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Collaborative supply chain planning and scheduling of construction projects

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Abstract: In this study, we propose an integrated model for collaborative Construction Supply Chain (CSC) planning that deals with the joint project scheduling and material ordering decisions. The main objective is to achieve more coordination and, therefore, to reduce the total CSC cost. More specifically, we consider a two-echelon Supply Chain (SC) composed of a manufacturer, a warehouse, and multiple construction sites where multiple independent construction projects are planned. The projects require different materials that are provided by the same manufacturer with a limited production capacity. The starting time of each activity is subject to materials availability in construction sites. A mixed-integer linear programming (MILP) model is developed to reduce the total costs while collaboration between contractors is possible. The model is implemented using the IBM ILOG® CPLEX® Optimization Studio and used to analyze the collaboration process through a numerical study to demonstrate the benefits of collaborative planning in construction project management. The decision model help also in finding practical construction projects' sequences as well as suitable materials ordering, manufacturing, and inventories plans for SC participants.

Keywords: construction supply chain, collaboration, production, inventory, project scheduling.

1. INTRODUCTION

Construction supply chains are complex networks with different relationships and resources, product/services, logistics, information, and money flows. Moreover, construction project planning and execution involve many participants from several organizations that require intensive communication efforts to deliver the project efficiently. The use of project-oriented management procedures is adding more obstacles since each project is unique. Supply Chain Management (SCM) in construction represents a significant opportunity for the construction sector (Le et al., 2018). Indeed, the lack of collaboration in the construction domain is one of the significant issues that the industry is facing. Work in a silo "*goes with the fear of losing one's territory and not accepting the benefits of this type of collaboration, particularly when it comes to saving time and money*."

SCM could drive massive cost-saving, provide real-time SC collaboration, and increase the ability to deliver the project on time. In construction, the application of SCM concepts is regularly utilized but limited to guide project managers in the CSC planning to achieve more collaboration with suppliers and obtain operational construction efficiency (Azambuja and O'Brien, 2008, Hsu et al., 2017). It includes the use of methods and techniques for making decisions related to material purchasing, material handling, onsite transportation, and construction project scheduling (Vaidyanathan and Howell, 2007). Project scheduling integrated with material ordering leads to issues that affect construction projects, especially costs and resources management, including inventory management.

Traditional inventory construction planning strategies based on non-aligned planning from the start of a project become problematic during construction project execution (Sajadieh et al., 2009). Therefore, recent efforts on CSC planning tried to overcome this issue. For instance, a previous research study identified other costs, such as renewable resource costs and back-ordering costs, which were introduced to tackle the limitation of traditional inventory management methods in construction projects (Fu, 2014). A recent study proposed a MILP model to support the operations of a general multi-projects, multi-resources, and multi-suppliers CSC (Golpîra, 2020). The model considered the Vendor Management Inventory (VMI) strategy and addressed the supply decision sharing strategy to integrate the CSC network design and facility location problems. Another study emphasized material buffers in construction, discussing the impact of buffers' deployment on project variability (Horman and Thomas, 2005). The results highlight the importance of managing buffer size carefully and analyze the relationship between inventory buffers and construction labor performance. The problem of inventory allocation was addressed through a mathematical model for optimizing the simultaneous planning of material procurement and the project schedule (Tabrizi and Ghaderi, 2016). Other researchers suggest more extensions to inventory management models in construction by adding transportation, information, and facilities drivers, which affect the CSC (Ko, 2010). Analytical models have been frequently used to model the CSC to optimize cost or minimize time subject to the project constraints. For example, Said and El-Rayes (2011) proposed a novel optimization model for the efficient

procurement and material storage on project sites that have the possibility to improve the productivity and the profitability of the construction projects. Hamdan et al. (2015) presented a framework that integrates Building Information Modelling (BIM) with simulation for inventory management to reduce inventory cost, as well as to increase the performance of the CSC. Finally, more recently, Golkhoo and Moselhi (2019) presented an automated method as part of a significant materials management system to generate an optimized material delivery schedule.
The literature reviewed raises issues in construction projects to do with the lack of collaboration amongst the SC participants. Each player has his schedule. Therefore, the collaboration between different SC players is critical to improving construction profitability (Dallasega et al., 2018). Although there is a rich literature about CSC collaboration, the coordination of production and inventory management along with multi-project scheduling has not been studied in previous research (Chen et al., 2018). Therefore, this paper has an objective to close this gap by proposing a novel model for the optimization of joint production, scheduling, and inventory management in multi-project construction supply chains. Moreover, this study demonstrates how to coordinate production, scheduling, and inventory management for the concurrent projects and show via a numerical example the value of CSC collaboration compared to the management of projects in an individual manner. The remainder of this paper is organized as follows. In section 2, we introduce the problem and model formulation. Section 3 presents a numerical example and the main results. Section 4 gives additional managerial insights. Finally, conclusions are stated in section 5.

2. MATHEMATICAL MODEL

This paper considers a multi-product and two-echelon CSC with one manufacturer, who provides finished modular construction products to the warehouse. The manufacturer and the warehouse are part of the leading focal company. The warehouse is responsible for delivering modular products to different construction sites (the consumers of finished products at a specific rate) managed by one or different contractors. Traditionally, each project is managed individually. In this study, we assume that collaboration between the focal company and the contractor(s) is possible, and it is beneficial for all parties. Such collaboration can be accomplished through modifications of the production operations, inventory management in the warehouse and construction sites, as well as the review of the project's schedules. Fig.1 captures the critical components of the real CSC.

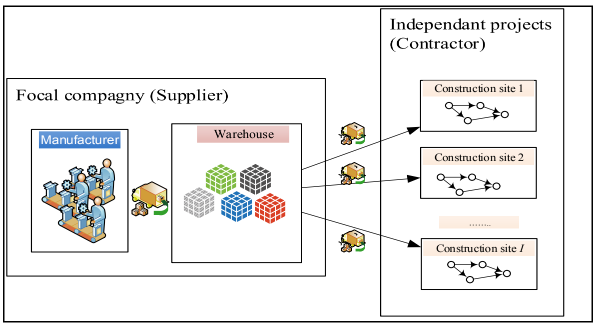

Fig. 1. Construction supply chain participants

All parties involved in the collaboration process have a common objective, which is the minimization of the overall cost of the CSC.

2.1 Assumptions and notations

The construction supply chain is composed of a network with one manufacturer, one warehouse, and a set of construction sites. There is one project in each construction site. Each project has a set of independent activities subject to precedence constraints. A list of non-renewable resources (materials) is required and must be available on the construction site before starting the execution of each activity. The precedence relations of activities are finish-to-start with zero lags. The first and last activities in each project are dummies and have a zero-completion time. Activity duration is a decision variable and can vary between the normal time and the crash time. To present the mathematical formulation of the proposed model, we first introduce the following notations.

Sets and indices

- $\boldsymbol{i}$: Index of construction sites (projects), $i = 1, 2,\dots, I$.
- $\boldsymbol{m}$: Index of materials, $m = 1, 2, \dots, M$.
- $\boldsymbol{t}$: Index of time, $t = 0, 1, 2, \dots, H$.
- $\boldsymbol{j, k}$: Index for activities of project i, $j, k = 1, 2,\dots, n_i$.
- $\boldsymbol{P_{ij}}$: Set of activities preceding activity j in project i.

Construction sites parameters

A. ***Activity-related parameters***

- $\boldsymbol{\alpha_{ij}}$: the crashing cost of activity j of project i.
- $\boldsymbol{\beta_{ij}}$: the cost of reducing the duration of activity j by one period of project i.
- $\boldsymbol{\mu_{ij}}$: upper bound for the duration of activity j (normal time) of project i.
- $\boldsymbol{v_{ij}}$: lower bound for the duration of activity j (crash time) of project i.
- $\boldsymbol{H}$: time horizon.
- $\boldsymbol{L}$: sufficient large number.

B. ***Materials-related parameters***

- $\boldsymbol{oc_m}$: ordering cost of material m.
- $\boldsymbol{\delta_{mij}}$: amount required from material m to process activity j of project i.
- $\boldsymbol{vol_m}$: volume of material m.
- $\boldsymbol{cap_i^c}$: maximum capacity of construction site i.
- $\boldsymbol{h_i^c}$: inventory cost for maintaining the materials for one period in the construction site i.

C. ***Project-related parameters***

- $\boldsymbol{d_i}$: due date of the project i after which a delay penalty cost is paid.
- $\boldsymbol{p_i}$: penalty cost per period for delaying project i beyond d_i.
- $\boldsymbol{r_i}$: reward paid per period for completing project i before d_i.

D. ***Manufacturer and warehouse-related parameters***

- $\boldsymbol{mr_m}$: maximum manufacturing capacity of material m per period.
- $\boldsymbol{mc_m}$: manufacturing cost per unit of material m.
- $\boldsymbol{cap^m}$: maximum inventory capacity of the manufacturer.
- $\boldsymbol{h^m}$: inventory cost for maintaining materials for one period at the manufacturer.

- $\boldsymbol{M_m}$: Initial inventory level of material m in the manufacturer site.
- $\mathbf{SC_m}$: set-up cost for producing material m in each period.
- $\boldsymbol{cap^w}$: maximum capacity of the warehouse.
- $\boldsymbol{h^w}$: inventory cost for maintaining materials one period in the warehouse.

E. Transportation-related parameters

- $\boldsymbol{tc^{mw}}$: transportation cost of materials from the manufacturer to the warehouse per truck.
- $\boldsymbol{tc_i^{wc}}$: transportation cost of materials from the warehouse to the construction site i per truck.
- $\boldsymbol{cap^{tmw}}$: capacity of a truck used between the manufacturer and the warehouse.
- $\boldsymbol{cap^{twc}}$: capacity of a truck used between the warehouse and construction sites.

Decision variables

- $\boldsymbol{\varphi_{mit}}$: binary variable, equal 1 if construction site i in period t order at least one unit of material m, and 0 otherwise.
- $\boldsymbol{\varpi_{ijt}}$: binary variable, equal 1 if activity j of project i is completed in period t, and 0 otherwise.
- $\boldsymbol{\zeta_{ijt}}$: binary variable, equal 1 if activity j of project i is started in period t, and 0 otherwise.
- $\boldsymbol{\lambda_{ij}}$: duration of activity j of project i.
- $\boldsymbol{\chi_{mt}}$: manufacturing quantity of material m in period t.
- $\boldsymbol{\theta_{mt}}$: binary variable, equal 1 if material m *is* manufactured in period t, and 0 otherwise.
- $\boldsymbol{I_{mit}^{c}}$: inventory level of material m at construction site i by the end of period t.
- $\boldsymbol{I_{mt}^{w}}$: inventory level of material m at the warehouse by the end of period t.
- $\boldsymbol{I_{mt}^{m}}$: inventory level of material m at the manufacturer by the end of period t.
- $\boldsymbol{\varepsilon_{mt}^{mw}}$: quantity of material m shipped from the manufacturer to the warehouse at period t.
- $\boldsymbol{\varepsilon_{mit}^{wc}}$: quantity of material m shipped from the warehouse to the construction site i at period t.

2.2 Model formulation

Based on the notations mentioned above and assumptions, the total cost for the CSC can be obtained by the sum of the different cost obtained by equations (1) to (6). The objective is to minimize the total cost which is equal to the summation of 1) the Manufacturing Cost (MC), 2) the Ordering Cost (OC), 3) the Activities Cost (AC), 4) the Transportation Cost (TC), and 5) the Inventory holding Cost (IC), and 6) the Reward /Penalty of project completion (RP) cost. Where:

$$MC = \sum_{m=1}^{M}\sum_{t=0}^{H}(mc_m\chi_{mt} + SC_m\theta_{mt}) \tag{1}$$

$$OC = \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{t=0}^{H} oc_m\,\varphi_{mit} \tag{2}$$

$$AC = \sum_{i=1}^{I}\sum_{j=1}^{n_i} \alpha_{ij} - \beta_{ji}(\lambda_{ji} - v_{ij}) \tag{3}$$

$$TC = \sum_{m=1}^{M}\sum_{t=0}^{H} vol_m * \left(\frac{tc^{mw}}{cap^{tmw}} * \varepsilon_{mt}^{mw} + \frac{1}{cap^{tmc}}\sum_{i=1}^{I} tc_i^{wc}\,\varepsilon_{mit}^{wc}\right) \tag{4}$$

$$IC = \sum_{m=1}^{M}\sum_{t=0}^{H}\left(h^m I_{mt}^{m} + h^w I_{mt}^{w} + \sum_{i=1}^{I} h_i^c * I_{mit}^{c}\right) \tag{5}$$

$$RP = \sum_{i=1}^{I}\sum_{t=d_i+1}^{H} p_i\,(t - d_i + 1)\varpi_{in_it} - \sum_{t=0}^{d_i+1} r_i(d_i + 1 - t)\varpi_{in_it} \tag{6}$$

The constraints of the model are as follows.

Constraints related to projects

$$\sum_{t=0}^{H} t\zeta_{ikt} + \lambda_{ik} \le \sum_{t=0}^{H} t\zeta_{ijt}\ \forall i = 1,\dots,I;\ j = 1,\dots,n_i;\ k \in P_{ij} \tag{7}$$

$$\varpi_{i10} = 1, \quad \forall i = 1,\dots,I \tag{8}$$

$$\lambda_{in_i} = 0 \quad \forall\, i = 1,\dots,I \tag{9}$$

$$\sum_{t=1}^{H} \zeta_{ijt} = 1 \quad \forall\, i = 1,\dots,I, j = 2,\dots,n_i \tag{10}$$

$$\sum_{t=0}^{H} \varpi_{jt} = 1 \quad \forall i = 1,\dots,I;\ j = 2,\dots,n_i \tag{11}$$

$$\sum_{t=0}^{H} t\zeta_{ijt} + \zeta_{ij} = \sum_{t=0}^{H} t\zeta_{ijt} \quad \forall\, i = 1,\dots,I;\ j = 2,\dots,n_i \tag{12}$$

$$\mu_{ij} \le \lambda_{ij} \le v_{ij} \quad \forall\, i = 1,\dots,I;\ = 1,\dots,n_i \tag{13}$$

$$\varepsilon_{mit}^{wc} \le L\varphi_{mit} \quad \forall m = 1,\dots,M; i = 1,\dots,I;\ t = 1,\dots,H \tag{14}$$

Constraint (7) ensures the precedence relations between the activities. Constraints (8) & (9) show that the first and last activities in all projects are dummies. Constraints (10) and (11) guarantee that each activity can only have one start and finish time. Besides, it forces the construction project to finish during the time horizon H. The duration of each activity is calculated by equations (12) and (13). Constraint (14) is a logic constraint and ensures that if a material is shipped to the construction site, there is an order placed in that period.

Constraints related to inventory balance

$$I_{m0}^{w} = I_{mi0}^{c} = 0 \qquad \forall m = 1,\dots,M;\ i = 1,\dots,I \tag{15}$$

$$I_{m0}^{m} = M_m \qquad \forall\, m = 1,\dots.M \tag{16}$$

$$I_{mt}^{m} = I_{m(t-1)}^{m} + \chi_{mt} - \varepsilon_{mt}^{mw}\ \forall m = 1,\dots,M, t = 1,\dots,H-1 \tag{17}$$

$$I_{mt}^{w} = I_{m(t-1)}^{w} + \varepsilon_{mt}^{mw} - \sum_{t=1}^{H}\varepsilon_{mit}^{wc} \qquad \forall m = 1,\dots.M;\ t = 1,\dots,H-1 \tag{18}$$

$$I_{mit}^{c} = I_{mi(t-1)}^{c} + \varepsilon_{mit}^{wc} - \sum_{j=1}^{ni}\delta_{mij}\zeta_{ijt} \qquad \forall m = 1,\dots,M;\ i = 1,\dots,I;\ t = 1,\dots,H-1 \tag{19}$$

Constraints (15)-(19) balance the inventory in each period, considering that there is an initial inventory at the manufacturer. Equation (19) is written, assuming that the required materials for each activity must be available before activities start.

Constraints related to capacity

$$I_{mt}^{m}\,vol_m \le cap^m \qquad \forall m = 1,\dots,M;\ t = 0,\dots,H-1 \tag{20}$$

$$I_{mt}^{w}\,vol_m \le cap^w \qquad \forall\, m = 1,\dots,M;\ t = 0,\dots,H-1 \tag{21}$$

$$I_{mit}^{c}\,vol_m \le cap_i^c \quad \forall m = 1,\dots.M, i = 1,\dots\dots,I, t = 0,\dots,H-1 \tag{22}$$

$$\chi_{mt} \le mr_m \qquad \forall\, m = 1,\dots,M;\ t = 0,\dots,H-1 \tag{23}$$

$$\chi_{mt} \le L\theta_{mt} \qquad \forall m = 1,\dots,M,\quad t = 0,\dots,H-1 \tag{24}$$

$$\sum_{m=1}^{M}\theta_{mt} \le 1 \qquad \forall t = 0,\dots.,H \tag{25}$$

Constraints (20)-(22) ensure that the inventory level in each period does not exceed the capacity. Constraint (23) states that the manufacturing quantity is within a pre-defined range during the period. Constraint (24) is a logic constraint and forces the decision variable θ_{mt} to be equal to 1 if $\chi_{mt} > 0$. Constraint (25) ensures that we can produce only one material per period.

3. NUMERICAL EXAMPLE

3.1 Data

In order to illustrate the benefits of the proposed approach, a numerical experiment is carried out for two types of modular materials (M=2) and two construction projects (I=2). For this example, each construction project is composed of eight (8) activities where the first and the last activities are dummies and represent the project starts and completion, respectively. The precedence relationships between all the activities are finish-to-start. Table 1 shows the number of modular products required for each construction site per activity. Moreover, we suppose that the two construction sites have similar demands.

Table 1. The demand of materials for activities

δ_{mij}	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8
m=1	0	2	1	2	2	2	1	0
m=2	0	2	2	2	1	1	1	0

The planning horizon is fixed to 20 periods (months), and the project due dates are equal to their critical path. We assume that the inventory cost in the construction site is higher than the inventory cost in the warehouse and the manufacturer. The initial inventory in the manufacturing site must satisfy the demand for the first activities. The warehouse has a relatively non-limited capacity. Moreover, the capacity of the construction site is very limited. Finally, more details about the preceding projects activities, project-related parameters (normal time, crash time, due date, the normal and crashing costs), materials, inventory, and transportation-related parameters can be found online in this link[1].

3.2 Computational results

The proposed model was implemented using the IBM ILOG CPLEX Optimization Studio (version 12.7). The mathematical relationships were captured using the OPL mathematical modeling language. The case problem was solved with satisfactory solutions within 1 min on average. Two scenarios are explored. Scenario 1 is the original case situation where the two projects managed individually (without collaboration). Scenario 2 is when collaboration is permitted between the two projects (with collaboration). To compare the two scenarios, we have considered as a baseline the case where the reward/ penalty is null to analyze the impact of integration on the project completion time and how flexibility in the project's completion time will help the CSC efficiency. When we analyze the results related to activities scheduling, we can notice that for scenario 1 *(without collaboration)*, the two projects were completed within their respective due date, which is period 19 for the first project and period 16 for the second project (see Fig. 2).

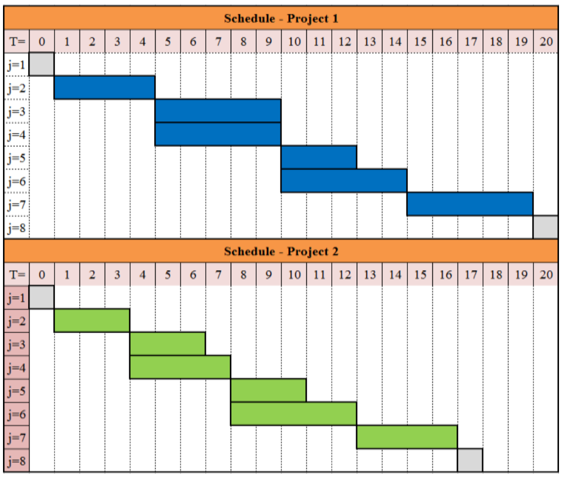

Fig. 2. Gantt chart for project activities in scenario 1

For scenario 2 (Fig. 3), when we consider an integrated CSC, the first project is completed in time (period 19) without any delay. However, the second project was delayed by two periods to finish in period 18. In this case, the contractor accepts delaying project two by two periods for the benefits that will ensure a more efficient CSC with a minimal cost.

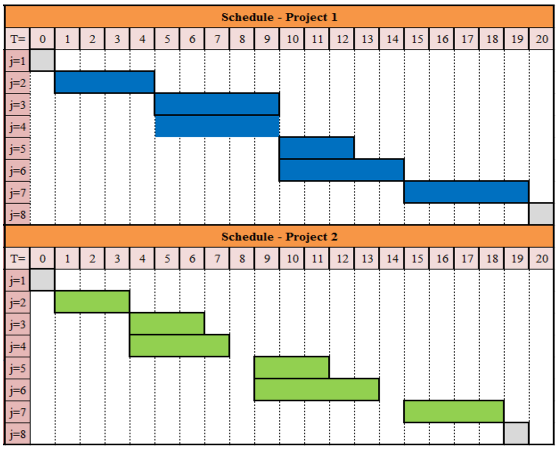

Fig.3. Gantt chart for projects activities in scenario 2

3.3 Benefits of the CSC with collaboration

The results for both scenarios are collected and compared with more details to understand the benefits of CSC collaboration. The logistics coordination and collaboration of the different projects in this specific case can bring a total of 3.07% savings. The high-cost reductions are observed in the setup-cost (2.61%) and inventory holding cost (0.47%).

Table 2. CSC costs comparison

	Scenario 2			Scenario 1			Scenario 2 versus	
	Project 1	Project 2	Projects (1+2)	Project 1	Project 2	Projects (1+2)	Cost saving ($)	Cost saving (%)
Manufacturing cost	6100	6100	12200	6100	6100	12200	0	0.00%
Setup cost	195	195	390	390	390	780	390	**2.61%**
Ordering cost	360	360	720	360	360	720	0	0.00%
Activities cost	385	325	710	385	325	710	0	0.00%
Transportation cost	145	145	290	145	145	290	0	0.00%
Inventory holding cost	100	90	190	130	130	260	70	**0.47%**
Reward	0	0	0	0	0	0	0	0.00%
Penalty paid	0	0	0	0	0	0	0	0.00%
Total Cost	7285	7215	14500	7510	7450	14960	460	**3.07%**

One of the main results provided by the optimization model for both projects is demand planning. Indeed, when collaboration is active, the final schedule for each project helps the planner in the determination of the demand plan based on the starting date of each activity and the materials needed. Having the required material quantity per activity for each construction site, the schedule of the two projects, and the activities duration, we can generate the demand plan for the construction sites (Fig. 4).

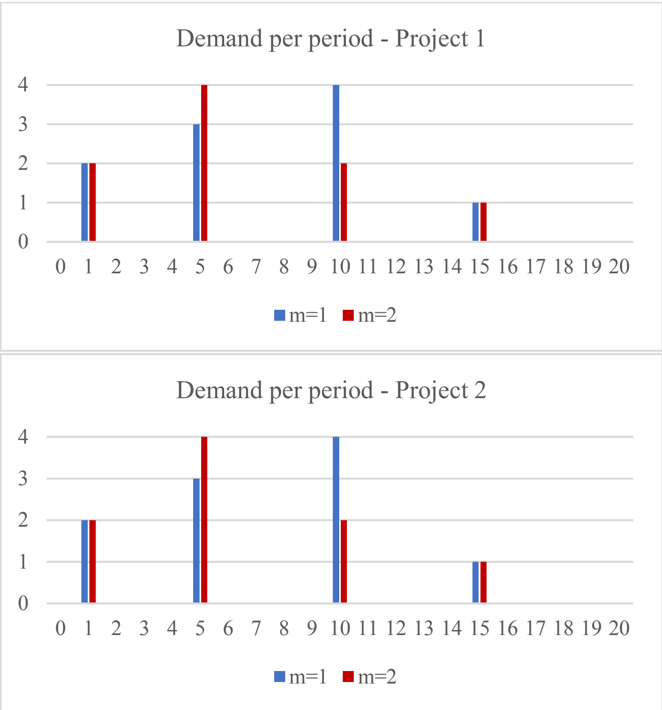

Fig. 4. Materials planning per period – Scenario 2

The manufacturing plan for materials required for both scenarios (with and without collaboration) are illustrated in Fig. 5. For instance, we can notice that when collaboration is active (scenario 2), the manufacturer produces the required quantities of material 1 (m=1) during five different periods. Nevertheless, the manufacturer uses nine different periods to produce material 1 in scenario 1.

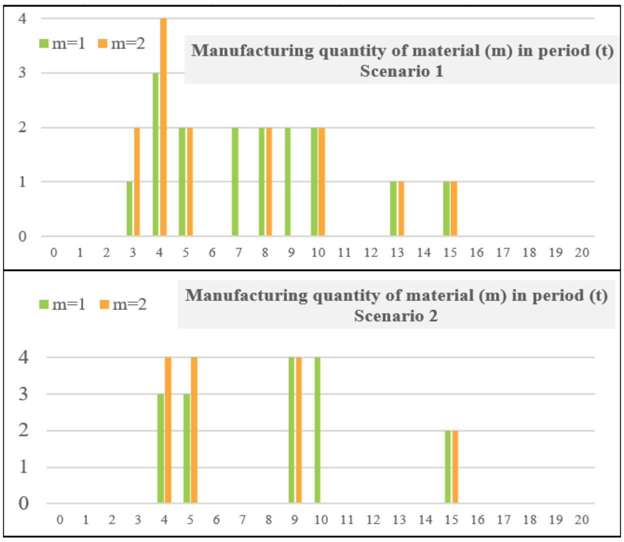

Fig. 5. Manufacturing plans for scenarios 1 and 2

Similar behavior is also observed for material 2. Therefore, when collaboration is active, the manufacturer succeeds in using the production capacity efficiently, and we observe a reduced setup cost and total cost for the whole SC members. In this case, since project two is delayed, the manufacturer can offer material price discounts for the contractor of project two as an incentive to accept the proposed delivery plan.

Fig. 6 shows the inventory levels of the different materials at the warehouse for both scenarios. When there is no collaboration and information sharing between the two projects, the inventory cost is higher due to the lack of coordination for materials management. Therefore, the lack of synchronization in demand planning and project sequencing generates higher inventory in the warehouse and increase the total CSC. The integrated master plan reduced the material inventory in the warehouse and construction sites, which helps to reduce site congestion and achieve a lower cost for the entire CSC.

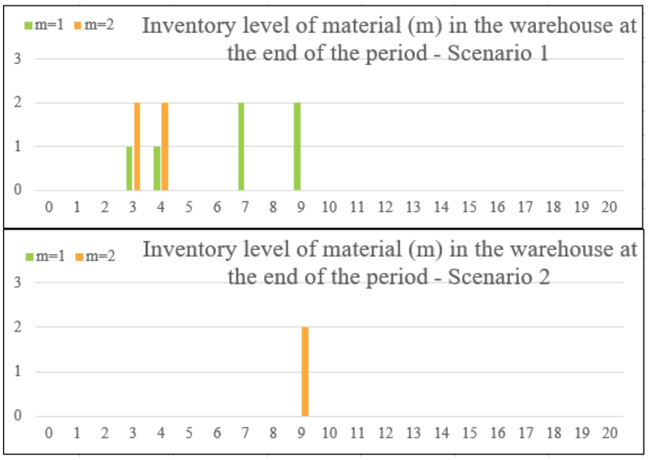

Fig. 6. Inventory in the warehouse for scenarios 1 and 2

4. MANAGERIAL INSIGHTS

4.1 Sensitivity analysis related to Penalty

We also analyze the results when the penalty paid in case of project delay is increasing, and we notice that project two is still delayed by two periods in the case of a penalty that reaches $10. When the penalty reaches $20, project two is delayed by only one period. Finally, the project finishes on time without delay when the penalty is higher than $30. Project 1 is not delayed. A detailed analysis of the different costs shows particularly that the total cost remains under control and demonstrates the advantage of collaboration.

Table 3. CSC cost comparison under penalty variation

Penalty ($)	Total Cost ($) Scenario 2	Total Cost ($) Scenario 1	Cost-saving (%)
0	14 500	14 960	3,07%
10	14 520	14 960	2,94%
20	14 535	14 960	2,84%
30	14 540	14 960	2,81%
40	14 540	14 960	2,81%
300	14 540	14 960	2,81%
800	14 540	14 960	2,81%

The primary cost reduction for high penalty values (more than 30 $) is obtained from a better optimization of inventory, as shown in Fig. 7

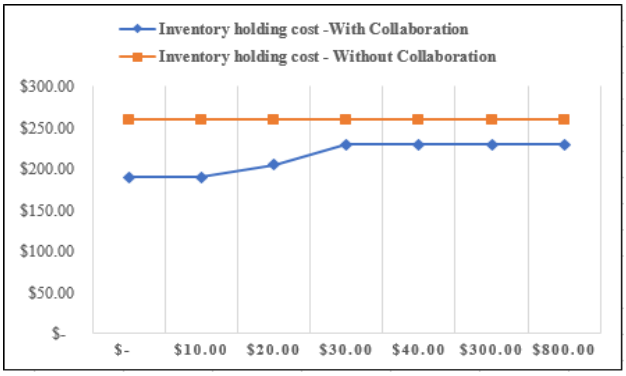

Fig. 7. Inventory costs with penalty variation

B-Impact of Changing the Inventory Holding Cost

To show the impact of changing the inventory holding cost at the different levels of the CSC, we have considered two cases. For the first case, we assume that the inventory holding cost at the manufacturer, in the warehouse, and construction sites are the same. This case reflects the situation where projects are located in rural areas where the space for inventory is not very limited. For the second case, we assume that the manufacturer and the warehouse inventory holding costs are kept the same as in scenario 1, whereas we increase the inventory holding cost at the construction site. This situation reflects more the case where construction projects are in urban areas. When we compare the plans and results obtained for the first and second case, we can notice that while increasing the inventory holding cost at the construction site (other parameters remaining the same), the model with collaboration reduced inventory level at the construction sites, which helps to reduce site congestion, and generated a lower total inventory cost for the entire CSC.

5. CONCLUSIONS

In this paper, we propose a new model for collaborative SC planning and scheduling of independent construction projects. A MILP model is developed considering one manufacturer, one warehouse, and multi-construction sites. Numerical examples are used to demonstrate the value of collaboration in the construction sector using SCM principles. The CSC participants can use the decision model as a tool for better coordination of activities sequencing and materials management, which contributes to cost reduction for all SC members.

This research can be extended in different ways. First, numerical examples with more activities and projects should be subject to future work. Indeed, it is not difficult to see that the problem is NP-hard, and it is important to test some heuristics solution approaches for solving large instances. Second, the current model could be extended to include renewable resources and other objectives to evaluate CSC performance. Finally, we can extend this study for stochastic CSC in which the objective function is to minimize the expected total cost. Indeed, different parameters, such as demand, activities durations, and capacities, could be subject to uncertainty.

6. REFERENCES

AZAMBUJA, M. & O'BRIEN, W. J. 2008. Supply Chain Modeling: Issues and Perspectives. *Construction supply chain management handbook*.

CHEN, W., LEI, L., WANG, Z., TENG, M. & LIU, J. 2018. Coordinating supplier selection and project scheduling in resource-constrained construction supply chains. *International Journal of Production Research,* 56**,** 6512-6526.

DALLASEGA, P., RAUCH, E. & LINDER, C. 2018. Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry,* 99**,** 205-225.

FU, F. 2014. Integrated scheduling and batch ordering for construction project. *Applied Mathematical Modelling,* 38**,** 784-797.

GOLKHOO, F. & MOSELHI, O. 2019. Optimized Material Management in Construction using Multi-Layer Perceptron. *Canadian Journal of Civil Engineering*.

GOLPÎRA, H. 2020. Optimal integration of the facility location problem into the multi-project multi-supplier multi-resource Construction Supply Chain network design under the vendor managed inventory strategy. *Expert Systems with Applications,* 139**,** 112841.

HAMDAN, S. B., BARKOKEBAS, B., MANRIQUE, J. D. & AL-HUSSEIN, M. A BIM-based simulation model for inventory management in panelized construction. ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, 2015. IAARC Publications, 1.

HORMAN, M. J. & THOMAS, H. R. 2005. Role of inventory buffers in construction labor performance. *Journal of Construction Engineering and Management,* 131**,** 834-843.

HSU, P.-Y., AURISICCHIO, M. & ANGELOUDIS, P. Establishing Outsourcing and Supply Chain Plans for Prefabricated Construction Projects Under Uncertain Productivity. *In:* BEKTAŞ, T., CONIGLIO, S., MARTINEZ-SYKORA, A. & VOß, S., eds. Computational Logistics, 2017 Cham. Springer International Publishing, 529-543.

KO, C. H. 2010. An integrated framework for reducing precast fabrication inventory. *Journal of Civil Engineering and Management,* 16**,** 418-427.

LE, P. L., ELMUGHRABI, W., DAO, T. M. & CHABAANE, A. Decision-making in construction logistics and supply chain management: Evolution and future directions. ILS 2018 - Information Systems, Logistics and Supply Chain, Proceedings, 2018. 646-655.

SAID, H. & EL-RAYES, K. Optimal material logistics planning in congested construction sites. Proceedings, Annual Conference - Canadian Society for Civil Engineering, 2011. 2505-2514.

SAJADIEH, M. S., SHADROKH, S. & HASSANZADEH, F. 2009. Concurrent project scheduling and material planning: A genetic algorithm approach. *Scientia Iranica. Transaction E, Industrial Engineering,* 16**,** 91.

TABRIZI, B. H. & GHADERI, S. F. 2016. A robust bi-objective model for concurrent planning of project scheduling and material procurement. *Computers & Industrial Engineering,* 98**,** 11-29.

VAIDYANATHAN, K. & HOWELL, G. Construction supply chain maturity model–conceptual framework. Proceedings IGLC, 2007. 170-180.