Impacts of Multi-skills on Project Productivity and Completion Time: A Building Renovation Case Study

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Abstract –

This paper delves into the complexities of integrated supply chain planning decisions and project management in the construction industry, specifically about multi-skill, resource-constrained, and multi-project scheduling problems. To address this issue, we propose a mathematical mixed-integer linear programming (MILP) model that optimizes schedules for multiple projects involving different activities, renewable resources, and skill sets. We test our solution in a real-world case study using data from a construction company in Canada specializing in building renovation. In addition, we conduct a sensitivity analysis to test the robustness of our model and how it can support managerial decision-making. Our results prove that the proposed decision support system (DSS) can help project managers and logistic coordinators achieve optimal integrated project scheduling and supply chain resource planning. Furthermore, it allows for better control over the impact of multi-skill requirements and renewable resources on construction supply chain performance. Finally, our new DSS provides valuable collaborative information to find areas for improved decision-making of project completion and workforce compression times.

Keywords –

Construction project management; Scheduling; Assignment; Optimization; Multi-Skills

1 Introduction

The construction industry has faced many challenges, including rising costs, stagnant productivity, and alarming levels of waste. These obstacles have become even more daunting as the demand for increasingly complex structures, higher sustainability standards, and elevated customer expectations has skyrocketed. Exploring and implementing new analytical models, resolution methods, and decision-support tools from supply chain and logistics perspectives is crucial to support the industry's ongoing efforts toward industrialization and digital transformation. An integrated approach that accounts for project management and supply chain management (SCM) decisions while allocating multiple resources and workforce skills is essential to promote efficiency, resilience, and a customer-centric approach to construction projects [1].

A real-world scenario involving a construction company based in Canada inspired this research. The company specializes in delivering and repairing modular and traditional construction projects for Canadian clients. They also provide high-quality foundation and structural repair solutions. Their challenge was to allocate multiple resources across different projects while managing different schedules. In search of a new DSS, the company sought to optimize its project scheduling and resource allocation for its current portfolio of projects. Building upon this case, we propose a model to streamline supply chain operations and project management aspects of construction projects, ultimately reducing project completion time and improving resource allocation.

Successful project management requires a combination of knowledge, skills, tools, and technology to execute project activities and achieve predetermined goals effectively. Project scheduling is a crucial aspect of project management, which involves allocating resources and determining timelines for implementing project tasks. The challenge lies in that these tasks follow predetermined precedence relationships and compete for scarce resources, resulting in the optimal schedule for achieving specific goals. The problem is known as the resource-constrained project scheduling problem (RCPSP), first defined by [2], and is widely recognized in project scheduling across various fields, including engineering, construction, manufacturing, software development, and logistics management. It is important to note that the RCPSP is a well-known NP-hard problem, which adds to its complexity.

The primary goal of the Resource-Constrained Multi-Project Scheduling Problem (RCMPSP) is to create a schedule that accounts for the sequence of activities across multiple projects while also considering resource limitations. This problem is complicated because real-world projects come with various time and cost constraints [3]. These factors are essential to consider, as they significantly affect the overall efficiency of the project construction supply chain (CSC).

So, construction schedulers must carefully manage resources, prioritize activities, and create feasible and effective schedules. However, it is essential to note that some schedules may be infeasible due to limited resource availability. In particular, the availability of renewable resources, such as skilled labor and managers, and non-renewable resources, such as construction materials in building projects, are finite and complicated, and managing several concurrent projects is a sophisticated task that deals with sharing limited resources among multiple projects. Hence, the scheduling process becomes complicated when managing simultaneous projects and resources [4]. Managing several concurrent projects is a sophisticated task that deals with sharing limited resources among multiple projects [5]. After considering these intricacies, the simple scheduling problem becomes a Multi-Skill, Resource-Constrained, Multi-Project Scheduling Problem (MSRCMPSP), which we will denote as a $\mathcal{P}$ for the rest of the paper.

We have selected and compared the latest research papers in reputable journals with our work. We classified them based on multi-project, multi-skill, and supply chain management, considering renewable and non-renewable resources and supplier parameters and whether they applied to real-world projects. Notably, the study conducted by [6] in 2023 comprehensively analyzes skill-based assignments within this domain. They even considered skills familiarity level per renewable resource but should have considered non-renewable resources, supplier selection, and supply chain times in their mathematical model. They used numerical examples to test their model. Another study considered a skill-based assignment and scheduling optimization model [7]. This paper focused on the dynamic nature of the skill level of human resources and its effects on project schedules. They build an optimization model to maximize the value of each renewable resource while optimizing project completion time. They did not consider non-renewable resources. Another paper [8] considered all types of resources. However, they focused on a single project. To encapsulate, no paper in our literature review has simultaneously considered multiple projects, non-renewable resources with supplier selection, and renewable resources based on skill assignment and applied them to a real case study.

Therefore, the main contribution of this paper is to provide a solution method to manage this problem by presenting the MILP model for planning level that optimizes schedules of multiple projects involving multiple activities and renewable resources with multiple skills assignments applied to actual data. We also show the impact of multi-skills and advanced supply chain planning using a real-life case introduced in the introduction of the building renovation sector. A limited number of papers have explored resource constraint scheduling problems, is shown in Table 1.

Table 1. CSC Optimization Papers Review

Reference	Multi-project	Multi-Skill	SCM	Real Case	Objective (s)
[8]		•	•	•	T, C
[9]			•		T
[6]	•	•			T, C
[10]			•		C, P, R
[11]				•	T, C
[7]	•	•		•	T
[12]				•	P
[13]	•				T
[14]	•			•	T, C
This Work	•	•	•	•	T

SCM: Supply chain management; T: Time; C: Cost; P: Profit; R: Risk

2 Problem Description & Assumptions

This paper describes the problem as a variant of RCMPSP. The problem consists of a set of projects, each of which is made up of a subset of jobs or activities. The construction supply chain's key players are the clients, suppliers, and contractors. Once the contractor wins a project bid from the client, he must complete several jobs or activities. The contractor has a fixed number of shared renewable resources for all concurrent projects as shown in Figure 1.

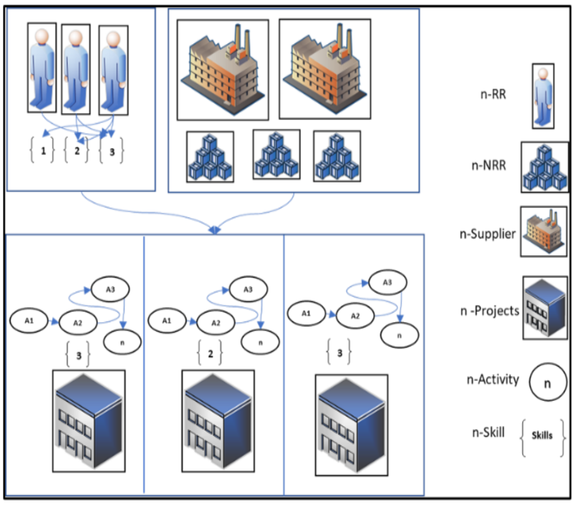

Figure 1. Construction Supply Chain

Each project has a specific release date, the time from which the jobs can start, and a desired date representing the time the project should be completed. Each job within a project has a processing time and a quantity required for each type of resource. A "Team Leader" and a "Manager" (renewable resources) are required to complete a project. All project activities have established end-start precedence relationships, which means that an activity can only begin after a set of predecessor activities have been completed. A feasible schedule for this problem involves assigning start times to each activity within each project while respecting the precedence relationships between jobs and the availability of resources at each period.

2.1 Model Definitions and Assumptions

To achieve coordination of the construction supply chain, integrated advanced planning and scheduling, including supplier selection and resource assignment optimization, should be solved. To achieve this objective, we model the coordinated operations of the construction supply chain in Figure 1, capturing critical components of the real-life construction project described in Section 1. The supply chain network consists of a set of projects denoted $by\,P$. For each project, we consider an independent set of activities across projects. For each project, we must procure K non-renewable resources to each project P by supplier U. Also, we need to assign renewable resources L team leads and M managers to each project based on skill set S requirements. The network diagram is shown in Figure 1.

The model is implemented in the case company, and the model is developed as per their requirements. These requirements are considered assumptions for the model's generality, such as renewable resources (managers and team leads) are assigned to projects, not activities. This work was carried out by the company that assigns these resources to projects. The second assumption is that all non-renewable resources required for the project will arrive before the start of the project's first activity, as in the case of this company. The third assumption is that a team lead can only be assigned one project at a time. The fourth assumption is that once the project is started, it will continue without interruptions from other projects until it is finished. The fifth assumption is that once the team leads and managers are assigned to any project, they will remain assigned until it is completed.

2.2 Mathematical Model Details

We introduce the following notations to formulate the MILP mathematical for problem $\mathcal{P}$. The details of the model are given below.

2.2.1 Sets

- P : set of projects.
- $A(p), p \in P$: set of activities to be completed in project p.
- S : set of skills.
- U : set of Suppliers for non-renewable resources.
- L : set of team leaders.
- M : set of managers.
- K : set of Non-renewable resources.
- T : set of time periods.

2.2.2 Parameters

The parameters considered for this problem are the data we receive from the case company, which includes scheduling-related data, cost-related data, supplier and non-renewable resources data, team lead and manager skills data, and suppliers' shipping and release time data. The shipping time depends upon the supplier and project location. In contrast, supplier release time depends upon the supplier and type of resource. Different resources require different preparation times once the order is received, which we have described in the parameters sub-section.

- $Dur_{pa}, p \in P, a \in A$: Duration of Activity a of Project p
- $Delay_p, p \in P$: Anticipated delay in Project p
- $DS_P, p \in P$: Due starting date of Project p
  $FS_P, p \in P$: Due finishing date of Project p
- $Q_{pk}, p \in P, k \in K$: Non-renewable resource units of k required by Project p
- $Cap_{uk}, u \in U, k \in K$: Capacity of providing Non-renewable resources of k units by Supplier u
- $C_{uk,} u \in U, k \in K$: Cost of Non-renewable resource of k per unit required by Supplier u
- $\mathrm{Re}\,q_{ps}, p \in P, s \in S$: Skills required by Project p
- $Avl_{ls}, l \in L, s \in S$: Skill$s$ possessed by Team Leader l
- $Mag_{ms}, m \in M, s \in S$: Skill$s$ possessed by Manager m
- $Tran_{lp}, l \in L, p \in P$: Distance between Team Leader l and Project p's location in km
- $MSal_m, m \in M$: Salary of Manager m in CAD ($)
- $LSal_l, l \in L$: Salary of Team Leader l in CAD ($)

- $Bud_p, p \in P$: Budget of Project p
- $\mathrm{Re}l_{uk}, u \in U, k \in K$: Release time of non-renewable resource k by Supplier u
- $Shp_{up}, u \in U, p \in P$: Shipping time by Supplier u for Project p
- M = The Big M.

2.2.3 Decision Variables

Since the problem we tackle is scheduling and assignment of multiple resources based on multiple skills to multiple projects, the kind of decision variables formed is relevant to the problem; therefore, two decision variables are for non-renewable resource assignment to a project by a supplier, four decision variables are for selection for team lead and manager to project at any period while two decision variables are formed for the scheduling optimization purpose starting time and completion time of project.

- W_{puk} : binary variable, equal one if a supplier $u \in U$ is selected for the project $p \in P$ to provide non-renewable resource $k \in K$
- Z_{puk} : quantity of non-renewable resources $k \in K$ supplied by supplier $u \in U$ to Project $p \in P$
- ST_{pa} : Starting time of Activity, $a \in A$ of Project $p \in P$
- CT_p : Completion time of Project $p \in P$
- Y_{pl} : binary variable, equal 1, if Team Leader $l \in L$ is assigned to Project $p \in P$ (Binary variable)
- X_{plt} : binary variable, equal 1, if Team Leader $l \in L$ is assigned to Project $p \in P$ at Time Period $t \in T$
- R_{pm} : binary variable, equal 1, if Manager $m \in M$ is assigned to Project $p \in P$ (Binary variable)
- E_{pmt} : binary variable, equal 1 if Manager $m \in M$ is assigned to Project $p \in P$ at Time Period $t \in T$

2.2.4 Objective Function and Constraints

The objective of this problem is to minimize the total "completion time" of all the projects simultaneously based on the optimized assignment of resources, as shown in the following equation.

$$\min \sum_{p \in P}((\sum_{l \in L}\sum_{t \in T} X_{plt} \times \mathrm{t}) + \mathrm{C}_p) \tag{1}$$

The constraints of the model, which can be divided into various categories, are as follows.

a) Assignment Constraints

$$\sum_{l \in L} Y_{pl} = 1 \,\forall\, p \in P \tag{2}$$

$$\sum_{m \in M} R_{pm} = 1 \,\forall\, p \in P \tag{3}$$

$$\mathrm{Re}q_{ps} - Avl_{ls} \leq 2 \times (1 - Y_{pl})\, l \in L, s \in S, p \in P \tag{4}$$

$$\mathrm{Re}q_{ps} - Mag_{ms} \leq 2 \times (1 - Y_{pl})\, m \in M, s \in S, p \in P \tag{5}$$

$$\sum_{t \in T} X_{plt} = Y_{pl} \,\forall\, l \in L, p \in P \tag{6}$$

$$\sum_{t \in T} E_{pmt} = R_{pm} \,\forall m \in M, p \in P \tag{7}$$

$$\sum_{l \in L} X_{plt} \times t = \sum_{m \in M} E_{pmt} \times t \,\forall p \in P, t \in T \tag{8}$$

$$\sum_{t \in T} E_{pmt} \leq 5 \,\forall\, m \in M, p \in P \tag{9}$$

b) Budget Constraint

$$\sum_{m \in M}\sum_{l \in L}(Y_{pl} \times LSal_l + R_{pm} \times MSal_m + Y_{pl} \times Tran_{lp}) \leq Bud_p \quad p \in P \tag{10}$$

c) Scheduling Constraints

$$\sum_{l\in L}\sum_{t\in T}(X_{plt}\times t)\geq DS_p \ \forall p\in P \tag{11}$$

$$\sum_{l\in L}\sum_{t\in T}(X_{plt}\times t)\geq Delay_p \ \forall p\in P \tag{12}$$

$$\sum_{l\in L}\sum_{t\in T}(X_{plt}\times t)+C_p\leq FS_p \ \forall p\in P \tag{13}$$

$$\sum_{l\in L}\sum_{t\in T}(X_{plt}\times t)\leq ST_{pa} \ \forall p\in P, a\in A, \tag{14}$$

$$ST_{pa}+Dur_{pa}\leq C_p \ \forall a\in A, p\in P \tag{15}$$

$$ST_{pi}+Dur_{pi}\leq ST_{pj} \ \forall i\in A, j\in A, p\in P, i\neq j \tag{16}$$

d) Non-renewable Resources Constraint

$$\sum_{p\in P}Z_{puk}\leq Cap_{uk} \ \forall u\in U, k\in K \tag{17}$$

$$\sum_{u\in U}Z_{puk}=Q_{pk} \ \forall p\in P, k\in K \tag{18}$$

$$\sum_{k\in K}\sum_{u\in U}(Z_{puk}\times C_{uk})\leq Bud_p \ \forall p\in P \tag{19}$$

$$Z_{puk}\leq M\times W_{puk} \ u\in U, p\in P, k\in K \tag{20}$$

$$\sum_{u\in U}((\mathrm{Re}l_{uk}+Shp_{up})\times W_{puk})+1\leq\sum_{l\in L}\sum_{t\in T}(X_{plt}\times t) \quad \forall p\in P, k\in K \tag{21}$$

Equation 2 ensures that each project is assigned only one team lead. Equation 3 ensures the same for the manager. Equations 4 and 5 make the model force assign the project to the team lead and the manager with the required skills. Equations 6 and 7 limit the model to select any other team lead and manager except for the ones assigned to it over any time for any project. Equation 8 will ensure that the project's starting time for the assigned team lead and manager should be the same.

While a team lead cannot be assigned to more than one project at any period, a manager can assign a maximum of 5 projects at any time; equation 9 is for this purpose. Constraint 10 in Equation 10 shows each project's budget limit. Since the case company specializes in delivering renovation projects to its customers, it needs to ensure that each project is completed within the allocated budget to maintain profitability and customer satisfaction. Equation 11 will ensure the project does not start before its due date. Equation 12 is for the anticipated project delay, and it will make sure that the project starts after its delay period. Equation 13 is for the projects' finishing due dates. So, it will ensure the project is completed within its due date.

The scheduling decision variable ST should be greater or equal to the starting time of the project; constraint 13 in equation 14 will serve this purpose. Equation 15 is that the completion time of each project should be greater than the starting time of all activities and the duration of its project. Equation 16 is for establishing precedence, and it is only activated on a phased approach. Ultimately, equations from 17 to 19 are assigned to each project and its supplier selection for non-renewable resources. Equation 20 triggers a significant M constraint, which will be activated for suppliers selected to supply non-renewable resources. The last equation, 21, is to ensure that the project will start once all the non-renewable resources necessary are received for that project, incorporating the starting time of the project to be greater than the release time and arrival time of resources on the project location.

3 Case Study

As mentioned, the model is implemented on a real construction company based in Canada. For experimentation purposes, we selected the case of 10 projects, having eight activities in each project with different precedence relationships. The company data is described below. The skills (S) that team leaders (TL) possess are shown in Table 2, while the skills required by the ten projects (P) are shown in Table 3.

Table 2. Team leader's skill availability

Skills / Team Leaders		TL 1	TL 2	TL 3	TL 4	TL 5	TL 6	TL 7	TL 8
S1	Digging	•	•			•			•
S2	Complex piles	•				•			•
S3	Decontamination	•				•			•
S4	Structure	•			•	•			•
S5	Interior drain	•	•	•	•	•			

Table 3. Project skill requirement

Skills / Projets	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
S1	●				●					●
S2							●	●		
S3									●	
S4				●		●				
S5		●	●							

3.1 Initial experimentation

The model is implemented in Pyomo, a Python-based open-source optimization modeling language, and we use the solver Gurobi solver. The solution method used is the branch and bound, which is an exact solution method. For this paper, we tested this model on three instances: 3 projects, 5 projects, and 10 projects. For 10 project instances, we received a solution in around 1 minute, which is a promising result given the fact that it is a type of RCPSP problem. The summary of the first results and their computational time is shown in Table 4.

Table 4. Initial Results

No of Projects	Total Completion Time (Days)	Projects Finishing Time (Days)	Solution Time (Secs)
3	72	37	20,4
5	125	37	35,4
10	313	53	64,8

Upon further analysing the 10 projects, we see the finishing time of the last project, which, in this instance, is 53 days, as can be seen in the Gantt chart of Figure 2. The Gantt chart shows that managers, such as M, and team leaders, such as TL, are assigned to projects. This can be considered aggregate-level planning because we assign projects and track the start, duration, and finish times of these projects.

With this model, we can also check the same for each project's activities. For example, the activities Gantt chart of Project 6th is shown in Figure 3. The sixth project starts on the first day and finishes on the 15th; during this time, all eight activities are executed according to their precedence relationship, as shown in Figure 3. In the next section, we analyze the impact of skill change and the number of team leaders on the total completion time of the 10 projects.

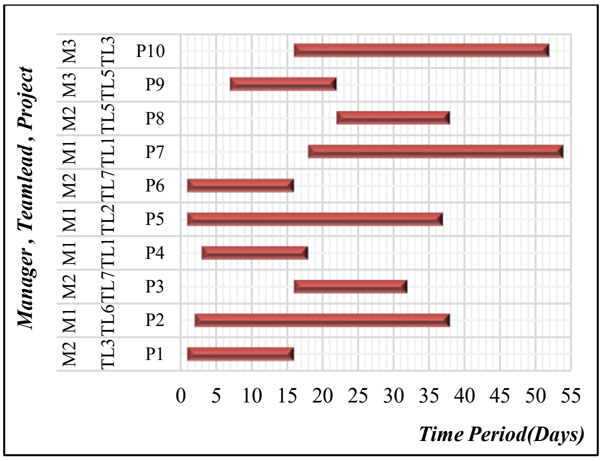

Figure 2. Aggregated Gantt Chart 10 Projects

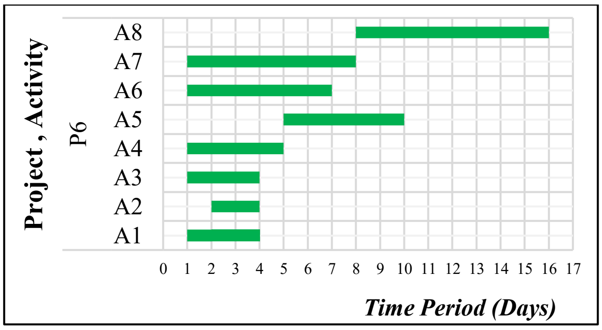

Figure 3. Timeline Gantt Chart of Project 6 with Activities

3.2 Impact of team lead and skills on project scheduling and procurement

For this purpose, an analysis is done concerning the number of team leaders and their skills. How does the availability of a skillful team lead affect project completion time? We test 7 hypothetical scenarios (Sc) on the same 10 project instances described below and compare them with the initial result of Table 3.

- Sc1: Result in Table 3 for 10 projects with 8 TL.
- Sc2: With 4 TL (50% of staff).
- Sc3: With 2 TL (25% of staff).
- Sc4: With 4 TL and all trained-on skill S1.
- Sc5: With 4 TL and all trained-on skill S2.
- Sc6: With 8 TL and all trained-on skill S1.
- Sc7: With8 TL and all trained-on skill S2.
- Sc8: With 8 TL and all trained-on skills S1 & S2.

In evaluating the resource plan for 10 projects, we found that 8 capable team leaders available. However, it is sometimes difficult to keep this level of staffing (safety reasons, COVID-19 restrictions, disruptions), so we explored the effects of reducing our staff by 50% and 25% on project completion times. Unfortunately, we saw a significant increase in total completion time for all 10 projects. For example, under Scenario 2, the total project completion time was 406 days, an increase of 93 days from Scenario 1. Under Scenario 3, the completion time rose to 582 days, an increase of 269 days. Ultimately, there were more practical options for improving productivity than downsizing, as it had a negative impact on completion time. This is unacceptable for some customers and would damage the company's reputation. To address this, we tested Scenarios 4 and 5, which focused on providing skill training to staff on the critical skills needed for each project.

To ensure project success, we identified vital skills S1 and S2 and provided training to team leaders lacking these abilities. Most projects require these skills, making them crucial for the team. After the training, we evaluated the impact of S1 and S2 on project completion time in scenarios S4 and S5. Our findings revealed that training on skill S1 (digging) did not significantly affect project completion time, while training on skill S2 (Complex piles) reduced the time by 36 days, resulting in a completion time of 370 days compared to Sc 2. However, compared to Sc1, solution Sc 5 still had a 57-day increase in completion time. To further test our results, we conducted the same training with 8 team leaders, resulting in scenarios Sc 6, Sc 7, and Sc 8, all of which yielded an optimum completion time of 284 days, a 29-day reduction from Sc1.

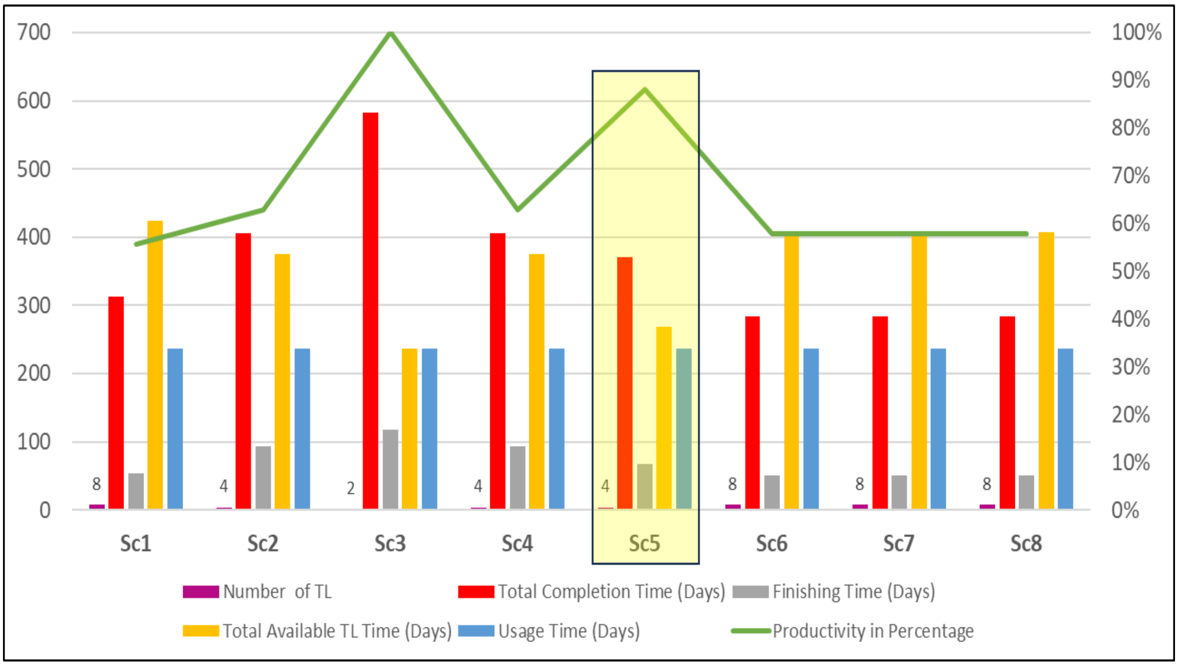

Figure 4. Comparison of scenarios solution

The sensitivity analysis as shown in Figure 4 reveals potential time and cost savings in the current model. Prioritizing customer satisfaction and project completion time suggests keeping the entire staff despite lower productivity (55%) and increased idle time for team leaders. Alternatively, downsizing may be preferable for cost reduction or higher team leader productivity. Scenario 5, with 88% productivity and a total completion time of 370 days, appears as the most optimal solution. Therefore, S2 is identified as the most critical skill requiring training

Based on this analysis, several factors must be considered when deciding on the "ideal solution" to such challenges. These factors include the cost of keeping and training staff, the duration it takes to complete a project, the availability of staff, and the company's goals. Luckily, our model can manage these complexities to support more thoughtful decision-making.

4 Conclusion

Managing concurrent construction projects is complex and involves both external and internal factors. Externally, it consists of obtaining permits and coordinating with suppliers and clients. Internally, it involves resource management, addressing diverse project needs, skills allocation, and meeting project deadlines.

The proposed mathematical model can be used at the tactical level to estimate multiple project schedules at their operational level. The second novelty is the MILP model, which can optimize and assign multiple project schedules, resource assignments, and supplier selection, thus integrating supplier information into the model. Although the full model is presented in this paper, only the effects of skill and team leaders on project completion time are analyzed. The third contribution is to address the research gap highlighted by the study of [15], which shows an urgent need for master scheduling at the planning level that integrates resources needed at the operational level. This research emphasizes the significance of effective collaboration between different supply chain stakeholders through information sharing. This approach can lead to more accurate project scheduling, ensuring better resource planning and coordination for a more efficient construction supply chain. Dealing with resource-constrained multi-project reactive scheduling problems amid uncertainties is critical. Disruptive events, such as a new project, changes in resource availability, or transportation delays, can cause uncertainty. The process of rescheduling the detailed plan to obtain an updated schedule is a challenging task and requires further research.

5 References

[1] Le, P.L., et al., Present focuses and future directions of decision-making in construction supply chain management: a systematic review. International Journal of Construction Management, 2020. **20**(5): p. 490-509.

[2] Dike, S.H., Project scheduling with resource constraints. IEEE Transactions on Engineering Management, 1964(4): p. 155-157.

[3] Gonçalves, J.F., J.J. Mendes, and M.G. Resende, A genetic algorithm for the resource constrained multi-project scheduling problem. European journal of operational research, 2008. 189(3): p. 1171-1190.

[4] García‐Nieves, J., et al., The multimode resource‐constrained project scheduling problem for repetitive activities in construction projects. Computer‐Aided Civil and Infrastructure Engineering, 2018. 33(8): p. 655-671.

[5] Kumanan, S., G. Jegan Jose, and K. Raja, Multi-project scheduling using an heuristic and a genetic algorithm. The International Journal of Advanced Manufacturing Technology, 2006. 31: p. 360-366.

[6] Hosseinian, A.H. and V. Baradaran, A two-phase approach for solving the multi-skill resource-constrained multi-project scheduling problem: a case study in construction industry. Engineering, Construction and Architectural Management, 2023. 30(1): p. 321-363.

[7] Li, Q., et al., The Integrated Problem of Construction Project Scheduling and Multiskilled Staff Assignment with Learning Effect. Journal of Construction Engineering and Management, 2023. 149(8): p. 04023064.

[8] Mirnezami, S.-A., et al., An integrated chance-constrained stochastic model for a preemptive multi-skilled multi-mode resource-constrained project scheduling problem: A case study of building a sports center. Engineering Applications of Artificial Intelligence, 2023. 126: p. 106726.

[9] Xie, L.-L., et al., Knowledge extraction for solving resource-constrained project scheduling problem through decision tree. Engineering, Construction and Architectural Management, 2023.

[10] Ghoroqi, M., et al., An Integrated Model for Multi-Mode Resource-Constrained Multi-Project Scheduling Problems Considering Supply Management with Sustainable Approach in the Construction Industry under Uncertainty Using Evidence Theory and Optimization Algorithms. Buildings, 2023. 13(8): p. 2023.

[11] Chauhan, M. and R. Kumar, Integrating the multi-objective particle swarm optimization-based time–cost trade-off model with earned value management. Asian Journal of Civil Engineering, 2023: p. 1-11.

[12] Wang, J., H. Liu, and Z. Wang, Stochastic Project Scheduling Optimization for Multi-stage Prefabricated Building Construction with Reliability Application. KSCE Journal of Civil Engineering, 2023: p. 1-16.

[13] Srimathi, K., A. Padmarekha, and K. Anandh, Automated construction schedule optimisation using genetic algorithm. Asian Journal of Civil Engineering, 2023: p. 1-8.

[14] Ghoroqi, M., et al., Integration of resource supply management and scheduling of construction projects using multi-objective whale optimization algorithm and NSGA-II. Soft Computing, 2024.

[15] Zaalouk, A., S. Moon, and S. Han, Operations planning and scheduling in off-site construction supply chain management: Scope definition and future directions. Automation in Construction, 2023. 153: p. 104952.