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Article

Joint finance-based scheduling in construction: Internal interest rate approach

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Abstract: Realistic project scheduling and control are critical for running a profitable enterprise in the construction industry. Finance-based scheduling aims to produce more realistic schedules by considering both resource and cash constraints. Since the introduction of finance-based scheduling, its literature has evolved from a single-objective model to a multi-objective model and also from a single-project problem to a multi-project problem for a contractor. This study investigates the possibility of cooperation among contractors with concurrent projects to minimize financial costs. Contractors often do not use their entire credit and may be required to pay a penalty for the unused portions. Therefore, contractors are willing to share these unused portions to decrease their financing costs and consequently improve their overall profits. This study focuses on the partnering of two contractors in a joint finance-based scheduling where contractors are allowed to lend credit to or borrow credit from each other at an internal interest rate. We apply this approach to an illustrative example in which two concurrent projects have the potential for partnering. Results show that joint finance-based scheduling reduces the financing cost for both contractors and leads to additional overall profits. Our further analyses highlight the intricate dynamics impacting additional net profit, revealing optimal scenarios for cooperation in complex project networks.

Keywords: finance-based scheduling; construction; partnering; joint resource management; project network

1. Introduction

In the past decades, productivity in construction has lagged the productivity in the overall economy (Barbosa et al., 2017) while construction costs and competition levels among construction companies have increased resulting in lower profit margins and a higher number of bankruptcy cases in the construction industry (Kangari, 1988). To overcome this challenge, there is an industry-wide tendency towards increasing productivity mainly through adopting new technologies and proven management methods (WEF, 2016). Partnering has been suggested as an effective way of reducing costs and improving productivity (Asgari et al., 2014). The Construction Industry Institute (CII, 1991) defines partnering as “a long-term commitment between two or more organizations to achieve specific business objectives by maximizing the effectiveness of each participant’s resources”. Partnering not only results in enhanced construction performance, higher quality, and owner satisfaction by aligning long-term interests but also leads to faster innovation adaptation and creates an atmosphere based on mutual respect and trust (Barlow, 2000; DeVilbiss and Leonard, 2000).

Construction projects usually offer many partnering opportunities. Partnering within a project may form among companies at the same level, horizontal cooperation, or at different levels of the construction supply chain, vertical cooperation (Asgari et al., 2014). Partnering may also form among companies that are working on different projects but they can overcome the obstacles to their cooperation such as distance (geographically depressed). Resource pooling or joint resource management is one of the partnering practices (Asgari et al., 2014). In resource pooling, cooperating companies agree to put their resources in a joint pool and allocate the collected resources based on the most cost-effective plan (Asgari et al., 2014). Previous studies, despite their contribution to the literature, focused only on pooling the physical and human resources and failed to consider sharing financial resources. Moreover, the finance-based scheduling literature only focuses on optimizing a sole contractor's objectives under its financial constraints. Our paper aims to address this gap in the literature. Specifically, we focus on the cooperation between two contractors whose independent projects run in parallel to one another. In this case, there is a potential opportunity for contractors' cooperation to minimize the overall financial costs and then share the resulting savings. The opportunity exists because a finance-based schedule developed for a single contractor minimizes the maximum required credit limit (overdraft) which only occurs at limited times during the project. When many banks demand a penalty for the unused portions of the credit line, contractors may consider sharing the unused portions of their line of credit to reduce the possible penalty imposed by lenders and consequently improve their overall profits. Furthermore, cooperation between two contractors in finance-based scheduling decreases the required credit limit needed for their projects, making securing the line of credit more attainable with more favorable terms. The idea of cooperation among contractors for financing their projects is novel in the construction industry; however, joint liability loans and lines of credit are common practices in finance. Looking at the finance literature, there are several advantages to obtaining a joint liability line of credit. First, a joint liability loan enables borrowers with low credit scores or insufficient credit history, which are conditions applicable to many construction contractors, to obtain a loan as these borrowers are enabled to provide a joint collateral or loan guarantee that is sufficient for the lender. Second, borrowers who share the joint liability loans have the incentive to screen and monitor each other to assure loan repayment. This will result in lower transaction costs for financial institutions and consequently lower the borrowing cost for the borrowers.

The paper is organized as follows: the "background" section reviews the key concepts of construction finance-based scheduling, partnering in construction, and joint liability loans in finance. The "methodology" section presents a joint finance-based scheduling model. We apply the developed model to an illustrative example and present the results. Finally, we conclude with a discussion of the study applications and limitations and provide suggestions for future studies.

2. Background

2.1. Literature review of finance-based scheduling

Money is the most important resource in construction projects (Hwee and Tiong, 2001). Unlike other consumable resources such as manpower, machines, and materials, money (or cash) is a reversible resource that can be transformed by construction operations into different work items that will generate cash. Moreover, yielded cash can be used as a resource for the remainder of the project. Traditional techniques used to manage other resources fail to consider this distinctive feature of money. Therefore, the resulting schedule may not simulate reality since it does not incorporate financial constraints and cash availability. This issue becomes more pressing as over 60% of failures in construction contracts are due to financial issues (Kangari, 1988; Russel, 1991). Finance-based scheduling, initially introduced by Elazouni and Ghab-Allah (2004) in 2004, aims to integrate financial considerations and constraints including financing methods into the traditional scheduling and planning of construction projects. Developing critical path method (CPM) schedules that are constrained by a specified credit limit involves extending rather than compressing initial schedules. Therefore, Elazouni and Ghab-Allah (2004) devised an extension increment for the project duration, then they used integer programming to minimize the project extension when cash availability is a constraint in each period of the project.

The literature on finance-based scheduling can be divided into single-objective, multi-objective, and multi-project scheduling models as shown in **Table 1**. To solve these models, researchers have employed a variety of optimization techniques including linear programming, integer programming, constraint programming, mixed integer nonlinear programming, genetic algorithm, and simulated annealing. They have also considered different objectives to optimize, e.g., financing cost, profit, net present value, and project duration.

Single-objective scheduling models assume a predetermined credit limit and then modify the initial schedule of the project accordingly. However, the optimal required credit considering all constraints and the current situation of the contractor and the bank may be different. To overcome this shortcoming, researchers extended finance-based scheduling to a multi-objective optimization problem. Finance-based scheduling can also be applied to the case of a contractor with several concurrent projects of different sizes. The problem can be formulated again as a multi-objective optimization problem in which the objective function (e.g., profit) of each individual project constitutes a set of multiple conflicting objectives. The resulting Pareto-optimal solutions allow the decision-makers to select the best solution based on their preference. For example, projects of regular clients have a high potential to substantially increase corporate profit in the long term (focal business goal). Therefore, decision-makers are inclined to select the pareto-optimal solution that maximizes the profit of this particular project rather than the solution that maximizes the profit of the entire project portfolio during the limited planning period. It is worth mentioning that in the case of multiple concurrent projects, the calculation of financing cost should be modified to cover all possible conditions of a contractor's overdraft account. **Table 1** summarizes the literature based on the type of problem and optimization techniques used.

2.2. Literature review of partnering in construction

Different forms of partnering have been investigated in the construction management literature. Rahman (2004) suggested that partnering and alliancing through rational contracting can develop a project culture aiming at joint management of risks during the project life cycle. Using a cooperative game theoretic approach, Perng et al. (2005) showed that improving profitability and optimizing the cost could be earned by joining and collaborating with several independent formwork subcontractors.

Table 1. Summary of the finance-based scheduling literature.

Category	Research: Method
Single-objective	Elazouni and Gab-Allah (2004): Integer programming Elazouni and Metwally (2005): Genetic algorithm Liu and Wang (2008): Constraint programming Abido and Elazouni (2009): Genetic algorithm Alghazi, Selim, and Elazouni (2012): Shuffled frog-leaping algorithm Alghazi, Elazouni, and Selim (2013): Genetic algorithm Elazouni et al. (2015): Comparison of genetic algorithm, simulated annealing, and shuffled frog-leaping algorithm Al-Shihabi and AlDurgam (2017): Ant colony optimization algorithm
Multi-objective	Elazouni and Metwally (2007): Genetic algorithm Liu and Wang (2009): Constraint programming Afshar and Fathi (2009): Non-dominated sorting genetic algorithm and Fuzzy-sets theory Fathi and Afshar (2010): Genetic algorithm Jiang et al. (2011): Pareto optimality efficiency network Elazouni and Abido (2013): Genetic algorithm Elazouni and Abido (2014): Strength Pareto evolutionary algorithm Gajpal and Elazouni (2015): Heuristic Abido and Elazouni (2021): Evolutionary programming algorithm Liu et al. (2021): Heuristics-based GA Liu et al. (2023): Integer programming for small networks and non-dominated sorting genetic algorithm for large networks
Multi-project	Elazouni (2010): Heuristic method Liu and Wang (2010): Constraint programming Abido and Elazouni (2011): Strength Pareto evolutionary algorithm Elazouni and Abido (2011): Strength Pareto evolutionary algorithm El-Abbasy et al. (2016, 2017, 2020): Non-dominated sorting genetic algorithm

By gathering and analyzing empirical measurements, Eriksson (2007) used a game theory approach and suggested that clients and contractors should establish long-term strategic partnering instead of focusing on single projects to increase incentives for cooperation. Homberger (2007) studied the project resource-sharing problem by allocating resources through negotiation among different project-planning agents. Confessore et al. (2007) considered a decentralized multi-project scheduling problem in terms of limited shared resources availability and proposed a multi-agent system model to complete all the project activities, satisfying resource constraints, and minimizing each project schedule length. Laan et al. (2011) provided insights into how a project alliance contract becomes conducive to the development of cooperative relationships between client and contractor organizations in the conditions of the internal and external risks to their relationship. Homberger (2012) described a coordination mechanism based on mediated negotiation for an agreement between project planning agents regarding the use of shared resources, taking asymmetric information, and opportunistic behavior into account. Xu et al. (2013) established a multi-objective multistage model under a fuzzy environment for the concept of resource sharing problem including two aspects of space and time-sharing for the allocation of construction equipment. Asgari et al. (2014) used a resource-leveling model to create subcontractors' payoff functions and then compared various cooperative game theoretic methods to allocate cooperative gains in joint resource management as a case of short-term partnering among subcontractors. Liu et al. (2018) focused on analyzing onsite construction equipment sharing among contractors by applying Stackelberg's game with incentive contracting to build the contractors' gain functions and simulated the equipment sharing process. Javanmardi et al. (2018) quantified the benefit of cooperation among subcontractors by integrating a simulation model with a cost model and then utilized different benefit-allocation models including cooperative game theory to allocate the costs and benefits of high-reliable planning among subcontractors.

2.3. Literature review of joint liability loans

Joint liability loans and their impact on both borrowers and lenders have been the subject of many studies. Classical economists such as Stiglitz (1990), Varian (1990), Banerjee et al. (1994), Besley and Coate (1995), and Ghatak (1999), have explored joint liability loans in the context of information asymmetry and contract theory in that joint liability loans reduce the risk for lenders and result in better repayment. These studies focused on joint liability loans from a theoretical standpoint. More recently, researchers have moved their focus on empirical evidence and the effectiveness of joint liability loans; Ahlin and Townsend (2007), Karlan (2007) and Cassar et al. (2007).

The effectiveness of joint liability loans is partly measured by repayment success rate which can be determined by a variety of factors. These factors can be present prior to the borrowing by selecting reliable co-borrowers and during the life of the loan by monitoring and if necessary, pressuring the co-borrower(s). Varian (1990) attributes the success of the loan to peer selection. Ghatak (1999, 2000) shows that a joint liability loan encourages co-borrowers to select peers with similar levels of risk. This homogeneous peer selection results in risk reduction which rewards the co-borrowers with a discount on the cost of borrowing (Ahlin, 2020). Credit literature has shown that lenders use credit scores and similar metrics to measure borrowers' risk levels with higher risk borrowers increasingly paying higher interest rates (Edelberg, 2006). This practice is common for consumers (Edelberg, 2006) and corporations (Liu et al., 2009). For example, low-risk consumers receive better mortgage rates and low risk corporations maintain lower bond yields (Liu et al., 2009). In other words, the interest rates intrinsically imply the risk level of the borrowers. Moreover, co-borrowers are more likely to select peers with similar types of risk that exist among peers active in the same industry (Ahlin, 2020).

Armendariz de Aghion (1999) attributes this success to the effectiveness of monitoring among a group of borrowers. Besley and Coate (1995) cite pressure from other borrowing group members to improve repayment performance. Floro and Yotopoulos (1991) show that the existence of social ties among borrowers would improve repayment performance. Moreover, on the empirical side, some scholars have found evidence of the effectiveness of joint liability loans (Ahlin and

Townsend, 2007).

Joint liability loans might impose some cost on co-borrowers during the peer selection and peer monitoring phase (Besley and Coate, 1995). However, this cost can be less significant if co-borrowers are in close proximity. Moreover, joint liability loans may only succeed if co-borrowers are willing to pressure the member(s) who fail to meet their obligations (Kevane, 1996). Ahlin (2015) shows that joint liability loans are as effective as screening borrowers in terms of risk management. Hence, by aggregating borrowers, lenders can reduce the screening cost while achieving a similar level of risk.

3. Modeling

In this section, we introduce finance-based scheduling models for a single contractor form and a cooperative form between two contractors. First, we explain the development of a model for each individual contractor c where $c \in \{1,2\}$. Later, we expand the single contractor model to a joint one. We assume a critical path method (CPM) scheduling of activities has been established for each subcontractor's network.

3.1. Model formulation in a single form

3.1.1. Cash flows for a project

We assume a working day to be the time unit of activity p duration denoted by i. The total cost of an activity is composed of direct and indirect costs (Fathi and Afshar, 2010; Peterson, 2013). The direct costs incurred by an activity (DC) are the total sum of costs incurred by a contractor to pay for materials, labor, equipment, and subcontractors (Peterson, 2013). The indirect costs are made up of the sum of fixed overhead, variable overhead, and mobilization and bonding costs (Peterson, 2013). Fixed overhead (FO) tends to be constant over the duration of a project (Peterson, 2013). Variable overhead (VO) tends to vary depending on the amount of work performed in a given period. We can estimate VO costs by multiplying the DC of an activity by a percentage VO_p calculated based on the contractor's historical record (Peterson, 2013; Afshar and Fathi, 2009; Fathi and Afshar, 2010):

$$VO_i = DC_i VO_p \tag{1}$$

The mobilization cost (MC) can be calculated as a percentage (MC_p) of the total direct costs and variable overhead costs (Elazouni and Metwally, 2005, 2007):

$$MC = MC_p \sum_{i=1}^{T} (DC_i + VO_i) \tag{2}$$

where T is the final period.

In the case where the project's activity lengths are fixed and continuous and associated costs are known, the mobilization costs can be modeled as a one-time upfront payment to the project's total costs. The markup (MP) cost for all the work done in a period can be calculated by summing all the above costs and multiplying them with a markup multiplier, MP_p:

$$MP = MP_p(\sum_{i=1}^{T}(DC_i + VO_i + FO_i) + MC) \tag{3}$$

3.1.2. The financing flow for a project

We assume a working period t to be comprised of m working days. All following financial terms presented in this section conform to the terminology used by Au and Hendrickson (1986). We denote all cash outflows for a single activity by y_{pi}. The total cash flow at time i can be calculated as:

$$y_i = \sum_{p=1}^{n} DC_{pi}x_{pi}, i = 1,2, \dots, T \tag{4}$$

where n is the total number of activities in the contractor's schedule and x_{pi} is a binary variable equal to one when activity p is active at period i, zero otherwise.

Typically, disbursements are accrued until the end of a working period, denoted by E_t, after which a payment request P_t is submitted to the owner:

$$E_t = \sum_{i=1}^{m} y_i + O_t \tag{5}$$

where O_t is the sum of all indirect costs accrued in this period

$$P_t = KE_t \tag{6}$$

where K is the agreed-upon retainage percentage.

The cumulative cash flow at the end of period t is:

$$F_t = N_{t-1} + E_t \tag{7}$$

where N denotes the net cash flow and can be calculated as:

$$N_{t-1} = F_{t-1} + P_{t-1} \tag{8}$$

The total interest charges due at the end of period t is:

$$I_t = rN_{t-1} + r\frac{E_t}{2} + r'(W - \hat{F}_{t-1}) \tag{9}$$

where r is the interest rate per period, r' is the interest rate on unused credit portions, and W is the credit limit of the contractor.

The first term of I_t represents the interest per period due to accumulated deficits, the second term approximates the period's interest on the total disbursements, and the third term represents the interest due to unused portions of the available credit. The cumulative cash flow with the added interest charges is denoted as:

$$\hat{F}_t = F_t + \hat{I}_t \tag{10}$$

where:

$$\hat{I}_t = \sum_{l=1}^{t} I_l(1 + r)^{t-l} \tag{11}$$

$\hat{I}_t$ are the accumulated financing costs until the end of period t. The net cash flow including accumulated interest charges is denoted as:

$$\hat{N}_t = \hat{F}_t + P_t \tag{12}$$

3.1.3. Objective function

The objective of the proposed model is to maximize the profit generated at the end of the project. This is achieved by minimizing the cumulative cash flow including the interest charges $\hat{F}_t$. Thus, the objective function can be written as:

$$Minimize\ Z = \hat{F}_T \tag{13}$$

where the decision variables are x_{pi}.

3.1.4. Activity duration constraint

We ensure that for each non-critical activity, the total number of active time units is equal to the activity duration:

$$\sum_{i=ES_p}^{LF_p} x_{pi} = T_p \tag{14}$$

where ES_p and LF_p are the early start and late finish times of activity p respectively, and T_p is the total duration of activity p.

3.1.5. Network logic constraint

The precedence relationships among non-critical activities are ensured by the following constraints (Hariga and El-Sayegh, 2011). We determine the start and finish time of an activity by the following:

$$S_p = (T_p + 1) - \max\{(T_p + 1 - i)x_{pi}: i = ES_p, ES_p + TF_p\} \tag{15}$$

where S_p is the start time and TF_p is the total float time of activity p.

$$F_p = max\{ix_{pi}: i = LF_p - TF_p, LF_p\} \tag{16}$$

where F_p is the finish time of activity p.

If the optimization software used for solving the problem does not support the use of the $max()$ function, Equations (15) and (16) can be substituted by the following equation respectively:

$$S_p + (T_p + 1 - i)x_{pi} \leq T_p + 1 \tag{17}$$

where $i = ES_p, ES_p + TF_p$.

$$F_p - ix_{pi} \geq 0 \tag{18}$$

where $i = LF_p - TF_p, LF_p$.

Subsequently, the precedence constraint between two activities p and k will be:

$$S_k \geq F_p + 1, \text{for all } k \in succ(p), p = 1,2, \dots, nn \tag{19}$$

where $succ(p)$ is the set of all non-critical activities immediately following p.

3.1.6. Activity continuity constraint

All activities need to be continuous for their duration. First, we detect the total number of splits occurring over the course of the activity (Hariga and El-Sayegh, 2011):

$$L_{pi} = max(x_{pi} - x_{p(i+1)}) \tag{20}$$

where L_{pi} is 1 when a split occurs in activity p after period i.

$$NL_p = \sum_{i=ES_p}^{LF_p} L_{pi} - 1 \tag{21}$$

where NL_p is the number of splits that occur in activity p over its duration.

To ensure continuity, we set the number of splits to 0 ($NL_p = 0$).

3.1.7. Credit limit constraint

At any time period, the contractor cannot exceed their available credit limit.

This is achieved by constraining the remaining credit limit to be non-negative.

$$W - \hat{F}_t \geq 0 \tag{22}$$

3.2. Model formulation in a joint form

3.2.1. Joint financial flow

In the case of cooperation between contractors, the proposed model needs to be solved for the overall project network, consisting of all participating contractors' subprojects. While all decisions are made by the coalition on a cooperative basis, each subcontractor will still be responsible for managing their own finances. Each subnetwork will still be subject to the same constraints, but we need to expand the financial terms to allow for borrowing and lending between contractors, at an internal interest rate r_{int}, which participants in the coalition agree upon. We first define a new variable z_{i*}^{c} which will be a continuous non-negative decision variable quantifying the loan amount from contractor c at period i^* where $i^* \in T(1 \cap 2)$ the period covered by overlapping contractor schedules. The internal interest earned by contractor c for loaning z_i^c at time i is:

$$I_{int_i}^{c} = r_{int} z_{i-1}^{c} \tag{23}$$

It follows that the internal amount paid by the second contractor c^* is:

$$P_{int_i}^{c^*} = I_{int_i}^{c} \tag{24}$$

The net amount of interest earned or paid by a contractor is:

$$NI_{int_i}^{c} = I_{int_i}^{c} - P_{int_i}^{c} \tag{25}$$

Because of the additional money flowing in a contractor's finances, we need to update Equations (11) and (12) respectively:

$$\hat{I}_t^{\,c} = \sum_{l=1}^{t} (I_l^c + NI_{int_l}^{c})(1+r)^{t-l} \tag{26}$$

$$\hat{N}_t^{\,c} = \hat{F}_t^{\,c} + P_t^c - z_i^c + z_i^{c^*} \tag{27}$$

3.2.2. Joint model objective function

For the joint form of our model, the objective function is:

$$Minimize\ Z = \hat{F}_{T_1}^{1} + \hat{F}_{T_2}^{2} \tag{28}$$

where our decision variables are z_i^c and x_{pi}^c

3.2.3. Joint model constraints

Our expanded model will be subject to the same constraints presented in the single form in Equations (14) through (22). We will add the following balance constraint, to ensure no outstanding balances remain at the end of the cooperation period between the participating contractors:

$$\sum_{i \in T(1\cap 2)} (z_i^c) - \sum_{i \in T(1\cap 2)} (z_i^{c^*}) = 0 \tag{29}$$

4. Illustrative examples

For a better illustration of our proposed model, we provide two illustrative examples. Consider two contractors with concurrent projects that are exploring the possibility of joint finance-based scheduling and the potential benefit of partnering.

Example 1: **Figure 1** shows the contractors' schedules in a Gantt chart style and **Table 2** provides the relationships between the activities and their associated daily cost rates. We assume that both contractors have a 20% markup, 10% retainage, 10% variable overhead cost, $5000 fixed overhead cost, and $100,000 credit limit.

Table 2. Example 1—Network information.

Activity	Duration (days)	ES	EF	LS	LF	TF (days)	Cost
Contractor 1							
A1	3	1	3	7	9	6	$2100
B1	6	1	6	1	6	0	$1550
C1	6	1	6	8	13	7	$1675
D1	2	5	6	11	12	6	$2250
E1	4	7	10	7	10	0	$825
F1	2	9	10	14	15	5	$950
G1	5	11	15	11	15	0	$1650
Contractor 2							
A2	5	4	8	4	8	0	$700
B2	5	9	13	9	13	0	$975
C2	5	4	8	9	13	5	$1225
D2	3	12	14	14	16	2	$1500
E2	2	15	16	18	19	3	$1800
F2	6	14	19	14	19	0	$1875

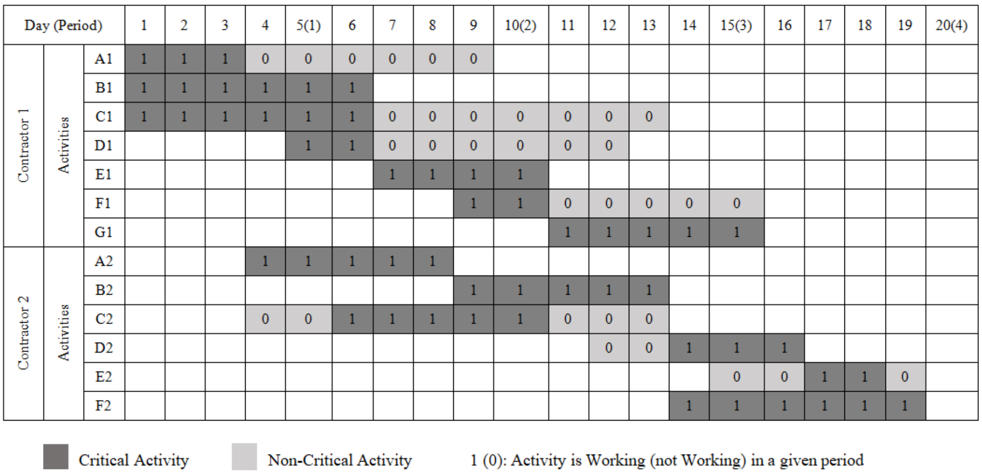

Figure 1. Example 1—Individual finance-based schedule of contractors 1 and 2 (prior to partnering).

First, we solve the finance-based scheduling problem for each contractor. As shown in **Figure 1**, all activities start at their early start (ES) which is understandable given the small size of the activity networks. Then, we solve the joint finance-based scheduling problem for the case of cooperation between the two contractors and present the optimized networks and the credit exchanged in **Figure 2**. There is a 12-day overlapping period between the two projects which allows the two contractors to exchange credit with one another. The results clearly show that contractor 1 is a pure loan giver and contractor 2 is a pure loan taker. In larger and more complex project networks and in the case of cooperation among more than two contractors, this may not be the case; cooperating contractors in joint finance-based scheduling may be a loan giver or taker at different times during the overlapping period.

Day (Period)		1	2	3	4	5(1)	6	7	8	9	10(2)	11	12	13	14	15(3)	16	17	18	19	20(4)
Contractor 1 (C1) Activities	A1	1	1	1	0	0	0	0	0	0											
	B1	1	1	1	1	1	1														
	C1	1	1	1	1	1	1	0	0	0	0	0	0	0							
	D1					1	1	0	0	0	0	0	0								
	E1							1	1	1	1										
	F1									1	1	0	0	0	0	0					
	G1											1	1	1	1	1					
Contractor 2 (C2) Activities	A2				1	1	1	1	1												
	B2									1	1	1	1	1							
	C2				1	1	1	1	1	0	0	0	0	0							
	D2												1	1	1	0	0				
	E2															1	1	0	0	0	
	F2														1	1	1	1	1	1	
C1 loans to C2					$47,597	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0					
C2 loans to C1					$0	$0	$16,930	$0	$12,860	$0	$0	$17,807	$0	$0	$0	$0					

Critical Activity   Non-Critical Activity   1 (0): Activity is Working (not Working) in a given period

$ Internal Loans Between Contractors

Figure 2. Example 1—Joint finance-based schedule of contractors 1 and 2 (after partnering).

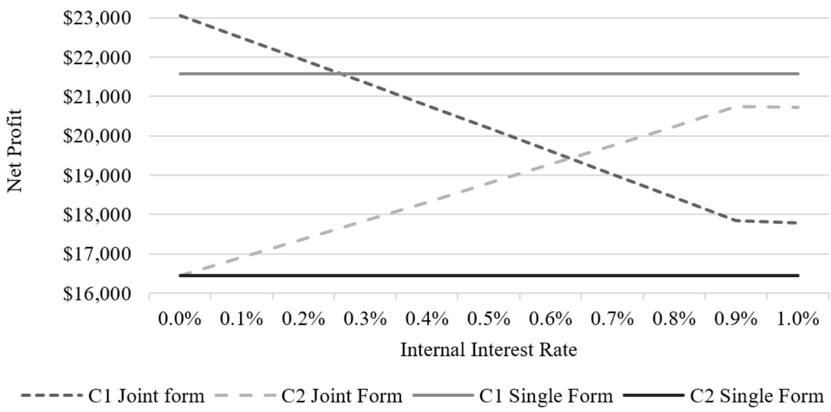

Figure 3. Model 1—Net profit of contractors in single and joint forms of finance-based scheduling under different Internal interest rates.

Figure 3 shows the net profit of contractors 1 and 2 in both joint finance-based scheduling under different internal interest rates (dashed lines) and single-form finance-based scheduling (solid lines). As the internal interest rate increases, the net profit of contractor 1 decreases and the net profit of contractor 2 increases.

Figure 4 shows that joint finance-based scheduling between contractors 1 and 2 results in additional net profit from cost savings in financing the project overdraft. The additional net profit decreases as the internal interest rate increases. At the internal interest rate of 1%, which is equal to the rate of interest both contractors get their loan from the banks, joint finance-based scheduling leads to the least amount of additional net profit because the loan-taking contractor gets no additional benefit from using the other contractor's unused credit. This shows that charging any internal interest rate is not beneficial to the cooperation if the goal is to divide the additional net profit between the two contractors fairly.

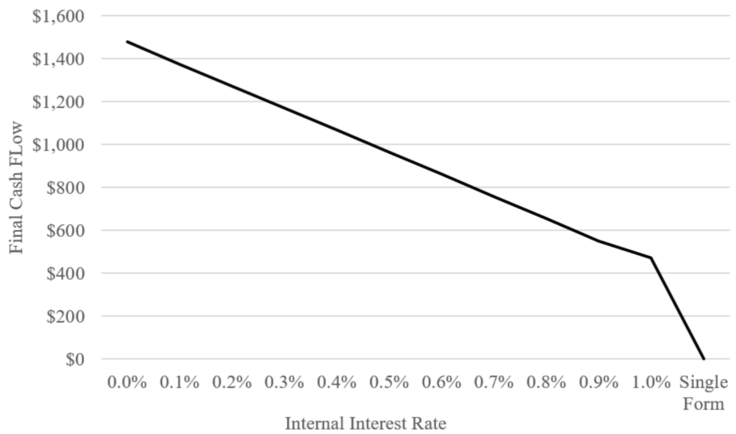

Figure 4. Model 1—Additional net profit from joint finance-based scheduling under different Internal interest rates.

We run a sensitivity analysis on penalty rates on the unused credit and credit limit for both contractors and present the additional net profit under each scenario in **Figures 5** and **6**. The results show that the largest net profit is created when the loan-giving contractor has the highest penalty rate and the loan-taking contractor has the lowest penalty rate. The cooperation is least beneficial when both contractors have the same penalty rate.

Contractor 1 Penalty Rate											
1.0%	680	609	540	470	402	334	266	199	132	66	0
0.9%	614	544	474	405	336	268	200	133	66	0	144
0.8%	548	478	408	339	270	202	134	67	0	145	289
0.7%	482	412	342	273	204	136	68	1	145	291	435
0.6%	415	345	275	206	137	69	1	146	292	437	582
0.5%	348	278	208	139	70	2	145	293	439	585	729
0.4%	281	210	141	72	3	145	293	441	587	733	877
0.3%	213	143	73	4	144	294	442	590	736	882	1026
0.2%	145	75	5	143	294	443	592	740	886	1031	1176
0.1%	76	6	142	293	444	594	743	890	1037	1182	1326
0.0%	7	140	293	445	595	745	893	1041	1187	1333	1477
	0.0%	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%

Contractor 2 Penalty Rate

Figure 5. Model 1—Additional net profit from joint finance-based scheduling under different penalty rates.

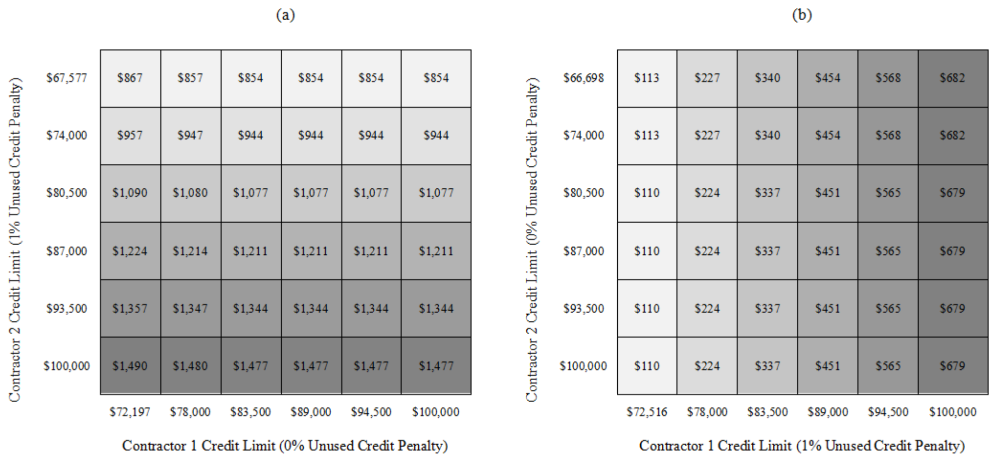

Figure 6. Model 1—Additional net profit from joint finance-based scheduling under different credit limits.

Table 3. Example 2—Network information.

Activity	Duration (days)	ES	EF	LS	LF	TF (days)	Cost
Contractor 1							
A1	5	1	5	1	5	0	$1100
B1	6	6	11	6	11	0	$1500
C1	4	12	15	12	15	0	$850
D1	3	1	3	4	6	3	$1500
E1	4	4	7	6	9	2	$800
F1	2	6	7	14	15	8	$1300
G1	2	9	10	11	12	2	$750
H1	3	10	12	13	15	3	$1800
Contractor 2							
A2	5	4	8	4	8	0	$1100
B2	7	9	15	9	15	0	$900
C2	4	16	19	16	19	0	$1300
D2	2	4	5	7	8	3	$1700
E2	3	7	9	10	12	3	$800
F2	4	9	12	12	15	3	$1400
G2	4	12	15	16	19	4	$1200

Example 2: **Figure 7** shows the contractors' schedules in a Gantt chart style and **Table 3** provides the relationships between the activities and their associated daily cost rates. We assume that both contractors have a 25% markup, 10% retainage, 10% variable overhead cost, $5000 fixed overhead cost, and $100,000 credit limit. Similar to the previous example, we solve the finance-based scheduling problem for each contractor and then the joint finance-based scheduling problem for the case of cooperation between the two contractors and present the optimized networks and the credit exchanged in **Figure 8**. As **Figure 9** shows, with increasing the internal interest rate, the net profit of contractor 1 decreases and the net profit of contractor 2 increases as well. **Figure 10** illustrate that the joint finance-based scheduling

between contractors 1 and 2 results in additional net profit from cost savings in financing the project overdraft. Again, the additional net profit decreases as the internal interest rate increases. At the internal interest rate of 1, joint finance-based scheduling results in the least amount of additional net profit in this example too as the borrowing contractor gains no added advantage from leveraging the remaining credit of the other contractor. This illustrates that applying any internal interest rate does not offer advantages to cooperation when the objective is to equitably distribute the additional net profit between the two contractors. Finally, we conduct a sensitivity analysis for this example and provide the results in **Figures 11** and **12**. The findings of example 1 are confirmed; the greatest net profit is generated when the loan-providing contractor imposes the highest penalty rate while the loan-receiving contractor applies the lowest penalty rate. Conversely, collaboration is least advantageous when both contractors impose identical penalty rates.

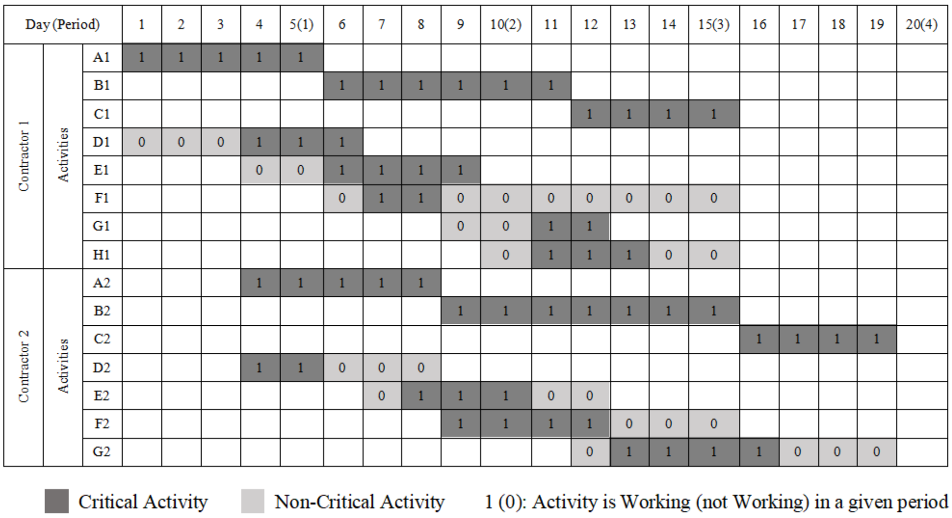

Figure 7. Example 2—Individual finance-based schedule of contractors 1 and 2 (prior to partnering).

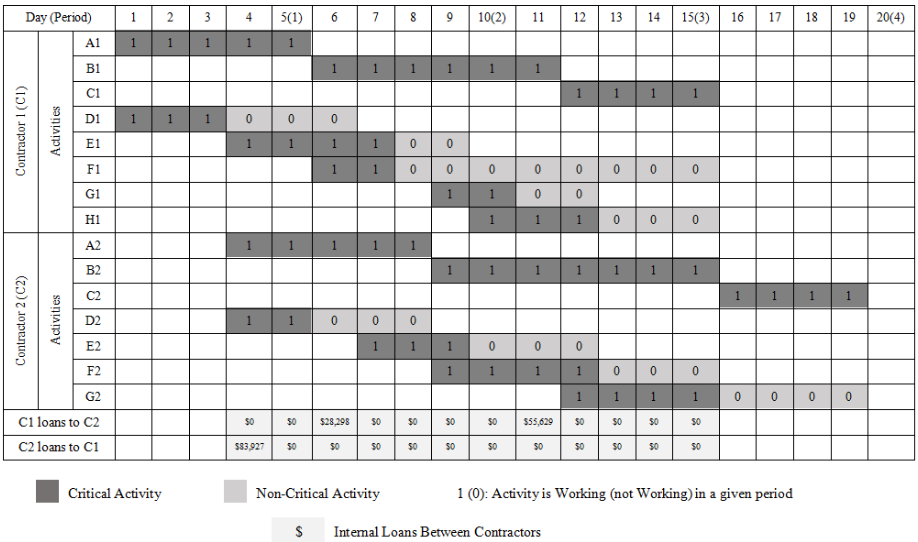

Figure 8. Example 2—Joint finance-based schedule of contractors 1 and 2 (after partnering).

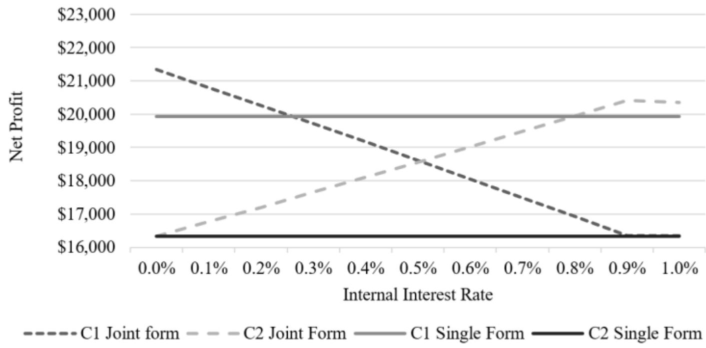

Figure 9. Example 2—Net profit of contractors in single and joint forms of finance-based scheduling under different Internal interest rates.

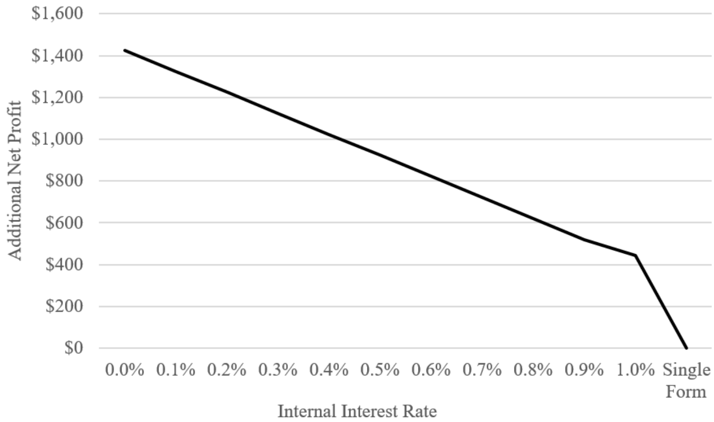

Figure 10. Example 2—Additional net profit from joint finance-based scheduling under different Internal interest rates.

Contractor 1 Penalty Rate											
1.0%	956	857	759	662	565	469	374	279	186	92	0
0.9%	863	765	667	569	473	377	282	187	93	0	139
0.8%	770	672	574	477	380	284	189	94	1	140	279
0.7%	677	579	481	383	287	191	96	1	140	280	419
0.6%	583	485	387	289	193	97	2	140	281	422	561
0.5%	489	390	292	195	99	3	142	283	424	564	703
0.4%	394	296	198	100	4	140	283	425	566	706	845
0.3%	299	200	102	5	139	283	426	568	710	850	989
0.2%	203	105	7	138	283	427	570	713	854	994	1133
0.1%	107	8	136	283	428	572	715	859	1000	1139	1278
0.0%	10	135	282	428	574	718	861	1003	1144	1284	1424
	0.0%	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%

Contractor 2 Penalty Rate

Figure 11. Example 2—Additional net profit from joint finance-based scheduling under different penalty rates.

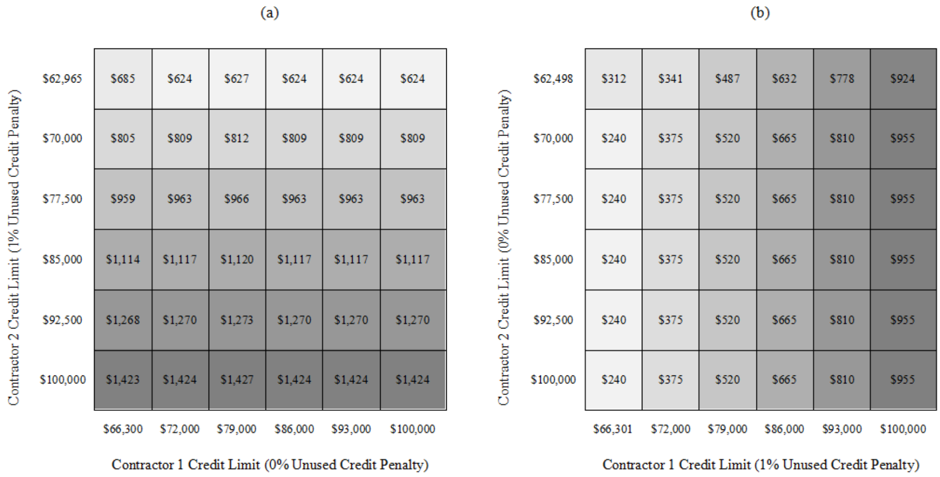

Figure 12. Example 2—Additional net profit from joint finance-based scheduling under different credit limits.

We also run a sensitivity analysis on the credit limit of two contractors for two extreme cases of the penalty rates on unused credit and present the additional net profit under each scenario in **Figure 6**. The results indicate that lowering the credit limit for the loan-taking contractor has no impact on the additional net profit while lowering the credit limit for the loan-giving contractor reduces the additional net profit, making the cooperation less attractive. Another benefit of joint finance-based scheduling is its need for a lower combined credit limit. The single-form finance-based scheduling problem of contractors 1 and 2 (with no penalty on the unused credit and internal interest rate of 0%) becomes infeasible for any credit limit lower than $87,684 and $72,691, respectively, while their joint finance-based scheduling problem is feasible for a considerable percentage below the combined credit limit of $160,375 ($87,684 + $72,691).

5. Discussion

The results of our proposed joint finance-based scheduling show that cooperation is beneficial and worth exploring for both contractors, in particular, those with financial limitations. The results also show that there are factors that increase the cooperation gains such as heterogeneity of cooperating contractors in terms of the penalty rate on the unused credit and lower internal interest rates and transaction costs between contractors. Although it is not directly derived from the result of this study, it can be shown that flexibility and size of contractors' schedules will directly impact the cooperation gains; This is aligned with the work of Asgari et al. (2014) as they show the larger network schedules and the ones with more non-critical activities offer a higher chance and value for cooperation.

Moreover, cooperation is likely to lower the interest rate as the lender is willing to charge the borrowers a lower interest rate on the line of credit. If the cooperating contractors apply for a joint liability loan or line of credit, all borrowers are responsible for the repayment of the loan. These trusted parties' joint responsibility in loan repayment makes the loan less risky for the lender and is likely to decrease the cost of borrowing. Additionally, the lower-risk nature of joint liability loans enables the co-borrowers to access a higher credit limit as the lender perceives the joint liability loan as more likely to be repaid.

The impact of joint finance-based scheduling on credit limit is twofold: (1) It allows projects, that otherwise would not be feasible or that have to be extended due to low credit limit, to become financially feasible. In other words, joint liability loans act as the only viable option for contractors (borrowers) who otherwise may not be able to secure a large enough loan. Joint liability loans are especially popular among entities with low credit scores or insufficient credit history, which are conditions applicable to many contractors. In the absence of information and the presence of risk, lenders may ask the borrower for collateral to guarantee repayment (Besley, 1995). However, smaller companies, or companies without sufficient credit history may lack collateral and hence fail to secure a loan or line of credit or a sufficient amount of loan or credit limit. (2) Even in cases where the two contractors do not expect any issues with their credit limit in the future, joint finance-based scheduling increases the reliability of their schedule and offers an extra safeguard if unforeseen circumstances happen. Sharing the unused portions of the overdraft lowers the required overdraft maximum that can be used for other purposes and shortens the project duration, increasing the probability of completing the project on time. From a financial perspective, joint liability loans may also be favored by financial institutions as screening loan applicants, monitoring borrowers, and auditing applicants will impose higher transaction costs on lenders which will eventually spill over to borrowers in the form of higher interest (Akerlof, 1970). Pooling borrowers may make it less costly for lenders and enable them to offer lower interest rates to borrowers. It is documented that co-borrowers are more likely to better select and monitor the peers with whom they share the loan since one party's failure to repay the loan will affect the rest as well (Stiglitz, 1990; Armendariz de Aghion, 1999). Co-borrowers that belong to the same industry, as is the case in our study, are likely to show a more effective peer selection and monitoring as they are more familiar with their co-borrowers' credentials and performance. This more effective peer screening and monitoring by co-borrower(s) is likely to further improve the repayment performance of the loan resulting in additional risk reduction for the lenders. Consequently, the lender is likely to grant the co-borrowers a better interest rate (lower borrowing cost) as the risk is shared among co-borrowers.

As a policy recommendation, establishing an agreement and the necessary guarantees to facilitate the safe transaction of credit may become costly for contractors. When a contractor lends to the other contractor, the lending party needs assurances that the funds will be returned. This may result in additional costs for both parties. For example, the lending contractor may ask for collateral and need to verify it. Alternatively, a financial institution can take the role of facilitator similar to the utilization of a Letter of Credit by importers and exporters to ensure borrowed funds are returned to lenders. For this, the financial institution can create a financial product such as linked lines of credit to facilitate a secure transfer of credit between two parties. The return of borrowed funds is guaranteed by the financial institution using the collateral posted by each party.

6. Conclusion

Finance-based scheduling aims to create more practical schedules by taking into account financial factors and limitations. The literature on finance-based scheduling has advanced from a single-objective to a multi-objective approach and from an individual project to encompassing multiple projects for a contractor. In this study, we explore the potential collaboration among contractors managing concurrent projects to minimize financing costs. Contractors often do not fully utilize their available credit and might face penalties for unused portions. This creates an opportunity to share their credits, reducing their financing costs and ultimately enhancing overall profits. Joint finance-based scheduling enables cooperating contractors to lend or borrow credit at an internal interest rate. We apply and analyze the proposed joint finance-based scheduling approach to an illustrative example involving two concurrent projects. The results suggest that joint finance-based scheduling can offer considerable benefits to contractors, particularly those facing financial constraints. Factors enhancing these gains include diverse penalty rates on unused credit, lower internal interest rates, and reduced transaction costs among contractors. Larger and more flexible schedules tend to yield higher cooperation benefits, aligning with previous research. Cooperation, especially in joint liability loans, reduces the risk for lenders, either cooperating contractors or financial institutions, by providing more effective peer screening and peer monitoring among borrowers from the same industry. This risk reduction results in lower interest rates, and/or an increase in credit limits for borrowers. Joint finance-based scheduling makes otherwise infeasible projects viable and provides a safety net in unforeseen circumstances, shortening project durations and increasing reliability. From the lender's perspective, pooling borrowers via joint liability loans can reduce transaction costs for lenders, leading to lower interest rates with lower implied risk while increasing revenue. However, implementing secure credit transactions may incur additional costs for contractors, necessitating collateral or financial institution intervention, like creating linked lines of credit to ensure secure credit transfers.

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