

**אוניברסיטת בר-אילן**

**מחלקה לניהול**

**Thesis Proposal**

**Parallel management of several infrastructure projects and contracting with suppliers**

**הצעת מחקר לתואר שני**

**ניהול מקביל של מספר פרויקטי תשתית והתקשרות עם ספקים**

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1. **Introduction**
   1. **The challenges in managing** **infrastructure projects**

Projects in the field of construction and infrastructure serve political, social development, economic growth, and technological progress (Chen et al., 2018). According to the spokeswoman of the Ministry of Transportation in Israel, approximately $14 billion will be invested between 2023-2027[[1]](#footnote-1). This investment is intended to promote transportation in coming years in Israel, with the emphasis on public transportation and mass transit systems, improving road infrastructure and road safety. This is the largest budget invested to date in road infrastructure and public transportation in Israel and that may lead to a reduction in the cost of living. Another example of well-known large-scale construction project is Neom – “smart city,” a territory in Saudi Arabia that will house multiple cities, resorts, and other developments. According to Nadhmi Al-Nasr, CEO of the Saudi development business, the Public Investment Fund will invest $500 billion into the program. This project fits the Saudi Vision 2030 plan to diversify the economy and lessen reliance on oil.[[2]](#footnote-2)

In the contemporary era, with the development of technology, socio-economic changes and changing environmental requirements, construction and infrastructure projects are becoming more complex and challenging than ever before (Chen et al., 2018). They are challenging due to their inherent complexity, budget limitations, time constraints, regulatory requirements, safety regulations, and other risk factors. According to the research of Hartman and Ashrafi (2004), 50% of all construction projects exceed their budget by 40% - 200%. In the study by Flyvbjerg et al. (2003) cost overruns were noted as a "normal" phenomenon of transportation infrastructure projects. The authors collected and analyzed data from 258 transportation infrastructure projects in 20 countries and found that rail projects show the highest overrun rate, approximately of 45% and that road projects are less disposed to cost overruns with an average of approximately 20%. Data published by the German Federal Parliament (Flyvbjerg et al., 2003) show that 214 road construction projects from the 2004 requirements program have approximately 10% - 720% difference between estimated and approved costs.

Another unwelcomed phenomenon is not meeting the planned schedule. An example of the inability to deliver infrastructure projects on time and meet the budget can be found in the paper by Safapour et al. (2020). According to the authors, in the last decade there has been a sharp increase in the number of transportation infrastructure projects in the US, and on any given day there are hundreds of projects of various sizes, with the common goal of ensuring that millions of traveler's experience smoothly operating transportation networks. Safapour et al. (2020) claim that transportation agencies and project managers are experiencing unprecedented pressure to deliver projects on time and under the given budget; however, the projects often fail to meet the owner's expectations in terms of cost and schedule performance. Thomsen et al. (2010) conducted a study that showed that between 40% and 50% of all construction projects fall behind their baseline schedule. When a construction project is delayed, construction must be accelerated, or its completion date might be extended, causing cost overruns. An obvious response to this pressure is to improve the project delivery process by adopting available successful project management methods. This study issues both budget and scheduling considerations, while attempts to delve into the effective strategies for successful project execution and project management.

The management of infrastructure projects has evolved in recent decades, and now enables dynamic decision-making based on data, under which the gathering of information and calculations occur in real time (Hu et al., 2023). The daily challenges and dealing with changing demands require the decision makers to make up-to-date changes in the management tools, in the development and establishment of the projects through the integration of modern technologies such as smart information systems and digital means for management and construction processes (Pan and Zhang, 2021). The current study develops computational tools that consider the main challenges in the field and improve the efficiency of the planning and construction processes.

* 1. **The need for parallel management of several projects**

Traditionally, each project is managed individually. Yet, repetitive construction projects, such as high-rise buildings and highways, typically require construction crews to replicate their work at different locations in the project, shifting from one location to another (Abdelbasset et al., 2023). These types of projects require to be scheduled in such a way that enables their construction crews to move from section to another without having to wait until their predecessor crews finish working in the same section (Hassan et al., 2006). This scheduling requirement for such projects is frequently referred to crew work continuity constraint. Complying with this continuity constraint proved useful for retaining skilled labor, maximizing the benefits of the learning curve effect (Abdelkhalek et al., 2020), and eliminating the idle time of utilized crews (Jaskowski et al., 2019).

Parallel project management involves overseeing multiple projects concurrently (Wani et al. (2012)). While numerous studies have examined the implications of traditional project management, there has been relatively little focus on the challenges and outcomes of simultaneously managing multiple projects. Factors like scheduling, budgeting, and maintaining quality are already significant hurdles for project managers handling a single project. The question which arises is what are the implications for project managers tasked with juggling multiple projects simultaneously?

Managing projects concurrently within large organizations involves integrating and synchronizing multiple project management offices (PMOs) to support the streamlined execution of numerous projects simultaneously (Tsaturyan and Müller, 2015). This entails implementing standardized processes, tools, and communication channels across PMOs to ensure cohesive project management practices. Additionally, centralizing functions, optimizing resource allocation, fostering active collaboration, and jointly addressing risks are essential aspects of effectively managing parallel projects. By aligning PMO functions with parallel project management needs, organizations can enhance efficiency and coordination across their project portfolios. According to (Chen et al., (2018), the contractor manages multiple concurrent projects, where efficient coordination of their operations can be beneficial.

* 1. **The challenges of contracting with suppliers**

Typically, project managers (especially in infrastructure and construction industries) delve into the intricate challenges within supplier relationships in the supply chain industry (Chen et al., 2018). Arguably, the most salient challenge is the complexity inherent in these relationships. Crafting contracts with suppliers' entails navigating a multitude of factors such as pricing structures, quality standards, delivery timetables, and service level agreements. Managing this complexity can prove daunting, particularly when dealing with numerous suppliers across disparate geographic locations or industries. In practice, suppliers may have their supply capacity constrained and supplier capacity may vary from period to period, therefore the project manager needs to select multiple suppliers for a particular resource type (Asadujjaman et al., 2021). Furthermore, a decision should be made on inventory policy when the warehouse does not have enough capacity to hold all resource types. Zheng et al (2021) claim that many researchers have paid attention to supplier selection and order quantity allocation. Most of suppliers’ selection problems in the literature can be classified into single and multiple sourcing problems, single and multiple item problems, as well as single and multiple period problems.

* 1. **Expected contribution of the proposed research**

In this research proposal, as mentioned above, we focus on the theme of management of several construction and infrastructure parallel projects. In the contemporary era, where there is a great need for effective solutions for managing projects in this field, there are unique challenges. Focusing on several projects that have common suppliers is one of the main challenges that this study will deal with. Effective management of multiple suppliers requires comprehensive engagement and precise planning, which are based on a thorough understanding of the work processes and specific requirements of each supplier. Effective management of this confrontation requires thinking about technological systems and tools that enable strong and efficient communication with all suppliers, providing transparency and control over the processes. The concurrent projects require a high level of coordination, efficiency in time management, and the ability to identify and deal with different occurrences in each project so that there are no delays in delivering the overall project. Such effective management requires precise planning, and the ability to activate and communicate between projects in a selective and efficient manner.

The main expected contributions of this study are:

(1) This research focuses on the specific challenges characterizing management of infrastructure projects.

(2) A mathematical optimization model is formulated to minimize total project cost (including penalties) subject to certain budget.

(3) An efficient algorithm for solving small to medium scale projects is developed.

(4) We apply the suggested algorithm in a real-life case-study addressing an infrastructure industry application in Israel.

1. **Literature review**

The scientific methodology of project management is an effective means for improving work processes and producing successful results. In this section we present the main concepts proposed in the existing literature of project management. We review papers dealing with project management in infrastructure and construction industries, as well as a group of papers dealing with supplier selection in the context of project management. Studies dealing with the goal of minimizing delivery times and fines for project delivery delays are also presented. The review shows that the goals of minimizing delays and completing the project in the shortest possible time are intertwined. The literature emphasizes the economic and systemic aspects of penalty measures to complete a project on time and under given budget. Among the variety of studies, are approaches that use advanced technologies (such as schedule tracking technology and task management) to optimize project management and reduce the risks and fines resulting from time constraints. In this fascinating literature review, we focus on trends, challenges encountered in project management, and the recent techniques made available to project managers.

* 1. **Models for managing infrastructure and construction projects**

Abdelbasset et al. (2023) have developed a sophisticated and efficient solution method to the complex problem of scheduling repetitive construction projects. The overall goal is to minimize both, the duration of the project and its associated , simultaneously. Their approach involves a multi-objective optimization model with three key components. First, the scheduling module which ensures smooth coordination among multiple crews working on different tasks. This component considers factors such as varying productivity rates, constraints related to work continuity, and the order in which tasks need to be completed. The second module focuses on costs, by incorporating various contractual components. This allows contractors to thoroughly evaluate project expenses, considering different contract terms and providing flexibility in cost assessments. The third module employs a genetic algorithm for optimization. This algorithm identifies the best combinations of crews working simultaneously and the optimal sequence of their tasks. To validate their model, the researchers applied it to a real-world example from the infrastructure industry. The results demonstrate significant improvements, with an 8% reduction in project duration and a 0.78% decrease in overall costs compared to previous models. This highlights the superiority of their approach in optimizing the scheduling of repetitive construction projects.

The goal of the study by Kivilä et al. (2017) is to identify the control practices employed by a project organization for sustainable project management. The researchers conducted a qualitative single-case study on a large-scale infrastructure project involving the construction of a road tunnel in a challenging environment, with multiple stakeholders engaged under an alliance contract. The findings reveal that sustainable project management is implemented through a holistic control package, utilizing control mechanisms differently for various sustainability dimensions. Project planning is enhanced with sustainable project governance, establishing connections between the project and its external stakeholders and regulatory frameworks. The alliance contract activates partners to explore innovation opportunities, thereby promoting economic, environmental, and social sustainability.

[Eriksson and Pesämaa (2017)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Eriksson%20Pesamaa.pdf) develop and empirically test a model for flexibility-focused project management practices with the objective of improving time performance in complex infrastructure projects. Using data from 138 construction projects managed by the Swedish Transport Administration, their study employed a structural equation model (a multivariate technique to test and evaluate multivariate causal relationships). The results of the analysis demonstrate that complexity and collaboration between project actors serve as drivers for explorative learning. This, in turn, leads to improved adaptation, ultimately resulting in enhanced time performance. Therefore, the empirical test supports the conclusion that flexibility-focused project management practices, characterized by collaboration, explorative learning, and adaptation, contribute to improved time performance in complex infrastructure projects.

The study by [Eriksson et al. (2023)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Eriksson%202023.pdf) investigates how complexity can be governed through coordinative and collaborative supply chain integration, and how their interplay affects performance in project-based buyer-supplier relationships. The authors apply structural equation modeling using dyadic empirical data from 102 infrastructure projects. The overall results verify the developed model and highlight how the interplay between contractual and relational governance, in terms of coordinative and collaborative SCI, mediates the effect of technical and organizational complexity on project performance. This study contributes to theory and practice by distinguishing between contractual governance based on formal coordinative SCI and relational governance based on emerged collaborative SCI, as well as showing how their interplay affects performance in project-based supply chains.

* 1. **Project management models that incorporate supplier selection**

According to Habibi et al. (2019), according to the traditional project planning approach, the manager first schedules the project activities and then plans the material ordering timetable accordingly. Yet, using this approach, the tradeoff between the project total costs as well as time and ordering expenses is disregarded. This approach is also ill-suited for modern organizations, typically are under growing public pressure to support inter and intra generational justice and introduce environmental and social objectives to their competitive strategy and business mission. Their paper provides an integrated framework for the Project Scheduling and Material Ordering (PSMO) problem with sustainability considerations. They proposed framework consisting of two phases: (a) quantifying the environmental and social merits of the potential suppliers of the project resources, and (b) constructing and solving a mathematical model based on the acquired data. The model can determine the activities schedule, material ordering time and quantity, and the supplier selection that maximize the project NPV and the environmental and social benefits of its suppliers. The presented model falls within the class of NP-Hard problems, so two multi-objective metaheuristic algorithms, namely NSGA-II and MOPSO were modified to serve as solution methods for this model. For small problems, the performance of these methods was compared with that of second version of the augmented e-constraint (AUGMECON2) method. For larger problems, where the exact method was unable to produce a solution within a reasonable time, these two algorithms were compared with each other. The results show that regardless of problem size, NSGA-II outperforms MOPSO in the majority of evaluation metrics. The paper also includes a case study conducted on the construction project in Section 5 of Mianeh-Bostanabad-Tabriz railway in Iran, which demonstrates the applicability of the proposed model and provide an illustrative example.

[Chen et al. (2018)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Chen%202018.pdf) study the problem of coordinating supplier selection and project scheduling, motivated by a real-life operational challenge encountered in the construction industry. The authors consider a project network consisting of multiple concurrent projects, with the objective of minimizing the total tardiness of all projects. These projects are independent in operation but are subject to shared suppliers and the final quality inspection by the same committee, which then leads to the need for project review sequencing. The earliest starting time of each activity in a project depends on the availability of required resources (both renewable and non-renewable), as well as the activity precedence constraints. The authors formulate this problem as a mixed-integer linear programming model and proposed a mathematical programming-based heuristic to solve the model. The heuristic decomposes the model into subproblems and solves the subproblems through an iterative process. Each subproblem has a much smaller size and can be solved quickly and independently. The information obtained in solving subproblems is used to guide the search process. Numerical examples show the computational effectiveness of the proposed heuristic, and the benefits of coordination.

According to [Asadujjaman et al. (2021)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Asadujjaman.pdf) integration of project scheduling (PS) with materials ordering has received greater attention in the last three decades as an approach to ensure the profitability of a project. The fundamental concern of the material ordering integrated PS is to select the right supplier of the right material by placing an order at the right time so that the ordering, purchasing, and holding cost of the materials are minimized which finally maximizes the project’s profitability. This study proposes a mathematical model and solution approach for a resource constrained project scheduling and material ordering problem with discounted cash flows (RCPS-MOP-DC). The mathematical model considers decisions regarding materials ordering, supplier selection, transportation, and inventory of the raw materials. A mixed -integer programming (MIP) model has been proposed for this RCPS-MOP-DC with the objective to maximize the project’s net present value (NPV). A meta-heuristic approach by hybridizing genetic algorithm (GA) and immune algorithm (IA) is proposed as a potential solution approach for this RCPS-MOP-DC model. Performance of this hybridized GA and IA (IGA) approach is compared with its constituent algorithms (GA and IA) to validate the effectiveness of this hybridization. Performance of the IGA is further improved by applying a forward–backward improvement (FBI) based on local search technique. A restart mechanism is also incorporated in the algorithms which ensures diversity and helps to avoid becoming trapped in local optima. The Taguchi Design of Experiment (DOE) is used to investigate the impact of various parameters and to determine the appropriate set of parameters for the proposed algorithms. The performance of this proposed solution approach has been tested on varied self-generated RCPS-MOP-DC instances ranging from 30 to 120 activities. The results show that the hybrid IGA outperforms GA and IA in terms of the project’s NPV.

The study by [Zheng et al. (2021)](file:///D:\new_comp\Bar-Ilan\second_deg\Teza\מאמרים%20שהשתמשתי\Zheng%20et%20al%202021%20(1).pdf) investigates a multi-project, multi-period, multi-factory and multi-objective supplier selection problem with project life cycles and demand uncertainty. For this problem, the authors establish a multi-stage mixed integer stochastic programming model with three objectives: the procurement cost; number of quality defects; and delayed delivery quantity. An adapted chaos optimization algorithm based on a maximum similarity method was developed to solve the model. The effectiveness of the solutions is validated by the real data from the auto industry. The sensitivity analysis indicates that the values of the three objectives increase and then decrease with the project life cycle.

* 1. **Models of managing parallel projects**

[Halman et al. (2009)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Halman%202009.pdf) investigate the problem of scheduling parallel projects when the decision makers’ goal is to minimize project execution costs and overall completion time subject to the constraints of execution dates and budget. The mentioned problem is a non-linear and handles several projects that can be seen as a network. The author developed a polynomial-time approximate solution methods for both problems (time and cost minimization) using K-approximation functions together with serial and parallel reductions.

[Browning and Yassine (2010)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Browning%20and%20yassine%202010.pdf) discuss the challenges faced by managers overseeing multiple projects with constrained resources. Their study focuses on addressing the resource-constrained multi-project scheduling problem (RCMPSP) with two lateness objectives: project lateness and portfolio lateness. The research analyzes 20 priority rules on 12,320 test problems, considering various project, activity, and resource-related characteristics. The findings highlight situations where commonly recommended priority rules may perform poorly and emphasize that portfolio managers and project managers may have different preferences based on their objectives. The results are summarized in two decision tables, providing managers with a qualitative framework to choose priority rules based on project complexity, resource contention, and distribution.

The research of [Sánchez et al. (2023)](file:///C:\Users\user\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\מאמרים%20שהשתמשתי\Sánchez%20et%20al.%20(2023).pdf) delves into the Resource-Constrained Multi-Project Scheduling Problem (RCMPSP), a critical aspect of project management in competitive sectors such as manufacturing and services. The RCMPSP involves scheduling tasks for multiple projects simultaneously, considering job dependencies, limited resources, and time constraints. The study categorizes and analyzes various problem variants based on jobs, projects, relationships, resources, and time management, providing a comprehensive taxonomy. It also reviews and classifies solution methods and benchmarks used for validation. The paper concludes by discussing the practical implications of RCMPSP and proposing future research opportunities considering recent advancements.

The research by Mao et al. (2020) is aimed to provide an assistant decision-making method to support effective task dispatching and multi-party cooperation for better utilization of the distributed resources and to help project managers control the shipbuilding process. The paper initially establishes an agent-based complex shipbuilding project collaborative planning and symmetric scheduling framework, simulating the distributed collaborative decision-making process and bridging the multi-project planning with the individual project scheduling in much detail, which fills the research gap. A negotiation method based on iterative combination auction is further proposed to solve the integration problem of project planning and task scheduling, and an illustrative example is conducted to demonstrate the effectiveness and rationality of the methods. Finally, an application case using a prototype system on shipbuilding projects collaborative planning and scheduling is reported as a result.

* 1. **The closest research and the contribution regarding existing models in the literature**

In this study we focus on a unique field of project management in the construction and infrastructure industry, combining the selection of suppliers and the management of several projects at the same time. Special characteristics of the thesis are expressed in several key points. Starting with supplier selection, we try to solve the management challenges in this area, including bid management, supplier selection and contract tracking. The developed model offers solutions to problems in selecting suppliers, upgrades the decisions through automatic processes and uses a combination of advanced tools in project management. Another point is managing several projects at the same time is another area under which we explore the challenges and possible solutions. The suggested model offers new approaches to the simultaneous planning and management of several projects, related to the integration of operations, and adjustment so that the projects progress in a filtered and efficient manner. In doing so, we offer an integrated and innovative approach to project management in the field of construction and infrastructure, and improve the ability of organizations to promote projects in an efficient and advanced manner. Table 1 illustrates the main gaps of our model.

**Table 1.** Related papers

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Case study | Budget consideration | Infrastructure and construction projects | Supplier selection | Parallel multiple projects | Delay/duration time minimizing | Cost minimizing |  |
| √ |  | √ |  | √ |  | √ | Abdelbasset et al.,(2023) |
|  |  |  | √ |  |  | √ | Asadujjaman et al.(2021) |
|  |  |  |  | √ | √ | √ | Browning & Yassine (2010) |
|  | √ |  | √ | √ | √ |  | Chen et al., (2018) |
|  | √ | √ |  | √ | √ |  | Eriksson& Pesämaa (2017) |
| √ | √ |  | √ |  | √ | √ | Habibi et al.(2019) |
|  |  |  |  | √ |  |  | He et al. (2022) |
|  | √ | √ |  | √ | √ | √ | Halman et al .(2009) |
| √ | √ | √ |  | √ |  |  | Kivilä et al.,(2017) |
|  |  | √ |  | √ | √ |  | Mao et al. (2020) |
|  |  |  |  | √ |  | √ | Shastri et al. (2021) |
|  |  |  |  | √ |  |  | Salomone (2019) |
|  | √ |  |  | √ | √ |  | Sánchez et al (2023) |
|  |  |  | √ | √ |  | √ | Tayyar et al., (2015) |
| √ |  |  | √ |  |  | √ | Zheng et.al (2021) |
|  |  | √ |  |  |  |  | Eriksson et al.(2023) |
| **√** | **√** | **√** | **√** | **√** | **√** | **√** | **Our study** |

1. **Model**

In this section we formulate the problem of infrastructure project management through an optimization model. In addition, the modeling process is accompanied by a small numerical example for better clarification of the suggested model. In this example, three simultaneous projects are carried out by an electrical infrastructure project management. These projects deal with typical work needed for construction of roads, lighting, and communication infrastructures. The essence of the work in the three projects is similar to each other in terms of ordering raw materials from suppliers and execution stages. The goal of the project manager is to minimize the total monetary penalties due to the delays with regard to their planned deliveries. In addition, the project manager must correctly choose the suppliers of raw materials considering their delivery times, target dates of each project, the capacity of the suppliers, the quantities of raw materials required and their purchase prices. Table 2 presents the quantity needed from each material by each project, while Table 3 presents target date of each project.

**Table 2.** The required quantity of raw material *k* needed to complete all the activities of project*j* .

|  |  |  |  |
| --- | --- | --- | --- |
| **Project** | | | **Raw material** |
| *j*=3 | | *j*=2 | *j*=1 |  |
| 640 | | 560 | 720 | Light poles (*k*=1) |
| 640 | | 560 | 720 | Light fixture (*k*=2) |
| 640 | | 560 | 720 | Arm light fixture (*k*=3) |
| 360 | | 320 | 200 | A2 (*k*=4) |

**Table 3.** Target makespan of project *j* for completion of all activities and audit pass, .

|  |  |  |  |
| --- | --- | --- | --- |
| **Project** | | |  |
|  |  |  |
| 1080 days | 870 days | 1200 days | **Target makespan** |

Complex and large projects in general, may include several partial target dates, each referring to a specific phase or sub-project during the overall project. The target date of a particular sub-project is the deadline for the completion of all activities of the project, including the passing of an inspection so that it is ready for use or delivery to the final customer. This date is the result of a precise planning process for the project, which includes the activities themselves, the duration of each action, the resources (personnel and equipment) required to successfully completion the project, needed raw materials, costs, and other factors. It is determined according to the customer's requirement subject to the agreement of the service provider.

The delivery time for a given raw material from a given supplier is the period in which the supplier has committed to fulfill the order. This is the estimated time when the supplier will complete the preparation, production and transportation of raw materials and deliver them to the project’s site. The supplier’s order execution duration is considered a key parameter in the project management and logistics planning of the project and its various stages since it affects the overall project times. Thus, it is estimated in advance and determined according to the agreement between the supplier and the project managers. Table 4 presents capacity of each supplier.

**Table** **4.** Capacity of raw material *k* at supplier *s* ,

|  |  |  |
| --- | --- | --- |
| **Capacity** | **Supplier** | **Raw material** |
| 500 | 1 | Light poles (*k*=1) |
| 300 | 2 |
| 700 | 3 |
| 650 | 4 |
| 1000 | 1 | Light fixture (*k*=2) |
| 1200 | 2 |
| 400 | 1 | Arm light fixture (*k*=3) |
| 350 | 2 |
| 700 | 3 |
| 620 | 4 |
| 220 | 1 | A2 (*k*=4) |
| 400 | 2 |
| 500 | 3 |

Table 5 summarizes estimated delivery times and costs for raw materials. Usually, the shipping time from a certain supplier to a certain project longs several days, during which the supplier transports the shipment from the source point to the destination point of the project. Shipping time may vary depending on several factors, including:

* Geographic distance: the distant the supplier is from the project’s site, the longer the delivery time may be.
* Shipping method: the shipping method used by the supplier (for example, land transport, air, sea).
* Flowing conditions: if there are constraints on the transport resources such as the delivery time may change.

**Table** **5.** Estimated delivery time of raw material *k* from supplier *s* to project *j* in days, ; and cost of a unit (in NIS) of raw material *k* purchased from supplier *s* for project *j* (the cost includes purchase cost and shipping cost) .

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cost of a unit (in NIS)** | | | **Order delivery time (days)** | | | | | **Raw material** | **Supplier** |
| **Project** | | | **Project** | | | | |
| *j*=3 | *j*=2 | *j*=1 | *j*=3 | | *j*=2 | | *j*=1 |
| 2596 | 2761 | 2700 | 20 | 20 | | 14 | | Light poles (*k*=1) | 1 |
| 2588 | 2760 | 2790 | 17 | 15 | | 10 | | Light poles (*k*=1) | 2 |
| 2600 | 2790 | 2803 | 16 | 16 | | 11 | | Light poles (*k*=1) | 3 |
| 2700 | 2785 | 2715 | 15 | 13 | | 15 | | Light poles (*k*=1) | 4 |
| 2610 | 2703 | 2830 | 14 | 14 | | 10 | | Light fixture (*k*=2) | 1 |
| 2625 | 2720 | 2850 | 10 | 10 | | 14 | | Light fixture (*k*=2) | 2 |
| 274 | 843 | 235 | 20 | 20 | | 14 | | Arm light fixture (*k*=3) | 1 |
| 280 | 650 | 240 | 17 | 15 | | 10 | | Arm light fixture (*k*=3) | 2 |
| 285 | 450 | 290 | 16 | 16 | | 11 | | Arm light fixture (*k*=3) | 3 |
| 290 | 460 | 290 | 16 | 15 | | 12 | | Arm light fixture (*k*=3) | 4 |
| 1796 | 1734 | 1550 | 11 | 10 | | 8 | | A2 (*k*=4) | 1 |
| 1800 | 1780 | 1560 | 8 | 14 | | 10 | | A2 (*k*=4) | 2 |
| 1810 | 1775 | 1600 | 10 | 9 | | 7 | | A2 (*k*=4) | 3 |

Table 6 presents duration of project activities, while Table 7 presents daily penalty due to the delay in project.

**Table** **6.** Duration of activity *i* for project *j* in days, , and raw material utilization rate

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Duration of operation (days) | | | Raw material utilization rate (raw unit per days) | | | | Preliminary activities | Activity | *i* |
| Project | | | Raw material | | | |
| *j*=3 | *j*=2 | *j*=1 | *k*=4 | *k* =3 | *k* =2 | *k*=1 |
| 15 | 13 | 18 |  |  |  |  |  | Excavation | 1 |
| 6 | 5 | 7 |  |  |  |  | 1 | Pipe laying | 2 |
| 45 | 40 | 20 | 4 |  |  |  | 1 | Installation A2 | 3 |
| 4 | 3 | 5 |  |  |  |  | 1,2,3 | Excavation cover | 4 |
| 7 | 5 | 8 |  |  |  |  | 1,2,3,4 | Excavation and casting of foundations | 5 |
| 32 | 28 | 36 |  |  |  | 10 | 1,2,3,4,5 | Installation of light poles | 6 |
| 16 | 14 | 18 |  | 20 |  |  | 1,2,3,4,5 | Installing an arm for a light pole | 7 |
| 16 | 14 | 18 |  |  | 20 |  | 1,2,3,4,5 | Installation of a light fixture | 8 |
| 32 | 28 | 36 |  |  |  |  | 1,2,3,4,5,6,7,8 | Threading cables in pipelines | 9 |
| 16 | 14 | 18 |  |  |  |  | 1,2,3,4,5,6,7,8 | Installation of a lighting switchboard | 10 |
| 15 | 13 | 18 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Excavation | 11 |
| 6 | 5 | 7 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Pipe laying | 12 |
| 45 | 40 | 20 | 4 |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Installation A2 | 13 |
| 4 | 3 | 5 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Excavation cover | 14 |
| 7 | 5 | 8 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Excavation and casting of foundations | 15 |
| 32 | 28 | 36 |  |  |  | 10 | 1,2,3,4,5,6,7,8,9,10 | Installation of light poles | 16 |
| 16 | 14 | 18 |  | 20 |  |  | 1,2,3,4,5,6,7,8,9,10 | Installing an arm for a light pole | 17 |
| 16 | 14 | 18 |  |  | 20 |  | 1,2,3,4,5,6,7,8,9,10 | Installation of a light fixture | 18 |
| 32 | 28 | 36 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Threading cables in pipelines | 19 |
| 16 | 14 | 18 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10 | Installation of a lighting switchboard | 20 |
| 7 | 7 | 7 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20 | Making electrical connections | 21 |
| 3 | 3 | 3 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21 | Electrical integrity check | 22 |
| 35 | 32 | 40 |  |  |  |  | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22 | Checked the project | 23 |

**Table** **7.** Daily penalty (in NIS) due to the delay in project *j*, .

|  |  |  |  |
| --- | --- | --- | --- |
| **Project** | | | **Daily penalty** |
|  |  |  |
| 2500 | 3000 | 1500 |

Determining the priorities and maintaining resources such as time, energy and funds for a particular project is essential. Due to subjectivity in determining weights and the difficulty in determining them, sum of the fines for delays will be used in this work as the main objective to ensure that the project is implemented on time and properly. When there is a possibility of setting fines for delays, it arouses the interest of the staff and the suppliers to meet the schedule and standards.

The important notations used throughout this paper defined as follows:

|  |  |
| --- | --- |
| **Indices** | |
|  | Index of project |
|  | Index of project activities |
|  | Index of resource types |
|  | Index of order |
|  | Index of supplier |
|  | Index of time |
| **Sets** | |
|  | Set of suppliers for raw material |
|  | Set of raw materials |
|  | Set of activities |
|  | Set of projects |
|  | Precedence set |
|  | Set of active activities at time t |
| **Parameters** | |
|  | Required quantity of raw material *k* needed to complete all the activities of project*j* |
|  | Target makespan of project *j* for completion of all activities and audit pass |
|  | Capacity of raw material *k* at supplier *s* |
|  | Estimated delivery time of raw material *k* from supplier s to project *j* (in days) |
|  | Cost of a unit of raw material *k* purchased from supplier s for project *j* (includes purchase cost and shipping cost) (in NIS) |
|  | Duration of activity *i* in project *j* (in days) |
|  | Daily penalty due to the delay in project *j* (in NIS) |
| |  |  | | --- | --- | |  | weight (relative importance) of optimization criterion | |  | Utilization rate of raw material *k* in activity *i* (unit per unit of time) |   **Decision variables** | |
|  | Start time of activity i of project j |
|  | Finish time of activity i of project j |
|  |  |
|  | Tardiness of project j |
|  | Inventory level of raw material *k* at time *t* |
|  | Quantity of raw material *k* ordered from supplier *s* for activity *i* of project *j* at time *t* |
|  |  |
|  |  |
|  | Maximal makespan of projects |

An objective function is to minimize the target date of project j for completion of all activities and audit pass.

(1)

The constraints of the model are as follows.

(2)

(3)

Constraint (3) means that the shipping quantity from each supplier is subject to its capacity constraint,

, (4)

Constraint (4) means that a project is considered completing construction once all its activities are completed.

(5)

Constraint (5) is the precedence constraint of the project activities. According to this constraint, an activity can start once its predecessor activities are completed.

(6)

Constraint (6) specifies the tardiness of each project.

, and

, (7)

Constraint (7) maintains the balance of raw materials.

(8)

(9)

Constraints (8) and (9) set the relationship between the binary and the continues variables.

(10)

Constraint (10) states that an activity can start only once.

(11)

Constraint (11) states set the relationship between two binary variables.

(12)

Constraint (12) states that raw material is demanded for the start of an activity at more than once.

(13)

Constraint (13) states that raw material is demanded for the start of an activity at more than once.

(14)

Constraint (14) states that each activity can begin only after the needed materials are acquired.

(15)

(16)

(17)

(18) (19)

(20)

(21)

(22)

(23)

(24)

Constraints (15)-(23) define the domains of decision variables.

1. **Timetable**

|  |  |
| --- | --- |
| **Task** | **Target date** |
| Completing the literature review | 2 months |
| Detailed mathematical formulation | 3 months |
| Building a detailed software for the solution method | 3 months |
| Collecting and analyzing relevant data of the case study | 2 months |
| Validating the model in a real-life case study | 2 months |
| Sensitivity analysis of the mathematical results | 2 months |
| Finalizing and writing results, conclusions and editing | 3 months |

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