3 3 2 3 4 3 3 3 3 1 4 1 3 1 1 5 2 1 1 5 3 2 3 5 5 1 4 4 2 3
92	571	6493430	79.791	3 1 1 2 1 1 3 3 1 1 1 1 1 3 1 2 3 4 3 4 2 2 2 3 3 1 3 3 3 1 4 3 2 3 3 3 3 3 1 1 3 2 3 1 1 1 4 2 5 2 4 5 1 5 2 5 5 5 5 4 5 5 4
93	571	6472350	79.361	1 4 4 2 4 1 2 1 1 4 1 4 3 1 4 2 3 1 2 3 5 3 2 4 2 3 4 2 4 2 2 4 2 2 3 2 3 4 2 1 4 2 1 3 1 1 2 1 5 2 2 2 1 5 4 1 3 2 1 4 5 2 3
94	572	6493000	80.221	4 1 4 3 4 1 2 2 1 2 2 1 1 1 4 2 4 1 1 4 1 4 2 2 1 1 5 2 5 3 2 1 3 3 3 4 1 3 4 1 2 4 2 4 2 4 1 5 5 1 1 5 2 3 1 4 5 2 5 4 5 5 5
95	573	6481880	79.651	3 1 1 3 3 4 2 2 1 3 1 1 4 1 1 2 4 2 1 2 2 4 2 3 2 2 3 3 4 3 3 1 3 3 3 3 5 2 3 1 4 2 2 1 3 4 1 4 5 1 2 4 2 5 2 2 5 5 3 2 3 5 5
96	573	6462705	79.541	1 3 1 3 4 3 1 1 3 3 2 4 1 4 2 2 4 2 1 3 1 4 3 2 1 2 2 2 4 1 4 2 3 2 2 4 2 3 2 5 4 1 1 1 3 3 1 3 5 2 1 2 5 5 5 2 5 2 2 2 5 2 4

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
97	574	6488115	79.961	1 4 1 3 4 3 1 4 1 1 3 1 1 4 1 2 3 1 3 2 2 2 5 4 3 3 4 4 3 1 2 1 3 3 3 2 3 4 3 3 3 3 1 4 1 3 1 1 5 2 1 1 5 3 2 3 3 1 2 2 5 2 5
98	575	6539690	82.621	2 4 1 3 1 1 2 2 1 4 3 4 3 4 4 2 3 4 2 3 3 5 2 5 3 1 5 1 1 3 2 1 5 4 2 2 2 4 5 3 4 2 2 4 3 2 1 1 5 1 1 1 3 5 4 5 5 2 2 4 3 2 2
99	575	6486690	79.781	4 1 3 3 3 2 1 4 2 4 1 1 1 4 1 3 2 4 1 3 1 2 1 5 3 1 5 2 4 1 4 2 3 2 2 4 2 3 2 5 4 1 1 1 3 3 1 3 5 2 1 2 5 5 5 5 3 2 1 4 5 2 2
100	576	6602430	84.851	4 4 2 3 4 2 2 3 2 2 1 4 1 4 1 2 4 3 3 3 2 2 4 3 4 1 4 3 1 5 3 1 4 3 5 2 4 3 3 4 4 2 2 4 3 2 4 2 3 3 3 5 3 3 5 2 5 1 3 5 4 5 5
101	577	6723980	86.711	2 4 1 3 3 2 4 3 3 4 3 4 2 4 1 2 4 3 3 3 1 1 2 2 5 1 5 3 3 2 2 4 3 2 3 3 5 4 4 4 4 5 4 4 4 4 3 3 4 4 5 4 1 5 5 5 5 5 5 3 5 4 5
102	578	6558460	83.061	4 4 4 2 3 1 1 3 2 3 1 4 4 3 3 2 2 2 2 3 1 1 1 1 4 2 3 1 4 3 3 1 3 3 3 1 3 2 4 5 4 4 4 4 1 3 4 4 4 1 4 1 5 5 5 3 5 4 5 4 5 5 5
103	579	6599200	84.401	4 4 1 3 4 2 4 4 2 3 1 3 2 4 3 3 3 1 1 3 3 1 4 2 4 3 1 3 3 5 3 1 5 2 3 3 3 3 5 5 4 4 1 2 3 3 4 5 4 2 2 1 5 5 2 3 5 5 4 4 5 5 4
104	579	6490290	80.371	1 2 4 3 4 2 1 3 1 5 1 2 1 1 1 3 2 2 2 4 2 2 4 1 4 3 5 3 4 1 2 1 3 3 3 4 2 1 3 3 4 3 1 2 2 1 4 4 4 2 1 2 1 5 5 3 5 3 5 2 5 5 5
105	579	6472440	79.601	4 3 2 3 2 1 1 1 4 3 1 3 1 3 3 1 4 3 2 2 2 3 2 5 2 5 4 4 5 5 2 1 2 1 2 1 1 3 1 3 3 3 4 2 1 1 1 1 5 2 1 1 4 5 1 4 4 3 2 5 4 4 3
106	579	6451160	77.051	1 4 3 1 1 2 1 1 1 1 1 4 2 2 1 2 2 2 1 2 3 2 2 1 2 1 2 3 2 1 2 1 1 4 3 2 2 1 4 2 3 3 2 4 1 1 2 4 5 4 1 5 1 5 5 1 5 4 1 5 5 5 5
107	579	6439670	76.621	2 1 2 3 1 2 1 1 2 1 3 4 3 2 3 2 3 2 2 2 2 4 2 1 3 1 1 4 3 2 1 3 3 4 3 2 4 2 2 1 2 2 2 4 2 1 1 1 5 1 2 1 2 4 1 3 5 2 2 5 5 3 3
108	580	6730715	86.851	4 4 1 3 4 3 3 1 3 4 5 1 4 4 3 1 1 4 3 4 5 3 4 4 5 5 3 5 4 3 3 4 3 3 3 3 2 3 5 5 3 4 5 4 1 3 3 1 4 1 2 4 3 5 3 5 5 4 4 3 5 5 3
109	580	6544480	82.861	2 3 1 1 3 2 4 1 2 4 1 1 4 4 3 2 4 1 3 3 1 2 2 4 5 1 5 3 3 2 3 3 1 4 3 2 3 5 2 2 4 1 2 4 1 4 3 4 4 2 1 2 1 5 2 3 5 2 5 5 5 5 5
110	580	6436355	76.751	3 1 1 2 4 3 1 1 1 1 2 4 1 3 1 2 1 1 1 1 2 2 1 5 5 2 5 4 4 5 2 4 3 2 3 2 4 1 1 2 2 1 1 2 2 1 1 5 5 2 2 4 2 3 1 2 5 5 1 5 5 3 5
111	581	6553275	83.251	4 4 1 3 4 3 4 3 2 2 2 2 2 3 4 2 2 2 1 2 2 2 2 2 5 2 4 3 1 4 1 2 3 3 3 3 3 2 4 4 4 1 4 5 1 4 3 3 4 1 1 5 3 5 5 5 5 2 5 4 5 5 5
112	581	6460630	79.341	2 1 4 3 1 1 1 2 2 4 2 1 3 2 2 1 4 1 1 3 1 2 5 2 2 3 5 3 4 3 1 4 4 4 3 2 4 1 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 4 5 5 5 2 5 5 1 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
113	581	6429510	76.401	3 4 1 1 1 4 1 1 1 4 2 1 1 3 1 3 2 3 1 1 2 1 2 2 5 3 5 1 4 5 2 3 1 3 3 1 4 1 1 1 4 2 1 3 1 1 2 1 5 2 2 2 1 5 4 3 1 3 1 3 3 2 5
114	582	6543660	82.711	1 1 1 3 1 2 3 4 3 4 1 3 1 4 1 2 4 2 2 3 2 2 4 4 3 1 5 3 3 5 1 3 5 2 2 1 5 3 4 2 4 5 5 2 1 5 4 4 4 1 1 1 2 5 5 4 5 2 5 5 5 5 5
115	582	6461300	79.741	3 1 1 3 4 1 2 3 2 3 1 2 1 3 1 3 3 1 1 3 2 2 2 2 2 1 5 2 4 3 2 1 5 2 3 3 5 5 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 4 5 5 5 2 5 5 2 3
116	583	6496540	81.691	3 3 3 3 4 2 2 2 1 4 1 1 1 4 3 2 4 2 2 1 4 1 1 2 2 1 5 2 4 3 2 1 5 2 3 3 5 5 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 4 5 5 5 2 5 5 2 3
117	583	6457120	78.691	2 1 2 2 1 2 2 2 1 2 2 1 3 3 1 2 3 1 1 4 1 2 3 4 3 2 2 2 3 1 2 3 4 3 3 1 3 3 4 4 4 4 4 4 1 4 2 3 4 1 1 3 2 5 1 2 4 1 2 2 5 5 5
118	583	6454680	78.361	3 2 1 1 1 4 1 3 4 3 1 1 2 4 2 2 3 2 1 3 2 2 2 2 2 2 5 3 2 2 3 2 2 1 2 3 3 1 4 1 3 2 4 1 3 1 3 4 5 1 1 3 2 5 5 3 2 4 4 5 5 3 5
119	584	6496215	80.941	4 1 1 2 3 3 2 3 4 4 2 1 4 3 3 2 4 1 3 2 3 2 1 2 3 3 3 5 4 4 3 4 1 1 4 2 3 2 2 2 3 4 2 2 1 1 3 1 3 2 1 5 2 5 5 1 5 5 2 1 4 5 5
120	585	6536080	82.781	4 4 3 2 3 1 4 1 1 4 1 1 2 4 1 1 4 1 3 2 1 5 2 2 2 3 3 2 2 1 4 1 1 2 3 3 4 2 5 2 4 4 4 1 4 1 1 5 4 1 3 5 5 5 2 3 5 2 3 5 5 5 5
121	585	6460230	78.871	3 3 1 2 1 1 1 3 1 2 1 3 1 3 1 2 1 2 1 4 1 3 3 3 2 3 3 3 2 3 3 4 3 3 2 1 3 2 4 3 3 2 2 1 1 4 1 2 5 1 4 5 1 5 5 4 5 5 1 1 5 5 5
122	587	6618625	85.461	4 4 3 3 4 3 2 3 1 5 1 3 4 4 4 2 2 3 3 4 1 3 4 2 5 3 4 1 1 5 3 1 2 1 4 2 3 1 5 5 3 3 5 1 3 1 1 5 3 1 4 5 5 5 3 4 5 2 3 4 5 5 1
123	588	6539690	83.001	3 3 2 3 3 4 3 1 2 3 3 2 4 4 4 2 3 1 2 4 1 4 2 3 5 1 1 1 4 2 2 1 2 4 3 4 4 3 4 3 4 1 3 3 2 3 5 3 3 2 1 1 5 4 1 5 4 2 3 4 5 4 5
124	588	6445000	78.801	4 3 1 3 3 4 4 3 4 3 2 1 2 4 2 2 2 1 1 3 1 5 1 2 3 2 2 5 4 3 1 2 3 3 1 1 3 3 4 4 4 1 1 2 2 2 2 3 5 2 1 1 2 1 3 3 4 5 3 1 5 1 4
125	590	6505740	81.701	3 3 3 3 4 2 2 2 1 4 1 1 1 4 3 2 4 2 2 1 4 1 1 2 2 1 5 2 4 3 2 1 5 2 3 3 5 5 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 5 1 4 3 2 5 3 5 3
126	590	6456350	78.911	4 4 2 3 2 2 4 2 1 4 2 4 3 1 3 4 1 1 1 1 1 1 2 3 4 2 2 2 5 3 1 5 2 1 2 3 5 2 3 5 4 2 1 2 3 1 1 2 5 1 1 3 3 5 2 1 3 4 2 4 2 5 5
127	591	6492030	80.851	2 4 4 1 4 2 1 1 3 5 2 2 1 4 1 3 3 1 2 1 1 2 2 1 3 1 4 3 2 3 1 4 3 4 3 1 3 2 4 1 3 4 4 2 2 1 2 3 4 1 4 4 2 5 5 5 5 2 5 3 3 5 5
128	591	6484130	80.161	3 2 3 3 1 1 2 4 1 5 1 1 2 4 1 3 2 1 2 2 3 2 2 3 3 1 3 3 1 2 1 1 4 3 3 3 3 3 3 4 3 4 4 4 1 1 2 4 4 1 1 1 5 5 5 4 4 5 1 2 4 5 5

Table A.4 Results of the proposed model for 63-activity problem with IC = \$3500/day.

Sol. #	Dur (Day)	Cost (\$)	Quality (%)	Mode Selection
129	591	6438750	77.861	3 3 2 3 4 1 2 2 3 1 1 1 1 1 2 2 2 1 3 2 2 1 2 2 2 5 1 3 5 2 3 3 2 2 2 4 2 4 4 3 1 1 2 2 1 4 4 5 1 1 4 4 5 5 3 5 4 3 5 2 1 3
130	592	6491640	80.401	4 2 4 2 4 1 1 1 2 2 4 1 4 4 1 2 2 1 1 4 1 4 5 1 3 1 2 4 3 4 3 1 1 3 3 2 5 3 1 4 2 4 5 2 1 2 2 3 4 1 1 3 2 5 5 5 5 5 1 4 3 5 5
131	593	6427390	76.931	3 1 2 1 1 1 1 3 1 1 1 5 1 3 3 2 1 2 1 4 1 2 1 2 2 2 5 1 3 5 2 3 3 2 2 2 4 2 4 4 3 1 1 2 2 1 4 4 5 1 1 4 2 4 1 2 4 2 3 1 5 5 5
132	596	6491990	80.471	3 4 1 3 4 2 4 4 1 4 1 1 1 3 1 2 2 2 1 1 2 1 4 2 4 1 5 3 2 5 3 4 3 1 2 4 3 1 1 3 4 2 5 3 1 1 5 2 4 1 1 1 4 5 4 5 5 5 2 4 5 4 5
133	596	6444800	79.001	3 2 1 2 4 1 2 1 1 1 1 1 2 3 3 2 2 2 1 3 2 2 2 4 4 1 3 2 3 1 5 3 3 3 3 3 3 3 3 4 4 4 3 2 1 1 1 5 3 1 1 5 2 5 1 1 4 5 1 3 4 5 5
134	597	6496530	80.991	4 1 4 3 1 1 3 2 1 3 2 1 2 3 3 2 4 2 1 3 1 1 2 2 5 1 5 2 3 1 1 3 4 2 3 2 4 4 2 1 4 5 4 2 1 4 3 2 3 2 1 1 5 5 4 4 4 1 5 5 5 5 5
135	597	6479975	80.421	4 4 4 1 4 3 2 3 2 1 1 1 1 4 2 2 3 2 2 4 1 2 1 2 2 1 3 3 4 1 4 4 3 4 1 3 3 3 1 4 4 1 3 1 2 1 1 3 4 1 4 4 1 5 4 3 5 2 5 3 5 5 5
136	597	6479090	80.081	1 4 3 3 2 4 3 1 1 1 1 1 1 4 2 1 1 1 2 3 2 1 2 3 2 2 5 2 4 2 3 4 3 4 2 1 3 1 3 5 4 3 1 4 3 3 4 4 4 1 1 3 1 5 1 2 3 5 3 5 5 2 5
137	598	6485580	80.591	1 4 3 3 3 4 1 1 1 2 1 3 3 4 1 4 3 1 2 2 2 3 2 1 2 1 5 3 2 3 2 3 3 3 2 5 1 3 3 4 2 1 1 2 2 1 4 2 4 1 4 3 2 5 1 5 5 2 1 5 5 5 5
138	602	6420700	76.251	2 4 1 3 4 1 2 3 1 1 1 1 1 1 1 2 1 1 1 2 1 2 1 2 3 2 2 3 3 1 4 3 1 4 3 1 3 2 4 2 3 5 1 1 1 1 4 4 4 1 1 2 4 4 5 1 5 2 3 5 3 1 5
139	603	6468420	79.771	4 2 1 2 1 1 4 1 1 1 1 1 1 4 1 1 3 1 1 4 4 1 2 2 2 1 4 4 2 2 3 4 4 3 3 1 4 4 5 3 3 4 4 1 2 4 4 2 3 1 1 4 4 5 3 1 5 4 3 2 5 1 5
140	604	6417440	76.801	1 3 3 1 3 2 3 3 1 5 2 1 4 3 1 3 2 1 1 4 1 2 1 2 2 3 4 1 2 1 3 1 2 1 2 2 3 3 1 4 4 3 2 2 1 3 4 2 3 1 4 1 3 2 2 5 5 3 2 2 5 1 4
141	607	6443460	78.501	1 3 2 1 1 2 4 4 1 2 1 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 5 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5
142	609	6434960	76.981	1 1 1 1 1 4 1 4 1 2 1 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 3 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5
143	609	6434960	76.981	1 1 1 1 1 4 1 4 1 2 1 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 3 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5
144	610	6433510	77.091	1 1 3 1 1 1 1 1 1 1 4 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 5 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5