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A FRAMEWORK FOR OPTIMIZING MATERIAL MANAGEMENT PROCESSES IN OIL AND GAS EPC PROJECTS

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ABSTRACT

In the specialized engineering, procurement, and construction (EPC) oil and gas industry, the monetary value of procurement equates to more than engineering and construction combined. However, material management processes are yet to evolve from conventional push systems to more efficient ones. The application of lean concepts to eliminate the waste embedded in the material flow processes of construction projects has become a proven practice for reducing cost overruns and schedule delays. To this end, the objective of this study is to develop a framework relying on just-in-time delivery and pull systems to enhance material management processes in EPC projects. Namely, the proposed framework introduces changes to the responsibility matrix and sets time limits for the concerned material flow stages based on data analysis for electrical and control equipment of an oil and gas EPC project in the Russian Far East. The framework is then tested using a probabilistic Monte Carlo simulation. The results show a significant decrease in the storage cost, as an example of waste reduction. The framework provides a practical material management solution for EPC companies that minimizes non-value-adding durations and ensures a continuous material flow with continuous feedback and accountability loops.

KEYWORDS

Supply chain management, design science, flow, integration, waste.

INTRODUCTION

Construction projects are getting more complex, uncertain, and quick with a growing competitive market. This is coupled with an increased client's demand for lower project costs and faster project completion. In the specialized engineering, procurement, and construction (EPC) oil and gas industry, the monetary value of procurement equates to more than engineering and construction combined where the cost of supplies and equipment accounts for roughly 60 to 70 percent of the overall direct cost of construction (Patel & Vyas, 2011). Traditional construction industry material management practices are push systems that depend on pre-set deadlines for releasing work into the following activities (Alves, Tommelein, & Ballard, 2006). As a result, these processes have typically been associated with ineffective results including large inventory buffers, cost overruns, lower safety standards, or even a lack of necessary items on site. This is mostly due to the fact that the material operations are

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frequently separated from the real workflow and dispersed across various departments (Arbulu et al., 2005). For instance, the planning team is in charge of creating baseline schedules that drive procurement operations, but the procurement team is responsible for making sure that items are on-site when needed.

Offsite and onsite material logistics are the two primary divisions of construction logistics. Offsite material logistics are dependent on numerous companies cooperating in the form of a network with the goal of moving material efficiently to cut costs and time and increase customer value (Hamzeh et al.2007). However, because temporary facilities are frequently housed on-site, onsite material management tries to lessen site congestion (Said & El-Rayes, 2013). Moreover, by designating places for resource delivery and optimizing storage, onsite material management tends to decrease non-value-adding material transportation (Thomas et al. 2005). Offsite material management received a lot of attention in the literature. For instance, the use of the Kanban system was highlighted by Arbulu et al. (2003). The idea of supplier Kanban is to replenish the site with a small selection of limited range, made to stock products. They discussed the positive effects of this process-driven lean strategy on productivity and time reduction and concluded that ordering small quantities rather than large batches is essential for the strategy's success. They also suggested a new position called a supply chain integrator to concentrate on the value stream of the supply chain. Other initiatives to connect supply and manufacturing have been made. As an example, Arbulu and Ballard (2004) used a web-based tool incorporated with the Last Planner system to reach this goal. This is accomplished by using that technology to manage daily production in order to improve workflow dependability and reduce demand fluctuation. Arbulu et al. (2005) differentiated themselves by using lean tools and concepts like Kanban and pull systems based on a just-in-time approach as well as Standard Procurement System (SPS) Production Manager and SPS Material Manager as software tools to improve the dependability of production level workflow and material supply. Hamzeh et al. (2007) also approached the issue differently by putting more emphasis on logistics centers. They emphasized that supply will be highly variable because it depends on hazy construction schedules. This will result in mismatches in supply and demand, driving up costs and lengthening processing times. Based on that, they used simulations to demonstrate the potential benefits of logistics centers in dealing with supply changes and portrayed these facilities as superior options to site inventories due to the issues the latter have.

On-site material logistics, however, did not receive as much attention in the literature. In order to address this issue, Ghanem et al. (2018) made the case that prior studies only treated the site storage area as the final destination of supplies, failing to account for the possibility that issues would arise when moving goods to the actual construction site. Congestion on the site is a drawback of poor site material management, which will harm worker productivity and safety measures (Singh 2010; El-Gohary & Aziz 2013). Furthermore, by examining elements that are associated to productivity, Seppänen et al. (2016) examined how onsite logistics will impact worker productivity. In order to examine the impact of onsite material management on building projects, Patil and Pataskar (2013) applied inventory control approaches. They discovered that the inability to get materials on site in a timely manner is one of the main reasons for project variation, accounting for 5% of all project variations. They suggested implementing a reward system to encourage staff employees to sign up for construction material management training, so they become aware of material planning and scheduling at every step. Additionally, they suggested adopting ABC and Economic Order Quantity analyses for annual inventory control. The former is a method of inventory management that categorizes items based on their importance and is also known as Pareto Analysis or the 80/20 rule. The latter is a mathematical formula used in inventory management that takes into account the cost of ordering, the cost of holding inventory, and the demand for the product to determine the optimal order quantity that minimizes the total cost of ordering and holding inventory. Abou Dargham et al. (2019) sought to apply lean thinking to create, simulate, and model an efficient and dynamic site plan that will result in a seamless flow of materials on site, minimizing time and expenses. By using a pull-based supply chain of Glass Reinforced Concrete units and integrating some process activities, the results indicated a 16% decrease in the overall cost and a 15% reduction in the overall simulation time compared to the base model of the process under consideration.

It becomes evident that the application of lean concepts is key to eliminating the waste embedded in the material flow processes and reducing cost overruns and schedule delays. However, no study was found to explicitly focus on the application of lean concepts to improve the overall material management process and its impact on project performance, in particular in the specialized oil and gas EPC industry. By analyzing real project data, this study aims to identify the bottlenecks in the material management process of EPC oil and gas projects and develop a framework for a lean material management process relying on just-in-time delivery and pull system.

METHODOLOGY

The objective of this study is to develop a framework that can be applied by EPC contractors to reduce the waste embedded in the material management process of oil and gas EPC projects. This is achieved by following the design science research methodology. Namely, the problem is first identified by surveying the conventional flow of material along with the material management procedures of an international EPC contractor. The material management procedure is a set of guidelines and steps that defines the sequence of material flow from suppliers bidding stage up to delivery and handling on site; it also defines a set of key documents issued with regards to each stage of material movement. Data corresponding to each of the material flow involved stages of an oil and gas EPC project executed by the same contractor was extracted from multiple delivery reports exported from the Site Material Management System (SMMS). This system is a tool used to track material delivery, receipt, and issuance. In particular, the extracted data corresponds to the electrical and control equipment installed in an electrical substation of and oil and gas project in the Russian far east and include key dates in the flow of material, which provides an overview of the material management process. The dates were used to estimate the durations of each stage. Following that, an analysis was conducted on these durations and compared with the baseline schedule to identify the bottlenecks and the waste embedded in the process. A framework that targets those bottlenecks was then developed. Finally, the framework is tested on the project data using a probabilistic Monte Carlo simulation to show the magnitude of storage cost reduction as an example of waste minimization providing an illustration of the optimized material management process.

DATA COLLECTION

In a typical EPC project, the process of material management includes five main stages: bidding, manufacturing, shipping, storage, and erection/installation. Figure 1 shows the flow of material starting from the receipt of the material specifications from the Client up to their onsite erection or installation; each stage is mapped along with its responsible manager(s) and their interface with other functions managers. A solid line represents a direct reporting protocol, and a dotted line represents an indirect reporting protocol; for instance, in email communication terms, a solid line reflects “from / to” email communication(s) and a dotted line reflects a “cc” in an email communication. Stage 1 starts when the contractor prepares and sends requests for quotation (RFQs) to the potential approved suppliers (vendors); this process is directly managed by the procurement manager (PRM). Upon receipt of RFQs, the suppliers compile and submit to the contractor their technical and commercial offers; these undergo a thorough review process (i.e., bidding negotiation and technical clarifications) that allows the contractor to identify the best bidder technically and commercially. Once a bidder is selected, the contractor issues a purchase order (PO) to the supplier to start manufacturing, signaling the end of Stage 1. The bidding negotiation process is managed by the PRM and supported by the Engineering Manager (EM).

The contractor, being responsible for the material, deploys resources to the supplier premises to ensure the quality of the material. Upon the completion of the manufacturing stage, the contractor conducts routine testing and issues an inspection release notice (IRN) to declare the material is of good quality, signaling the end of Stage 2. The supplier then prepares the material for shipping and requests the contractor's approval to ship, which is usually in the form of a shipping release note (SRN). Stage 3 corresponds to the shipping stage; the material is shipped through regulated logistics routes (e.g., sea freight, air freight or land freight). Upon receipt on site, the contractor checks the quality of the received material, and the site team issues a material receipt voucher (MRV) and transfers the material to the site store. The material remains in store until the responsible subcontractor requests it; the store then releases the material through a material issuance voucher (MIV), signaling the end of Stage 4. Once an MIV is issued, the material is cleared to be erected on site.

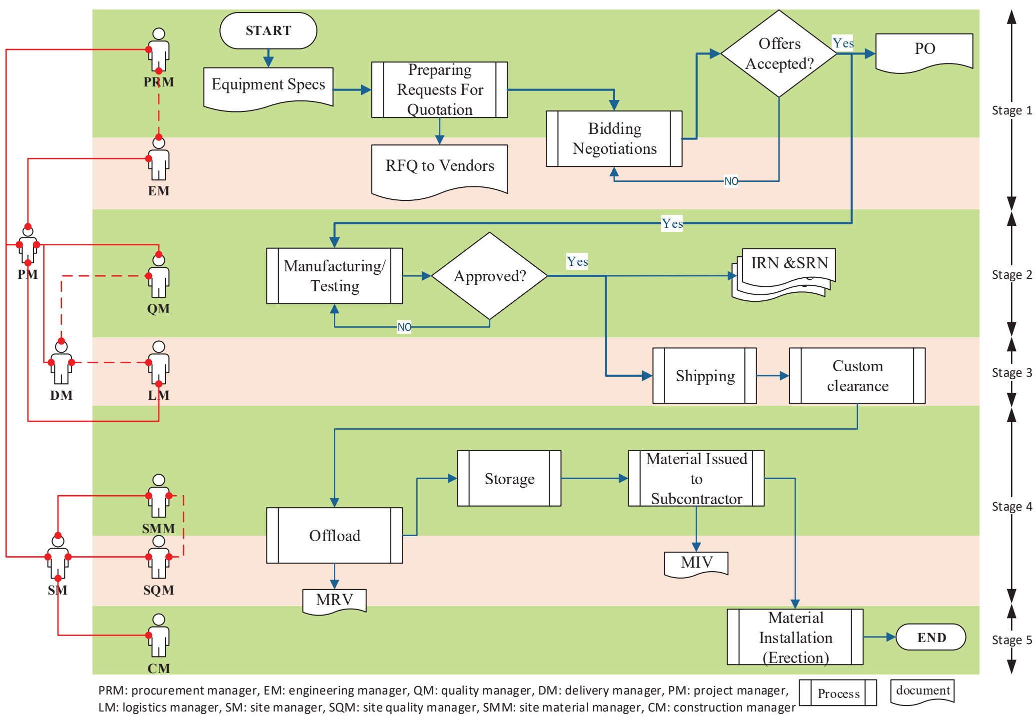

Figure 1: Material Management Process Flow Chart

To illustrate the waste embedded in the material management process, data was collected for 147 equipment installed in the electrical substation of an EPC oil and gas project in the Russian Far East. These were selected because they are tagged items that can be tracked efficiently. The selected equipment include electrical transformers, high voltage switchgears, uninterrupted power supplies (UPSs) and low voltage power panels, and cabinets for distributed control system (DCS), emergency shutdown system and fire and gas system. For each equipment in the substation, the dates corresponding to the RFQ, PO, shipping, site receipt, and erection milestones were extracted to calculate the duration of each stage in the process. The averages of these durations are illustrated in Table-1.

Table 1: Collected Data

Stage	Average Duration (Days)
Bidding	26
Manufacturing	71
Shipping	73
Storage	239

DATA ANALYSIS

The collected data show an alarming waste in the contractor's material management process. The root cause analysis of this data revealed three major bottlenecks. Starting with the bidding stage, an average of 26 days is a long time considering that the suppliers are familiar with the equipment and are able to submit the techno-commercial offers in less than two weeks. After a root cause analysis of this waste, the delay in this process is found to be caused by the heavy bureaucracy in the communication protocol whereby each revision of the offers must go through a lengthy approval process although the technical aspects are not time consuming (this is the first bottleneck). The second waste is illustrated in the manufacturing stage which takes up to 70 days on average. The analysis revealed that the equipment goes through quality checks prior to shipping from the supplier, which results in a substantial amount of rework to rectify the contractor's comments as the contractor inspects the equipment post-manufacturing (this is the second bottleneck). The shipping stage is considered within limits given the project's location.

The third and major waste, however, is manifested by the storage (idle) time on site (i.e., 239 days). To better analyze this waste, the progress of material arrival to site (i.e., cumulative percentage of total metric tonnage as a function of actual dates) is plotted along with the planned erection progress and the actual erection/execution progress of material (Figure 2). First, the figure shows a large gap between the material arrival and its planned erection. It could be argued that during the year between April-2020 and April-2021, the COVID-19 pandemic had a major influence on the workflow (the flow of both construction material and construction crew) which was the main cause for the piling of material at this time and also in pushing the execution of the project. However, this does not negate the fact that the erection was planned to take place starting Apr-2021 while the material arrival to site started in Apr-2020. This means that the equipment was going to be idle in the warehouse according to plan and that the erection activities were planned independently from the delivery plan. In other words, the procurement function's key performance indicator (KPI) being independent from the construction progress, there was no added value in delivering the equipment in Apr-2020 while the installation is only needed in Apr-2021, which indicates a major flaw in the management process (this is the third bottleneck). By analyzing the storage inventory area over time, it was found that the maximum inventory floor area was about 500sqm, which indicates the need for a storage facility for this substation to accommodate that area. Another observation from Figure 2 is the gap between the planned erection and the actual execution in terms of dates and durations as well (i.e., the planned duration is 81 days and the actual duration is 244 days), which can be traced to many intertwining factors. The actual execution matches with the planned execution, both of which are a year into the pandemic. However, during the pandemic, a significant shortage of workforce and material was experienced on site (although the case study equipment were already on site prior to the pandemic shutdowns, a lot of other material were obstructed). Therefore, the work that was supposed to be executed during the pandemic was heavily affected, and consequently, by Apr-21 although the erection works of the case study equipment commenced within planned time, priorities have changed due to the work obstructions during the pandemic and the pace of execution could not keep up with the plan. Another reason for the execution deviation can be traced to the manpower mobilization shortages from subcontractors due to financial issues.

To further illustrate the negative repercussions of the inventory waste, the storage cost is calculated. Based on actual storage cost data, and the fact that the selected equipment contains high quantity power electronics that need to be kept in a heated and well-preserved warehouse, the average cost of power requirement to preserve $1m^2$ of floor area in a site warehouse in the project site in the Russian Far East was found to be $1.55/$m^2$ per day. This cost covers the electrical power, manpower, and preservation costs. Considering each equipment floor area over its storage period, the total power cost to store all the equipment for their respective storage durations is found to be around $204,000. In fact, the analysis revealed that this range of storage duration is very common due to two main reasons. First, given that material delivery to site is the main milestone to claim payment from client, contractors tend to push material to site as soon as they can to collect cash payments. The second major factor is that site management and site material management are under pressure to handle piling quantities of arriving material whether these are needed at that time or not. This is mainly because the delivery manager and procurement manager's KPI is to deliver the material to site as soon as possible since they lack a direct reporting protocol with site management. It is noticed that a recurring theme in the bottlenecks is the fact that each function manager acts to achieve their KPI on priority, and sometimes in isolation, without consideration to other functions which leads to a local optimization. Therefore, any attempt to improve the flow would not be as effective without changing the KPIs.

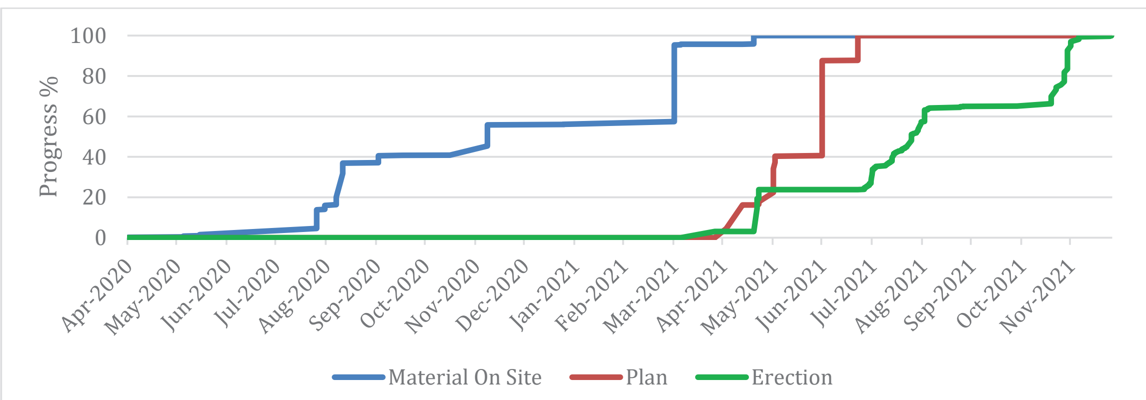

Figure 2: Material Delivery Vs. Erection Plan (measured in metric ton)

DEVELOPED FRAMEWORK

Based on the analysis of the data collected, three bottlenecks are found to impede the flow of material and its management process: the bidding bottleneck, the manufacturing bottleneck, and the storage bottleneck. These are viewed to negatively impact the project performance and are a critical indication for a substantial needed process improvement. The proposed framework is based on a pull system and a just-in-time material flow to reduce the process waste by introducing changes to the responsibility matrix and setting time limits based on data analysis. Namely, an enforceable timeline is introduced to managerially deal with each bottleneck. The timeline is determined based on oil and gas EPC industry best practices and may change depending on the industry and type of equipment/material. Starting with the bidding process, the timeline is set at 14 days with continuous communication between the engineering function and the procurement function and monitoring of the suppliers. This time limit is based on the activities of procurement in this project (2 days for floating the request for quotation to suppliers, 5 days for suppliers to compile and submit their offers, and 7 days for reviewing the offers and issuing purchase orders). Any delay in this process will be monitored by the project manager. Then, the manufacturing process timeline is set to 30 days. As described in the analysis section, a lot of the manufacturing time waste is due to rework resulting from the comments received during the inspection stage. Finally, the storage process timeline is set to be in the range of (0 to 7) days; this process is the most challenging bottleneck in the material flow due to the prolonged idle times of material in the warehouse. To this end, a pull system is implemented to regulate this process by signaling to the logistics teams the shipping date of the equipment that ensures its arrival at the site by the time it needs to be installed.

Moreover, the proposed framework includes changes to the responsibility matrix to ensure that the reporting structure supports a collaborative effort rather than being solely based on the achievement of individual milestones. Figure 3 illustrates the updated responsibility matrix and the newly introduced lines of communication (illustrated by solid lines) between different functions managers in addition to introducing the durations allowed to several activities to guide the process and make it more systematic. Namely, the proposed framework introduces the following changes:

- Adding a direct communication line between procurement manager and engineering manager for bidding process.
- Adding a direct communication line between delivery manager and quality manager for expedited manufacturing and testing at vendor sites.
- Adding a direct communication line between site material manager and site quality manager.
- Adding an indirect communication line (illustrated by dotted line) between site manager and procurement manager to initiate the procurement process in a timely manner.
- Adding an indirect communication line (illustrated by dotted line) between site manager and logistics manager to ensure material is delivered within a week of construction readiness based on the schedule.

To ensure the framework is followed and any deviation is escalated and consequential, new KPIs are introduced:

- Procurement manager: ensure the bidding process is done within 14 days - accountable for any excessive time.
- Delivery manager: ensure manufacturing is done within 30 days - accountable for any excessive time.
- Logistics manager: ensure delivery within 60 days.
- Site manager: timely signals to procurement and logistics (percentage)

Moreover, to maintain a feedback loop for any material that exceeds the 7 days limit, a root cause analysis must be conducted and reviewed by the site manager. However, given that the KPIs are not reviewed regularly, the material flow process needs to be monitored in the weekly inter-disciplinary meetings and to be continuously signaling to function managers. This process can be maintained using a frontend user friendly interface that takes the inputs from expediters or project engineers and sends alert signals to responsible managers based on the following questions represented in Figure 3:

- Are offers received and reviewed within 14 days?
- Is the shipping schedule within 60 days?
- Is the delivered equipment ready to be installed (logistics input)?
- Is equipment spending more than 7 days in the store?

The frontend interface will derive its protocol from Figure 3 and is illustrated in Figure 4.

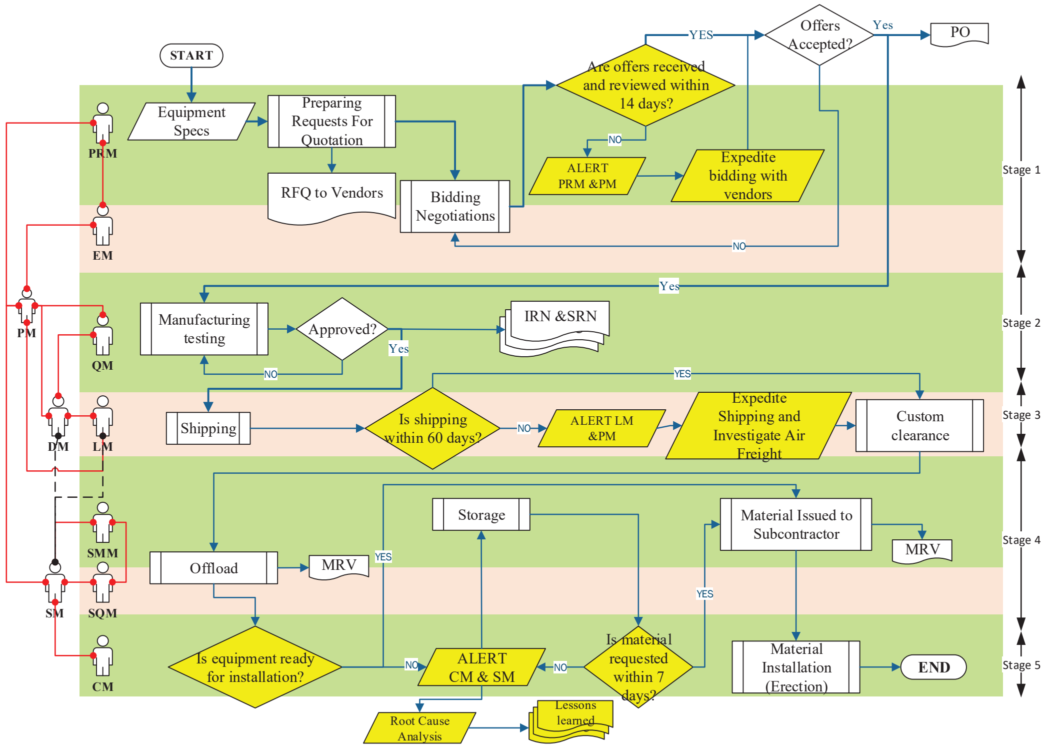

Figure 3: Flow of Material in the Proposed Framework

The input to the interface illustrated in Figure 4 is under the responsibility of the quality engineer, package engineer or material controller. The alerts will be sent automatically when the dates conflict with the set time limits. The alerts will be in the form of high priority emails to the respective function manager and will be raised in the weekly meetings. The number of alerts will be a key measure to determine the performance of each manager against the proposed KPIs.

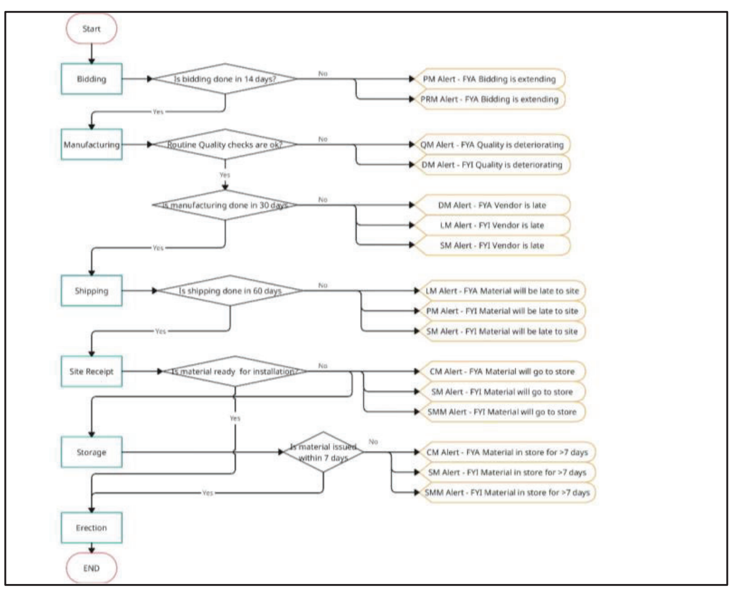

Figure 4: Frontend Interface for Material Tracking and Alerts

APPLICATION OF THE PROPOSED FRAMEWORK

To illustrate the enhanced material management process, the proposed framework is applied to the project data to show the magnitude of storage cost reduction (as an example of waste reduction and improved performance). To this end, a probabilistic model was built to measure the change in storage cost. The model considers an ideal scenario where the flow of material is not interrupted and the material arrives at site on time, and a worst-case scenario where the material remains in store for 7 days. The analysis was conducted using MS Excel and Palisade @Risk probabilistic tool. To check the effects of the proposed framework on the storage cost, the proposed system assumes that the material will ideally not spend any time in store, and if it does, it should be in storage for a maximum of 7 days. This was represented as a discrete probability density function with an 80% probability that the equipment will be erected within the same day of arrival without any time at store and a 20% probability that the equipment will be at the warehouse for 7 days as a worst-case scenario.

Using the $/sqm estimation calculated from the actual data, the output of this analysis is the summation of the storage cost for all items. This output is compared to the original storage cost of $204,000. The simulation was done using a Monte Carlo Simulation for 10,000 iterations. The results of the simulation for storage costs are illustrated in Figure 5.

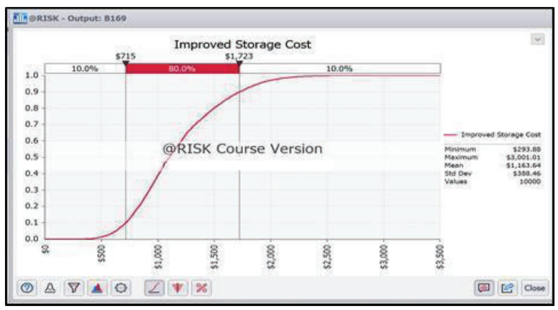

Figure 5: Simulation Results for Storage Costs

Figure 5 shows that there is a 90% probability that the storage cost will be less than $1,800. This figure represents a massive improvement compared to the original cost of $204,000. The simulation was repeated at different test conformity levels (50% and 30%). The results of the simulation are summarized in Table-2 and show the expected storage cost with a probability of 90%.

Table 2: Storage Cost Simulation Results

Conformity Level	Storage Cost at 90% Confidence
80%	$ 1710
50%	$ 3511
30%	$ 4489

The proposed system redefines the warehousing strategy and ensures equipment remain in the warehouse for the minimum days. This is almost a total elimination of the inventory waste in the warehousing system. Another important improvement can be noticed at the level of inventory management. The previous analysis showed that the inventory in the warehouse kept piling up for almost a year until it reached a maximum of about 500sqm floor area in the warehouse. Based on the new proposed framework, an inventory model was built considering the worst-case scenario of all items spending 7 days in the store, the inventory curve is shown in Figure 6.

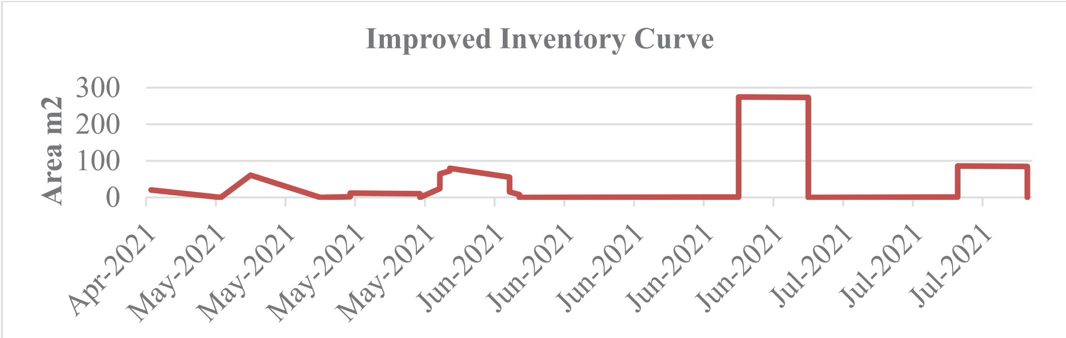

Figure 6: The Improved Inventory Curve

Figure 6 illustrates that the inventory is levelled at about 80sqm and keeps on emptying from the warehouse without piling up. This is a very good indicator that the system is effective in eliminating inventory waste. A spike is observed in June-2021, this is due to a large delivery lot. Although this would need a warehouse, it could be mitigated by renting space in the available warehouses on site to avoid the need for a new warehouse. For the other inventory peaks (May-21) the scenario can be eliminated by using other warehouses or simply by keeping the material in the truck for a couple of days to reduce handling cost and storage cost.

DISCUSSION

The simulation results provide an example of waste reduction as an illustration of the improved performance of the material delivery and management process. The simulation model derives its variables from the set time limits; these are project-specific and, therefore, are not rigid. Namely, the location of the case study was the driving factor in setting the time limits. The proposed framework, however, can be applied to other EPC projects since the material flow process is similar, but with necessary adjustments to the time limits and the KPI's derived from them. Additionally, the results illustrate an ideal scenario where unforeseen conditions are not affecting the erection of material. For instance, one of the reasons for the prolonged erection duration in the case study (244 days) is the breakout of the Covid-19 pandemic and lack of workforce on site. Should the proposed framework have been in place at that time, it would have helped in mitigating the delays and facilitating the implementation of a quick mechanism to compress the schedule due to the accountability loops. Moreover, beyond improving project performance in terms of schedule and cost reduction, the smooth and continuous flow of material is viewed to also ensure less material handling and congestion on site, therefore it is expected to improve the safety performance. However, a deeper investigation of these impacts presents an interesting future research opportunity.

CONCLUSION

The construction industry is witnessing an increased client's demand for a lower project cost and a faster project completion. In an EPC project, the monetary value of procurement contributes to more than engineering and construction combined. However, material management is yet to evolve from the conventional push system to a more efficient one. Following an analysis conducted on real EPC project data, the study shows that the flow of material in a conventional material management process is plagued with excessive waste. In-depth analysis of the waste embedded in each stage resulted in the identification of three major bottlenecks in the bidding, manufacturing, and storage stages. Accordingly, a framework based on a pull system and a just-in-time material flow is proposed. The framework aims to reduce the various waste embedded in the process by introducing changes to the responsibility matrix and setting time limits based on data analysis. Namely, an enforceable timeline is introduced to managerially deal with each bottleneck. The framework is tested using a probabilistic Monte Carlo simulation. The results show a significant decrease in the storage cost, as an example of waste reduction, providing an illustration of the enhanced material delivery and management process. The framework provides a practical solution to EPC companies that minimizes non-value adding durations and ensures a continuous material flow with continuous feedback and accountability loops.

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