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Feasibility Test of a Hybrid Simulation Approach for Optimized Resource Allocation and Cash Flow Management

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Abstract

Project cash flow management is one of the most critical aspects of construction management in this industry as it plays a vital role in resource allocation. Neglecting the availability of monetary support at each phase of a project can lead to catastrophic consequences such as a significant negative financial balance and even contractors' bankruptcy. Thus, when planning activities and their required resources, the financial support available at the time of implementation should be considered. However, current approaches for this problem require previous data or expensive modeling which is not available to small contractor who are most susceptible to this issue. To this end, this study aims to test the feasibility of using an easily adaptable hybrid-simulation model, which can be implemented without any previous data or expensive modeling processes. The proposed methods were tested on a linear infrastructure, pipeline construction, and after the sensitivity analysis, some adjustments to timelines and resources of activities were suggested. As a result, budget deficit improved significantly, improving cash flow stability. The findings support the hypothesis that hybrid-simulation can be utilized as an effective tool for analyzing and managing project cash flow.

Keywords: Hybrid Simulation; Cash Flow Management, Financial Planning, Resource Management

1. Introduction

Project scheduling faces multiple challenges as no construction project is without constraints (Liu and Wang 2008). The types of constraints can include manpower, machinery, or limited funds at certain stages of the project. Limited funds at specific milestones will significantly impact the cash flow of the project, which is an indicator of earned rewards and spent money in each phase (Needles et al. 2011; Russell 1991). In other words, the cash outflow of the project represents the expenses that contractors incur to proceed with activities, while the “cash in” is the reward received upon completion of project activities. In some cases, receiving the reward is not only contingent on completing an activity but also on the availability of funds from the owner, which are predetermined and outlined in the contract at the project's outset.

In the aforementioned cases, the typical scheduling of a project can place immense pressure on the contractor, forcing them to bear a negative financial balance for an extended period until the frozen rewards from the owner are released, resulting in an overall positive financial balance for the project. However, this approach is impractical, as many small contractors cannot sustain the negative cash flow and may end up bankrupt. The significance of this issue is underscored by previous research, which indicates that 60% of contractors' failures stem from financial issues (Russell 1991). A failed construction project may be abandoned (Alao et al. 2018), or handed over to other contractors, both of which involve complex processes and significant waste. In other words, unmanaged cash flow will drastically change the outcome of the projects and direct it toward the "unsuccessful" status that fails to meet the requirements set at the beginning of the project (Odeh and Battaineh 2002; Odeyinka et al. 2008; Windapo et al. 2017). To address this issue, this paper is proposing a hybrid-simulation approach to enhance project planning and scheduling by accounting for the project cash flow, especially for linear infrastructures.

This study is structured as follows: In the second section, a brief description of state of the art is presented. In the third section, the methodology, tools for simulation, project details, and available funds are discussed. The fourth section is dedicated to discussing the actions taken to improve scheduling and their results. Finally, a conclusion is presented in section 5 for this research work.

2. State of the art

Previous studies have attempted to reduce the negative effects of financial imbalance by adjusting the cash flow of the project (Omopariola et al. 2020; Zayed and Liu 2014). A linear programming model has been developed to optimize cash flow management in a Brazilian construction project, addressing specific industry challenges by visualizing cash flow inputs and variables (Barbosa and Pimentel 2001). Chiu and Tsai (Chiu and Tsai 2002) introduced a heuristic search scheduling rule for the resource-constrained multi-project scheduling problem with discounted cash flows, consisting of project delay penalties and early completion bonuses. Other previous attempts include investigating the significance of payment conditions and how they would affect the cash flow model (Chen et al. 2005). However, these attempts require previous experience and lessons learned from previous projects or complicated models to predict the unseen factors and their effects on predicted cash flows. The drawback of this method is the considerable cost and resources required to yield an accurate model that meets requirements and can be implemented in the real world, which means most small contractors, who are most susceptible to financial failure (Assaf et al. 2013; Haupt and Padayachee 2016), will not have access to the resources of the model and won't benefit from it.

With this background, this study aims to investigate the feasibility of combining continuous and discrete event simulation (Hybrid-simulation) to quantitatively assess the effects of activity timelines and their costs in order to provide meaningful insights to project manager for better scheduling and resource allocation while considering the budget deficit. The proposed approach is highly flexible to fit the requirements of different projects and is easily accessible and inexpensive so even small contractors can implement it. It helps project managers schedule the activities and required resources based on contractors' financial ability to support the unpaid phases of the project without violating the delivery time set at the project's commencement. The proposed method in this study is applied to a case study of a water pipeline in Iran, and the effectiveness of the simulation is validated. As a result, the contractors minimized the idle time on the construction site (Roser et al. 2002), which will reduce overhead costs and plan for the required resources to deliver the project on time.

3. Materials and Methods

To achieve the objective identified in the introduction, the first step is to develop a simulation model that represents the construction project with cumulative rewards and earned values at any stage of the project. Various simulation techniques are available for this purpose, such as Discrete Event Simulation (DES), Agent-based simulation, system dynamics, and hybrid simulation, which is a combination of DES and system dynamics (Alzraiee et al. 2015; Taghaddos et al. 2014, 2021). For cash flow modeling, DES can be used, but the process cannot be halted if the cumulative rewards are below the contractor's expectations; hence, it is not the right tool for this study. Agent-based modeling is a great fit for modeling safety enhancements and observing how agents interact with each other, which is not the purpose of this study. Therefore, a hybrid simulation model is chosen as the right tool to serve the identified goals. All the simulation, calculation, and visualization are done with Simphony.NET and Microsoft Excel software.

3.1. Project description and assumptions

The considered project is a pipeline construction project that spans 23 km, connecting a reservoir to an industrial village. The project is located in the southeast of Tehran, Iran, and the pipeline route has already been determined to minimize excavation and conflicts with private properties. This project is chosen as a case study because the activities timeline have enough flexibility so that they can be postponed and resume with more resources than usual to deliver the project in time. In addition, the project is facing limited funds at different milestones which makes it perfect for the proposed approach. The project activities follow the conventional process of any piping project, with the installation process involving the following steps: surveying, cleaning, routing (if necessary), excavation, pipe installation, valve installation, hydro tests, filling excavated locations, installing information systems, and backfill. The predecessor and successor activities, along with the contractor's criteria, are presented below and in Table 1:

1) Surveying, cleaning, and routing (phase 1) must be at least 1 km ahead of the excavation process (phase 2).
2) The excavation process must be at least 100 m ahead of pipe installation (phase 3).
3) Valves can be installed in the designed location if excavation is completed for that section; valves can be installed before, after, or concurrently with pipe installation.
4) The Hydro test must be carried out between 700 m and 1 km (phase 4).
5) There is a 10% chance of a hydro test failure for a section, requiring rework before conducting a second hydro test.
6) Every time a section fails the hydro test, the next hydro test failure chance reduces by 50 %.

Table 1. Project description

Work Package	Resource
Surveying, Routing, and cleaning	Surveying crew
Excavation	Excavation crew
Pipe Installation	Piping crew
Valve Installation	Piping crew
Hydro test	Hydro test crew
Lay and backfill	Lay and backfill crew

The project activities and conditions were simplified with the following assumptions to align with project goals and objectives: Phase 1 (surveying, cleaning, and routing) will be completed by one crew, considering that routing is not a significant task due to minimal off-road construction and good access to the location. Phase 2 is completed by a crew and a fleet of shovels and trucks, with specific crew details and elaboration outside the scope of this study. The piping crew is responsible for installing pipes and valves, while a specialized group conducts the hydro test. The filling, finalization, and installation of information systems are handled by one crew. All of the activities are done using a continuous model, but they interact with other activities through a DES model. An entity is created to represent time for the continuous section, allowing the contractor to adjust their budget based on their financial ability and exceed the owner's expectations by a limited amount. The simulation model for the aforementioned task is shown in Figure 1.

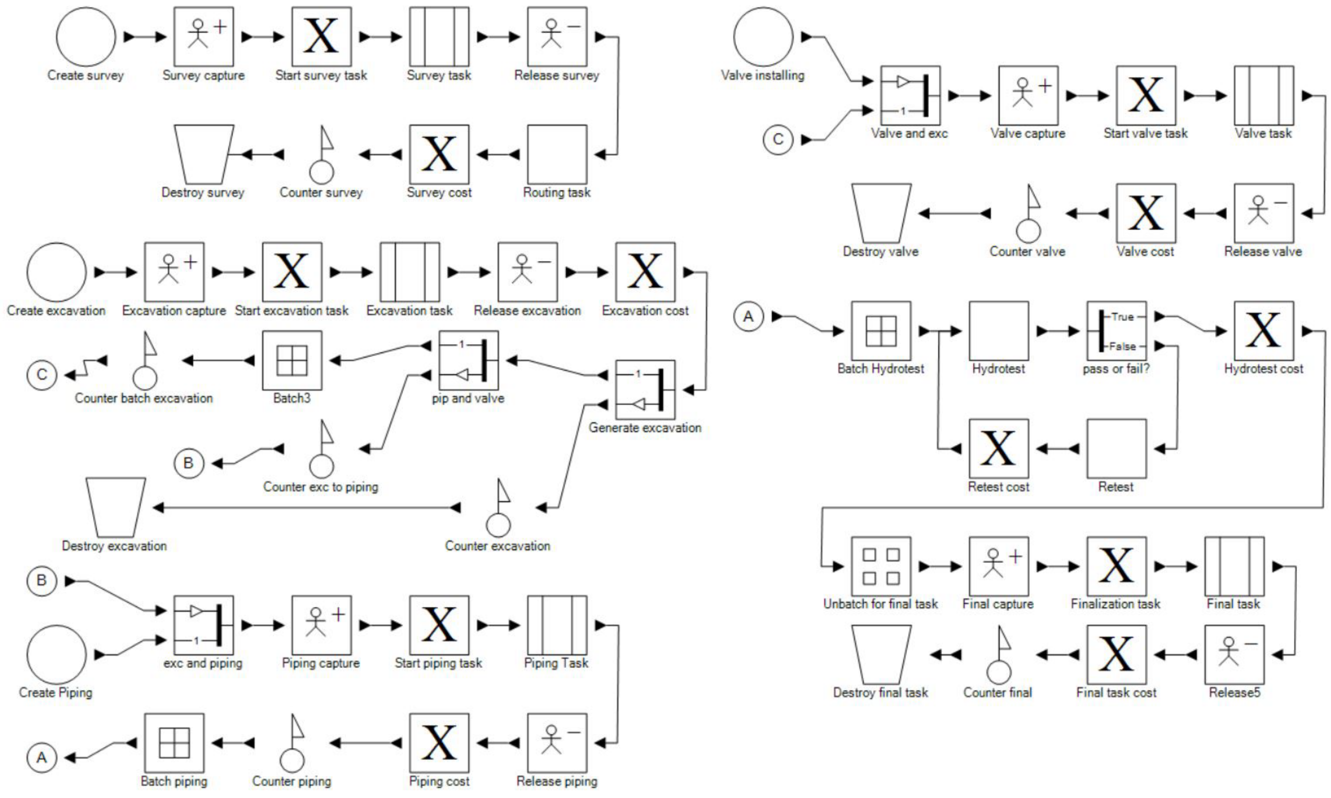


Figure 1. Simulation model

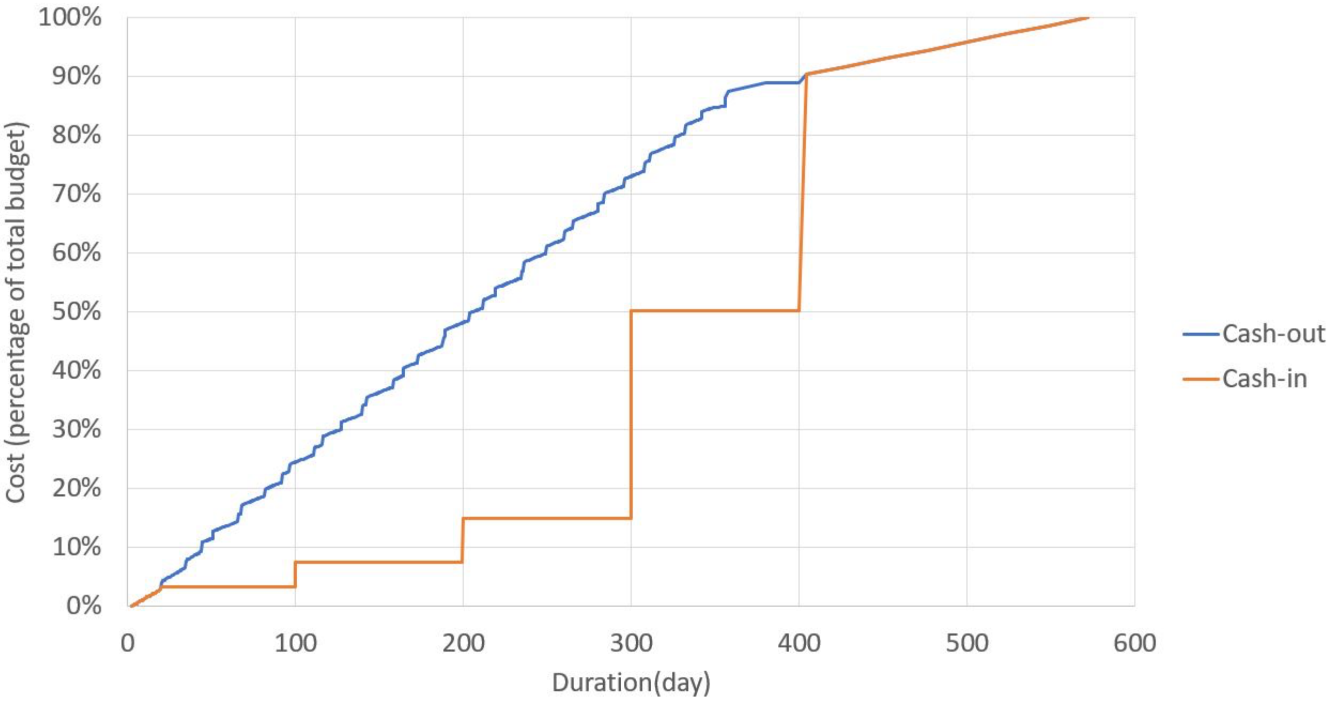


Figure 2. Cash flow of baseline scenario with ignoring the payment limitation

3.2. Base scenario and project limitations

As mentioned in the previous section, if the owner does not have any limitation for payment, the contractor will get paid for each completed activity. However, in some cases, this is not true, and the owner—in this case, the National Development Fund of Iran—has limited budgets at different periods of the project. This limitation is applied in such a way that even if the contractor completes a task, their cumulative reward will not exceed a certain amount within a time period until new funds are unfrozen by the owner, and the contractor can be compensated in the next time period. For instance, if the owner's budget ceiling is $1 million in the first year, the contractor will not get paid more than $1 million even if they deliver $2.5 million worth of work.

The aforementioned project has five different monetary limitation at different times which can be seen in the Table 2.

Table 2. Owner payment limitation schedule

Day	Maximum Available Payment ($Rials \times 10^3$)
100	245000
200	560000
300	1125000
400	3750000
500	7200000

If the contractor is significantly wealthy and does not object to the fact that their assets will be frozen by the owner for a set period, they can proceed with completing the project tasks without concerns about spending money without receiving immediate compensation. In that case, the cash flow will appear as depicted in Figure 2.

As seen in the figure above, the depicted cash flow appears highly risky for small contractors due to the substantial deficit between cash inflows and outflows. The maximum deficit, approximately 57 % of the entire revenue of the project, occurs just before the 300-day phase. This situation could lead to bankruptcy or necessitate seeking financial assistance through bank loans, which can negatively impact the construction project as discussed in the introduction. Therefore, the project schedule should be adjusted accordingly to minimize the deficit between cash inflows and outflows, thereby reducing the risk of financial failure. The proposed measures to mitigate the staircase effect on the project's cash inflow are discussed in the next section.

3.3. Validation and verification

Verification and validation of a model are one of the most crucial sections of simulation. Verification is related to ensuring that the model is built correctly while validation checks if the model output matches the situation in the real life. For instance, in simulating the flow of traffic in a city, verification would involve checking that the traffic simulation model accurately represents the rules of traffic flow, such as lane changes, traffic signals, and vehicle speeds. Validation, on the other hand, would involve comparing the simulated traffic patterns and congestion levels with real-world data from the same city to ensure that the model's output closely matches actual traffic conditions.

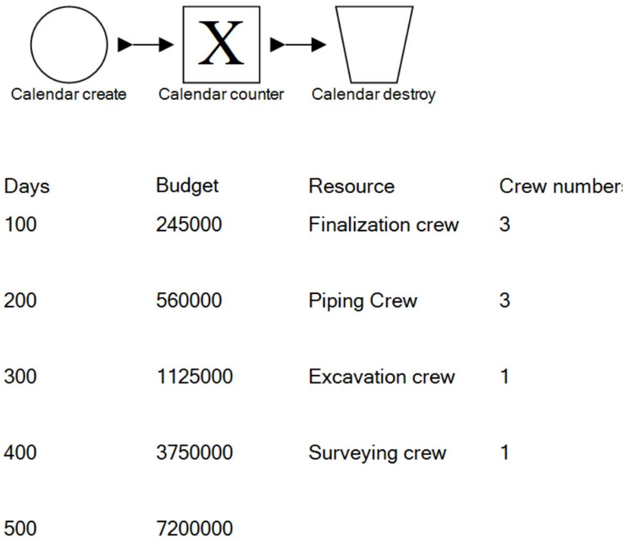
For verification, degenerate tests are used to make sure that the model behaves as expected in in the extreme conditions. Number of resources available is change drastically in each section for different activities. To this end, the number of surveying resource is set to 200. The logical results will be that the total duration of the model will not change as the surveying and phase 1 of the project is not the bottle neck and is not a time-consuming activity. The observed results confirmed this theory, and the total duration did not suffer drastic changes. The same process was applied for different scenarios with high or low number of resources to see how the total duration will change.

For validation of the model, a sensitivity analysis was conducted with an expert, an experienced project manager, to determine if the results match the excepted output based on the expert historical knowledge. Through a trial-and-error section, the expert interacted with the model to complete some scenarios and compare the results of simulation to his previous experience. The final model was approved by the expert.

4. Results and Discussion

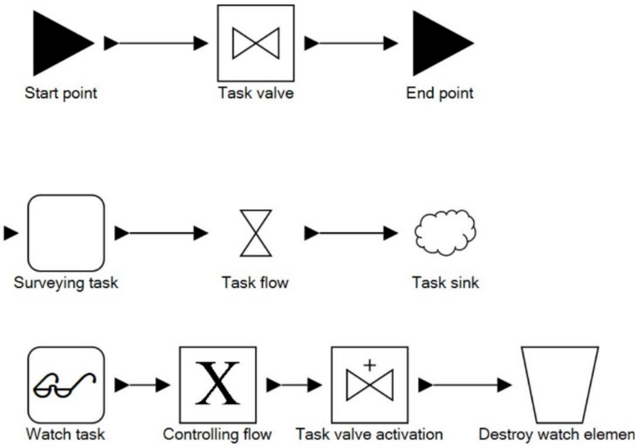
In this section the proposed adjustments are discussed, and the impact of each scenario is then considered to find a scenario that satisfies the requirements of this project. In the first step an alternative is represented to halt the process any time the contractor exceeds the limited budget and turn the construction site status to "idle". In this period no work is done and most of the staff are release until the project is resumed. So, the assumption is that during the idle period no significant expenses are made and the cash out flow will not change drastically.

At the first step a scenario is tried out in which the operation is halted, and the construction status turns to "idle" any moment the cash out will exceed the expected cash in. The continuous section design in the Simphony model is responsible for halting the process. The project manager can input his/her budget limit throw the interface that is designed in Figure 3 to halt the process whenever the total cost in that period exceeds the desirable amount. Also, the number of different resources can be adjusted as can be seen next to the budget limitations.



Days	Budget	Resource	Crew number
100	245000	Finalization crew	3
200	560000	Piping Crew	3
300	1125000	Excavation crew	1
400	3750000	Surveying crew	1
500	7200000		

a) User Interface



b) Continuous section of one activity

Figure 3. Continuous simulation section and user interface

The results of applying this budget limitation are shown in Figure 4. As indicated, only in some short period of times the cash-in diagram is higher that cash-out diagram. The maximum deficit between cash in and cash out is approximately 3% of the total budget which is far less than amount in the previous scenario. However, we can see that the duration of the project exceeds 800 days. So, the contractor may face financial penalty because of the delays in the project delivery.

Exceeding project duration aside, the existing scenario have the stair-steeping effect in which the construction idle time is substantial, and the productivity is zero. To address these issues, the following actions are proposed:

1) Adjusting the start date of different activities
2) Increasing different resources to complete the

tasks in a shorter time

Since every major phase of this project is dependent on the excavation task, the best case scenario is to carry this phase from the early section of the project so other activities will not wait for the excavation. Hence, as soon as phase 1 of the project is completed, phase 2 begins. However, because the pip installing (phase 3) is a costly task the start of this activity is postponed for a considerable time so that after a long period of time, the installing crew(s) would be hired to complete the installation of pipes in the excavated areas.

Backfill and finalization task would be best to start after the piping is done because it is a time consuming task and if it is postponed too much there would be a significant number of crews needed to complete this activity in time. Different combination of number of resources and starting date were tried based on the explained logical process to minimize the project delivery time with minimum number of resources. The final configurations of activities are presented in Table 3 and the cash flow is shown in Figure 5.

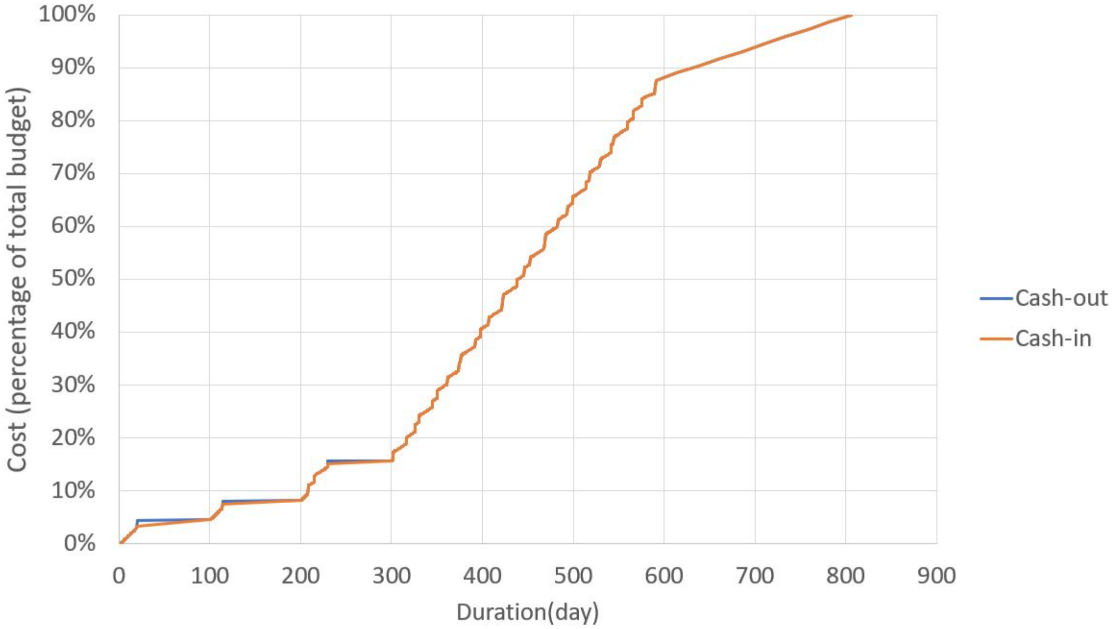


Figure 4. Halting the activities when they exceed the budget limit

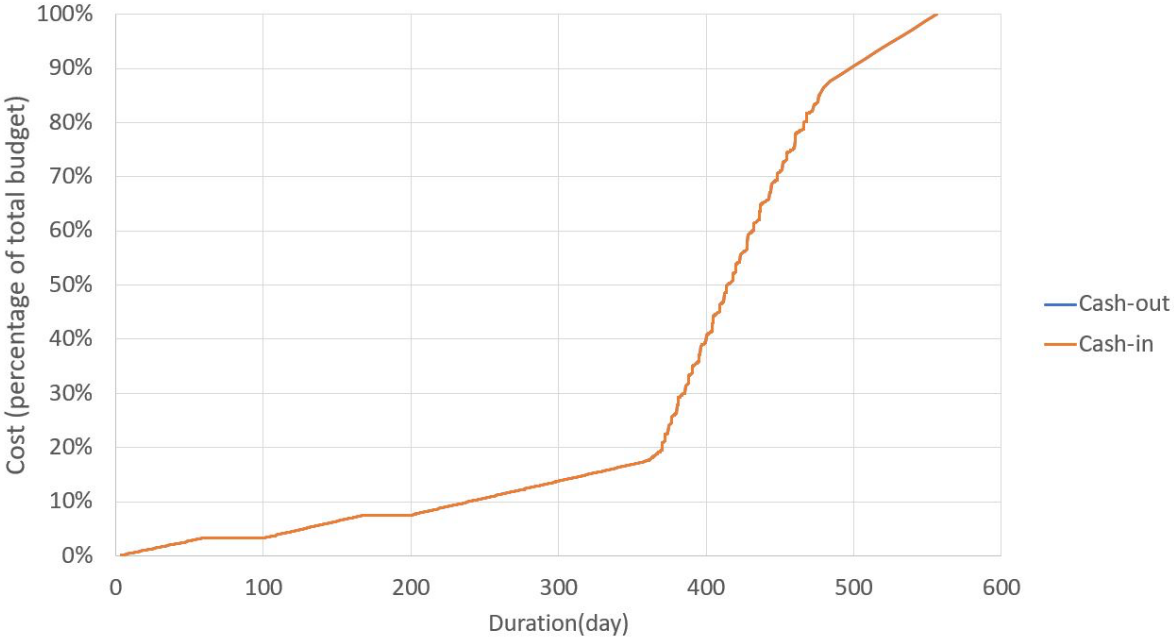


Figure 5. best scenario cash flow

Table 3. Final configuration of the project

Activity	Starting date	Resources
Survey	0	1
Excavation	45	1
Pipe installing	360	3
Backfill	360	3
Hydro test	NA	1

As indicated, the project was delivered before the 600 day deadline and the stair-stepped appearance is significantly mitigated to the previous scenario. These results emphasize the importance of resource allocation and project planning in a construction project to complete the required task within the designated time window with minimum financial pressure and project failure risk which will increase the chances of success.

5. Conclusions

This study has successfully demonstrated the potential of hybrid simulation in optimizing cash flow and resource allocation in pipeline construction projects. By incorporating both discrete and continuous simulation elements, the project model effectively aligns with the financial constraints and scheduling needs of contractors, particularly under limited funding conditions. The implementation of the hybrid simulation model resulted in a significant reduction in idle times and unnecessary expenditures, thereby enhancing overall project efficiency.

The case study of the pipeline project in Iran illustrates how strategic adjustments in resource scheduling and budget management can lead to substantial improvements in project delivery and financial stability. Through the adaptive scheduling techniques enabled by the hybrid simulation, the project could accommodate financial limitations without compromising on the timely completion of essential construction phases.

Furthermore, the model's validation and scenario analyses underscore its reliability and adaptability to real-world constraints, making it a valuable tool for project managers seeking to optimize construction processes under financial and resource-related constraints. It is anticipated that the adoption of such innovative simulation approaches will pave the way for more sustainable and economically viable construction practices, especially beneficial for small contractors who are most vulnerable to financial instability.

The study has unveiled the great potential of hybrid simulation in cash flow management, however, there exist some challenges for practical application and implementations in the real world that could be the main focus of the future research. The most important aspect is to generalize the proposed framework to include other types of construction projects that have more complex arrangement and do not follow a linear procedure. In addition, the current method improvements significantly depend on the project manager skills to rearrange the task scheduling and adopt the number of resources, which makes the process less automated and reduce the efficiency of the proposed simulation.

In conclusion, the integration of hybrid simulation into construction project management holds promising prospects for enhancing the efficiency, reliability, and financial outcomes of large-scale construction projects. Future research could further refine these models, expanding their applicability to a broader range of construction scenarios and incorporating more dynamic elements to respond to the ever-changing conditions of construction sites and market economics.

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