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# PROCUREMENT AND ACTIVITY PLANNING FOR A PRODUCTION LINE PROVIDER

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PROCUREMENT AND ACTIVITY PLANNING FOR A PRODUCTION LINE PROVIDER

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# PROCUREMENT AND ACTIVITY PLANNING FOR A PRODUCTION LINE PROVIDER


## Abstract

Consider a production line provider with the following problem. Turnkey production lines should be delivered to global clients by contractual due-dates. Machines in the production lines can be bought from suppliers or built in-house. Since the production lines for different clients are of the same type -albeit of different capacity- they consist of similar or same machines. Thus, their purchase and/or production need to be coordinated to reduce costs and production time. Furthermore, capital and workforce resources are constrained. Hence, not all activities can be done in parallel and should be spread across the planning horizon. Delivery delays have monetary fines proportional to the time past the due-dates. The company is concerned about making the due-dates by observing all resource constraints and carefully coordinating the activities of the concurrent projects. We give mixed-integer linear programming formulations for the investigated problems and report the results of the numerical experiments conducted using these formulations.



**Keywords: Industry, Multi-project planning, Supply chain management, Capital constraints, Tardiness, Mixed-integer programming**

# BİR ÜRETİM HATTI SAĞLAYICISI İÇİN SATIN ALMA VE FAALİYET PLANLAMASI

## Özet

Bu çalışmada bir üretim hattı sağlayıcısına ait bir problem ele alınmaktadır. Anahtar teslim üretim hatları sözleşmeli teslim tarihlerine göre küresel müşterilere teslim edilmelidir. Üretim hatlarındaki makineler tedarikçilerden satın alınabilir veya şirketin kendi bünyesinde üretilebilir. Farklı müşteriler için üretim hatları aynı türde olduğundan farklı kapasitelere rağmen aynı veya benzer makinelerden oluşur. Bu nedenle, satın alma ve / veya üretim maliyetlerini ve üretim zamanını azaltmak için projelerin koordine edilmesi gerekir. Ayrıca, şirketin sermayesi ve işgücü kaynakları sınırlıdır. Bu nedenle, tüm faaliyetler paralel olarak yapılamaz ve planlama ufkuna yayılmalıdır. Teslim gecikmeleri vadeleri geçmiş zamana orantılı olarak para cezalarına sahiptir. Şirket, tüm kaynak kısıtlamalarını gözönünde bulundurarak ve eşzamanlı projelerin faaliyetlerini koordine ederek proje teslim tarihlerini belirlemek istemektedir. Bu tez çalışmasında, incelenen problemler için karışık-tamsayılı doğrusal programlama formülasyonları ve bu formülasyonlar kullanılarak yapılan sayısal deneylerin sonuçları raporlanmaktadır.

**Anahtar kelimeler: Sanayi, Çok projeli planlama, Tedarik zinciri yönetimi, Sermaye kısıtlamaları, Gecikme, Karışık tamsayılı programlama**

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*To my country . . .*

# Table of Contents

# List of Tables

# List of Figures

## List of Abbreviations

| | |
|---|---|
| **AWM8** | **A**rc **W**elding **M**achine |
| **AWM1** | Valve Boss **W**elding **M**achine SAW |
| **AWM10** | Foot Ring **W**elding **M**achine |
| **AWM2** | Circumferential Seam **W**elding **M**achine SAW |
| **AWM3** | Valve Guard Ring (Collar) **W**elding **M**achine |
| **AWM4** | Foot Ring **W**elding **M**achine |
| **AWM5** | Foot Ring |
| **AWM6** | Double Head Circumferential **W**elding Unit |
| **AWM7** | Longitudinal **W**elding **U**nit |
| **AWM9** | Circumferential **W**elding Saw |
| **CHC** | Basic Conveyor Systems |
| **COMP** | **C**ompressor |
| **COT** | **C**ooling **T**ower |
| **CSL** | **C**omplete **S**litting **L**ine |
| **CT** | **C**asette **T**rollies |
| **DCM** | Triple Blanking Shear Press |
| **DDA** | **D**eep **D**rawing **A**utomation Load Unload |
| **DGU** | **D**egreasing **U**nit |
| **DSP** | **D**ie **S**et Sample **P**reparation |
| **EDP** | Double Layer Wet / Powder Painting Line |
| **ESP** | Powder Coating Line |
| **FLO** | **F**lux Heating Furnace |
| **FRDDI** | **F**irst **R**e-coating of the **D**eep **D**rawing **D**ies |
| **FTE** | **F**atigue **T**esting **E**quipment |

**GAMS** **G**eneral **A**lgebraic **M**odeling **S**ystem

**GEN** **G**enerator

**GRP** Second Color **P**ainting Line

**HTU** **H**eat **T**reatment Furnace

**K1** Die Set 1

**K10** Die Set10

**K11** Die Set 11

**K12** Die Set 12

**K13** Die Set 13

**K14** Die Set 14

**K15** Die Set 15

**K2** Die Set 2

**K3** Die Set 3

**K4** Die Set 4

**K5** Die Set 5

**K6** Die Set 6

**K7** Die Set 7

**K8** Die Set 8

**K9** Die Set 9

**LCBDAB** **L**ine **C**ontrol **B**etween **D**ecoiler and **B**lanking

**LPG** **L**iquified **P**etroleum **G**as

**MEE** **M**aterial Preparation

**MIP** **M**ixed **I**nteger **P**rogramming

**OHC** Crane

**OHCRI** Crane Rails and Installation

**P1** **P**roject 1

**P2** **P**roject 2

**P1+P2** Concurrent **P**1 and **P**2 **P**rojects

**PTL1** **P**neumatic Leakage **T**esting Machine

**PTL2** Valve Boss Cleaning Machine

| | |
|---|---|
| **PTL3** | Valve Screwing Machine |
| **PTL4** | **P**neumatic Leakage Testing Unit |
| **PTL5** | Neck Ring Threads Cleaning Unit |
| **PTL6** | Jet **T**are Stamp Station |
| **PTL7** | Air Purging Vacuum Unit |
| **PTM1** | Hydrostatic Testing Unit Semi Automatic |
| **PTM2** | Hydrostatic Testing Unit (35-45 kg) |
| **QLE1** | Tensile Machine, Universal Testing Machine |
| **QLE2** | Burst Test Equipment |
| **QLE3** | X-ray Machine with All Accessorries |
| **RBM1** | **R**ound **B**ending **M**achine |
| **RBM2** | **R**ound **B**ending **M**achine (35-45 Kg) |
| **RCMPSP** | **R**esource-**C**onstrained **M**ulti-**P**roject **S**cheduling **P**roblem |
| **RCPSP** | **R**esource-**C**onstrained **P**roject **S**cheduling **P**roblem |
| **SBM** | **S**hot **B**lasting **M**achine |
| **SEG** | **S**erigraphy Unit |
| **SP** | **S**pare **P**arts for the Warranty Period |
| **SPCT** | **S**hear **P**ress **C**utting **T**ool Set |
| **SSP** | Guillotine **S**hear |
| **USF1** | **U**ncoiler **S**traightener **F**eeder 15 ton |
| **USF2** | **U**ncoiler **S**traightener **F**eeder 2 tons |
| **V** | Trimming Joggling |
| **VIT** | Inspection Table |
| **VT** | Trimming Tooling |
| **WEU** | **W**ater **E**vacuation **U**nit |
| **WH** | **W**elder **H**oods |
| **WPS** | **W**elding **P**ower **S**ource |
| **WRS** | **W**elding **R**epair **S**tand |
| **X1** | Press 1 |
| **X2** | Press 2 |

| | |
|---|---|
| **X3** | Press 3 |
| **X4** | Press 4 |
| **X5** | Press 5 |
| **X6** | Press 6 |
| **X7** | Press 7 |
| **X8** | Press 8 |
| **X9** | Press 9 |
| **X10** | Press 10 |
| **ZSS** | **Z**inc **S**praying **S**ystem with Cabin |

# Chapter 1

# Introduction

In this thesis, a problem faced by an innovative production line provider for the liquified petroleum gas (LPG) cylinder industry located in İstanbul, Turkey, is considered. It provides turnkey production lines for LPG cylinders to its clients after building and testing them. Many of the machines in the production line are bought from suppliers while there are also some machines that are built in-house. A typical project lasts about a year and project budgets are in the order of millions of dollars. The costs increase with increasing production capacity. Contracts with clients include severe penalties for delayed deliveries hence it is important to deliver a working production line on time. To that end, it is crucial to carefully coordinate the purchasing, production, assembly and testing activities so that all projects are on time and within budget. Most of the machines that are bought from the suppliers are ready to use and they do not require much time to assemble; many times one worker suffices. However, there exist some delivery lead times. The company receives discounts for orders with multiple machines. Machines that are built in-house require some time to build and need more workforce. Potentially, one could buy or build all machines at the very beginning of a project and make the due-date of the project. However, such action is not preferred as not to tie up all capital right from the beginning. Furthermore, all necessary funds may not be available and it is more difficult to borrow larger amounts. Therefore, the company prefers a uniform capital outflow spread over the planning horizon. Thus, careful planning is needed in coordinating projects activities to make all due-dates and stay within capital constraints. Moreover, there may be workforce constraints limiting the amount of work that can be done in parallel. Another complicating factor is the existence of predecessors for some activities, i.e. those activities can not be started before work on all of their predecessors finishes. In this thesis report, we model and solve manufacturing companys project planning problem. The problem consists of several notions from the literature that are normally studied separately because of their hard nature. Since there are limited capital and workforce available, it is a constrained project scheduling problem. In the standard constrained project scheduling problem, the objective is to minimize the makespan, the completion time, of a single project. However, we have multiple projects. Furthermore, we are interested in minimizing total weighted tardiness rather than the completion time. Due-date related scheduling problems are normally more difficult to solve than the ones with makespan objectives. Total weighted tardiness instead of total tardiness is used as the objective to accommodate criticality differences among projects.

This thesis report first reviews relevant literature. Then, mixed-integer linear models used to solve the companys problem instances are provided. Since the problem is a combination of several difficult problems, one would normally expect not to be able to solve many problem instances. However, companys instances could be solved with standard solvers in a short period of time. After the mathematical model formulations, results obtained with real data are presented and discussed followed by a conclusion. This thesis is organized as follows. In Chapter 2, studies in the literature to short. In the third section, general information about the company is explained and discusses the structure of the project and data set . In Chapter 3 , the data of the real life problem is given and the model established according to these data is coded in the GAMS program. In Chapter 4 explain the mathematical model about the LPG prdouction line projects. The linear decision model to be used for the solution of the problem is indicated. In Chapter 5 examines the result for P1 and P2, and results of 2 concurrent projects.

These projects have been transferred to the GAMS model according to the data we have. Afterwards, the data was pulled from the GAMS program to excel with the help of a code in order to see prices, suppliers and payments more easily. Finally, in Chapter 6, results of the study are discussed and evaluated. Chapter 6 also suggests some potential extensions of the provided mathematical model.

# Chapter 2

# Literature Survey

The production line is a system in which components of a product are assembled by means of material handling on a number of workstations. The production line is the most vital business area of a manufacturer. On the other hand, raising the orders at the promised time is one of the most important elements that ensure the trust of the customers. In this context, many studies have been carried out for the best scheduling of the production phase. In this part of the thesis, the definition of resource-constrained projects, scheduling problem and solution approaches will be explained.

## 2.1 Resource-Constrained Project Scheduling Problem (RCPSP)

Today, organizations prefer to direct their business through projects. For the successful completion of the projects, project teams are formed and financing, time, resource and budget plans are made for each project. Thus, it is aimed to use limited resources with maximum efficiency in order to ensure timely growth of each project. Such projects are defined as projects with limited resources or Resource-Constrained Project Scheduling Problem (RCPSP) [1]. The resource constrained project scheduling problem is the best scheduling of the activities that make up a project using limited resources, without violating the order of priority of its objectives.Although it is possible to remove some of these assumptions and go to different definitions of problems, the main points to be considered in the solution of the problem are as follows[2]:

- Duration of activity is deterministic
- The use of resources per unit time of activities is fixed.
- The resource assigned to an activity is used by that activity during the activity.
- Each activity initiated must be completed without interruption.
- Every activity within the scope of the project must take place.

## 2.2 Components of Project Scheduling Problem

There are some basic components in project scheduling. These components should be clearly identified in order to achieve success in solving the project scheduling problem. Figure 2.1 shows these components of resource-constrained project scheduling problems[3].

### 2.2.1 Resources

According to the divisibility of resourcesare divided into two groups as discrete and continuous. Discrete resources can be counted and expressed as a number of resources, while continuous resources are sources such as energy cannot be divided.The resources used to carry out the activities are divided into various classes. There are four groups in classification according to time: renewable resources, non-renewable resources,partially renewable resources and doubly constrained resources[1]:

- Renewable resources; have limited use over time in activities but can be reused in other activities. For example, wind, electricity, solar energy or business machines mentioned.

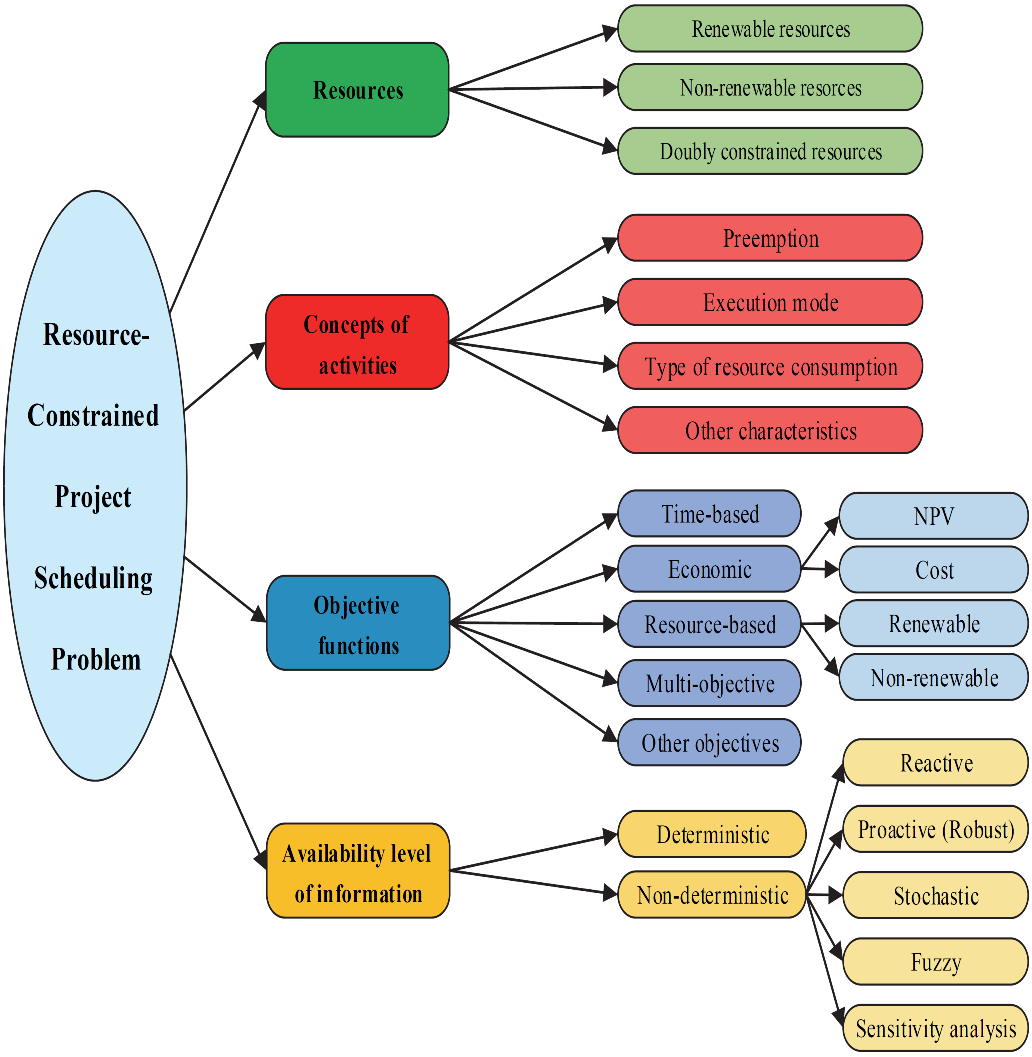


Figure 2.1: Components of Resource-Constrained Project Scheduling Problems (RCPSP) [3].

- Non-renewable resources are exhausted after being used in one activity and cannot be used in other activities. They may use a limited amount during the project period.

- Partially renewable resources; allows to model different resource usage in specific time periods. For example, during the scheduling, the shift system can also participate in the problem.

- Doubly constrained resources; are resources that have limited use both in time and quantity during a project. Money is limited both in time and the amount spent on the project.

### 2.2.2 Activities

Activities, which are one of the main components of project scheduling, form indivisible parts of a project. All the activities of the project should be clearly and clearly defined in order for the scheduling to successfully accomplish the objective of the completion of the project.Each activity has its own resources, duration and budget [4].

### 2.2.3 Precedence Relationship

Activities should be listed in the process of realization of the project. Depending on the phases within the project, the activities that must be done before are defined as the preliminary activities and the activities that are programmed to start after the completion of an activity are defined as successive activities.The start and end times of an activity are important for starting the activities in the schedule at the right time and for completing the project on time. Some activities in the project depend on the completion of other activities. If there are concurrent projects, both projects use the same resources and time effectively on the schedule depends on the determination of the precursors. For all activities within the project, start-end, start-start, end-start relationships must be determined. It is also important to determine the maximum and minimum waiting times for each activity [2].

### 2.2.4 Constraints

Constraints include the amount of time allocated to the activities to be carried out in the project, the amount of resources such as workers, machinery, raw materials and freedom of use. In multiple projects or between different modes of the same project, the primacy relationship forms the constraints of the project. One of the most important problems for the completion of a project is the overcoming of barriers to constraints [5].

### 2.2.5 Purpose function

Optimizing the objective function is one of the most important problems in project schedules. The complex purpose of the value of time and money resources required optimization of the function. Objective functions commonly used in charts are: [4]

- Minimizing project duration
- Optimize resource utilization
- Optimizing the project to its current net worth
- Optimizing project costs to present value
- Optimization of cash flows to present value

In a Resource-Constrained Project Scheduling Problem (RCPSP), the duration of the project is one of the most important performance criteria. It is aimed to complete the project with limited resources in minimum time. The objective function used in the first project scheduling demonstrations, which are assumed to have no resource constraints, is to minimize the project duration. Early completion and delays are tried to be balanced in different project objective functions such as minimizing the delays that may occur in the project activities and producing just in time [6].

In aResource-Constrained Project Scheduling Problem (RCPSP), the other important performance criteria is maximizing total cost or total profit. In order to achieve this, the present value of the money is calculated and the changes in the value of money over time are eliminated from the cash flow and traded over its present value. Objective functions can be grouped into three main groups: [7]

- Time-based objective functions
- Economic objective functions (Cost-based objective functions, Net Present Value)
- Resource-based objective functions (Renewable resource objective functions, Non-renewable resource objective functions, Other objective functions, Multi-objective problems)

### 2.3 Multi-Project Scheduling

With increasing competition in the globalizing world, companies have to increase their production coefficient. For this reason, they have to make very good planning in order to train incoming projects.The management of multiple simultaneousprojects is a challenging task.In order to overcome this difficult task,researchers developed new tools via of developing technology.Developed on the basis of mathematical algorithms, with these tools aimed and planed the most efficient use of limited time and limited resources in simultaneous projects [8].

The first scheduling models developed by Bellmann[9] and Dijkstra [10] in the late 1950s are quite simple. It is based on a linear programming that does not allow negative, variable or cycles and has many generalization there in. The time-cost trade-off problem was first shown in 1959 by Kelley and Walker[11] and they gave a solution based on linear programming. In 1961 Fulkerson[12] and Kelly[13] gave the solution based onbased on maximal flow algorithm. It is defined as problem Scheduled Problem to plan the activities to use the limited resources in the most effective way [14].

The history of the scheduling problem is quite old. From the Gantt Diagram developed by Henrry Gantt [15], the scheduling and project management process has become more complex and difficult. Mathematical methods are no longer sufficient for scheduling complex and large projects and are not preferred due to processing times and difficulty in setting up the model. The solution times of these difficult problems called polynomial time are searched by heuristic methods [16].

There is a relationship between the resources used in an activity and the duration of the activity. In the application modelled as time-cost trade-off, the increase in the resource used per unit time is expected to increase the cost and decrease the operating time. The fact that the resource used is discrete and continuous also affects this relationship. In discrete activities, each cost-time pair is defined as a mode.Firms may have to run multiple projects simultaneously to increase their profits [17]. Projects that have to use the same resources, the same time frame, and machines of this type are defined as multi-mode projects. They contain multiple cost-time pairs. In the activities defined as resource-resource trade-off, the duration is fixed but different resources are used. The same project is completed in the same time with the number of different people different number of machines [2].

New product development, various product production, maintenance of systems, infrastructure arrangements are vital in a multi-purpose environment. When projects have to be executed simultaneously, they should share limited resources simultaneously, paying attention to priorities. Each activity in a project must be carried out in a mode determined by the specified time and resources.The planning of available limited resources and time is an important problem for manufacturers. It requires quite attention. The materials to be used in the projects must be procured, logistics, production stage and planning should be made to the customer. In the scheduling, the start and end times of the activities are also included.In particular, the multimodal resource constrained project scheduling problem was developed based on the fact that the activity could be performed in shorter or longer periods with different resource utilization rates. When preparing the activity schedule for this problem, which mode of activities should be used should also be selected. It is more difficult to solve than single mode problems and has longer processing times [18,19].

### 2.4 Solution Approaches of RCPSP Problems

Managing multiple projects is a complex task. It involves the integration of varieties of resources and schedules. The researchers have proposed many tools and techniques for single project scheduling. All the information about the project is needed to reach the best possible solution in project scheduling. If all information is available, deterministic solutions are used. However, it is not always possible to access and use all information. In case of uncertainty, an approach to solution is provided with probability calculations [3].

#### 2.4.1 Deterministic

Deterministic approaches include scheduling methods developed based on the assumption that all information on project activities is complete and usable.However, these methods prepare the calendaring before the project and are based on estimates. Therefore, the data is not accurate. Therefore, non-deterministic approaches were developed afterwards [1]. Mathematical models in which the problems are defined primarily from the engineering point of view, their constraints are determined and the solution set within these constraints are reached are a classical approach in operations research. In these classical approaches, the data of the problem is accepted with certainty and the modeling is established in such a way that it does not change, and the solution set or optimum result is reached.This classical approach, called Linear Mathematical Programming, has been used in relation to game theory since the 1920s, and has become a widely used method for solving transportation, assignment and decision problems in the following years. While linear mathematical programming gives very good results in real life problems where the boundaries are limited and the interactions are low, it is seen that it is inadequate in real life problems where the boundaries cannot be fully drawn and the interactions are more intense. Assignment problems in production processes have become a common tool and need to be used. Assignment problems Linear Mathematical Programming is a common method, but in order to select the right method in real life problems, firstly, data analysis must be done correctly and advanced with the right methodology [20,21].

### 2.4.2 Nondeterministic

Problems with resource-constrained project scheduling often arise due to uncertainties. These uncertainties may be due to the fact that activities take less or longer than anticipated. Insufficient resources may slow down or stop the operation of the project. The start or end times of the activities may be postponed or hampered for any reason. New activities may be added or some activities may be abandoned due to the introduction of other concurrent projects.All of these causes can lead to increased uptime and costs. Therefore, since certain solutions do not include these uncertainties, approaches to uncertainty based on probability calculations have been developed.The procedures that provide more precise results in the uncertainty environment can be examined under five headings: reactive scheduling, stochastic scheduling, fuzzy scheduling, proactive (robust) scheduling, sensitivity analysis [3].

#### 2.4.2.1 Reactive scheduling

This approach, developed by utilizing the application information obtained during the project, does not include uncertainty in the scheduling time table.The biggest advantage of reactive scheduling is that it reacts instantly to unexpected events.The program is structured on two basic questions: When should the schedule be renewed first? How to create a new timeline [3]?

#### 2.4.2.2 Stochastic scheduling

In this approach, these are models developed with probability calculations assuming that project scheduling parameters contain uncertainties.There are four general problems of stochastic project scheduling [3].

1. Stochastic Resource-Constrained Project Scheduling Problem
2. Project scheduling problems with stochastic activity interruptions
3. Stochastic discrete time/cost trade-off problem
4. Stochastic project scheduling problems with economic objective functions.

#### 2.4.2.3 Fuzzy scheduling

Fuzzy scheduling developed due to the inability to distribute probability in the absence of historical information on the activities in the project.This approach is used to determine project activity times under unique conditions. Literature studies show that fuzzy numbers are more preferred than random numbers in modeling [3].

#### 2.4.2.4 Proactive (robust) scheduling

In this approach, all delays that may occur while scheduling are estimated and taken into account. It is aimed to predict delays by performing strong and stable scheduling. Thus, the unexpected effects are intended to change the main schedule to a minimum.At the same time, with this scheduling method, the completion time of the project can be kept constant while allowing some activities to be spread in a more flexible range [3].

#### 2.4.2.5 Sensitivity analysis

Sensitivity analysis is a method developed by finding answers to some questions in case of uncertainty. These questions are generally aimed at searching for optimal values of project scheduling components[3].

- When will the project duration remain optimal?
- How does the objective function of the project remain optimal?
- What is the range of changes of the parameters to maintain the optimal solution?
- What is the best cost range for changing parameters?
- What kind of sensitivity analysis should be used to ensure the stability of the optimization?

## 2.5 Algorithms Used in the Solution of Multi Project Schedule

There are two types of algorithms that schedule multiple projects based on mathematical modeling.One of them is heuristic and the other is genetic [22]. Heuristic algortihms has been studied extensively in the literature and has made significant progress in the problem of graphing. Kolisch and Drexl [20] conducted extensive research on 536 test problems and four different heuristic methods, which researched these algorithms to find the best solution. They found that heuristic algorithms were not consistent with the feasible solutions[5].

For the first time, genetic algorithms proposed by Holland [23] have been explained in more detail by Goldberg [24]. Genetic algorithms developed by using natural selection and genetic concepts enable historical performance to be improved by scheduling the project. Genetic algorithms can produce the same number of solutions instead of a single solution. So you can search in parallel.

The solution of the problem is expressed by a chromosome consisting of genes. The genetic algorithm is initiated by a generation of a series of solutions. A new generation is created by the processes of reproduction, crossover and mutation. Better chromosomes are transferred to the next generation and used in subsequent solutions. Thus, the current rule of evolution that the strong one lives is reflected in genetic codes. Genetic algorithms are very successful in solving resource constrained project scheduling problems [25].

## 2.6 Related studies

Lawrence and Morton [26] emphasized that delays in different projects will lead to different costs. They calculated weighted tardiness costs in order to minimize different damages in different projects. Therefore, for resource constraint multi project scheduling problem RCMPSP, they developed a cost-benefit scheduling policy with resource pricing. Smith-Daniels et al. [27] emphasized that the capital constrained project scheduling problem is a more difficult management problem than RCPSP and developed an heuristic model for capital constrained projects. Lee and Kim [28] used a single-point crossover with random key representation in their genetic algorithm and applied parallel scheduling.

Hartmann [29] examined all three impressions. In each demonstration, single-point crossover, two-point crossover and uniform crossover methods were tested. Again, serial representation is used for each representation. The sequence of activities on the chromosome in the activity list representation is feasible in terms of precedence. The chart is created by making the earliest possible main assignment according to the order on the chromosome. Hartmann used the LFT, LST, MTS, MSLK, WRUP and GRPW priority rules for priority representation. In random key representation, each gene has a value in the range [0,1] corresponding to the priority value. In his study, Hartmann proposed a genetic algorithm that adapted itself to the problem for RCPSP. The proposed algorithm chooses one of two different coding structures (serial scheduling and parallel scheduling) according to the nature of the problem [30].

Ulusoy et al. [25] the genetic algorithm developed with assumed non-preemptive, zero-time lag multi-project scheduling problem with multiple modes and limited renewable and nonrenewable resources, a two-stage hierarchical mathematical modeling. It aims to optimize cash flows and time-dependent renewable resource requirements during the macro-activity phase. Kolisch et al. [31]developed PROGEN, an algorithm that generates resource constrained project scheduling problems. They solved the problems created by this algorithm by using serial scheduling method using priority rule [2].

Kumanan et al. [5] developed an heuristic and genetic algorithm to minimize the production makespan of projects and for scheduling a multi-project environment. Voss et al. [32] developed hybrid flow shop scheduling as a multi-mode multi-project scheduling problem with batching requirements. Gonalves et al. [33] developed a genetic algorithm for RCMPSP based on priorities, release times and delay times and presented with a chromosome representation Leyman and Vanhoucke developeda new scheduling technique technique for maximized NPV for RCPSP with cash flow as a solution to resource investment problems [34-36].

He et al. [37] developed a program to maximize their net present value (NPV) by creating different payment plans operating modes for multi-mode capital-constrained project payment scheduling problems.Tabrizi's works [38-40] has focused on the development of project scheduling on concurrent project planning, material ordering, and minimizing project costs. Kanagasabapathi et al. [41] developedin resource-constrained multiple projects to minimize the weighted tardiness and weighted earliness of projects. Roghanian et al., [42] developed mathematical model for a preemption multi-mode multi-objective resource-constrained project scheduling problem with distinct due dates and positive and negative cash flows.

# Chapter 3

# Mathematical Model

In this section, an integer linear model for our problem is provided. First, a model that considers only budgetary resource constraints will be given. As a future study this model will be extended to include payments in installments. Many of the tasks are not demanding in terms of workforce needs. Components supplied by the suppliers are mostly ready to use and can be set up in a short period of time by little workforce. Next, the notation used in the formulation of the mathematical models is given followed by the models.

## 3.1 Sets

$C$ = Set of all components that can be used by projects, $c = 1, ..., |C|$.

$C_p$ = Components needed by project $p$, a subset of $C$. $c_{last_p}$ refers to the last component of each project. Typically, these are testing equipments used in line testing activities. If an integration and testing phase does not exist a dummy component that succeeds all real components should be defined as the last component of each project for modeling purposes.

Succ(c)$_p$= Components that must be worked on in project $p$ after finishing work on component $c$.

I = Number of units a component can be ordered in, $i = 0, ..., |I|$.

P = Projects, $p = 1, ..., |P|$.

S = Suppliers, $s = 1, ..., |S|$.

$S_c$= Suppliers that can supply component $c$.

T = Planning horizon, $t = 1, ..., |T|$.

## 3.2 Parameters

$a_{p,c}$ = Assembly/production time in weeks for component $c$ of project $p$.
$d_p$ = Week project $p$ is due.
$l_{p,c,s}$ = Lead time of supplier $s$ in weeks for component $c$ of project $p$.
$M_1$ = Penalty for exceeding available capital of each week. When $M_1 = 1$ the penalty is equal to the additional capital needed.
$M_2$ = Maximum number of units that can be ordered of any component.
$m_t$ = Available capital in week $t$ .
$n_{p,c}$ = Number of units of component $c$ needed in project $p$.
$u^i_{c,s}$ =Unit price of component $c$ if $i$ units are ordered from supplier $s$ . The unit price may decrease as the number of ordered units per order increases.
$w_p$ = Penalty of delaying project $p$. By using different penalty coefficients for each project in the objective function, projects can be prioritized among each other. Projects normally have contractual monetary delay penalties.
Integration1 and Integration2 = A dummy activity that is preceded by all other activities in the project. This activity may involve the testing for the integrated production line.

## 3.3 Decision Variables

$b_{p,c,t}$= 1 if work on component $c$ of project $p$ starts in week $t$; 0 otherwise.

$e_p$= Tardiness of project $p$.

$f_t$= Additional capital needed in week $t$.

$k_{p,c,s}$= number of units of component $c$ for project $p$ ordered from supplier $s$.

$o_{p,c,s,t}$= 1 if component $c$ of project $p$ is ordered from supplier $s$ in week $t$; 0 otherwise.

$q_{c,s,t}$ = payment made to supplier $s$ for component $c$ in week $t$.

$x_{p,c,s}$ = 1 if component $c$ of project $p$ is ordered from supplier $s$; 0 otherwise.

$y^i{}_{c,s,t}$ = 1 if $i$ units of component $c$ is ordered from supplier $s$ in week $t$; 0 otherwise.

z= The weighted sum of project delays and weekly capital needs exceeding capital at hand.

## 3.4 Model with Budget Constraints

$$min \quad z = \sum_p w_p \cdot e_p + \sum_c \sum_s \sum_t q_{c,s,t} + \sum_t M_1 \cdot f_t \tag{3.1}$$

subject to:

$$\sum_{s \in S_c} x_{p,c,s} = 1 \quad \forall p \in P, \forall c \in C_p \tag{3.2}$$

$$\sum_s x_{p,c,s} = 0 \quad \forall p \in P, \forall c \notin C_p \tag{3.3}$$

$$k_{p,c,s} \leq M_2 \cdot x_{p,c,s} \quad \forall p \in P, \forall c \in C_p, \forall s \in S_c \tag{3.4}$$

$$\sum_{s \in S_c} k_{p,c,s} = n_{p,c} \quad \forall p \in P, \forall c \in C_p \tag{3.5}$$

$$\sum_{s} k_{p,c,s} = 0 \quad \forall p \in P, \forall c \notin C_p \tag{3.6}$$

$$\sum_{s \notin S_c} k_{p,c,s} = 0 \quad \forall p \in P, \forall c \in C_p \tag{3.7}$$

$$\sum_{t} o_{p,c,s,t} = x_{p,c,s} \quad \forall p \in P, \forall c \in C, \forall s \in S \tag{3.8}$$

$$\sum_{i} y^{i}_{c,s,t} \leq |I| \cdot \sum_{p} o_{p,c,s,t} \quad \forall c \in C, \forall s \in S, \forall t \in T \tag{3.9}$$

$$\sum_{t} b_{p,c,t} = 1 \quad \forall p \in P, \forall c \in C_p \tag{3.10}$$

$$\sum_{t} t \cdot b_{p1,Integration,t} + a_{p1,Integration} - e_{p1} \leq d_{p1} \quad p = p1, c = Integration \tag{3.11}$$

$$\sum_{t} t \cdot b_{p2,Integration2,t} + a_{p2,Integration2} - e_{p2} \leq d_{p2} \quad p = p2, c = Integration2 \tag{3.12}$$

$$\sum_{t} t \cdot b_{p,c,t} + a_{p,c} \leq \sum_{t} t \cdot b_{p,c',t} \quad \forall p \in P, \forall c \in C_p \backslash c_{last_p}, \forall c' \in Succ(c)_p \tag{3.13}$$

$$\sum_{s \in S_c} \sum_{t} t \cdot o_{p,c,s,t} + \sum_{s \in S_c} l_{p,c,s} \cdot x_{p,c,s} \leq \sum_{t} t \cdot b_{p,c,t} \quad \forall p \in P, \forall c \in C_p \tag{3.14}$$

$$\sum_{c} \sum_{s} q_{c,s,t} - f_t \leq m_t \quad \forall t \in T \tag{3.15}$$

$$q_{c,s,t} \geq \sum_i i \cdot u^i_{c,s} \cdot y^i_{c,s,t} \quad \forall c \in C, \forall s \in S, \forall t \in T \tag{3.16}$$

$$\sum_p k_{p,c,s} = \sum_i \sum_t i \cdot y^i_{c,s,t} \quad \forall c \in C, \forall s \in S \tag{3.17}$$

$$\sum_i y^i_{c,s,t} \leq 1 \quad \forall c \in C, \forall s \in S, \forall t \in T \tag{3.18}$$

$$b_{p,c,t} \in \{0,1\} \quad \forall p \in P, \forall c \in C_p, \forall t \in T \tag{3.19}$$

$$e_p \geq 0 \quad \forall p \in P \tag{3.20}$$

$$f_t \geq 0 \quad \forall t \in T \tag{3.21}$$

$$k_{p,c,s} \in \mathrm{Z}^+_0 \quad \forall p \in P, \forall c \in C_p, \forall s \in S \tag{3.22}$$

$$o_{p,c,s,t} \in \{0,1\} \quad \forall p \in P, \forall c \in C_p, \forall s \in S, \forall t \in T \tag{3.23}$$

$$q_{c,s,t} \geq 0 \quad \forall c \in C, \forall s \in S, \forall t \in T \tag{3.24}$$

$$x_{p,c,s} \in \{0,1\} \quad \forall p \in P, \forall c \in C_p, \forall s \in S \tag{3.25}$$

$$y^i_{c,s,t} \in \{0,1\} \quad \forall i \in I, \forall c \in C, \forall s \in S, \forall t \in T \tag{3.26}$$

$$z \geq 0 \tag{3.27}$$

Constraint 3.1 minimizes the sum of weighted tardiness of the projects and total payments to the suppliers for the components, and also penalizes exceeding the available capital. Constraint 3.2 and Constraint 3.3 guarantee that each project component is ordered from exactly one supplier which carries that component. By leaving this constraint out, an order for a project component can be split up among different suppliers. Constraint 3.4 relates the ordering decisions from suppliers and the number of units ordered, and makes sure that zero units are ordered from a supplier if a supplier is not used for a component. Constraint 3.5 sets the total number of units of a component ordered from all suppliers equal to the needed number of units of that component in that project. Constraint 3.6 and Constraint 3.7 make sure no orders are placed for components that are not needed in a project. Different projects may need different number of units for a component due to line capacity differences. Constraint 3.8 says that a component can be ordered from a supplier only in one week. It is also possible that a component is not ordered from a supplier in which case related $o_{p,c,s,t}$ variables will be set to 0. Constraint 3.9 relates the ordering time from a supplier to the variables that control the number of units ordered from the supplier. Work on each component is made to start in only one week with Constraint 3.10. Constraint 3.11 and 3.12 helps with observing the due-dates of the projects. However, these are soft constraints, and the project deliveries can be delayed albeit at a cost specified in the contract. Constraint 3.13 states that work on succeeding components of a machine cannot be started before work on that machine finishes. Similarly, work on a machine cannot be started before the machine arrives from its supplier by Constraint 3.14. Constraint 3.15 limits the total expenditure in a given week with the available capital in that week. Exceeding capital limits is allowed when necessary but this is penalized in the objective function. Constraint 3.16 determines the payments made to each supplier for each component. The objective function has a term that corresponds to the sum of all payments which is also minimized. As the unit component prices normally decrease when more than one unit is ordered, the model will prefer to order the components in bulk. However, this may not always be possible due to capital limits and potential project delays when components are ordered late. Constraint 3.17 says the order placed to a supplier for a component should be consistent with the needed number of components. $y^i_{c,s,t}$ variables are auxiliary variables for determining the unit prices paid to each supplier and they need to be consistent with $k_{p,c,s}$ variables. Constraint 3.18 specifies that each week at most one order should be placed with each supplier for each component. Finally, variable types are specified.

# Chapter 4

# Data Description

## 4.1 General information about the company

Company is a provider of turn-key complete production plants for the metal forming sector as well as a designer, manufacturer and supplier of key metal forming machines for the global market, with a well established reputation for outstanding performance.

Recognized worldwide for its proprietary design and manufacturing know how.Company has been selling sheet metal forming equipment to producers across the globe since 1978.

Company is a diligent supplier of custom-made solutions strictly focused on customer requirements with three decades of track record for challenging conventional methods to come up with ingenious superior results.

## 4.2 Data Set

This section represents the results of the single projects and concurrent projects.In this study there are two project about LPG cylinders line. There are 68 machines in the P1 project. There are 72 machines in the P2 project.52 machines the same for 2 projects. The reason for the difference in these projects is customer expectation and production process (capacity). Their capacity is 150 cylinder/hour for

P1, 210 cylinder/hour for P2. There are four main part in the line. These are ; upper-lower half part , guard-foot ring part, welding line and the painting line. The machines are located in these four main parts. Figure 4.1 and 4.2 shows the flow chart about the production line provider.

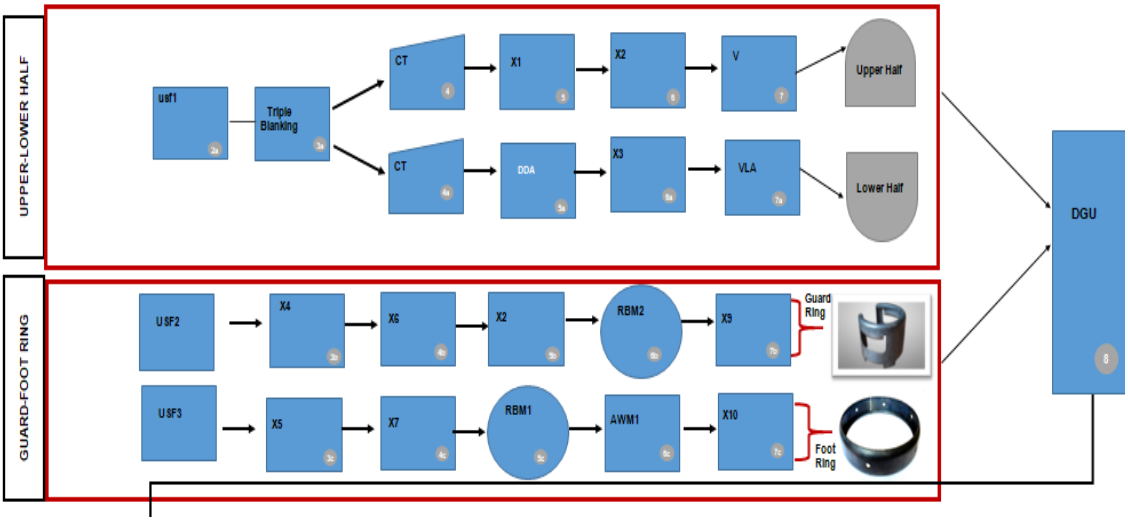


Figure 4.1: Upper and lower half, guard and foot ring for production line provider.

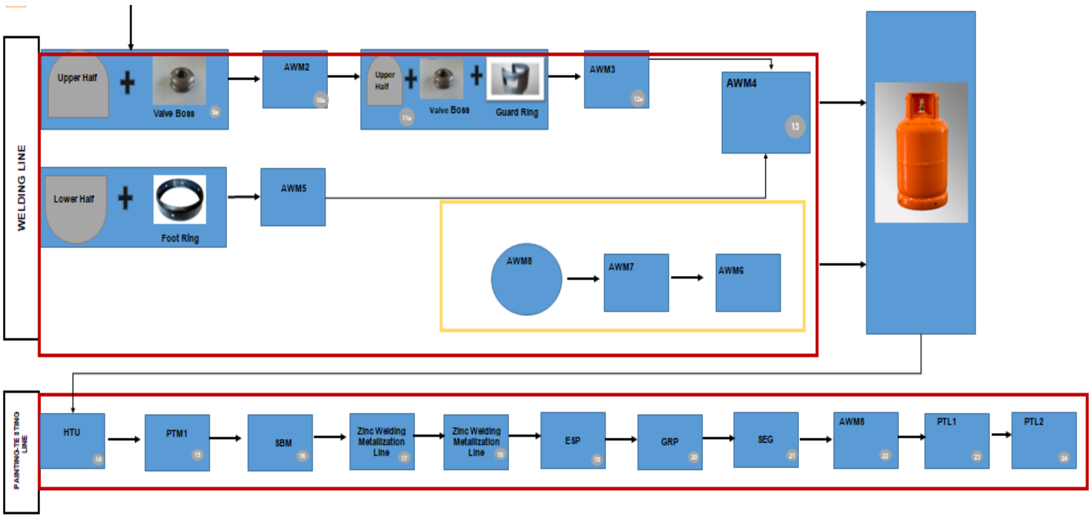


Figure 4.2: Welding line, painting and testing line for production line provider.

Each machine has its own code (machine name) and includes lead time, quantity, assembly time and suppliers from which the machine is supplied. Each project has delivery times and weekly budget. All information is given in the tables below.

There is also a line integration process at the end of the project. Different integration times are defined for both projects and projects must end before this integration period.

In this study, we are writing a program; (MIP) in GAMS developer which determines which machine will be purchased from which supplier for which week and how much. In this programme we have some parameter about the projects. In this section, we describe the units we use for parameters. $M_1$ means penalty for exceeding available capital of each week and its unit is euro. $M_2$ means maximum number of units that can be ordered of any component and its unit is quantity. $m_t$ means available capital in week $t$ and its unit is euro. $w_p$ means Penalty of delaying project $p$. By using different penalty coefficients for each project in the objective function, projects can be prioritized among each other. Projects normally have contractual monetary delay penalties and its unit is euro. $T$ means Planning horizon, $t = 1, ..., |T|$ and its unit is week. All units are units of quantity. All time units are considered as weeks and all currencies as eur

## 4.3 Machine Name, Quantity and Supplier for P1 and P2

In this project every machine has a max 3 suppliers. In Table 4.1 and 4.2 shows the names of suppliers for P1 and P2 project. The maximum quantity for both projects is 6. Suppliers are the same for machines that are the same in project P1 and P2.

| **Machine Name** | **Quantity** | **Supplier 1 P1** | **Supplier 2 P1** | **Supplier 3 P1** |
|---|---|---|---|---|
| USF1(15 TON) | 1 | Coiltech | Dkotomasyon | Pressline |
| DCM | 1 | Company X | Cogeim | - |
| SPCT | 1 | Company X | Cogeim | - |
| CT | 4 | Company X | Matesan | VRGMakine |
| X1 | 2 | Company X | Ceis | Koclu Pres |
| DDA | 2 | Company X | Ozkan Pres | Koclu Pres |
| X2 | 1 | Company X | Ceis | Oguzlar |
| K1 | 1 | Hak Makine | Form2000 | Ceis |
| K2 | 4 | Hak Makine | Form2000 | Ceis |
| K3 | 4 | Hak Makine | Form2000 | Ceis |
| K4 | 2 | Hak Makine | Form2000 | Ceis |
| V | 2 | Company X | Sheet Metal | Ceis |
| VT | 2 | Company X | Sheet Metal | ZimekMakina |
| LCBDAB | 1 | Company X | Semens | - |
| AWM1 | 3 | Wicon | Magmaweld | Hrtek |
| AWM2 | 6 | Wicon | Magmaweld | Hrkon |
| AWM3 | 3 | Wicon | Hrtek | Hrkon |
| AWM4 | 4 | Wicon | Hrtek | Hrkon |
| WPS | 1 | Magmaweld | Esab | Lincoln |
| HTU | 1 | Sistem Makine | Sistem Teknik | - |
| FLO | 1 | Yakamoz Bulut Makine | Alfa | - |
| WH | 1 | Wicon | Magmaweld | Lincoln |
| USF2 (2 ton) | 2 | Coiltech | Dkotomasyon | Pressline |
| X3 | 2 | Company X | Ceis | BestMakina |
| X4 | 1 | Company X | Ceis | BestMakina |
| X5 | 1 | Company X | Ceis | BestMakina |
| X6 | 1 | Company X | Ceis | BestMakina |
| X7 | 1 | Company X | Ceis | BestMakina |
| X8 | 1 | Company X | Ceis | BestMakina |
| X9 | 1 | DKOtomasyon | Ceis | Oguzlar |
| RBM1 | 2 | Company X | ahinler | Akyapak |
| AWM5 | 2 | Wicon | Magmaweld | Lincoln |
| K5 | 1 | Hak Makine | Form2000 | Ceis |
| K6 | 1 | Hak Makine | Form2000 | Ceis |
| K7 | 1 | Hak Makine | Form2000 | Ceis |
| K8 | 1 | Hak Makine | Form2000 | Ceis |
| K9 | 1 | Hak Makine | Form2000 | Ceis |
| K10 | 1 | Hak Makine | Form2000 | Ceis |

| Machine Name | Quantity | Supplier 1 P1 | Supplier 2 P1 | Supplier 3 P1 |
|---|---|---|---|---|
| K11 | 1 | Hak Makine | Form2000 | Ceis |
| K12 | 1 | Hak Makine | Form2000 | Ceis |
| K13 | 1 | Hak Makine | Form2000 | Ceis |
| K14 | 1 | Hak Makine | Form2000 | Ceis |
| K15 | 1 | Hak Makine | Form2000 | Ceis |
| DGU | 1 | Everest | Botersan | Akm Boya |
| SBM | 1 | Cogeim | Euroblast | - |
| ZSS | 1 | Alfatechnic | Metallisation | Company X |
| ESP | 1 | Botersan | Enbotek | Dersan |
| GRP | 1 | Enbotek | Botersan | Dersan |
| PTM1 | 3 | FCImpianti | Meka Mhendislik | - |
| PTL1 | 1 | FCImpianti | Meka Mhendislik | - |
| PTL2 | 1 | FCImpianti | Meka Mhendislik | - |
| PTL3 | 2 | FCImpianti | Meka Mhendislik | - |
| CHC | 1 | Matesan | Snmez Makine | Atlm |
| AWM6 | 1 | Wicon | Magmaweld | Lincoln |
| AWM7 | 1 | Wicon | Lincoln | - |
| RBM2 | 1 | Akyapak | ahinler | Durmazlar |
| PTM2 | 1 | FCImpianti | Meka Mhendislik | - |
| PTL4 | 1 | FCImpianti | Meka Mhendislik | - |
| QLE1 | 1 | Ala | Labthink | - |
| QLE2 | 1 | Company X | Meka Mhendislik | - |
| QLE3 | 1 | Balteau | Metemak | Polimek |
| DSP | 1 | Company X | Ceis | Hak Makine |
| CSL | 1 | Birlik Makine | Zhengchuang | - |

| Machine Name | Quantity | Supplier 1 P1 | Supplier 2 P1 | Supplier 3 P1 |
|---|---|---|---|---|
| COT | 1 | NibaSu | Form Klima | - |
| SP | 1 | Company X | Ceis | Form2000 |
| COMP | 1 | Atlas Copco | Dalgakiran | - |
| FRDDI | 1 | Company X | Ceis | Form2000 |
| Integration | 1 | Company X | - | - |
| SSP | 1 | Coiltech | Dkotomasyon | Pressline |

Table 4.1: Machine Name,Supplier Name And Quantity for P1.

| Machine Name | Quantity P2 | Supplier 1 P2 | Supplier 2 P2 | Supplier 3 P2 |
|---|---|---|---|---|
| DCM | 1 | Company X | Cogeim | - |
| SPCT | 1 | Company X | Cogeim | - |
| CT | 6 | Company X | Matesan | VRGMakine |
| X1 | 2 | Company X | Ceis | Koclu Pres |
| DDA | 2 | Company X | Ozkan Pres | Koclu Pres |
| X2 | 1 | Company X | Ceis | Oguzlar |
| K1 | 2 | Hak Makine | Form2000 | Ceis |
| K2 | 2 | Hak Makine | Form2000 | Ceis |
| K3 | 2 | Hak Makine | Form2000 | Ceis |
| V | 2 | Company X | Sheet Metal | Ceis |
| VT | 2 | Company X | Sheet Metal | ZimekMakina |
| VLA | 2 | Company X | Sheet Metal | ZimekMakina |
| AWM1 | 4 | Wicon | Magmaweld | Hrtek |
| AWM2 | 6 | Wicon | Magmaweld | Hrkon |
| AWM3 | 5 | Wicon | Hrtek | Hrkon |
| AWM4 | 4 | Wicon | Hrtek | Hrkon |
| WPS | 1 | Magmaweld | Esab | Lincoln |
| HTU | 1 | Sistem Makine | Sistem Teknik | - |
| FLO | 1 | Yakamoz Bulut Makine | Alfa | - |
| USF2 (2 ton) | 2 | Coiltech | Dkotomasyon | Pressline |
| USF3 (12 ton) | 2 | Coiltech | Dkotomasyon | Pressline |

| Machine Name | Quantity P2 | Supplier 1 P2 | Supplier 2 P2 | Supplier 3 P2 |
|---|---|---|---|---|
| X3 | 1 | Company X | Ceis | BestMakina |
| X4 | 2 | Company X | Ceis | BestMakina |
| X5 | 1 | Company X | Ceis | BestMakina |
| X6 | 1 | Company X | Ceis | BestMakina |
| X7 | 1 | Company X | Ceis | BestMakina |
| X8 | 1 | Company X | Ceis | BestMakina |
| X9 | 1 | DKOtomasyon | Ceis | Oguzlar |
| X10 | 1 | Company X | Ceis | BestMakina |
| RBM1 | 2 | Company X | ahinler | Akyapak |
| AWM5 | 2 | Wicon | Magmaweld | Lincoln |
| K5 | 1 | Hak Makine | Form2000 | Ceis |
| K6 | 2 | Hak Makine | Form2000 | Ceis |
| K7 | 1 | Hak Makine | Form2000 | Ceis |
| K9 | 1 | Hak Makine | Form2000 | Ceis |
| K10 | 1 | Hak Makine | Form2000 | Ceis |
| K11 | 1 | Hak Makine | Form2000 | Ceis |
| K13 | 1 | Hak Makine | Form2000 | Ceis |
| K15 | 1 | Hak Makine | Form2000 | Ceis |
| K16 | 2 | Form 2000 | Ayyildiz Tarim | Ceis |
| DGU | 1 | Everest | Botersan | Akm Boya |
| SBM | 1 | Cogeim | Euroblast | - |
| ZSS | 1 | Alfatechnic | Metallisation | Company X |
| PTM1 | 3 | FCImpianti | Meka Mhendislik | - |
| PTL1 | 1 | FCImpianti | Meka Mhendislik | - |
| PTL3 | 2 | FCImpianti | Meka Mhendislik | - |
| CHC | 1 | Matesan | Snmez Makine | Atlm |
| QLE1 | 1 | Ala | Labthink | - |

| Machine Name | Quantity P2 | Supplier 1 P2 | Supplier 2 P2 | Supplier 3 P2 |
|---|---|---|---|---|
| QLE2 | 1 | Company X | Meka Mhendislik | - |
| QLE3 | 1 | Balteau | Metemak | Polimek |
| DSP | 1 | Company X | Ceis | Hak Makine |
| COT | 2 | NibaSu | Form Klima | - |
| SP | 1 | Company X | Ceis | Form2000 |
| COMP | 3 | Atlas Copco | Dalgakiran | - |
| FRDDI | 1 | Company X | Ceis | Form2000 |
| VIT | 1 | Company X | Parker | Meshweld |
| WRS | 1 | Company X | Parker | Meshweld |
| AWM8 | 1 | Wicon | Magmaweld | Hrtek |
| AWM9 | 2 | Wicon | Magmaweld | Hrkon |
| AWM10 | 3 | Wicon | Hrtek | Hrkon |
| WEU | 1 | Company X | Tekzen | Purpanel |
| EDP | 1 | Company X | Botersan | Enbotek |
| PTL5 | 2 | FCImpianti | Meka Mhendislik | - |
| PTL6 | 3 | Teknosin | Meka Mhendislik | - |
| PTL7 | 1 | FCImpianti | Meka Mhendislik | - |
| SEG | 1 | Company X | Botersan | Enbotek |
| MEE | 1 | Company X | Polyform | Buehler |
| FTE | 1 | Company X | Siemens | Besmak |
| OHC | 2 | Abus | Urcan Makine | TeknoVinc |
| OHCRI | 2 | Abus | TeknoVinc | Gralp |
| GEN | 2 | Aksa | Emsa | GksuMakina |
| Integration2 | 1 | Company X | | |
| SSP | 2 | Coiltech | Dkotomasyon | Pressline |

Table 4.2: Machine Name,Supplier Name And Quantity for P2.

## 4.4 Lead Time and Assembly Time

In this project every machine has a lead time and assembly time. GAMS programme takes these times into consideration and finds the optimal result to get the job done before the deadlineboth projects on time. In Table 4.3 and 4.4 shows the lead time and assembly time for P1 and P2 project.

.

| Machine Name | Supplier 1 Lead Time 1 | Supplier 2 Lead Time 2 | Supplier 3 Lead Time 3 | Assembly Time |
|---|---|---|---|---|
| USF1(15 TON) | 14 | 18 | 20 | 4 |
| DCM | 22 | 25 | - | 8 |
| SPCT | 22 | 25 | - | 5 |
| CT | 8 | 8 | 10 | 2 |
| X1 | 22 | 25 | 26 | 5 |
| DDA | 12 | 12 | 10 | 5 |
| X2 | 22 | 25 | 25 | 5 |
| K1 | 18 | 15 | 15 | 3 |
| K2 | 18 | 15 | 15 | 3 |
| K3 | 18 | 15 | 15 | 3 |
| K4 | 18 | 15 | 15 | 3 |
| V | 22 | 25 | 26 | 3 |
| VT | 17 | 20 | 20 | 3 |
| LCBDAB | 10 | 8 | - | 5 |
| AWM1 | 20 | 22 | 18 | 6 |
| AWM2 | 20 | 22 | 18 | 6 |
| AWM3 | 20 | 22 | 18 | 6 |
| AWM4 | 20 | 22 | 18 | 6 |
| WPS | 20 | 22 | 18 | 6 |
| HTU | 25 | 30 | - | 6 |
| FLO | 8 | 12 | - | 2 |
| WH | 5 | 7 | 7 | 5 |
| USF2 (2 ton) | 5 | 8 | 8 | 4 |
| X3 | 22 | 25 | 20 | 5 |
| X4 | 22 | 25 | 20 | 5 |
| X5 | 22 | 25 | 20 | 5 |
| X6 | 22 | 25 | 18 | 5 |
| X7 | 22 | 25 | 20 | 5 |
| X8 | 22 | 25 | 20 | 5 |
| X9 | 7 | 10 | 8 | 5 |
| RBM1 | 12 | 15 | 16 | 3 |
| AWM5 | 20 | 25 | 22 | 9 |
| K5 | 16 | 18 | 15 | 3 |
| K6 | 16 | 18 | 15 | 4 |
| K7 | 16 | 18 | 15 | 4 |
| K8 | 16 | 18 | 15 | 4 |
| K9 | 16 | 18 | 15 | 4 |
| K10 | 16 | 18 | 15 | 4 |
| K11 | 16 | 18 | 15 | 4 |
| K12 | 16 | 18 | 15 | 4 |

| **Machine Name** | **Supplier 1 Lead Time 1** | **Supplier 2 Lead Time 2** | **Supplier 3 Lead Time 3** | **Assembly Time** |
|---|---|---|---|---|
| K13 | 16 | 18 | 15 | 4 |
| K14 | 16 | 18 | 15 | 4 |
| K15 | 16 | 18 | 15 | 4 |
| DGU | 19 | 20 | 18 | 7 |
| SBM | 25 | 30 | - | 8 |
| ZSS | 18 | 20 | 15 | 6 |
| ESP | 26 | 28 | 30 | 8 |
| GRP | 22 | 25 | 28 | 8 |
| PTM1 | 22 | 25 | - | 3 |
| PTL1 | 22 | 25 | - | 3 |
| PTL2 | 22 | 25 | - | 3 |
| PTL3 | 22 | 25 | - | 3 |
| CHC | 10 | 15 | 15 | 4 |
| AWM6 | 20 | 25 | 22 | 9 |
| AWM7 | 20 | 25 | 22 | 9 |
| RBM2 | 6 | 8 | 8 | 6 |
| PTM2 | 22 | 25 | - | 2 |
| PTL4 | 22 | 25 | - | 2 |
| QLE1 | 12 | 15 | - | 5 |
| QLE2 | 12 | 15 | - | 5 |
| QLE3 | 8 | 10 | 12 | 5 |
| DSP | 15 | 13 | 12 | 2 |
| CSL | 29 | 35 | - | 6 |
| COT | 4 | 5 | - | 1 |
| SP | 5 | 8 | 8 | 2 |
| COMP | 13 | 10 | - | 5 |
| FRDDI | 5 | 5 | 6 | 6 |
| Integration | - | - | - | 4 |
| SSP | 15 | 15 | 18 | 2 |

Table 4.3: Machine Names, Supplier Lead Time and Assembly Time for P1.

| Machine Name | Supplier 1 Lead Time 1 | Supplier 2 Lead Time 2 | Supplier 3 Lead Time 3 | Assembly Time |
|---|---|---|---|---|
| DCM | 22 | 25 | - | 8 |
| SPCT | 22 | 25 | - | 5 |
| CT | 8 | 8 | 10 | 2 |
| X1 | 22 | 25 | 26 | 5 |
| DDA | 12 | 12 | 10 | 5 |
| X2 | 22 | 25 | 25 | 5 |
| K1 | 18 | 15 | 15 | 3 |
| K2 | 18 | 15 | 15 | 3 |
| K3 | 18 | 15 | 15 | 3 |
| V | 22 | 25 | 26 | 3 |
| VT | 17 | 20 | 20 | 3 |
| VLA | 12 | 9 | 15 | 3 |
| AWM1 | 20 | 22 | 18 | 6 |
| AWM2 | 20 | 22 | 18 | 6 |
| AWM3 | 20 | 22 | 18 | 6 |
| AWM4 | 20 | 22 | 18 | 6 |
| WPS | 20 | 22 | 18 | 6 |
| HTU | 25 | 30 | - | 6 |
| FLO | 8 | 12 | - | 2 |
| USF2 (2 ton) | 5 | 8 | 8 | 4 |
| USF3 (12 ton) | 10 | 12 | 11 | 4 |
| X3 | 22 | 25 | 20 | 5 |
| X4 | 22 | 25 | 20 | 5 |
| X5 | 22 | 25 | 20 | 5 |
| X6 | 22 | 25 | 18 | 5 |
| X7 | 22 | 25 | 20 | 5 |
| X8 | 22 | 25 | 20 | 5 |
| X9 | 7 | 10 | 8 | 5 |
| X10 | 22 | 25 | 20 | 5 |
| RBM1 | 12 | 15 | 16 | 3 |
| AWM5 | 20 | 25 | 22 | 9 |
| K5 | 16 | 18 | 15 | 3 |
| K6 | 16 | 18 | 15 | 4 |
| K7 | 16 | 18 | 15 | 4 |
| K9 | 16 | 18 | 15 | 4 |
| K10 | 16 | 18 | 15 | 4 |
| K11 | 16 | 18 | 15 | 4 |
| K13 | 16 | 18 | 15 | 4 |
| K15 | 16 | 18 | 15 | 4 |
| K16 | 18 | 17 | 15 | 4 |
| DGU | 19 | 20 | 18 | 7 |
| SBM | 25 | 30 | - | 8 |

| Machine Name | Supplier 1 Lead Time 1 | Supplier 2 Lead Time 2 | Supplier 3 Lead Time 3 | Assembly Time |
|---|---|---|---|---|
| ZSS | 18 | 20 | 15 | 6 |
| PTM1 | 22 | 25 | - | 3 |
| PTL1 | 22 | 25 | - | 3 |
| PTL3 | 22 | 25 | - | 3 |
| CHC | 10 | 15 | 15 | 4 |
| QLE1 | 12 | 15 | - | 5 |
| QLE2 | 12 | 15 | - | 5 |
| QLE3 | 8 | 10 | 12 | 5 |
| DSP | 15 | 13 | 12 | 2 |
| COT | 4 | 5 | - | 1 |
| SP | 5 | 8 | 8 | 2 |
| COMP | 13 | 10 | - | 5 |
| FRDDI | 5 | 5 | 6 | 6 |
| VIT | 8 | 10 | 6 | 3 |
| WRS | 10 | 12 | 8 | 3 |
| AWM8 | 20 | 22 | 18 | 6 |
| AWM9 | 20 | 22 | 18 | 6 |
| AWM10 | 20 | 22 | 18 | 6 |
| WEU | 2 | 3 | 3 | 1 |
| EDP | 8 | 6 | 5 | 6 |
| PTL5 | 22 | 25 | - | 3 |
| PTL6 | 20 | 25 | - | 3 |
| PTL7 | 22 | 25 | - | 3 |
| SEG | 24 | 25 | 26 | 6 |
| MEE | 5 | 4 | 3 | 2 |
| FTE | 10 | 9 | 8 | 4 |
| OHC | 8 | 6 | 9 | 3 |
| OHCRI | 9 | 8 | 10 | 3 |
| GEN | 6 | 5 | 6 | 1 |
| Integration2 | - | - | - | 6 |
| SSP | 15 | 15 | 18 | 2 |

Table 4.4: Machine Names, Supplier Lead Time And Assembly time for P2.

### 4.5 Price for Each Supplier

In this project every machine has a price for each supplier. GAMS programme takes these prices finds the optimal result by taking into account the weekly budget constraint. In Table 4.5 and 4.6 shows the unit prices for each suppliers in P1 and P2 project.

| **Machine Name** | **Price for Supplier 1** | **Price for Supplier 2** | **Price for Supplier 3** |
|---|---|---|---|
| USF1(15 TON) | 110,000.00 | 120,000.00 | 115,000.00 |
| DCM | 132,000.00 | 120,000.00 | - |
| SPCT | 1,020.00 | 2,000.00 | - |
| CT | 1,000.00 | 1,500.00 | 1,700.00 |
| X1 | 81,540.00 | 78,000.00 | 85,000.00 |
| DDA | 15,000.00 | 13,000.00 | 20,000.00 |
| X2 | 36,300.00 | 45,000.00 | 36,000.00 |
| K1 | 10,000.00 | 12,000.00 | 15,000.00 |
| K2 | 11,000.00 | 15,000.00 | 13,873.00 |
| K3 | 4,056.00 | 5,000.00 | 8,000.00 |
| K4 | 13,877.00 | 15,000.00 | 12,000.00 |
| V | 47,000.00 | 55,000.00 | 50,000.00 |
| VT | 1,500.00 | 2,000.00 | 1,200.00 |
| LCBDAB | 10,000.00 | 15,000.00 | - |
| AWM1 | 5,500.00 | 6,500.00 | 6,200.00 |
| AWM2 | 5,000.00 | 5,500.00 | 6,000.00 |
| AWM3 | 6,750.00 | 5,500.00 | 6,500.00 |
| AWM4 | 4,500.00 | 5,000.00 | 5,200.00 |
| WPS | 83,510.00 | 65,000.00 | 85,000.00 |
| HTU | 205,000.00 | 180,000.00 | - |
| FLO | 1,850.00 | 2,500.00 | - |
| WH | 7,000.00 | 5,500.00 | 6,000.00 |
| USF2 (2 ton) | 20,000.00 | 22,000.00 | 21,000.00 |
| X3 | 71,950.00 | 65,000.00 | 85,000.00 |
| X4 | 60,650.00 | 65,000.00 | 63,000.00 |
| X5 | 51,300.00 | 60,000.00 | 55,000.00 |
| X6 | 51,300.00 | 60,000.00 | 55,000.00 |
| X7 | 51,300.00 | 60,000.00 | 55,000.00 |
| X8 | 25,000.00 | 27,000.00 | 28,000.00 |
| X9 | 8,845.00 | 7,500.00 | 10,000.00 |
| RBM1 | 7,000.00 | 8,000.00 | 8,500.00 |
| AWM5 | 6,600.00 | 5,800.00 | 6,400.00 |
| K5 | 11,000.00 | 11,000.00 | 13,000.00 |
| K6 | 11,000.00 | 11,000.00 | 13,000.00 |
| K7 | 11,000.00 | 11,000.00 | 13,000.00 |
| K8 | 11,000.00 | 11,000.00 | 13,000.00 |
| K9 | 11,000.00 | 11,000.00 | 13,000.00 |
| K10 | 11,000.00 | 11,000.00 | 13,000.00 |
| K11 | 11,000.00 | 11,000.00 | 13,000.00 |
| K12 | 11,000.00 | 11,000.00 | 13,000.00 |
| K13 | 11,000.00 | 11,000.00 | 13,000.00 |
| K14 | 11,000.00 | 11,000.00 | 13,000.00 |

| Machine Name | Price for Supplier 1 | Price for Supplier 2 | Price for Supplier 3 |
|---|---|---|---|
| K15 | 11,000.00 | 11,000.00 | 13,000.00 |
| DGU | 83,500.00 | 85,000.00 | 90,000.00 |
| SBM | 115,000.00 | 120,000.00 | - |
| ZSS | 102,644.00 | 105,000.00 | 95,000.00 |
| ESP | 132,500.00 | 125,000.00 | 95,000.00 |
| GRP | 66,250.00 | 55,500.00 | 70,000.00 |
| PTM1 | 25,000.00 | 30,000.00 | - |
| PTL1 | 20,000.00 | 25,000.00 | - |
| PTL2 | 9,000.00 | 15,000.00 | - |
| PTL3 | 17,000.00 | 20,000.00 | - |
| CHC | 90,000.00 | 100,000.00 | 95,000.00 |
| AWM6 | 8,500.00 | 8,000.00 | 8,500.00 |
| AWM7 | 9,500.00 | 15,000.00 | - |
| RBM2 | 19,470.00 | 20,000.00 | 15,000.00 |
| PTM2 | 15,000.00 | 20,000.00 | - |
| PTL4 | 20,000.00 | 22,000.00 | - |
| QLE1 | 37,360.00 | 40,000.00 | - |
| QLE2 | 44,100.00 | 50,000.00 | - |
| QLE3 | 15,000.00 | 25,000.00 | 22,000.00 |
| DSP | 1,400.00 | 1,500.00 | 1,200.00 |
| CSL | 350,000.00 | 360,000.00 | - |
| COT | 1,973.00 | 2,000.00 | - |
| SP | 40,000.00 | 45,000.00 | 43,000.00 |
| COMP | 8,200.00 | 9,500.00 | - |
| FRDDI | 2,000.00 | 2,500.00 | 4,000.00 |
| SSP | 35,000.00 | 28,000.00 | 27,500.00 |

Table 4.5: Unit Prices for All Suppliers in P1.

| Machine Name | Price for Supplier 1 | Price for Supplier 2 | Price for Supplier 3 |
|---|---|---|---|
| DCM | 132000 | 120000 | - |
| SPCT | 1020 | 2000 | - |
| CT | 1000 | 1500 | 1700 |
| X1 | 81540 | 78000 | 85000 |
| DDA | 15000 | 13000 | 20000 |
| X2 | 36300 | 45000 | 36000 |
| K1 | 10000 | 12000 | 15000 |
| K2 | 11000 | 15000 | 13873 |
| K3 | 4056 | 5000 | 8000 |
| V | 47000 | 55000 | 50000 |
| VT | 1500 | 2000 | 1200 |
| VLA | 20000 | 25000 | 22000 |
| AWM1 | 5500 | 6500 | 6200 |
| AWM2 | 5000 | 5500 | 6000 |
| AWM3 | 6750 | 5500 | 6500 |
| AWM4 | 4500 | 5000 | 5200 |
| WPS | 83510 | 65000 | 80000 |
| HTU | 205000 | 180000 | - |
| FLO | 1850 | 2500 | - |
| USF2 (2 ton) | 20000 | 22000 | 21000 |
| USF3 (12 ton) | 90000 | 85000 | 87000 |
| X3 | 71950 | 65000 | 85000 |
| X4 | 60650 | 65000 | 63000 |
| X5 | 51300 | 60000 | 55000 |
| X6 | 51300 | 60000 | 55000 |
| X7 | 51300 | 60000 | 55000 |
| X8 | 25000 | 27000 | 28000 |
| X9 | 8845 | 7500 | 10000 |
| X10 | 223000 | 225000 | 250000 |
| RBM1 | 7000 | 8000 | 8500 |
| AWM5 | 6600 | 5800 | 6400 |
| K5 | 11000 | 11000 | 13000 |
| K6 | 11000 | 11000 | 13000 |
| K7 | 11000 | 11000 | 13000 |
| K9 | 11000 | 11000 | 13000 |
| K10 | 11000 | 11000 | 13000 |
| K11 | 11000 | 11000 | 13000 |
| K13 | 11000 | 11000 | 13000 |
| K15 | 11000 | 11000 | 13000 |
| K16 | 20000 | 18000 | 22000 |

| Machine Name | Price for Supplier 1 | Price for Supplier 2 | Price for Supplier 3 |
|---|---|---|---|
| DGU | 83500 | 85000 | 90000 |
| ZSS | 102644 | 105000 | 95000 |
| SBM | 115000 | 120000 | - |
| PTM1 | 25000 | 30000 | - |
| PTL1 | 20000 | 25000 | - |
| PTL3 | 17000 | 20000 | - |
| CHC | 90000 | 100000 | 95000 |
| QLE1 | 37360 | 40000 | - |
| QLE2 | 44100 | 50000 | - |
| QLE3 | 15000 | 25000 | 22000 |
| DSP | 1400 | 1500 | 1200 |
| COT | 1973 | 2000 | |
| SP | 40000 | 45000 | 43000 |
| FRDDI | 2000 | 2500 | 4000 |
| VIT | 1500 | 2500 | 5000 |
| WRS | 3000 | 4000 | 6000 |
| AWM8 | 5000 | 8000 | 7500 |
| AWM9 | 6000 | 7000 | 7500 |
| AWM10 | 4000 | 5000 | 5500 |
| WEU | 19000 | 25000 | 22000 |
| EDP | 250000 | 300000 | 280000 |
| PTL5 | 15000 | 20000 | - |
| PTL6 | 18000 | 24000 | - |
| PTL7 | 35000 | 40000 | - |
| SEG | 12000 | 15000 | 18000 |
| MEE | 50000 | 55000 | 60000 |
| FTE | 15000 | 28000 | 20000 |
| OHC | 20000 | 15000 | 16000 |
| OHCRI | 8000 | 6000 | 7000 |
| GEN | 200000 | 250000 | 225000 |
| SSP | 35000 | 28000 | 27500 |

Table 4.6: Unit Prices for All Suppliers in P2.

# Chapter 5

# Results

The General Algebraic Modeling System (GAMS) is a high-level modeling system for mathematical programming and optimization. GAMS first compiles mathematical models formulated by the user at a high level, and then feeds them to a high-performance solver such as CPLEX. Problems were solved on an Intel Core i7, 2.9 GHz computer with a RAM of 8Gb using GAMS/CPLEX.

Typical problem sizes using data from Company X are given in Table 5.3 6,013,984 of the original variables are discrete. The numbers in parentheses are the sizes of the problems after CPLEX preprocesses the problem and eliminates redundant rows and columns.

| Iteration | Columns | Rows | Single Equations | Single Variables | Discrete Variables |
|---|---|---|---|---|---|
| 429 | 408753 | 1227394 | 418,087 | 1,239,692 | 1,103,034 |

Table 5.1: Problem size for P1.

| Iteration | Columns | Rows | Single Equations | Single Variables | Discrete Variables |
|---|---|---|---|---|---|
| 1821 | 800800 | 2410216 | 819,607 | 2,439,860 | 2,170,290 |

Table 5.2: Problem size for P2.

As we mentioned above in this thesis we have some parameter.$M_1$, $M_2$, $W_p$, $t$ and $m_{(t)}$. We will try to find the optimal result for the P1 and P2 project by changing the values given to these parameters.

| Iteration | Columns | Rows | Single Equations | Single Variables | Discrete Variables |
|---|---|---|---|---|---|
| 51932 | 986329 | 6290762 | 1,017,379 | 6,346,319 | 6,013,984 |

Table 5.3: Problem size for concurrent projects (P1 and P2 with together ).

## 5.1 P1 Project Analysis

| | | | | | **mt** | | |
|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **50,000** | **80,000** | **100,000** |
| **P1(a)** | 1 | 20 | 10000 | 52 Weeks | 3,896,027 | 3,475,977 | 3,278,477 |
| **P1(b)** | 10000 | 20 | 1 | 52 Weeks | 10,788,317,477 | 6,587,817,477 | 4,612,817,477 |
| **P1(c)** | 10000 | 20 | 10000 | 52 Weeks | 10,788,317,477 | 6,587,817,477 | 4,612,817,477 |

Table 5.4: A projects schedule with a small budget for P1 project.

Table 5.4 shows the P1 projects scenario. In this scenario time is 52 weeks. Small budgets are available weekly.There is not tardiness.These are 50,000, 80,000 and 100,000 euro. M2 value's is constant and it is 20. Other parameters have variable values. This variability is classified budget is more critical than due dates or due date is more critical than budget. P1(a) and P1 (b) . Figure 5.1, 5.2 and 5.3 shows payment plans. The payment plans are shown in the graph by taking a sample from each scenario for P1(a), P1(b) and P1(c). The green ones in the tables are the models with the lowest objective function.

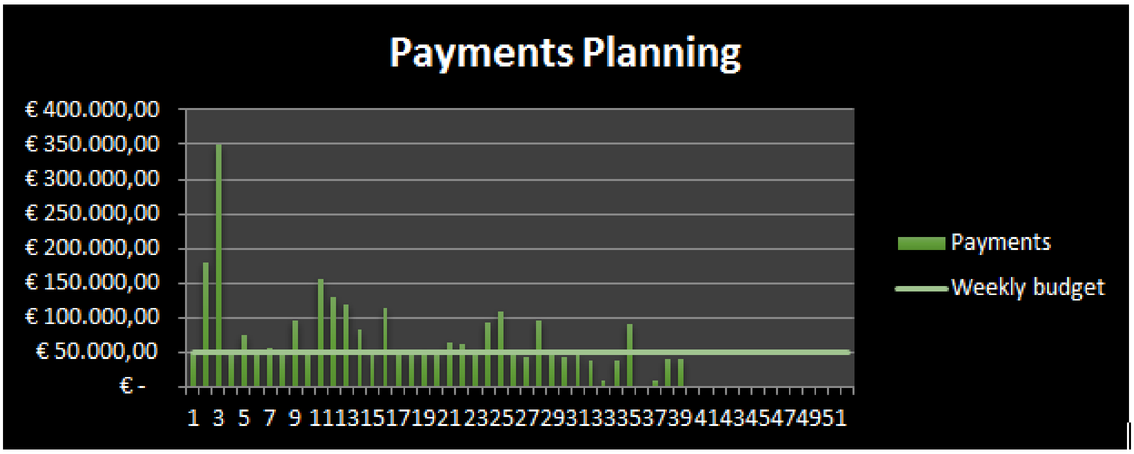


Figure 5.1: A projects payment schedule with a small budget above the data set for P1(a) ($m_{(t)} = 50.000$).

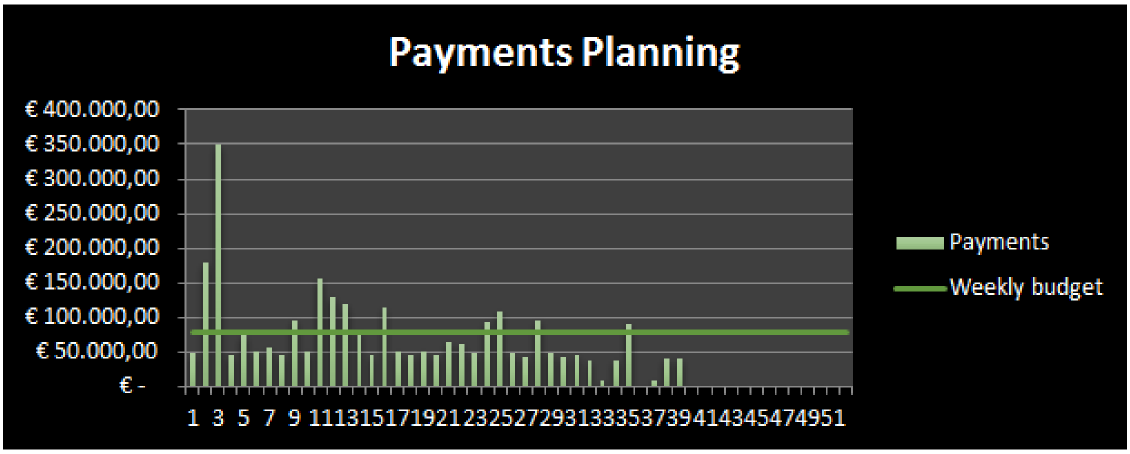


Figure 5.2: A projects payment schedule with a small budget above the data set for P1(b) ($m_{(t)} = 80.000$).

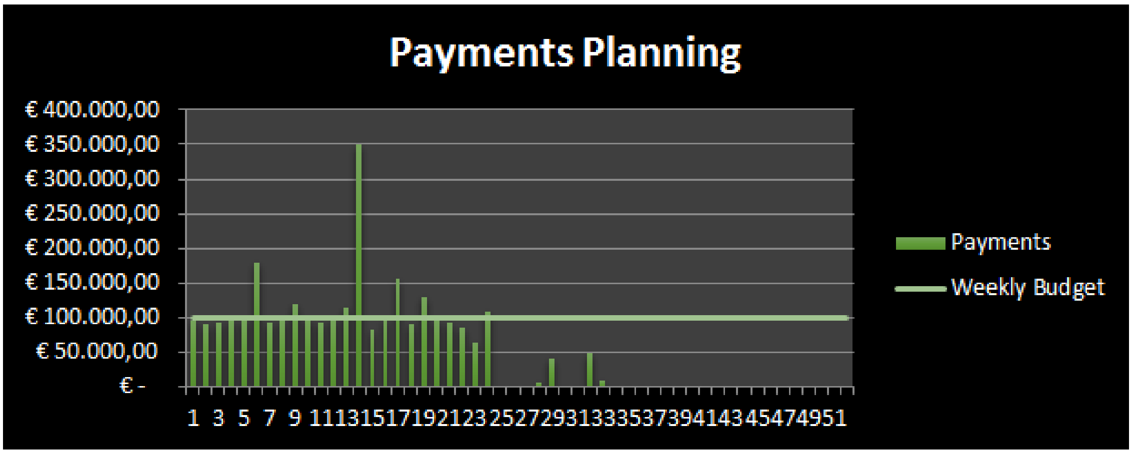


Figure 5.3: A projects payment schedule with a small budget above the data set for P1(c) ($m_{(t)} = 100.000$).

| **Budget** | 50000 | 80000 | 100000 |
|---|---|---|---|
| **Penalties** | 1,078,550 | 6,585,000,000 | 4,610,000,000 |

Table 5.5: Penalties for P1(a)=50000 , P1(b)=80000 and P1(c)=100000.

Table 5.5 shows the penalties for P1(a), P1(b) and P1(c) . When the budget is 50,000 euros, the penalty is 1,078,550.00. When the budget is 80,000 euros the penalty is 6,585,000,000.00. When the budget is 100,000 euros the penalty is 4,610,000,000.00.

| | | | | | **m(t)** | | |
|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **150,000** | **200,000** | **300,000** |
| **P1(d)** | 1 | 20 | 10000 | 52 Weeks | 3,053,477 | 2,967,477 | 2,867,477 |
| **P1(e)** | 10000 | 20 | 1 | 52 Weeks | 2,362,817,477 | 1,502,817,477 | 502,817,477 |
| **P1(f)** | 10000 | 20 | 10000 | 52 Weeks | 2,362,817,477 | 1,502,817,477 | 502,817,477 |

Table 5.6: A projects schedule with a large budget for P1 project.

Table 5.6 shows the values that occur when the weekly budget for the P1 project is slightly higher. When the weekly budget is given as 300,000, the value formed is more profitable for the company. An important point here is that the time given for the company is 52 weeks. We kept M1 penalty small and W (p) large. When we look at the table values and we keep M1 large, the cost is too high and this is not preferable for the company.

| **Budget** | 150,000 | 200,000 | 300,000 |
|---|---|---|---|
| **Penalties** | 236,000 | 1,500,000,000 | 50,000 |

Table 5.7: Penalties for P1(d)=150000 , P1(e):200000 , P1(f):300000.

When we look at the penalties in each scenario, we see that the minimum penalty is the highest in the weekly budget.

| | | | | | m(t) | | |
|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **150,000** | **200,000** | **300,000** |
| **P1(d)** | 1 | 20 | 10000 | 52 Weeks | 5,052,560 | 4,576,188 | 4,353,688 |
| **P1(e)** | 10000 | 20 | 1 | 52 Weeks | 15,160,518,393 | 10,581,518,388 | 8,356,518,388 |
| **P1(f)** | 10000 | 20 | 10000 | 52 Weeks | 15,160,568,388 | 10,581,518,388 | 8,356,518,388 |

Table 5.8: A projects schedule with a small budget for P2 project.

## 5.2 P2 Project Analysis

Table 5.8 shows the P2 projects scenario same with P1 project. In the P2 project, there are some different machines than P1. Therefore, payment times and objective funtion value is different in this scenario. Figure 5.9, 5.10 and 5.11 shows payment plans according to the budgets given for P2 (a) ,P2(b) and P2(c). The payment plans are shown in the graph by taking a sample from each scenario for P2 (a), P2(b) and , P2(c).

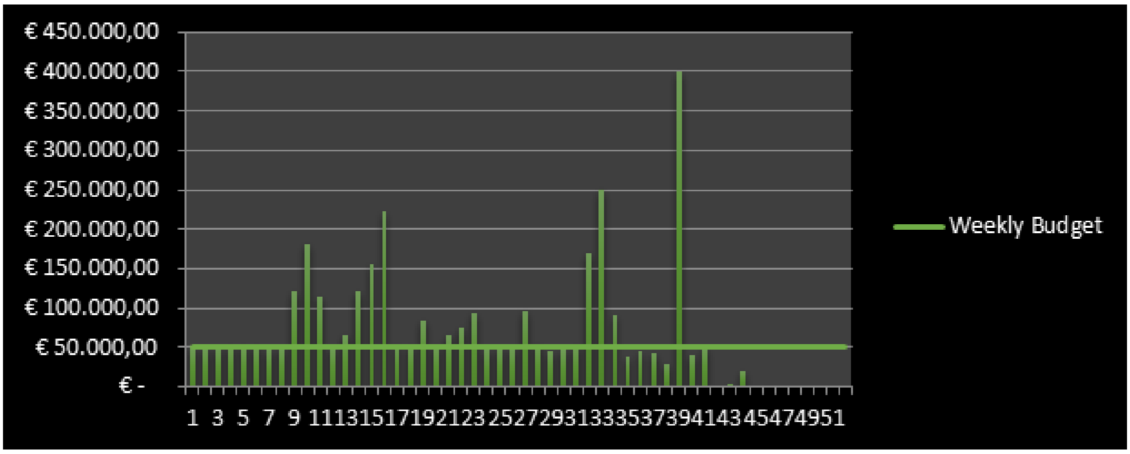


Figure 5.4: A projects payment schedule with a small budget above the data set for P2(a) ($m_{(t)} = 50000$).

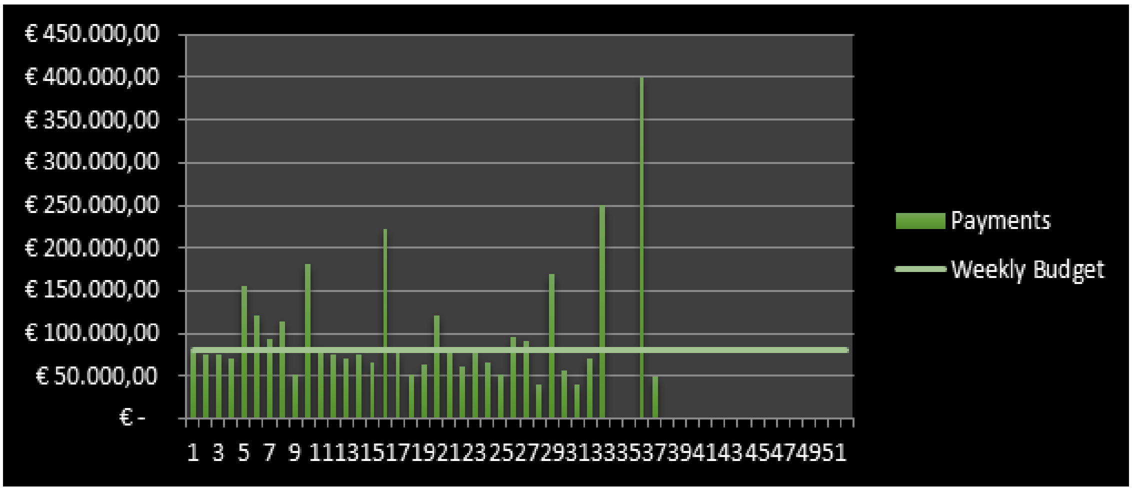


Figure 5.5: A projects payment schedule with a small budget above the data set for P2(b) ($m_{(t)} = 80000$).

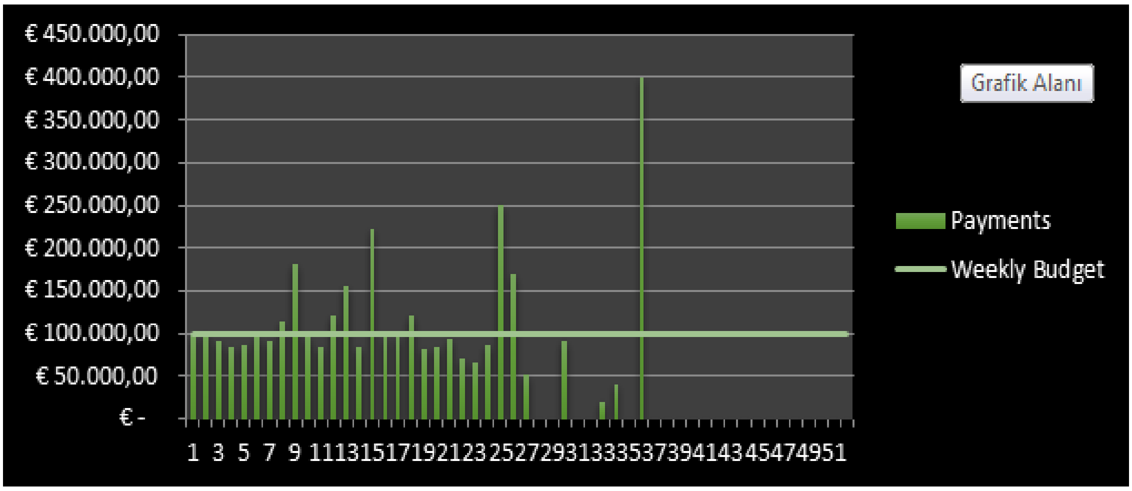


Figure 5.6: A projects payment schedule with a small budget above the data set for P2(c) ($m_{(t)} = 100000$).

.

| Budget | 50,000 | 80,000 | 100,000 |
|---|---|---|---|
| Penalties | 1,530,172<br>Tardiness=1 week | 10,578,000,000 | 8,353,000,000 |

Table 5.9: Penalties for P2(a)=50000 , P2(b)=80000 and P2(c)=100000 .

| | | | | | m(t) | | |
|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **150,000** | **200,000** | **300,000** |
| **P1(d)** | 1 | 20 | 10000 | 52 Weeks | 3,997,388 | 3,791,388 | 3,618,388 |
| **P1(e)** | 10000 | 20 | 1 | 52 Weeks | 4,793,518,388 | 2,733,518,388 | 1,003,518,388 |
| **P1(f)** | 10000 | 20 | 10000 | 52 Weeks | 4,793,518,388 | 2,733,518,388 | 1,003,518,388 |

Table 5.10: A projects schedule with a large budget for P2 project .

| **Budget** | 150,000 | 200,000 | 300,000 |
|---|---|---|---|
| **Penalties** | 236,000 | 1,500,000,000 | 50,000 |

Table 5.11: Penalties for P2 (d)=150000, P2 (e):200000, P2 (f):300000 .

## 5.3 Different Times for P1 and P2 Projects

| | | | | | m(t) | | | |
|---|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **50,000** | **80,000** | **100,000** | **Tardiness** |
| **P1** | 10000 | 20 | 10000 | 36 weeks | 16,885,465,777 | 11,105,235,253 | 8,251,613,677 | 3 weeks |
| **P1** | 1 | 20 | 10000 | 36 weeks | 4,614,031 | 4,036,031 | 3,738,547 | 3 weeks |
| **P1** | 10000 | 20 | 1 | 36 weeks | 16,885,435,780 | 11,105,205,256 | 8,251,583,680 | 3 weeks |
| **P2** | 10000 | 20 | 10000 | 34 weeks | 21,861,528,933 | 15,728,818,921 | 12,708,808,688 | 5 weeks |
| **P2** | 1 | 20 | 10000 | 34 weeks | 5,794,725 | 5,191,365 | 4,879,208 | 5 weeks |
| **P2** | 10000 | 20 | 1 | 34 weeks | 21,861,478,938 | 15,728,768,926 | 12,708,758,693 | 5 weeks |

Table 5.12: Minimum t value and results for a small budget with single P1 and single P2 project.

Table 5.12 and 5.13 gives the minimum t value and objective funciton for the P1 and P2 project. The program can solve a minimum of 36 weeks for the P1 Project and minimum 34 weeks for the P2 project. When we give values smaller than these values, you will see problem is integer infeasible. When we lok at the table we can see the giving 300,0000 weekly will be more beneficial for the company. But this value may be too much for the firm. That's why they have to run with small weekly budgets. There is a 3 weeks tardiness for the P1 project and a 5

| | | | | | m(t) | | | |
|---|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **150,000** | **200,000** | **300,000** | **Tardiness** |
| **P1** | 10000 | 20 | 10000 | 36 weeks | 2,724,256,857 | 1,552,929,057 | 502,909,977 | 3 weeks |
| **P1** | 1 | 20 | 10000 | 36 weeks | 3,225,037 | 3,084,057 | 2,959,977 | 3 weeks |
| **P1** | 10000 | 20 | 1 | 36 weeks | 2,727,226,860 | 1,552,899,060 | 502,879,980 | 3 weeks |
| **P2** | 10000 | 20 | 10000 | 34 weeks | 6,198,816,088 | 2,783,606,588 | 1,003,594,588 | 5 weeks |
| **P2** | 1 | 20 | 10000 | 34 weeks | 4,235,608 | 3,884,588 | 3,694,588 | 5 weeks |
| **P2** | 10000 | 20 | 1 | 34 weeks | 6,198,766,093 | 2,783,556,593 | 1,003,544,593 | 5 weeks |

Table 5.13: Minimum t value and results for a large budget with single P1 and single P2 project.

weeks tardiness for the P2 project. Given the company's criteria, it is appropriate to give 100,000 euros per week.

## 5.4 Concurrent P1 and P2 Projects

In this Chapter concurrent P1 and P2 project parameters were examined by changing. Small and large budgets, such as the tables given above, were solved in the GAMS. When 2 projects are executed simultaneously, you can solve the result again in a minimum of 36 weeks. In less than 36 weeks, the result is infeasible solution. In the tables above, we mentioned about our variable values and objective function. When we change these values, we see that the activities in the project are also affected. For example, for the CSL machine, in the single project P2 (a), the project pays 12 weeks. When 2 projects arrive at the same time, they pay the 3rd week. Since this machine has high cost and procurement time, other projects pay in the beginning so that it does not exceed time and budget.

| | | | | | m(t) | | |
|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **50,000** | **80,000** | **100,000** |
| **P1+ P2** | 1 | 20 | 10000 | 52 weeks | 10,406,001 | 9,174,941 | 8,374,371 |
| **Tardiness** | | | | | P2=5, P1=0 | P2=5, P1=2 | P2=5, P1=2 |
| **P1+ P2** | 10000 | 20 | 10000 | 52 weeks | 39,970,886,865 | 27,035,549,025 | 24,221,342,901 |
| **Tardiness** | | | | | P2=5,P1=2 | P2=5, P1=3 | P2=5, P1=3 |
| **P1+ P2** | 10000 | 20 | 1 | 52 weeks | 39,994,668,218 | 27,027,107,960 | 21,950,850,033 |
| **Tardiness** | | | | | P1=3, P2=5 | P2=5, P1=3 | P2=5, P1=3 |
| **P1+ P2** | 1 | 20 | 10000 | 36 weeks | 11,408,311 | 10,639,941 | 10,154,371 |
| **Tardiness** | | | | | P2=5, P1=3 | P2=5, P1=3 | P2=5, P1=3 |
| **P1+ P2** | 10000 | 20 | 10000 | 36 weeks | 48,845,984,365 | 40,710,636,525 | 35,935,021,525 |
| **Tardiness** | | | | | P1=3, P2=5 | P2=5, P1=3 | P2=5, P1=3 |
| **P1+ P2** | 10000 | 20 | 1 | 36 weeks | 48,845,904,373 | 40,710,556,533 | 35,934,941,533 |
| **Tardiness** | | | | | P1=3, P2=5 | P2=5, P1=3 | P2=5, P1=3 |

Table 5.14: Concurrent Projects Results table for small budget.

| | | | | | m(t) | | |
|---|---|---|---|---|---|---|---|
| **Project** | **M1** | **M2** | **Wp** | **t** | **150,000** | **200,000** | **300,000** |
| **P1+ P2** | 1 | 20 | 10000 | 52 weeks | 7,078,509 | 6,758,865 | 6,485,865 |
| **Tardiness** | | | | | P2=0, P1=1 | 0 | 0 |
| **P1+ P2** | 10000 | 20 | 10000 | 52 weeks | 7,195,416,865 | 4,236,335,865 | 1,506,335,865 |
| **Tardiness** | | | | | P2=5, P1=3 | 0 | 0 |
| **P1+ P2** | 10000 | 20 | 1 | 52 weeks | 7,156,335,873 | 4,236,335,865 | 1,506,335,865 |
| **Tardiness** | | | | | P2=5, P1=3 | 0 | 0 |
| **P1+ P2** | 1 | 20 | 10000 | 36 weeks | 9,008,065 | 8,111,855 | 6,799,155 |
| **Tardiness** | | | | | P2=5, P1=3 | P2=5, P1=3 | P2=5, P1=3 |
| **P1+ P2** | 10000 | 20 | 10000 | 36 weeks | 24,304,341,813 | 15,891,423,365 | 2,590,941,065 |
| **Tardiness** | | | | | P2=5, P1=3 | P2=5, P1=3 | P2=5, P1=3 |
| **P1+ P2** | 10000 | 20 | 1 | 36 weeks | 24,304,261,821 | 15,891,343,373 | 2,587,361,073 |
| **Tardiness** | | | | | P2=5, P1=3 | P2=5, P1=3 | P2=5, P1=3 |

Table 5.15: Concurrent Projects Results table for large budget.

### 5.5 Summary for Projects

In this study, the models developed for the firm are examined and it is decided that the ones marked with green are the most ideal values for the firm. The company decided that the budget that it can give weekly could be 100,000 for single projects and 200,000 for multiple projects.

| **Parameters** | **100,000** | **200,000** | **300,000** |
|---|---|---|---|
| **t** | 52 weeks | 52 weeks | 52 weeks |
| **M1** | 1 | 1 | 1 |
| **Wp** | 10000 | 10000 | 10000 |
| **Objective function for P1** | 3,278,477 | 2,967,477 | 2,867,477 |
| **Objective function for P2** | 4,353,688 | 3,791,388 | 3,618,388 |
| **Objective function for P1+P2** | 8,374,371 | 6,758,865 | 6,485,865 |
| **Tardiness for P1+P2** | P2=5, P1=2 | - | - |
| **Tardiness for P1** | - | - | - |
| **Tardiness for P2** | - | - | - |

Table 5.16: Summary Table for Projects.

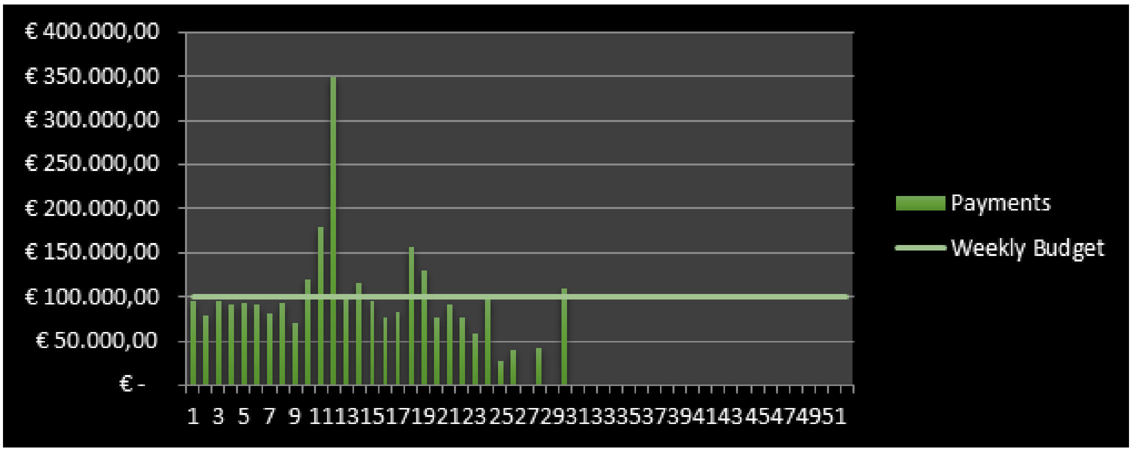


Figure 5.7: The ideal payments planning for the company in the P1 project.

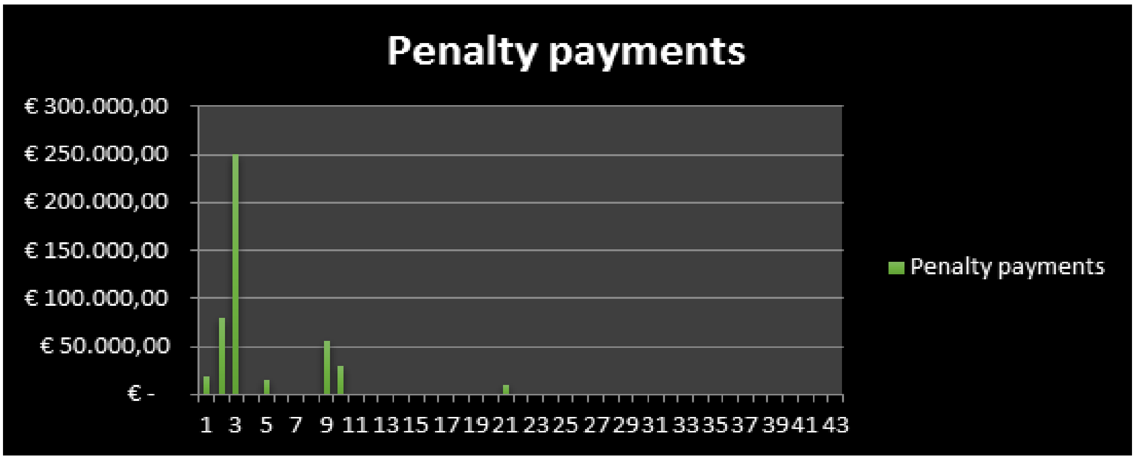


Figure 5.8: Penalty payments plan for figure 5.7.

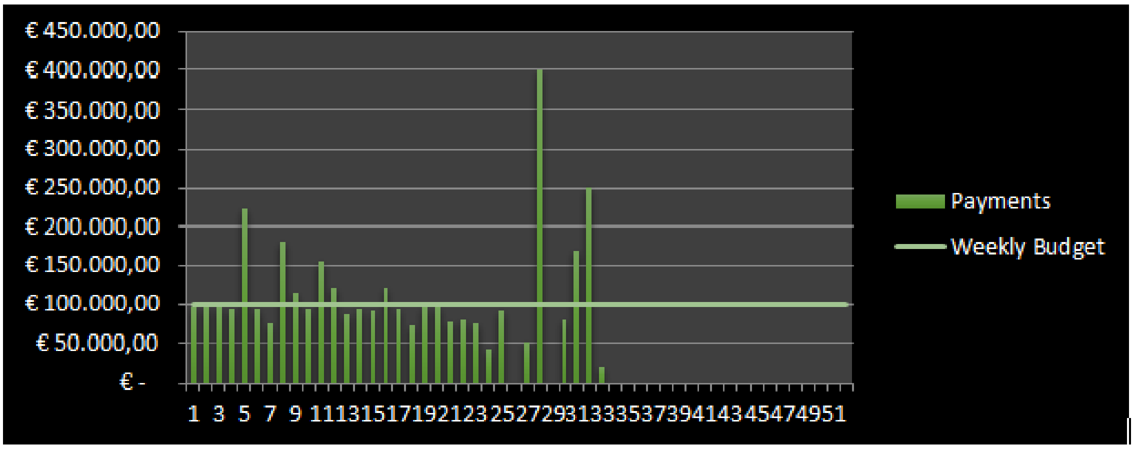


Figure 5.9: The ideal payment plan for the company in the P2 project.

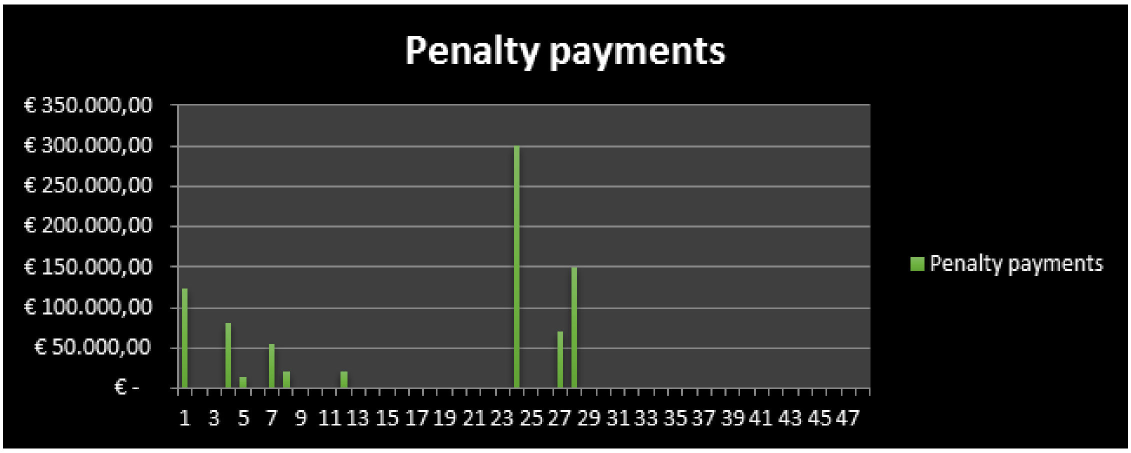


Figure 5.10: Penalty payments plan for figure 5.9.

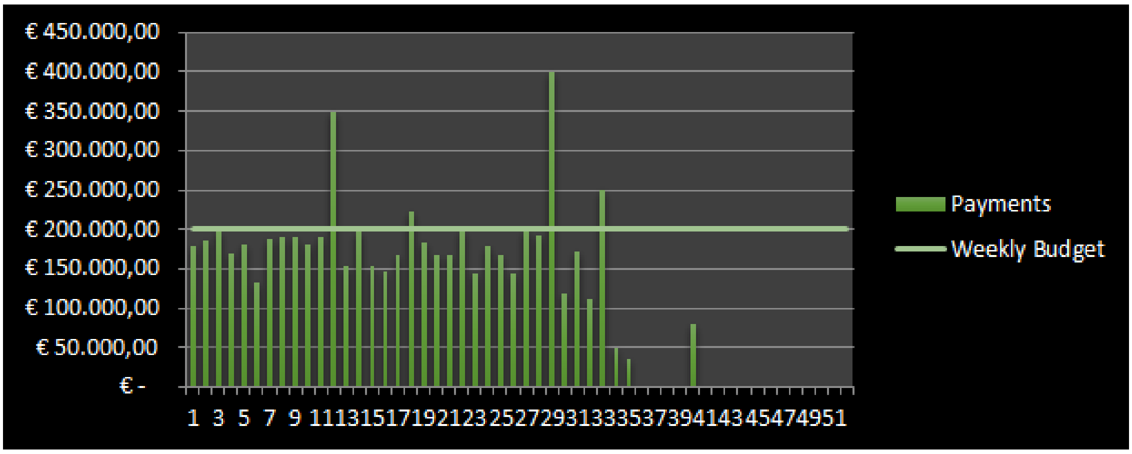


Figure 5.11: The ideal payment plan for the company in the P1+P2 project.

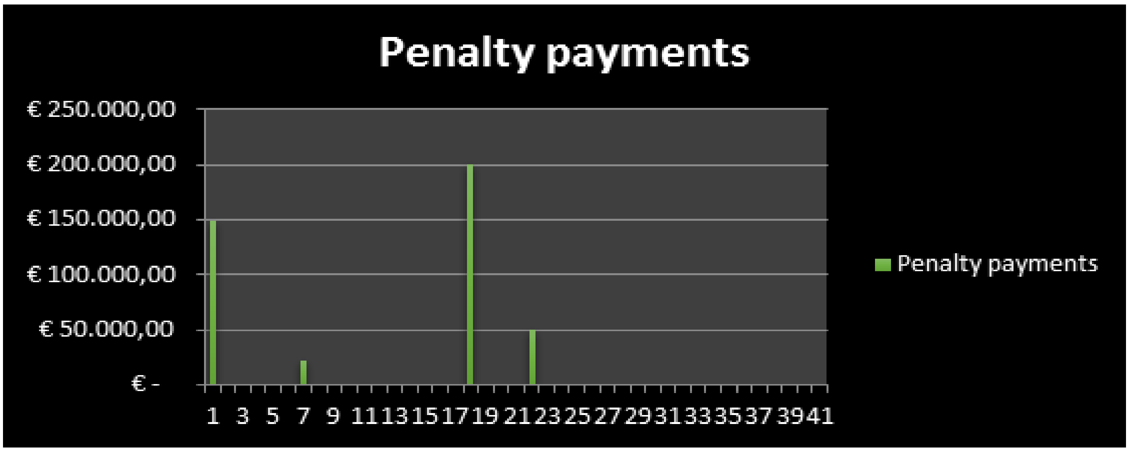


Figure 5.12: Penalty payments plan for figure 5.11.

| Projects | P1 | P2 | P1+P2 |
|---|---|---|---|
| **Budget** | 100,000 | 100,000 | 200,000 |
| **Penalties** | 461,000 | 835,300 | 423,000 |

Table 5.17: Penalties for Projects.

# Chapter 6

# Conclusion and Future Study

Within the scope of the thesis, multi-project and capital constrained project scheduling problem which minimizes the tardiness of projects and cost with the objective function is studied.

In order to facilitate the use of the company, the data of the problem was written as an input to the Excel file and the data was interpreted in this direction. In the Excel file you can see which machine is paying from which supplier and in which week. This provided great convenience in solving the problem.

As a result, the aim of the thesis study can be defined as planning of supplier payments, times and budget required to deliver the project with minimum cost as soon as possible when more than one concurrent projects enters.

In this thesis, there are 2 projects, so there are 2 production line. Each projects have machines in each production line. Some machines are the same, others are different, and the quantities may vary.Each machine has different lead times and prices from different suppliers. Many of the machines in the production line are bought from suppliers while there are also some machines that are built in-house. In this project, labor costs were ignored. In the future, a more detailed cost plan can be made considering labor costs.

There are penalties in the objective function of the project. These are named M1 and $w_P$. These penalties for tardiness and exceeding the available capital.

Each project has a delivery time.(t). Each project has weekly capital. Each machine in the production line has assembly times and is the responsibility of this company.Furthermore, when the production line is completed, each machine has integration time. Therefore, all the machines in the line must be completed before the integration period.

In this study, weekly budgets that can be met by the firm are given and they are operated by using GAMS program. It was observed how M1 and W (P) values affect the cost according to the priority of the project. According to the solutions obtained Penalty for exceeding available capital of each week So when the value of M1 is small cost was found to be less. All projects and results were solved using mip minimizing in the GAMS program. GAMS also includes 3 different scenarios. P1 project alone, P2 project alone and concurrent P1 and P2 solutions are presented.

Optimal scenario for a single Project to be delivered to the customer without tardiness is 52 weeks.Also The firm can make its decision based on the current project intensity.

In some cases it may take less than 52 weeks, in others it may take longer. This is entirely determined by the country in which the project was taken and the decision of the board of directors. Considering the minimum level that the company can provide weekly, it is appropriate to have a weekly capital of 100,000 . The weekly capital may also vary according to the current financial situation of the company and the decision of the board of directors.

The two projects given in this thesis were obtained from the data of the company. Consequently, two projects were considered at the same time and the GAMS were solved with using mip minimizing objective function. When the company goes to growth in the future, 3 projects and more can come simultaneously and the program can be developed accordingly. Currently, 2 projects are sufficient for the company.

Optimal scenario for a concurrent Projects to be delivered to the customer without tardiness is again 52 weeks. There is no doubt that since the number of machines and the number of projects is high, the minimum amount of weekly capital is 200.000. When 2 or more projects are entered at the same time, agreements can be made with the suppliers and installments can be made and discounts can be applied. As a future study we will modelize the payment installment planning. This model is mentioned in Chapter 6.1.

## 6.1 Model with Payment Planning

In the mathematical model it was assumed that payments due to a supplier were made after an order was placed in one installment. In most solutions the model also chooses this lumpsum payment to coincide with the placement of the order rather than delaying it. In practice, however, most payments are made to the suppliers in several installments. To allow for this type of payment planning, we now enrich the model with additional constraints. Following new notation is needed.

### 6.1.1 New Set

J = Installments for a payment, $j = 1, ..., |J|$. Typically, there are three installments.

### 6.1.2 New Parameters

$g_{j,s}$ = The percentage of the $j^{th}$ installment from the payment due to supplier $s$. These percentages have been agreed upon with the suppliers, and they are normally not component-dependent.

$M_3$ = A large payment amount that no real payment can exceed.

$u_{j,c,s}$ = $j^{th}$ payment installment's waiting time in weeks after the previous installment is due for component $c$ to supplier $s$. The first payment occurs only after the component is ordered.

### 6.1.3 New Decision Variables

$q_{j,c,s,t}$ = $j^{th}$ payment installment made to supplier $s$ for component $c$ in week $t$.

$q'_{j,c,s,t}$ = 1 if $j^{th}$ payment installment is made to supplier $s$ for component $c$ in week $t$; 0 otherwise.

### 6.1.4 Updated Objective Function

There is a slight change in the calculation of the total payment by also summing over the installments.

$$min \quad z = \sum_{p} w_p \cdot e_p + \sum_{j} \sum_{c} \sum_{s} \sum_{t} q_{j,c,s,t} + \sum_{t} M_1 \cdot f_t \tag{6.1}$$

### 6.1.5 Updated Constraints

Constraint 3.11 and Constraint 3.12 need to be rewritten as follows to accommodate payment installments with the new variables.

$$\sum_{j} \sum_{c} \sum_{s} q_{j,c,s,t} - f_t \leq m_t \quad \forall t \in T \tag{6.2}$$

$$\sum_{j} q_{j,c,s,t} \geq g_{j,s} \sum_{i} i \cdot u^{i}_{c,s} \cdot y'_{i,c,s,t} \quad \forall c \in C, \forall s \in S, \forall t \in T \tag{6.3}$$

### 6.1.6 Additional Constraints

$$q'_{1,p,c,s,t_1} = o_{p,c,s,t} \quad \forall p \in P, \forall c \in C_p, \forall s \in S, \forall t \leq |T| - v_{1,c,s}, t_1 = t + v_{1,c,s} \tag{6.4}$$

$$q'_{j,p,c,s,t_1} = q'_{j-1,p,c,s,t} \quad \forall j \geq 2, \forall p \in P, \forall c \in C_p, \forall s \in S, \forall t \leq |T| - v_{j,c,s}, t_1 = t + v_{j,c,s} \tag{6.5}$$

$$q_{j,c,s,t} \leq M_3 \cdot q'_{j,c,s,t} \quad \forall j \in J, \forall c \in C, \forall s \in S, \forall t \in T \tag{6.6}$$

$$q_{j,c,s,t} \geq 0 \quad \forall j \in J, \forall c \in C, \forall s \in S, \forall t \in T \tag{6.7}$$

$$q'_{j,c,s,t} \in \{0, 1\} \quad \forall j \in J, \forall c \in C, \forall s \in S, \forall t \in T \tag{6.8}$$

Constraint 6.2 limits the total payments from all installments due in a week to the available weekly budget. Additional borrowing is allowed if absolutely needed. Constraint 6.3 determines the amount of payment to a supplier during a week for a component. Constraint 6.4 and Constraint 6.5 determine the timings of the installments. The first installment occurs after ordering a component whereas subsequent installments follow the previous installment by agreed-upon time delays. Constraint 6.6 sets the amount of payment at a given week to 0 if there is no payment to be made during that week. Finally, variable types are specified.

## 6.2 Model with Workforce Constraints

Now, the additional notation and constraints needed to model workforce related considerations are given.

### 6.2.1 New Parameters

$r_{p,c}$= Amount of workers needed to assemble component $c$ of project $p$.

$M_5$ = Penalty for exceeding available workforce during a week.

$W$= Total number of workers available during a week. This number is assumed to be equal for each week during the planning horizon. The model can easily be adjusted to make the number of workers change from one week to another.

### 6.2.2 New Decision Variables

$h_t$= Additional workforce needed in week $t$.

### 6.2.3 Updated Objective Function

The objective function has a new term to express the penalties the company incurs when the workforce limitations during a week need to be exceeded to make the due-dates.

$$min \quad z = \sum_p w_p \cdot e_p + \sum_c \sum_s \sum_t q_{c,s,t} + \sum_t M_1 \cdot f_t + \sum_t M_4 \cdot h_t \tag{6.9}$$

### 6.2.4 Additional Constraints

$$\sum_p \sum_c r_{p,c} \sum_{t_1=max(0,t-a_{p,c}+1)}^{t} b_{p,c,t_1} - h_t \leq W \quad \forall t \in T \tag{6.10}$$

$$h_t \geq 0 \quad \forall t \in T \tag{6.11}$$

Constraint 6.10 guarantees that workforce limitations are observed. They are only exceeded at a penalty. For each week, the summations determine the needed resources for all activities that are going on during that week. In a given week, work on a component is still being done if that activity has started on a week in the past that is closer than the given week minus the assembly time for the component.

# Appendix A

## Appendix: Sample Application GAMS Code for Concurrent P1 and P2 Project

**t=52 week, M1=1, M2=20, m(t)=80000 ,W(p)=10000**

Sets

c components

USF1, DCM, SPCT, CT, X1, DDA, X2, K1, K2, K3, K4, V, VT,VLA, LCBDAB, AWM1, AWM2, AWM3, AWM4,WPS, HTU, FLO, WH, USF2,USF3, X3, X4, X5, X6,X7,X8,X9,X10,RBM1, AWM5,K5,K6, K7, K8, K9, K10, K11, K12, K13, K14,K15,K16, DGU, SBM, ZSS, ESP, GRP, PTM1, PTL1, PTL2, PTL3, CHC, AWM6, AWM7,RBM2, PTM2, PTL4, QLE1, QLE2, QLE3,DSP, CSL, COT, SP, COMP, FRDDI, Integration,VIT,WRS, AWM8,AWM9,AWM10, WEU, EDP, PTL5, PTL6, PTL7, SEG, MEE, FTE, OHC, OHCRI, GEN, SSP, Integration2
/

p projects /P1, P2/

cp(p,c) components needed by project p subset of c /

P1.USF1, P1.DCM, P1.SPCT, P1.CT, P1.X1, P1.DDA, P1.X2, P1.K1, P1.K2, P1.K3, P1.K4, P1.V, P1.VT, P1.LCBDAB, P1.AWM1, P1.AWM2, P1.AWM3, P1.AWM4, P1.WPS, P1.HTU, P1.FLO, P1.WH, P1.USF2, P1.X3, P1.X4, P1.X5, P1.X6,P1.X7,P1.X8,P1.X9, P1.RBM1, P1.AWM5, P1.K5, P1.K6, P1.K7, P1.K8,

P1.K9, P1.K10, P1.K11, P1.K12, P1.K13, P1.K14, P1.K15, P1.DGU, P1.SBM, P1.ZSS, P1.ESP, P1.GRP, P1.PTM1, P1.PTL1, P1.PTL2, P1.PTL3, P1.CHC, P1.AWM6, P1.AWM7, P1.RBM2, P1.PTM2, P1.PTL4, P1.QLE1, P1.QLE2, P1.QLE3, P1.DSP, P1.CSL, P1.COT, P1.SP, P1.COMP, P1.FRDDI, P1.SSP, P1.Integration,

P2.DCM, P2.SPCT, P2.CT, P2.X1, P2.DDA, P2.X2, P2.K1, P2.K2, P2.K3, P2.V , P2.VT, P2.VLA, P2.AWM1, P2.AWM2, P2.AWM3, P2.AWM4, P2.WPS, P2.HTU, P2.FLO, P2.USF2, P2.USF3, P2.X3, P2.X4, P2.X5 , P2.X6, P2.X7, P2.X8, P2.X9 , P2.X10 , P2.RBM1, P2.AWM5, P2.K5, P2.K6, P2.K7, P2.K9 , P2.K10, P2.K11, P2.K13, P2.K15, P2.K16, P2.DGU, P2.SBM, P2.ZSS, P2.PTM1 , P2.PTL1 , P2.PTL3 , P2.CHC, P2.QLE1 , P2.QLE2, P2.QLE3, P2.DSP, P2.COT, P2.SP, P2.COMP, P2.FRDDI, P2.VIT, P2.WRS, P2.AWM8, P2.AWM9, P2.AWM10, P2.WEU, P2.EDP, P2.PTL5, P2.PTL6, P2.PTL7, P2.SEG, P2.MEE, P2.FTE, P2.OHC, P2.OHCRI, P2.GEN, P2.SSP, P2.Integration2

/;

alias(c, c1);

scalar nOrder /3/;

Sets

succ(c,c1,p) components that must be worked on in project p /

USF1.Integration.P1, DCM.Integration.P1 , SPCT.Integration.P1 , CT.Integration.P1, X1.Integration.P1, DDA.Integration.P1, X2.Integration.P1,

K1.Integration.P1,K2.Integration.P1, K3.Integration.P1, K4.Integration.P1, K5.Integration.P1, V.Integration.P1, VT.Integration.P1,

LCBDAB.Integration.P1, AWM1.Integration.P1,AWM2.Integration.P1, AWM3.Integration.P1, AWM4.Integration.P1, WPS.Integration.P1,

HTU.Integration.P1, FLO.Integration.P1 , WH.Integration.P1,
USF2.Integration.P1, X3.Integration.P1, X4.Integration.P1,

X5.Integration.P1,X6.Integration.P1,X7.Integration.P1, X8.Integration.P1,
X9.Integration.P1, RBM1.Integration.P1, AWM5.Integration.P1,
K6.Integration.P1, K7.Integration.P1, K8.Integration.P1, K9.Integration.P1,
K10.Integration.P1, K11.Integration.P1, K12.Integration.P1,
K13.Integration.P1, K14.Integration.P1,K15.Integration.P1,
DGU.Integration.P1, SBM.Integration.P1, ZSS.Integration.P1,
ESP.Integration.P1, GRP.Integration.P1, PTM1.Integration.P1,
PTL1.Integration.P1, PTL2.Integration.P1, PTL3.Integration.P1,
CHC.Integration.P1, AWM6.Integration.P1, AWM7.Integration.P1,
RBM2.Integration.P1, PTM2.Integration.P1, PTL4.Integration.P1,
QLE1.Integration.P1,QLE2.Integration.P1, QLE3.Integration.P1,
DSP.Integration.P1, CSL.Integration.P1, COT.Integration.P1 ,
SP.Integration.P1, COMP.Integration.P1 ,FRDDI.Integration.P1,
SSP.Integration.P1, DCM.Integration2.P2 ,SPCT.Integration2.P2 ,
CT.Integration2.P2 , X1.Integration2.P2 , DDA.Integration2.P2 ,
X2.Integration2.P2 , K1.Integration2.P2 , K2.Integration2.P2,
K3.Integration2.P2 , V.Integration2.P2 , VT.Integration2.P2,
VLA.Integration2.P2 , AWM1.Integration2.P2 , AWM2.Integration2.P2 ,
AWM3.Integration2.P2, AWM4.Integration2.P2 , WPS.Integration2.P2 ,
HTU.Integration2.P2 , FLO.Integration2.P2 , USF2.Integration2.P2,
USF3.Integration2.P2 , X3.Integration2.P2 , X4.Integration2.P2 ,
X5.Integration2.P2 , X6.Integration2.P2 , X7.Integration2.P2 ,
X8.Integration2.P2 , X9.Integration2.P2 , X10.Integration2.P2 ,
RBM1.Integration2.P2 , AWM5.Integration2.P2 , K5.Integration2.P2 ,
K6.Integration2.P2 , K7.Integration2.P2 , K9.Integration2.P2 ,
K10.Integration2.P2 , K11.Integration2.P2 , K13.Integration2.P2 ,
K15.Integration2.P2 , K16.Integration2.P2 , DGU.Integration2.P2 ,
SBM.Integration2.P2 , ZSS.Integration2.P2 , PTM1.Integration2.P2 ,

PTL1.Integration2.P2 , PTL3.Integration2.P2 , CHC.Integration2.P2 , QLE1.Integration2.P2 , QLE2.Integration2.P2 , QLE3.Integration2.P2 , DSP.Integration2.P2 , COT.Integration2.P2 , SP.Integration2.P2 , COMP.Integration2.P2 , FRDDI.Integration2.P2 , VIT.Integration2.P2 , WRS.Integration2.P2 , AWM8.Integration2.P2 ,AWM9.Integration2.P2, AWM10.Integration2.P2, WEU.Integration2.P2 ,EDP.Integration2.P2 , PTL5.Integration2.P2 , PTL6.Integration2.P2 , PTL7.Integration2.P2 , SEG.Integration2.P2 , MEE.Integration2.P2 ,FTE.Integration2.P2 , OHC.Integration2.P2 , OHCRI.Integration2.P2 , GEN.Integration2.P2 , SSP.Integration2.P2

/

i number of units that can be ordered /0*15/

s suppliers /

Coiltech, Company X, Pressline, OzkanPres,KocluPres,Oguzlar, ZimekMakina, Siemens, BestMakina, Ceis, Wicon, Magmaweld, SistemMakine, YakamozBulutMakina, Alfa, DKOtomasyon, HakMakine, Botersan, Cogeim,Euroblast, Metallisation, FCImpianti,MekaMuhendislik, Matesan,VrgMakine,Akyapak,Sahinler,Durmazlar, Balteau, BirlikMakine, Zhengchuang, AtlasCopco, NibaSu,FormKlima, Alsa, Labthink, Inhouse , Form2000 ,AyyildizTarim, Everest , SheetMetal , Hurtek , Hurkon, Esab, Lincoln , SistemTeknik ,AkmBoya, Alfatechnic ,Enbotek ,Dersan, Atilim, SonmezMakina,Metemak ,Polimek, Dalgakiran, Abus , Aksa , Teknosin ,SenMakina ,Emsa, Parker,Polyform,TeknoVinc,Tekzen, Purpanel, Urcan Makine,Besmak,Buehler,Guralp,GoksuMakina, Meshweld

/

sc(c,s) suppliers that can supply c /

USF1.Coiltech,USF1.DKOtomasyon,USF1.Pressline,
DCM.Company X, DCM.Cogeim , SPCT.Company X, SPCT.Cogeim, CT.Company X,
CT.Matesan,CT.VrgMakine,

X1*X8.Company X, X1*X8.Ceis,X1.KocluPres,X2.Oguzlar,
X3*X8.BestMakina, DDA.Company X, DDA.OzkanPres,DDA.KocluPres,

V.Company X, V.SheetMetal, V.ZimekMakina, VT.SheetMetal,
VT.Company X, VT.ZimekMakina,

LCBDAB.Company X,LCBDAB.Siemens, AWM1*AWM7.Wicon,
AWM1.Magmaweld, AWM1.Hurtek, AWM2.Magmaweld,AWM2.Hurkon,

AWM3.Hurtek, AWM3.Hurkon,AWM4.Hurtek, AWM4.Hurkon,
WPS.Magmaweld, WPS.Esab , WPS.Lincoln,

HTU.SistemMakine,HTU.SistemTeknik, FLO, YakamozBulutMakina,
FLO.Alfa, WH.Wicon, WH.Magmaweld, WH.Lincoln,

X9.DKOtomasyon, X9.Ceis, X9.Oguzlar,

RBM1.Company X, RBM1.Sahinler, RBM1.Akyapak, AWM5.Magmaweld,
AWM5.Lincoln,

DGU.Botersan,DGU.AkmBoya, DGU.Everest,

SBM.Cogeim,SBM.Euroblast, ZSS.Metallisation, ZSS.Alfatechnic,
ZSS.Company X, ESP.Botersan, ESP.Enbotek, ESP.Dersan,

GRP.Botersan,GRP.Enbotek,GRP.Dersan, PTM1.FCImpianti,
PTM1.MekaMuhendislik,

PTL1.FCImpianti,PTL1.MekaMuhendislik, PTL2.FCImpianti,
PTL2.MekaMuhendislik, PTL3.FCImpianti, PTL3.MekaMuhendislik

CHC.Matesan, CHC.Atilim,CHC.SonmezMakina, AWM6.Magmaweld, AWM7.Lincoln,

RBM2.Akyapak,RBM2.Sahinler, RBM2.Durmazlar, PTM2.FCImpianti, PTM2.MekaMuhendislik, PTL4.FCImpianti, PTL4.MekaMuhendislik

QLE1.Alsa, QLE1.Labthink, QLE2.Company X, QLE2.MekaMuhendislik, QLE3.Polimek, QLE3.Balteau, QLE3.Metemak,

DSP.Company X, DSP.Ceis, DSP.HakMakine, CSL.BirlikMakine, CSL.Zhengchuang,

COT.NibaSu, COT.FormKlima, SP.Company X, SP.Ceis , SP.Form2000,

COMP.AtlasCopco, COMP.Dalgakiran,FRDDI.Company X, FRDDI.Ceis, FRDDI.Form2000,SSP.Coiltech, SSP.DKOtomasyon, SSP.Pressline,

Integration.Inhouse

K1*K15.HakMakine, K1*K16.Form2000, K1*K16.Ceis, K16.AyyildizTarim,

VLA.Company X, VLA.SheetMetal, VLA.ZimekMakina

USF2*USF3.Coiltech,USF2*USF3.DKOtomasyon, USF2*USF3.Pressline,

X10.Company X, X10.Ceis, X10.BestMakina,

VIT.Company X, VIT.Parker, VIT.Meshweld,WRS.Company X, WRS.Parker, WRS.Meshweld,

AWM8*AWM10.Wicon, AWM8*AWM9.Magmaweld, AWM8.Hurtek, AWM9.Hurkon, AWM10.Hurtek, AWM10.Hurkon,

WEU.Company X, WEU.Tekzen, WEU.Purpanel,

EDP.Company X, EDP.Botersan, EDP.Enbotek,PTL5.FCImpianti,

PTL5*PTL7.MekaMuhendislik, PTL6.Teknosin, PTL7.FCImpianti, SEG.Company X, SEG.Botersan, SEG.Enbotek, MEE.Company X, MEE.Polyform, MEE.Buehler,

FTE.Company X,FTE.Siemens, FTE.Besmak, OHC.Abus, OHC.UrcanMakine, OHC.TeknoVinc

OHCRI.Abus,OHCRI.TeknoVinc, OHCRI.Guralp

GEN.Aksa,GEN.Emsa, GEN.GoksuMakina, Integration2.Inhouse /

t planning horizon /1*52/;

Parameters

a(p,c) assembly time in weeks for component c of project p /

P1.USF1 4, P1.DCM 8, P1.SPCT 5, P1.CT 2, P1.X1*X9 5, P1.DDA 5, P1.K1*K5 3, P1.K6*K15 4,

P1.V 3, P1.VT 3,P1.LCBDAB 5, P1.AWM1*AWM4 6, P1.AWM5*AWM7 9, P1.WPS 6 , P1.HTU 6, P1.FLO 2 ,P1.WH 5,P1.USF2 4 ,

P1.RBM1 3,P1.DGU 7 , P1.SBM 8, P1.ZSS 6, P1.ESP 8, P1.GRP 8 , P1.PTM1 3 ,P1.PTL1*PTL3 3 , P1.CHC 4,

P1.RBM2 6, P1.PTM2 2, P1.PTL4 2, P1.QLE1*QLE3 5 ,

P1.DSP 2, P1.CSL 6 , P1.COT 1 , P1.SP 2,P1.COMP 5, P1.FRDDI 6, P1.Integration 4, P1.SSP 2

P2.DCM 8, P2.SPCT 5, P2.CT 2, P2.X1*X10 5, P2.DDA 5, P2.K1*K3 3, P2.K5 *K7 3 ,

P2.K9*K11 4, P2.K13 4 , P2.K15*K16 4 ,

P2.V 3, P2.VT 3, P2.VLA 3 , P2.AWM1*AWM4 6 ,P2.AWM5 9, P2.AWM8*AWM10 6 ,P2.WPS 6 ,

P2.HTU 6, P2.FLO 2 ,P2.USF2 4 , P2.USF3 4 ,

P2.RBM1 3,P2.DGU 7 , P2.SBM 8, P2.ZSS 6 , P2.PTM1 3 ,
P2.PTL1 3 , P2.PTL3 3 , P2.CHC 4, P2.QLE1*QLE3 5 ,

P2.DSP 2, P2.COT 1 , P2.SP 2,P2.COMP 5, P2.FRDDI 6, P2.VIT 3,
P2.WRS 3, P2.WEU 1 , P2.EDP 6,

P2.PTL5*PTL7 3 , P2.SEG 6 , P2.MEE 2, P2.FTE 4, P2.OHC 3,
P2.OHCRI 3 , P2.GEN 1 , P2.SSP 2

P2.Integration2 6

/

d (p) week project p is due /

P1 52

P2 52/

l(p,c,s) lead time of suppliers s in week for component c of project p /

P1.USF1.Coiltech=14,P1.USF1.DkOtomasyon=18, P1.USF1.Pressline=20,

P1.DCM.Company X=22, P1.DCM.Cogeim=25,P1.SPCT.Company X=22,
P1.SPCT.Cogeim=25, P1.CT.Company X=8, P1.CT.Matesan=8,
P1.CT.VrgMakine=10

P1.X1*X8.Company X=22 , P1.X1*X8.Ceis=25, P1.X1.KocluPres=26,
P1.X2.Oguzlar=25, P1.X3*X5.BestMakina=20, P1.X6.BestMakina=18,

P1.X7*X8.BestMakina=20, P1.DDA.Company X=12,P1.DDA.OzkanPres=12,
P1.DDA.KocluPres=10, P1.K1*K4.Ceis=15, P1.K1*K4.Form2000=15,

P1.K1*K4.HakMakine=18,P1.V.Company X=22, P1.V.SheetMetal=25,
P1.V.ZimekMakina=26, P1.VT.Company X=17,

P1.VT.SheetMetal=20, P1.VT.ZimekMakina=20,P1.LCBDAB.Company X=10, P1.LCBDAB.Siemens=8,

P1.AWM1*AWM7.Wicon=20, P1.AWM1*AWM2.Magmaweld=22, P1.AWM1.Hurtek=18, P1.AWM1*AWM4.Hurkon=18, P1.AWM3*AWM4.Hurtek=22,

P1.AWM5*AWM7.Magmaweld=25, P1.AWM5*AWM7.Lincoln=22,

P1.WPS.Magmaweld=20, P1.WPS.Esab= 22, P1.WPS.Lincoln=18,

P1.HTU.SistemMakine= 25,P1.HTU.SistemTeknik=30, P1.FLO.YakamozBulutMakina= 8, P1.FLO.Alfa=12,

P1.WH .Wicon= 5 ,P1.WH.Magmaweld=7, P1.WH.Lincoln=7, P1.USF2.Coiltech= 5, P1.USF2.DkOtomasyon=8,P1.USF2.Pressline=8,

P1.X9.DkOtomasyon=7, P1.X9.Ceis=10, P1.X9.Oguzlar=8, P1.RBM1.Company X=12, P1.RBM1.Sahinler=15,P1.RBM1.Akyapak=16,

P1.K5*K15.HakMakine=16, P1.K5*K15.Form2000=18, P1.K5*K15.Ceis=15,

P1.DGU.Botersan= 20, P1.DGU.Everest=19, P1.DGU.AkmBoya=18, P1.SBM.Cogeim= 25, P1.SBM.Euroblast=30,

P1.ZSS.Metallisation= 20, P1.ZSS.Alfatechnic=18, P1.ZSS.Company X=15, P1.ESP.Botersan= 26,P1.ESP.Enbotek=28,P1.ESP.Dersan=30,

P1.GRP.Enbotek=22, P1.GRP.Botersan=25,P1.GRP.Dersan=28,

P1.PTM1.FCImpianti= 22,P1.PTM1.MekaMuhendislik=25, P1.PTL1.FCImpianti= 22, P1.PTL1.MekaMuhendislik=25,

P1.PTL2.FCImpianti= 22 ,P1.PTL2.MekaMuhendislik=25, P1.PTL3.FCImpianti= 22, P1.PTL3.MekaMuhendislik=25,

P1.CHC.Matesan=10,P1.CHC.Atilim=15,P1.CHC.SonmezMakina=15,
P1.RBM2.Akyapak= 6,P1.RBM2.Sahinler=8,P1.RBM2.Durmazlar=8,

P1.PTM2.FCImpianti= 22,P1.PTM2.MekaMuhendislik=25,
P1.PTL4.FCImpianti= 22, P1.PTL4.MekaMuhendislik=25,

P1.QLE1.Alsa= 12,P1.QLE1.Labthink=15,P1.QLE2.Company X=12,
P1.QLE2.MekaMuhendislik=15, P1.QLE3.Balteau= 8,

P1.QLE3.Polimek=12, P1.QLE3.Metemak=10,P1.DSP.Company X=15,
P1.DSP.Ceis=13, P1.DSP.HakMakine=12,P1.CSL.BirlikMakine= 29,
P1.CSL.Zhengchuang=35,

P1.COT.NibaSu= 4,P1.COT.FormKlima=5, P1.COMP.AtlasCopco= 13,
P1.COMP.Dalgakiran=10, P1.FRDDI.Company X=5, P1.FRDDI.Ceis=5,

P1.FRDDI.Form2000=6,P1.SP.Company X=5, P1.SP.Ceis=8,
P1.SP.Form2000=8,

P1.SSP.Coiltech=15, P1.SSP.DkOtomasyon=15, P1.SSP.Pressline=18,

P2.DCM.Company X=22, P2.DCM.Cogeim=25,P2.SPCT.Company X=22,
P2.SPCT.Cogeim=25,P2.CT.Company X=8, P2.CT.Matesan=8,
P2.CT.VrgMakine=10

P2.X1*X8.Company X=22 , P2.X1*X8.Ceis=25, P2.X1.KocluPres=26,
P2.X2.Oguzlar=25, P2.X3*X5.BestMakina=20, P2.X6.BestMakina=18,

P2.X7*X8.BestMakina=20, P2.X9.DkOtomasyon=7, P2.X9.Ceis=10,
P2.X9.Oguzlar=8,

P2.X10.Company X=22, P2.X10.Ceis=25, P2.X10.BestMakina=20,

P2.DDA.Company X=12,P2.DDA.OzkanPres=12,P2.DDA.KocluPres=10,
P2.K1*K3.HakMakine=18 ,P2.K1*K3.Form2000=15,

P2.K1*K3.Ceis=15,P2.V.Company X=22, P2.V.SheetMetal=25,
P2.V.ZimekMakina=26, P2.VT.Company X=17,

P2.VT.SheetMetal=20, P2.VT.ZimekMakina=20,P2.VLA.Company X=12,
P2.VLA.SheetMetal=9, P2.VLA.ZimekMakina=9,

P2.AWM1*AWM5.Wicon=20, P2.AWM2*AWM2.Magmaweld=22,
P2.AWM1.Hurtek=18, P2.AWM2.Hurkon=18, P2. AWM3*AWM4.Hurtek=22,
P2.AWM3* AWM4.Hurkon=18,

P2.WPS.Magmaweld=20, P2. WPS.Esab =22 , P2.WPS.Lincoln=18,

P2.HTU.SistemMakine= 25,P2.HTU.SistemTeknik=30,

P2.FLO.YakamozBulutMakina= 8,P2.FLO.Alfa=12,

P2.USF2.Coiltech= 5, P2.USF2.DkOtomasyon=8,P2.USF2.Pressline=8,

P2.USF3.Coiltech=10, P2.USF3.DkOtomasyon=12, P2.USF3.Pressline=11,

P2.RBM1.Company X=12, P2.RBM1.Sahinler=15,P2.RBM1.Akyapak=16,

P2.AWM5.Magmaweld=25, P2.AWM5.Lincoln=22,

P2.K5*K7.Ceis=15 ,P2.K5*K7.Form2000=18, P2.K5*K7.HakMakine=16,
P2.K9*K11.Ceis=15, P2.K9*K11.Form2000=18,

P2.K9*K11.HakMakine=16,P2.K13.HakMakine=16, P2.K13.Form2000=18,
P2.K13.Ceis=15,

P2.K15.HakMakine=16,P2. K15*K16.Form2000=18,P2.K15*K16.Ceis=15,
P2.K16.AyyildizTarim=17,

P2.DGU.Botersan= 20, P2.DGU.Everest=19, P2.DGU.AkmBoya=18,
P2.SBM.Cogeim= 25, P2.SBM.Euroblast=30,

P2.ZSS.Metallisation= 20, P2.ZSS.Alfatechnic=18, P2.ZSS.Company X=15,

P2.PTM1.FCImpianti= 22,P2.PTM1.MekaMuhendislik=25,
P2.PTL1.FCImpianti= 22, P2.PTL1.MekaMuhendislik=25,

P2.PTL3.FCImpianti= 22 ,P2.PTL3.MekaMuhendislik=25,
P2.CHC.Matesan=10,P2.CHC.Atilim=15,P2.CHC.SonmezMakina=15,

P2.QLE1.Alsa= 12,P2.QLE1.Labthink=15,P2.QLE2.Company X=12,
P2.QLE2.MekaMuhendislik=15, P2.QLE3.Balteau= 8,

P2.QLE3.Polimek=12, P2.QLE3.Metemak=10,P2.DSP.Company X=15,
P2.DSP.Ceis=13, P2.DSP.HakMakine=12 ,

P2.COT.NibaSu= 4,P2.COT.FormKlima=5, P2.SP.Company X=5,
P2.SP.Ceis=8, P2.SP.Form2000=8, P2.COMP.AtlasCopco= 13,

P2.COMP.Dalgakiran=10,P2.FRDDI.Company X=5, P2.FRDDI.Ceis=5,

P2.FRDDI.Form2000=6,

P2.VIT.Company X=8, P2.VIT.Parker=10, P2.VIT.Meshweld=6,

P2.WRS.Company X=10, P2.WRS.Parker=12, P2.WRS.Meshweld=8,

P2.AWM8*AWM10.Wicon=20, P2.AWM8*AWM9.Magmaweld=22,

P2.AWM8.Hurtek=18, P2.AWM9.Hurkon=18,

P2. AWM10.Hurtek=22, P2.AWM10.Hurkon=18,

P2.WEU.Company X=2, P2.WEU.Tekzen=3, P2.WEU.Purpanel=3,

P2.EDP.Company X=8, P2.EDP.Botersan=6, P2.EDP.Enbotek=5,
P2.PTL5.FCImpianti=22,P2.PTL5*PTL7.MekaMuhendislik=25,

P2.PTL6.Teknosin=20, P2.PTL7.FCImpianti=22, P2.SEG.Company X=24,
P2.SEG.Botersan=25, P2.SEG.Enbotek=26,

P2.MEE.Company X=5, P2.MEE.Polyform=4, P2.MEE.Buehler=3, P2.FTE.Company X=10,P2.FTE.Siemens=9,P2. FTE.Besmak=8,

P2.OHC.Abus=8, P2.OHC.UrcanMakine=6, P2.OHC.TeknoVinc=9,

P2. OHCRI.Abus=9,P2.OHCRI.TeknoVinc=8, P2.OHCRI.Guralp=10,

P2.GEN.Aksa=6,P2.GEN.Emsa=5, P2.GEN.GoksuMakina=6,

P2.Integration2.Inhouse=6

P2.SSP.Coiltech=15, P2.SSP.DkOtomasyon=15, P2.SSP.Pressline=18 / ;

scalar M1 /1/;

scalar M2 /20/;

Parameters

m(t) available capital in week t /

1*52 = 80000

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n(p,c) number of units of component c needed in project p /

P1.USF1=1 ,P1.DCM=1 ,P1.SPCT=1 ,P1.CT=4, P1.X1=2 , P1.DDA=2, P1.X2=1, P1.K1=1,P1.K2*K3=4,P1.K4=2, P1.V=2, P1.VT=2,

P1.LCBDAB=1 ,P1.AWM1=3 ,P1.AWM2=6,P1.AWM3=3,P1.AWM4=4 , P1.WPS=1, P1.HTU=1 ,P1.FLO=1,P1.WH=1 ,P1.USF2=2 ,P1.X3=2 , P1.X4=1 ,P1.X5*X9=1,

P1.RBM1=2 ,P1.AWM5=2,P1.K5*K15=1, P1.DGU=1,P1.SBM=1,P1.ZSS=1,

P1.ESP=1,P1.GRP=1, P1.PTM1=3, P1.PTL1=1,P1.PTL2=1,P1.PTL3=2, P1.CHC=1, P1.AWM6=1,P1.AWM7=1,P1.RBM2=1, P1.PTM2=1,

P1.PTL4=1,P1.QLE1=1,P1.QLE2=1,P1.QLE3=1,P1.DSP=1,P1.CSL=1, P1.SP=1 ,P1.COT=1 , P1.COMP=1, P1.FRDDI=1,P1.SSP=1, P1.Integration=1,

P2.DCM=1, P2.SPCT=1, P2.CT=6,P2.X1=2, P2.DDA=2, P2.X2=1, P2.K1*K3=2, P2.V=2, P2.VT=2, P2.VLA=2, P2.AWM1=4,

P2.AWM2=4, P2.AWM3=5, P2.AWM4=4, P2.WPS=1, P2.HTU=1, P2.FLO=1, P2.USF2=2, P2.USF3=2, P2.X3=1,P2.X4=2,P2.X5*X10=1,

P2.RBM1=2,P2.AWM5=2, P2.K5=1, P2.K6=2, P2.K7*K15=1, P2.K16=2, P2.DGU=1, P2.SBM=1, P2.ZSS=1, P2.PTM1=3, P2.PTL1=1,

P2.PTL3=2, P2.CHC=1, P2.QLE1*QLE3=1, P2.DSP=1, P2.COT=2, P2.SP=1, P2.COMP=3, P2.FRDDI=1, P2.VIT=1,P2.WRS=1,

P2.AWM8=1,P2.AWM9=4, P2.AWM10=3, P2.WEU=1, P2.EDP=1, P2.PTL5=2, P2.PTL6=3, P2.PTL7=1, P2.SEG=1, P2.MEE=1, P2.FTE=1,

P2.OHC=2, P2.OHCRI=2, P2.GEN=2, P2.SSP=2, P2.Integration2=1

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u(i,c,s) unit price of component c needed in project p /

1.USF1.Coiltech =110000,1.USF1.DkOtomasyon=120000, 1.USF1.Pressline=115000,

1.DCM.Company X = 132000, 1.DCM.Cogeim=120000, 2.DCM.Company X = 132000, 2.DCM.Cogeim=120000,

1.SPCT.Company X=1020, 1.SPCT.Cogeim=2000, 2.SPCT.Company X=1020, 2.SPCT.Cogeim=2000,

1.CT.Company X=1000 , 1.CT.Matesan=1500,1.CT.VrgMakine=1700, 2.CT.Company X=1000, 2.CT.Matesan=1500,2.CT.VrgMakine=1700,

3.CT.Company X=1000 , 3.CT.Matesan=1500,3.CT.VrgMakine=1700,
4.CT.Company X=1000, 4.CT.Matesan=1500,4.CT.VrgMakine=1700,

5.CT.Company X=1000 , 5.CT.Matesan=1500,5.CT.VrgMakine=1700,
6.CT.Company X=1000 , 6.CT.Matesan=1500,6.CT.VrgMakine=1700,

7.CT.Company X=1000 , 7.CT.Matesan=1500,7.CT.VrgMakine=1700,
8.CT.Company X=1000 , 8.CT.Matesan=1500,8.CT.VrgMakine=1700,

9.CT.Company X=1000 , 9.CT.Matesan=1500,9.CT.VrgMakine=1700,

10.CT.Company X=1000 , 10.CT.Matesan=1500,10.CT.VrgMakine=1700,

1.X1.Company X=81540,1.X1.Ceis=78000,1.X1.KocluPres=85000,

2.X1.Company X=81540,2.X1.Ceis=78000,2.X1.KocluPres=85000,

3.X1.Company X=81540,3.X1.Ceis=78000,3.X1.KocluPres=85000,

4.X1.Company X=81540,4.X1.Ceis=78000,4.X1.KocluPres=85000,

1.DDA.Company X=15000, 1.DDA.OzkanPres=13000,1.DDA.KocluPres=20000,

2.DDA.Company X=15000, 2.DDA.OzkanPres=13000,2.DDA.KocluPres=20000,

3.DDA.Company X=15000, 3.DDA.OzkanPres=13000,3.DDA.KocluPres=20000,

4.DDA.Company X=15000, 4.DDA.OzkanPres=13000,4.DDA.KocluPres=20000,

1.X2.Company X= 36300, 1.X2.Ceis=45000,1.X2.Oguzlar=36000,

2.X2.Company X= 36300, 2.X2.Ceis=45000,2.X2.Oguzlar=36000,

1.K1.HakMakine=10000, 1.K1.Form2000=12000, 1.K1.Ceis=15000,
2.K1.HakMakine=10000, 2.K1.Form2000=12000,

2.K1.Ceis=15000,3.K1.HakMakine=10000, 3.K1.Form2000=12000,
3.K1.Ceis=15000,

1.K2.HakMakine=11000 ,1.K2.Form2000=15000, 1.K2.Ceis=13873,
2.K2.HakMakine=11000 ,2.K2.Form2000=15000, 2.K2.Ceis=13873,

3.K2.HakMakine=11000 ,3.K2.Form2000=15000, 3.K2.Ceis=13873,
4.K2.HakMakine=11000 ,4.K2.Form2000=15000, 4.K2.Ceis=13873,

5.K2.HakMakine=11000 ,5.K2.Form2000=15000, 5.K2.Ceis=13873,
6.K2.HakMakine=11000 ,6.K2.Form2000=15000, 6.K2.Ceis=13873,

1.K3.HakMakine=4056, 1.K3.Form2000=5000, 1.K3.Ceis=8000,
2.K3.HakMakine=4056, 2.K3.Form2000=5000, 2.K3.Ceis=8000,

3.K3.HakMakine=4056, 3.K3.Form2000=5000, 3.K3.Ceis=8000,
4.K3.HakMakine=4056, 4.K3.Form2000=5000, 4.K3.Ceis=8000,

5.K3.HakMakine=4056, 5.K3.Form2000=5000, 5.K3.Ceis=8000,
6.K3.HakMakine=4056, 6.K3.Form2000=5000, 6.K3.Ceis=8000,

1.K4.HakMakine=13877,1.K4.Form2000=15000,1.K4.Ceis=12000,
2.K4.HakMakine=13877, 2.K4.Form2000=15000,2.K4.Ceis=12000,

1.V.Company X=47000, 1.V.SheetMetal=55000, 1.V.ZimekMakina=50000,
2.V.Company X=47000, 2.V.SheetMetal=55000, 2.V.ZimekMakina=50000,

3.V.Company X=47000, 3.V.SheetMetal=55000, 3.V.ZimekMakina=50000,
4.V.Company X=47000, 4.V.SheetMetal=55000, 4.V.ZimekMakina=50000,

1.VT.Company X=1500, 1.VT.SheetMetal=2000, 1.VT.ZimekMakina=1200,
2.VT.Company X=1500, 2.VT.SheetMetal=2000, 2.VT.ZimekMakina=1200,

3.VT.Company X=1500, 3.VT.SheetMetal=2000, 3.VT.ZimekMakina=1200,
4.VT.Company X=1500, 4.VT.SheetMetal=2000, 4.VT.ZimekMakina=1200,

1.LCBDAB.Company X=10000,1.LCBDAB.Siemens=15000,

2.VLA.Company X=20000, 2.VLA.SheetMetal=25000, 2.VLA.ZimekMakina=22000

1.AWM1.Wicon=5500, 1.AWM1.Magmaweld=6500, 1.AWM1.Hurtek=6200,
2.AWM1.Wicon=5500, 2.AWM1.Magmaweld=6500, 2.AWM1.Hurtek=6200,

3.AWM1.Wicon=5500, 3.AWM1.Magmaweld=6500, 3.AWM1.Hurtek=6200,
4.AWM1.Wicon=5500, 4.AWM1.Magmaweld=6500, 4.AWM1.Hurtek=6200,

5.AWM1.Wicon=5500, 5.AWM1.Magmaweld=6500, 5.AWM1.Hurtek=6200,
6.AWM1.Wicon=5500, 6.AWM1.Magmaweld=6500, 6.AWM1.Hurtek=6200,

7.AWM1.Wicon=5500, 7.AWM1.Magmaweld=6500, 7.AWM1.Hurtek=6200,

1.AWM2.Wicon=5000,1.AWM2.Magmaweld=5500,1.AWM2.Hurkon=6000,
2.AWM2.Wicon=5000,2.AWM2.Magmaweld=5500,2.AWM2.Hurkon=6000,

3.AWM2.Wicon=5000,3.AWM2.Magmaweld=5500,3.AWM2.Hurkon=6000,
4.AWM2.Wicon=5000,4.AWM2.Magmaweld=5500,4.AWM2.Hurkon=6000,

5.AWM2.Wicon=5000,5.AWM2.Magmaweld=5500,5.AWM2.Hurkon=6000,
6.AWM2.Wicon=5000,6.AWM2.Magmaweld=5500,6.AWM2.Hurkon=6000,

7.AWM2.Wicon=5000,7.AWM2.Magmaweld=5500,7.AWM2.Hurkon=6000,
8.AWM2.Wicon=5000,8.AWM2.Magmaweld=5500,8.AWM2.Hurkon=6000,

9.AWM2.Wicon=5000,9.AWM2.Magmaweld=5500,9.AWM2.Hurkon=6000,
10.AWM2.Wicon=5000,10.AWM2.Magmaweld=5500,10.AWM2.Hurkon=6000,

11.AWM2.Wicon=5000,11.AWM2.Magmaweld=5500,11.AWM2.Hurkon=6000,
12.AWM2.Wicon=5000,12.AWM2.Magmaweld=5500,12.AWM2.Hurkon=6000,

1.AWM3.Wicon=6750,1.AWM3.Hurtek=5500,1.AWM3.Hurkon=6500 ,
2.AWM3.Wicon=6750,2.AWM3.Hurtek=5500,2.AWM3.Hurkon=6500 ,

3.AWM3.Wicon=6750,3.AWM3.Hurtek=5500,3.AWM3.Hurkon=6500,
4.AWM3.Wicon=6750,4.AWM3.Hurtek=5500,4.AWM3.Hurkon=6500 ,

5.AWM3.Wicon=6750,5.AWM3.Hurtek=5500,5.AWM3.Hurkon=6500,
6.AWM3.Wicon=6750,6.AWM3.Hurtek=5500,6.AWM3.Hurkon=6500,

7.AWM3.Wicon=6750,7.AWM3.Hurtek=5500,7.AWM3.Hurkon=6500,
8.AWM3.Wicon=6750,8.AWM3.Hurtek=5500,8.AWM3.Hurkon=6500,

1.AWM4.Wicon=4500, 1.AWM4.Hurtek=5000,1.AWM4.Hurkon=5200,
2.AWM4.Wicon=4500, 2.AWM4.Hurtek=5000,2.AWM4.Hurkon=5200,

3.AWM4.Wicon=4500, 3.AWM4.Hurtek=5000,3.AWM4.Hurkon=5200,
4.AWM4.Wicon=4500, 4.AWM4.Hurtek=5000,4.AWM4.Hurkon=5200,

5.AWM4.Wicon=4500, 5.AWM4.Hurtek=5000,5.AWM4.Hurkon=5200,
6.AWM4.Wicon=4500, 6.AWM4.Hurtek=5000,6.AWM4.Hurkon=5200,

7.AWM4.Wicon=4500, 7.AWM4.Hurtek=5000,7.AWM4.Hurkon=5200,
8.AWM4.Wicon=4500, 8.AWM4.Hurtek=5000,8.AWM4.Hurkon=5200,

1.WPS.Magmaweld=83510, 1.WPS.Lincoln=65000, 1.WPS.Esab=80000,

2.WPS.Magmaweld=83510, 2.WPS.Lincoln=65000, 2.WPS.Esab=80000,

1.HTU.SistemMakine=205000,1.HTU.SistemTeknik=180000,
2.HTU.SistemMakine=205000,2.HTU.SistemTeknik=180000,

1.FLO.YakamozBulutMakina=1850,1.FLO.Alfa=2500,
2.FLO.YakamozBulutMakina=1850,2.FLO.Alfa=2500,

1.WH.Wicon=7000, 1.WH.Magmaweld=5500,1.WH.Lincoln=6000,

1.USF2.Coiltech=20000, 1.USF2.DKOtomasyon=22000,
1.USF2.Pressline=21000, 2.USF2.Coiltech=20000,
2.USF2.DKOtomasyon=22000, 2.USF2.Pressline=21000,

3.USF2.Coiltech=20000, 3.USF2.DKOtomasyon=22000,
3.USF2.Pressline=21000, 4.USF2.Coiltech=20000,
4.USF2.DKOtomasyon=22000, 4.USF2.Pressline=21000,

2.USF3.Coiltech=90000,2.USF3.DkOtomasyon=85000,
2.USF3.Pressline=87000

1.X3.Company X=71950,1.X3.Ceis=65000,1.X3.BestMakina=85000,
2.X3.Company X=71950,2.X3.Ceis=65000,2.X3.BestMakina=85000,

3.X3.Company X=71950,3.X3.Ceis=65000,3.X3.BestMakina=85000,

1.X4.Company X=60650,1.X4.Ceis=65000,1.X4.BestMakina=63000,
2.X4.Company X=60650,2.X4.Ceis=65000,2.X4.BestMakina=63000,

3.X4.Company X=60650,3.X4.Ceis=65000,3.X4.BestMakina=63000,

1.X5.Company X=51300 ,1.X5.Ceis=60000,1.X5.BestMakina=55000,
2.X5.Company X=51300 ,2.X5.Ceis=60000,2.X5.BestMakina=55000,

1.X6.Company X=51300, 1.X6.Ceis=60000,1.X6.BestMakina=55000,
2.X6.Company X=51300, 2.X6.Ceis=60000,2.X6.BestMakina=55000,

1.X7.Company X=51300,1.X7.Ceis=60000, 1.X7.BestMakina=55000,
2.X7.Company X=51300,2.X7.Ceis=60000, 2.X7.BestMakina=55000,

1.X8.Company X=25000, 1.X8.Ceis=27000, 1.X8.BestMakina=28000,
2.X8.Company X=25000, 2.X8.Ceis=27000, 2.X8.BestMakina=28000,

1.X9.DKOtomasyon=8845,1.X9.Ceis=7500, 1.X9.Oguzlar=10000,
2.X9.DKOtomasyon=8845,2.X9.Ceis=7500, 2.X9.Oguzlar=10000,

1.X10.Company X=223000, 1.X10.Ceis=225000 , 1.X10.BestMakina=250000,

1.RBM1.Company X=7000,1.RBM1.Sahinler=8000,1.RBM1.Akyapak=8500,
2.RBM1.Company X=7000,2.RBM1.Sahinler=8000,2.RBM1.Akyapak=8500,

3.RBM1.Company X=7000,3.RBM1.Sahinler=8000,3.RBM1.Akyapak=8500,
4.RBM1.Company X=7000,4.RBM1.Sahinler=8000,4.RBM1.Akyapak=8500,

1.AWM5.Wicon =6600,1.AWM5.Magmaweld=5800,1.AWM5.Lincoln=6400,

2.AWM5.Wicon =6600,2.AWM5.Magmaweld=5800,2.AWM5.Lincoln=6400,
3.AWM5.Wicon =6600,3.AWM5.Magmaweld=5800,3.AWM5.Lincoln=6400,

4.AWM5.Wicon =6600,4.AWM5.Magmaweld=5800,4.AWM5.Lincoln=6400,

1.K5.Ceis=13000 ,1.K5.Form2000=11000, 1.K5.HakMakine=11000,
2.K5.Ceis=13000 ,2.K5.Form2000=11000, 2.K5.HakMakine=11000,

1.K6.Ceis=13000,1.K6.Form2000=11000, 1.K6.HakMakine=11000,
2.K6.Ceis=13000,2.K6.Form2000=11000, 2.K6.HakMakine=11000,

3.K6.Ceis=13000,3.K6.Form2000=11000, 3.K6.HakMakine=11000,

1.K7.Ceis=13000 ,1.K7.Form2000=11000,1.K7.HakMakine=11000,
2.K7.HakMakine=11000, 2.K7.Ceis=13000 ,2.K7.Form2000=11000,

1.K8.Ceis=13000 ,1.K8.Form2000=11000,1.K8.HakMakine=11000,

1.K9.Ceis=13000 ,1.K9.Form2000=11000, 1.K9.HakMakine=11000,
2.K9.Ceis=13000 ,2.K9.Form2000=11000, 2.K9.HakMakine=11000,

1.K10*K11.Ceis=13000 ,1.K10*K11.Form2000=11000,
1.K10*K11.HakMakine=11000, 2.K10*K11.Ceis=13000,
2.K10*K11.Form2000=11000, 2.K10*K11.HakMakine=11000,

1.K12.Ceis=13000 ,1.K12.Form2000=11000, 1.K12.HakMakine=11000,

1.K13.Ceis=13000 ,1.K13.Form2000=11000, 1.K13.HakMakine=11000,

2.K13.Ceis=13000 ,2.K13.Form2000=11000, 2.K13.HakMakine=11000,

1.K14.Ceis=13000 ,1.K14.Form2000=11000, 1.K14.HakMakine=11000,

1.K15.Ceis=13000 ,1.K15.Form2000=11000, 1.K15.HakMakine=11000,
2.K15.Ceis=13000 ,2.K15.Form2000=11000, 2.K15.HakMakine=11000,

2.K16.Form2000=20000,2.K16.AyyildizTarim=18000, 2.K16.Ceis=22000,

1.DGU.Everest=83500,1.DGU.Botersan=85000, 1.DGU.AkmBoya=90000,

2.DGU.Everest=83500,2.DGU.Botersan=85000, 2.DGU.AkmBoya=90000, 1.SBM.Cogeim=115000,1.SBM.Euroblast=120000, 2.SBM.Cogeim=115000, 2.SBM.Euroblast=120000,

1.ZSS.Alfatechnic=102644,1.ZSS.Metallisation=105000,1.ZSS.Company X=95000, 2.ZSS.Alfatechnic=102644,2.ZSS.Metallisation=105000,2.ZSS.Company X=95000,

1.ESP.Botersan= 132500, 1.ESP.Enbotek= 125000,1.ESP.Dersan=95000,

1.GRP.Botersan=66250, 1.GRP.Enbotek=55500, 1.GRP.Dersan=70000

1.PTM1.FCImpianti=25000, 1.PTM1.MekaMuhendislik=30000,
2.PTM1.FCImpianti=25000, 2.PTM1.MekaMuhendislik=30000,
3.PTM1.FCImpianti=25000, 3.PTM1.MekaMuhendislik=30000,

4.PTM1.FCImpianti=25000, 4.PTM1.MekaMuhendislik=30000,
5.PTM1.FCImpianti=25000, 5.PTM1.MekaMuhendislik=30000,
6.PTM1.FCImpianti=25000, 6.PTM1.MekaMuhendislik=30000,

1.PTL1.FCImpianti=20000,1.PTL1.MekaMuhendislik=25000,
2.PTL1.FCImpianti=20000,2.PTL1.MekaMuhendislik=25000,

1.PTL2.FCImpianti=9000,1.PTL2.MekaMuhendislik= 15000,

1.PTL3.FCImpianti= 17000,1.PTL3.MekaMuhendislik=20000,
2.PTL3.FCImpianti= 17000,2.PTL3.MekaMuhendislik=20000,

3.PTL3.FCImpianti= 17000,3.PTL3.MekaMuhendislik=20000,
4.PTL3.FCImpianti= 17000,4.PTL3.MekaMuhendislik=20000,

1.CHC.Matesan=90000,1.CHC.SonmezMakina=100000,
1.CHC.Atilim=95000, 2.CHC.Matesan=90000,
2.CHC.SonmezMakina=100000,2.CHC.Atilim=95000,

1.AWM6.Wicon=8500,1.AWM6.Magmaweld=8000,1.AWM6.Lincoln=8500,
1.AWM7.Wicon=9500,1.AWM7.Lincoln=15000,

1.RBM2.Akyapak=19470,1.RBM2.Sahinler=20000,
1.RBM2.Durmazlar=15000,

1.PTM2.FCImpianti=15000,1.PTM2.MekaMuhendislik=20000,
1.PTL4.FCImpianti=20000, 1.PTL4.MekaMuhendislik=22000,

1.QLE1.Alsa= 37360, 1.QLE1.Labthink=40000, 2.QLE1.Alsa= 37360,
2.QLE1.Labthink=40000,

1.QLE2.Company X=44100, 1.QLE2.MekaMuhendislik=50000,
2.QLE2.Company X=44100, 2.QLE2.MekaMuhendislik=50000,

1.QLE3.Balteau=15000, 1.QLE3.Metemak=25000,1.QLE3.Polimek=22000,
2.QLE3.Balteau=15000, 2.QLE3.Metemak=25000,2.QLE3.Polimek=22000,

1.DSP.Company X=1400, 1.DSP.Ceis=1500, 1.DSP.HakMakine=1200,
2.DSP.Company X=1400, 2.DSP.Ceis=1500, 2.DSP.HakMakine=1200,

1.CSL.BirlikMakine=350000,1.CSL.Zhengchuang=360000,

1.SP.Company X=40000, 1.SP.Ceis=45000, 1.SP.Form2000=43000,
2.SP.Company X=40000, 2.SP.Ceis=45000, 2.SP.Form2000=43000,

1.COT.Nibasu= 1973, 1.COT.FormKlima=2000,2.COT.Nibasu= 1973,
2.COT.FormKlima=2000, 3.COT.Nibasu= 1973, 3.COT.FormKlima=2000,

1.COMP.AtlasCopco=8200, 1.COMP.Dalgakiran=9500,
2.COMP.AtlasCopco=8200, 2.COMP.Dalgakiran=9500,

3.COMP.AtlasCopco=8200, 3.COMP.Dalgakiran=9500,
4.COMP.AtlasCopco=8200, 4.COMP.Dalgakiran=9500,

1.FRDDI.Company X=2000,1.FRDDI.Ceis=2500, 1.FRDDI.Form2000=4000,
2.FRDDI.Company X=2000,2.FRDDI.Ceis=2500, 2.FRDDI.Form2000=4000,

1.VIT.Company X=1500 , 1.VIT.Parker=2500,1.VIT.Meshweld=5000, 1.WRS.Company X=3000,1.WRS.Parker=4000, 1.WRS.Meshweld=6000,

1.AWM8.Wicon=5000, 1.AWM8.Magmaweld=8000,1.AWM8.Hurtek=7500,

1.AWM9.Wicon=6000, 1.AWM9.Magmaweld=7000,1.AWM9.Hurkon=7500,

2.AWM9.Wicon=6000, 2.AWM9.Magmaweld=7000,2.AWM9.Hurkon=7500,

3.AWM10.Wicon=4000, 3.AWM10.Hurtek=5000, 3.AWM10.Hurkon=5500,

1.WEU.Company X=19000,1.WEU.Tekzen=25000,1.WEU.Purpanel=22000,

1.EDP.Company X=250000,1.EDP.Botersan=300000,1.EDP.Enbotek=280000,

2.PTL5.FCImpianti=15000,2.PTL5.MekaMuhendislik=20000,

3.PTL6.Teknosin=18000, 3.PTL6.MekaMuhendislik=24000,

1.PTL7.FCImpianti=35000, 1.PTL7.MekaMuhendislik=40000,

1.SEG.Company X=12000, 1.SEG.Botersan=15000, 1.SEG.Enbotek=18000,

1.MEE.Company X=50000, 1.MEE.Polyform=55000, 1.MEE.Buehler=60000,

1.FTE.Company X=15000, 1.FTE.Siemens=28000, 1.FTE.Besmak=20000,

2.OHC.Abus=20000, 2.OHC.UrcanMakine=15000, 2.OHC.TeknoVinc=16000,

2.OHCRI.Abus=8000, 2.OHCRI.TeknoVinc=6000, 2.OHCRI.Guralp=7000,

2.GEN.Aksa=200000, 2.GEN.Emsa=250000, 2.GEN.GoksuMakina=225000,

1.SSP.Coiltech=35000, 1.SSP.DKOtomasyon=28000,1.SSP.Pressline=27500,

2.SSP.Coiltech=35000, 2.SSP.DKOtomasyon=28000,2.SSP.Pressline=27500,

3.SSP.Coiltech=35000, 3.SSP.DKOtomasyon=28000,3.SSP.Pressline=27500

/

w(p) penalty of delaying project p /

P1 10000

```
P2 10000

/;

Free variable z;

Binary variables b(p,c,t), o(p,c,s,t), x(p,c,s), y(i,c,s,t);

Positive Variables e(p), f(t), q(c,s,t);

integer variable k(p,c,s);

Equations

eq1 amaç fonksiyonu

eq2

eq3

eq4

eq5

eq6

eq7

eq8

eq9

eq10

eq11

eq11a

eq12
```

```
eq13

eq14

eq15

eq16

eq17

;

eq1.. z =e= sum(p,w(p)* e(p)) + sum((c,s,t),q(c,s,t)) + sum(t,M1*f(t));

*Kısıtlar

eq2(p,c)$(cp(p,c)).. sum(s$sc(c,s),x(p,c,s)) =e= 1;

eq3(p,c)$(not cp(p,c)).. sum(s,x(p,c,s)) =e= 0;

eq4(p,c,s)$(cp(p,c) and sc(c,s)).. k(p,c,s) =l= M2*x(p,c,s);

eq5(p,c)$(cp(p,c)).. sum(s$sc(c,s),k(p,c,s)) =e= n(p,c);

eq6(p,c)$(not cp(p,c)).. sum(s,k(p,c,s)) =e= 0;

eq7(p,c)$(cp(p,c)).. sum(s$(not sc(c,s)),k(p,c,s)) =e= 0;

eq8(p,c,s).. sum(t,o(p,c,s,t)) =e= x(p,c,s);

eq9(c,s,t).. sum(i,y(i,c,s,t)) =l= nOrder*sum(p,o(p,c,s,t));

eq10(p,c)$(cp(p,c)).. sum(t,b(p,c,t)) =e= 1;

eq11('P1','Integration').. sum(t,(ord(t)-1)*b('P1','Integration',t))
+ a('P1','Integration') - e('P1') =l= d('P1') ;

eq11a('P2','Integration2').. sum(t,(ord(t)-1)*b('P2','Integration2',t))
+ a('P2','Integration2') - e('P2') =l= d('P2') ;
```

```
eq12(p,c,c1)$(cp(p,c) and succ(c,c1,p)).. sum(t,(ord(t)-1)*b(p,c,t))
+ a(p,c) =l= sum(t,(ord(t)-1)*b(p,c1,t));

eq13(p,c)$(cp(p,c)).. sum((s,t)$sc(c,s),(ord(t)-1)*o(p,c,s,t))
+ sum(s$sc(c,s),l(p,c,s)*x(p,c,s)) =l= sum(t,(ord(t)-1)*b(p,c,t));

eq14(t).. sum((c,s),q(c,s,t))- f(t) =l= m(t);

eq15(c,s,t).. q(c,s,t) =g= sum(i,(ord(i)-1)*u(i,c,s)*y(i,c,s,t));

eq16(c,s).. sum(p,k(p,c,s)) =e= sum((i,t),(ord(i)-1)*y(i,c,s,t));

eq17(c,s,t).. sum(i,y(i,c,s,t)) =l= 1 ;

Model Tardiness /all/;

Tardiness.reslim = 600;

Tardiness.workspace=30;

Tardiness.optcr = 0.0;

Tardiness.limrow=500;

Solve Tardiness using mip minimizing z;

execute_unload 'sonuc.gdx',q;

execute 'gdxxrw sonuc.gdx output=payments.xlsx squeeze
=n var=q.l rng=Sheet1!A1';
```

# Appendix B

## Appendix: P1(a) Scenario weekly budget = 80,000

| **Machine Names** | **Supplier** | **Lead time** | **Assembly time** | **b(P1)** | **o(P1)** | **q(P1)** | **Penalties (exceed 80,000 )** |
|---|---|---|---|---|---|---|---|
| USF1(15 TON) | Coiltech | 14 | 4 | 45 | 30 | 110,000 | 30,000 |
| DCM | Cogeim | 22 | 8 | 39 | 14 | 120,000 | 40,000 |
| SPCT | CompanyX | 22 | 5 | 23 | 1 | 1,020 | |
| CT | CompanyX | 8 | 2 | 22 | 12 | 4,000 | |
| X1 | Cei | 25 | 5 | 40 | 13 | 156,000 | 76,000,00 |
| DDA | OzkanPres | 12 | 5 | 44 | 28 | 26,000 | |
| X2 | Oguzlar | 25 | 5 | 44 | 3 | 36,000 | |
| K1 | Hak Makine | 18 | 3 | 35 | 4 | 10,000 | |
| K2 | Hak Makine | 18 | 3 | 29 | 6 | 44,000 | |
| K3 | Hak Makine | 18 | 3 | 22 | 2 | 16,224 | |
| K4 | Cei | 15 | 3 | 45 | 18 | 24,000 | |
| V | CompanyX | 22 | 3 | 45 | 21 | 94,000 | 14,000 |
| VT | Zimek makine | 20 | 3 | 42 | 1 | 2,400 | |
| LCBDAB | CompanyX | 10 | 5 | 21 | 2 | 10,000 | |
| AWM1 | Wicon | 20 | 6 | 34 | 6 | 16,500 | |
| AWM2 | Wicon | 20 | 6 | 36 | 15 | 30,000 | |
| AWM3 | Hurtek | 22 | 6 | 37 | 15 | 16,500 | |
| AWM4 | Wicon | 20 | 6 | 29 | 2 | 18,000 | |
| WPS | Lincoln | 18 | 6 | 43 | 7 | 65,000 | |
| HTU | Sistem Teknik | 30 | 6 | 43 | 10 | 180,000 | 100,000 |
| FLO | Yakamoz Bulut Makine | 8 | 2 | 40 | 31 | 1,850 | |
| WH | Magmaweld | 7 | 5 | 35 | 1 | 5,500 | |

| Machine Names | Supplier | Lead time | Assembly time | b (P1) | o (P1) | q(P1) | Penalties (exceed 80,000 ) |
|---|---|---|---|---|---|---|---|
| USF2 (2 ton) | Coiltech | 5 | 4 | 45 | 25 | 40,000 | |
| X3 | Ceis | 25 | 5 | 44 | 17 | 130,000 | 50,000 |
| X4 | Company X | 22 | 5 | 44 | 20 | 60,650 | |
| X5 | Company X | 22 | 5 | 44 | 9 | 51,300 | |
| X6 | Company X | 22 | 5 | 44 | 19 | 51,300 | |
| X7 | Company X | 22 | 5 | 32 | 4 | 51,300 | |
| X8 | Company X | 22 | 5 | 44 | 18 | 25,000 | |
| X9 | Cei | 10 | 5 | 16 | 4 | 7,500 | |
| RBM1 | Company X | 12 | 3 | 46 | 25 | 14,000 | |
| AWM5 | Magmaweld | 25 | 9 | 40 | 15 | 11,600 | |
| K5 | Hak Makine | 16 | 3 | 39 | 1 | 11,000 | |
| K6 | Form 2000 | 18 | 4 | 18 | 1 | 11,000 | |
| K7 | Hak Makine | 16 | 4 | 45 | 18 | 11,000 | |
| K8 | Form 2000 | 18 | 4 | 32 | 9 | 11,000 | |
| K9 | Hak Makine | 16 | 4 | 44 | 15 | 11,000 | |
| K10 | Hak Makine | 16 | 4 | 17 | 1 | 11,000 | |
| K11 | Hak Makine | 16 | 4 | 45 | 25 | 11,000 | |
| K12 | Form 2000 | 18 | 4 | 40 | 1 | 11,000 | |
| K13 | Form 2000 | 16 | 4 | 40 | 19 | 11,000 | |
| K14 | Hak Makine | 16 | 4 | 41 | 24 | 11,000 | |
| K15 | Form 2000 | 18 | 4 | 37 | 9 | 11,000 | |
| DGU | Everest | 19 | 7 | 36 | 16 | 83,500,00 | 3,500 |
| SBM | Cogeim | 25 | 8 | 34 | 5 | 115,000 | 35,000 |
| ZSS | Company X | 15 | 6 | 43 | 26 | 95,000 | 15,000 |
| ESP | Dersan | 30 | 8 | 41 | 8 | 95,000 | 15,000 |
| GRP | Enbotek | 22 | 8 | 41 | 12 | 55,500 | |
| PTM1 | FC Impianti | 22 | 3 | 44 | 22 | 75,000 | |
| PTL1 | FC Impianti | 22 | 3 | 26 | 2 | 20,000 | |

| **Machine Names** | **Supplier** | **Lead time** | **Assembly time** | **b (P1)** | **o (P1)** | **q(P1)** | **Penalties (exceed 80,000 )** |
|---|---|---|---|---|---|---|---|
| PTL2 | FC Impianti | 22 | 3 | 23 | 1 | 9,000 | |
| PTL3 | FC Impianti | 22 | 3 | 45 | 23 | 34,000 | |
| CHC | Matesan | 10 | 4 | 45 | 34 | 90,000 | 10,000 |
| AWM6 | Magmaweld | 25 | 9 | 29 | 1 | 8,000 | |
| AWM7 | Wicon | 20 | 9 | 39 | 18 | 9,500 | |
| RBM2 | Durmazlar | 8 | 6 | 33 | 3 | 15,000 | |
| PTL4 | FC Impianti | 22 | 2 | 44 | 12 | 20,000 | |
| QLE1 | Alsa | 12 | 5 | 40 | 27 | 37,360 | |
| QLE2 | Company X | 12 | 5 | 43 | 31 | 44,100 | |
| QLE3 | Balteau | 8 | 5 | 35 | 19 | 15,000 | |
| DSP | Hak Makine | 12 | 2 | 26 | 1 | 1,200 | |
| CSL | Birlik Makine | 29 | 6 | 43 | 11 | 350,000 | 270,000 |
| COT | Nibasu | 4 | 1 | 12 | 1 | 1,973 | |
| SP | Company X | 5 | 2 | 42 | 24 | 40,000 | |
| COMP | Atlas Copco | 13 | 5 | 38 | 15 | 8,200 | |
| FRDDI | Company X | 5 | 6 | 43 | 22 | 2,000 | |
| Integration | Inhouse | | 4 | 49 | | | |
| PTM2 | FC Impianti | 22 | 2 | 47 | 2 | 15,000 | |
| SSP | Pressline | 18 | 2 | 29 | 3 | 27,500 | |

Table B.1: Sample Application for P1 ( M1=1, M2=20, w(p)=10000, t=52 week, w(p)=80000 ).

| | |
|---|---|
| **Total payments** | 2,817,477 |
| **GAMS Value** | 3,475,977 |
| **Penalties** | 658,500 |

Table B.2: Results for Table B.1.

# Appendix C

## Appendix: Gant Chart for Table B.1

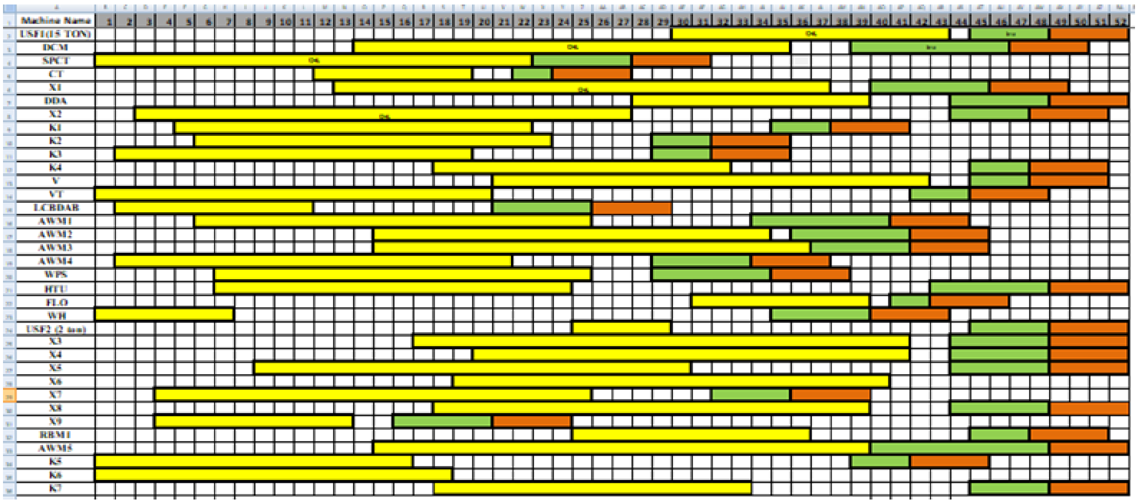


Figure C.1: Gant Chart for Table B.1.

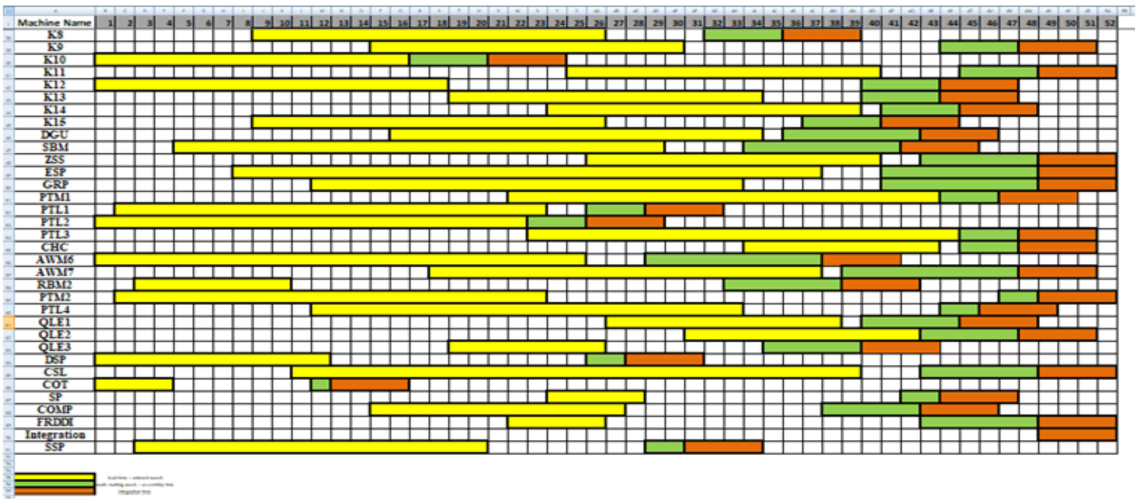


Figure C.2: Continuation of Figure C.

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