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MATERIAL AND FACILITY LAYOUT PLANNING IN CONSTRUCTION PROJECTS USING SIMULATION

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ABSTRACT

Layout planning for construction projects comprises two tasks: facility layout planning (FLP) and material layout planning (MLP), which has significant impacts on project cost and time. FLP specifies where to position temporary facilities on the site, and MLP determines the position of the material in the storage yard. This study focuses on MLP and describes a simulation-based method to improve material yard layout. In this method, simulation is employed for modeling the material handling process to evaluate material handling time. Due to the broad domain of possible solutions, simulation is integrated with genetic algorithm to heuristically search for a near optimum material layout with the least haulage time. The implementation of the proposed method is demonstrated in a case study which shows the superiority of the developed method over conventional methods. This paper also discusses how the results of this research can contribute to FLP.

1 INTRODUCTION

In construction projects, layout planning can be attributed to two tasks: facility layout planning (FLP) and material layout planning (MLP). In FLP, the location of temporary facilities on construction sites is determined, while MLP concerns where to position different materials in the material laydown yard. Although some differences exist between these two tasks, they have some similarities. In both tasks, facilities or materials are distributed and positioned. The main objective of both tasks is to minimize the transportation time/cost. In addition, there are some constraints apart from the transportation time/cost that should be considered in the positioning process of facilities or materials. Hence, the research conducted on one of the areas can be contributed to another one with some adjustments. This paper provides a brief description of FLP and MLP. Then, a simulation based approach for improving MLP is proposed. The contributions of the proposed approach to FLP are stated in the conclusion.

2 FACILITY LAYOUT PLANNING

Facility layout planning is part of construction site layout planning. In site layout planning, the type, size and location of temporary facilities such as offices and tool trailers, equipment, fabrication yards, laydown areas, warehouses, maintenance shops, batch plants, residence facilities, and parking lots ((Tommelein 1992, Sebt, Karan, and Delavar 2008) should be determined. The location of facilities influences different aspects of construction projects such as equipment, worker and material transportation time and cost, safety and environmental issues, and accessibility. Maximizing safety and minimizing transportation time/cost are the major objectives in FLP. Generally, the conventional FLP methods have attempted to optimize the following term as an objective function:

$$f = \sum_{i=1}^{N} \sum_{j=1}^{N} W_{ij} d_{ij} \tag{1}$$

where W_{ij} is the weight assigned to the interaction of the facilities i and j, d_{ij} is the distance between facility i and j, and N is the number of facilities. W_{ij} can be defined as the cost per unit length ($/m) for traveling from facility i to j to consider transportation cost, or it can be defined as a qualitative scale to consider transportation cost and/or some closeness constraints such as safety and environmental concerns, accessibility, technical issues or user preferences. In FLP, some of the safety risks such as “falls, falling objects, site transportation, and hazardous substances” can be prevented (Anumba and Bishop 1997). In the literature, three approaches have been adopted for taking safety and environmental issues into account in FLP, as follows:

- Qualitative approach, which determines closeness weights in the objective function (Equation 1). Elbeltagi, Hegazy, and Eldosouky (2004) and Sanad, Ammar, and Ibrahim (2008) used this approach as a part of their models.
- Quantitative approach, which tries to define a quantitative index for evaluating safety of sites. El-Rayes and Khalafallah (2005) developed a model to quantify construction safety in three sectors: crane safety, hazardous material safety, and safety of travel route intersections. Karan and Ardeshir (2008) followed El-Rayes and Khalafallah’s study by considering and quantifying three more safety factors including scaffolding safety, falls and falling objects, and excavation safety.
- Hard constraints approach, which defines safety considerations as hard constraints. Hard constraints are discrete, which means that they are either satisfied or not. This approach is suitable to identify hazard zones, and excludes them from the areas where the facilities can be positioned. Sanad, Ammar, and Ibrahim (2008) and El-Rayes and Said (2009) implemented this approach in their studies.

The layout of the facilities can be fixed for the entire project time and considered static site layout. In contrast with static layout, dynamic site layout planning, which is defined as “creating layouts that change over time as construction progresses” (Zouein and Tommelein 1999), is able to consider reuse of space, relocation of resources, and changing space requirements over time (Zouein and Tommelein 1999, Andayesh and Sadeghpour 2011). The main drawback of the developed models for dynamic site layout planning is that they divide the project time into several time spans and try to sequentially optimize layout in each span based on the correspondent objective function, while the combination of those layouts may not lead to the global optimum layout (Andayesh and Sadeghpour 2011). Even if these models consider relocation costs to rearrange existing facilities, it should be noted that relocation of facilities depends on the layout planned in the previous span. Thus, by altering the previous layout, it may be possible to avoid relocation and decrease the total cost. To address this drawback, the concept of global optimum layout was raised in recent years by El-Rayes and Said (2009).

FLP can be a complicated process when the objectives are conflicting and the influencing factors are interdependent. Furthermore, the layouts enhanced from optimizing the objective function are not guaranteed to be the optimal ones when facilities are interacting (Zhou, AbouRizk, and AL-Battaineh 2009). That is, this objective function cannot model and account for the reality of the construction projects. This drawback entails inefficiency of the developed site layout in practice, and is a root cause of the fact that the practitioners still rely on their experience for FLP. Hence, a more sophisticated approach is needed to predict the efficiency of the facility layout plan in real world construction processes. Simulation can address this drawback due to its capability to model complexity of construction operations and dynamic interactions of various factors. It can model the impact of facility layout on construction operations, and examine the efficiency of the facility layout in practice with a certain level of confidence. One of the first applications of simulation in construction site layout planning was presented by Tommelein (1999) to find the optimal number of tool rooms and their positions. After that, Zhou, AbouRizk, and AL-Battaineh (2009) implemented simulation to evaluate the optimized site layout resulting from GA optimization of the fitness function in tunneling projects. Recently, to design service facility layout in a renovation project of a train station, Lee (2012) integrated simulation with Ant Colony to minimize walking time of passengers. However, the full potential of simulation has not yet been employed in this area, and more research efforts are required for improving FLP in construction projects using simulation.

3 MATERIAL LAYOUT PLANNING

Material layout planning is a part of material management in construction projects and includes layout and organization of laydown areas and warehouse facilities and development of storage plans. Proper laydown yard management will bring about improved craft labor productivity due to easy, quick and inexpensive access to material, minimized material surplus and reduced rework. An optimized yard layout entails efficiency in terms of time and cost for decision makers who seek increased performance in material tracking, availability and accessibility. On large construction yards, equipment units such as different types of cranes, forklifts, trucks and carts are deployed to transport the material from the storage yard to the consumption unit as a destination. Timely delivery of the material is critical particularly when a construction schedule is tight. Additionally, equipment utilization should be considered to reduce costs. The location to place materials determined in MLP directly affects the abovementioned factors. Thus, experts seek tools by which they can quantify the best management techniques and identify the key steps towards finding the optimum layout design for construction material yards.

In practice, generally, materials are placed based on the availability of free laydown areas, and proximity to the destination (e.g. point of exit, or consumption unit) to reduce transportation time while satisfying yard constraints. That is, the main objective in MLP is minimizing material transportation time/cost for which Equation 1 can also be applied. Yard constraints depend on the type of materials and their characteristics such as compatibility constraints (only materials of the same type can be stacked in one laydown area) and safety concerns.

Similar to FLP, the layout proposed from simulation methods can be of great assistance in MLP because simulation can model the material handling process, consider resource interactions (e.g. equipment), and predict the material transportation time. In past studies, simulation has been implemented in MLP. Marasini, Dawood, and Hobbs (2001) tried to design and manage the stockyard layout of precast concrete products using simulation. The main objective of their study was to reduce the throughput time. Simulation was also used to evaluate two different strategies for storing material: central storage and decentralized storage, in construction projects by Voigtmann and Bargstadt (2008). In the next sections, the research methodology for MLP is described and applied to a case study.

4 RESEARCH METHODOLOGY

In this research, the main objective is to propose a model to find the optimum or near optimum layout for material laydown areas. The optimum layout is a feasible layout, which satisfies yard constraints with the minimum material handling time. Reducing material handling time results in less delay time for delivery of the material from the yard to its destination (e.g. consumption unit), and less transportation cost.

To this end, first, the current practice of MLP in a typical steel fabrication project is studied. In steel fabrication projects, given a material delivery schedule and material consumption schedule, the receiver (the person receiving the material from the provider of the material), can make a decision on where to place the material. Changes, disruptions and delays in material procurement, delivery, and consumption cause unpredictability in material delivery and material consumption schedules. To mitigate these problems, a proper change management system should be implemented. Based on the level of controlling construction uncertainties in projects, two material placement policies can be identified in MLP termed as "reactive placement policy" and "proactive placement policy." In the case of a high level of uncertainties, the receiver does not have the material arrival and consumption schedule for a long period of time informing him/her what material arrives at site and what material will be consumed and leave the storage yard on the days ahead. This information is provided for a very short time window (e.g. on a daily basis), and the receiver should react on that basis, that is, this approach is termed as "reactive placement policy." For the proactive placement policy, on the other hand, a low level of uncertainties can provide the receiver with a material arrival schedule and material consumption schedule for a longer period of time (e.g. on a monthly basis). In other words, the receiver has thorough information (in the form of a schedule) on the incoming and outgoing materials prior to their arrival and release, giving her/him leeway to decide where the material can be stocked.

For making decision on material placement in both approaches, the receiver should consider the following constraints and factors:

- Dynamics of material incoming and outgoing, and availability of space in the yard
- Material handling time
- Logistics of the yard (e.g. material handling methods and equipment)
- Geometry of the yard (e.g. yard dimensions)
- Yard constraints (e.g. reserved space for special jobs, and material compatibility)

The next step is to develop a model to optimize the material yard layout considering the abovementioned factors and constraints for the reactive and proactive placement policy. Since the model should be able to evaluate the material handling time, and consider the resource interactions and dynamics of the process, simulation is proposed to model the material handling operation. Simulation is capable of modeling the complex interaction between resources, measuring their utilization, waiting time and idle time, which are key components in determining the material handling time. This feature makes simulation superior to commonly-used methods such as optimizing the sum of weighted distance function (Equation 1). Simphony (Hajjar and AbouRizk 1996) is a simulation tool used for modeling purposes.

Moreover, due to a broad domain of possible solutions for placing materials, particularly for the proactive approach, which considers a longer period of time, it is impractical to examine all the solutions. As a result, a heuristic optimization method is implemented to find the near-optimum solution. In this research, genetic algorithm (GA) is employed to produce feasible solutions considering the yard constraints. See Mitchell (1999) for more information on GA. Through the optimization process, simulation and GA are fully integrated. Figure 1 demonstrates how simulation and GA interact in the proposed model. As seen in Figure 1, incoming and outgoing material schedules, yard geometry, and yard constraints are the inputs for GA. Based on that information, GA tries to produce feasible solutions for material layout. Those solutions are sent to the simulation model to examine the material handling time. The results are given back to GA to produce a new layout achieving less material handling time. While no improvement is achieved through this loop, the optimization operation stops and the near-optimum layout is determined. This interaction is done in both the reactive and proactive approaches.

The only difference in this process for the two approaches is that the layouts produced in the reactive approach are for a short period of time (e.g. a day), and those in the proactive approach are for a long period of time (e.g. 30 days). While the incoming and outgoing schedules are provided on a daily basis, the layout produced each day for the proactive approach can be influenced by the layout produced on the prior days, and can influence the layouts for the days ahead. These influences are due to the fact that the layout for each day creates new constraints based on space availability and yard constraints, as described earlier. As a result, GA should take into account these dynamic changes for producing the layout for each day in the proactive approach. Figure 2 shows the procedure of producing feasible layouts for the proactive approach for *n* days. On each day (*Di* where *i* is the day number) the input data for producing the feasible layout (*Layout (Di)*) are updated. It should be emphasized that the optimum layout is not an optimum layout for each day, but is a set of layouts that are optimum for all days. In other words, GA does not optimize the layouts separately, day by day, because the combination of those layouts does not necessarily lead to the minimum total transportation time due to the influence of each layout on the next layouts. In fact, GA tries to find the global optimum layout for all days, which results in the least total transportation time in the considered period of time.

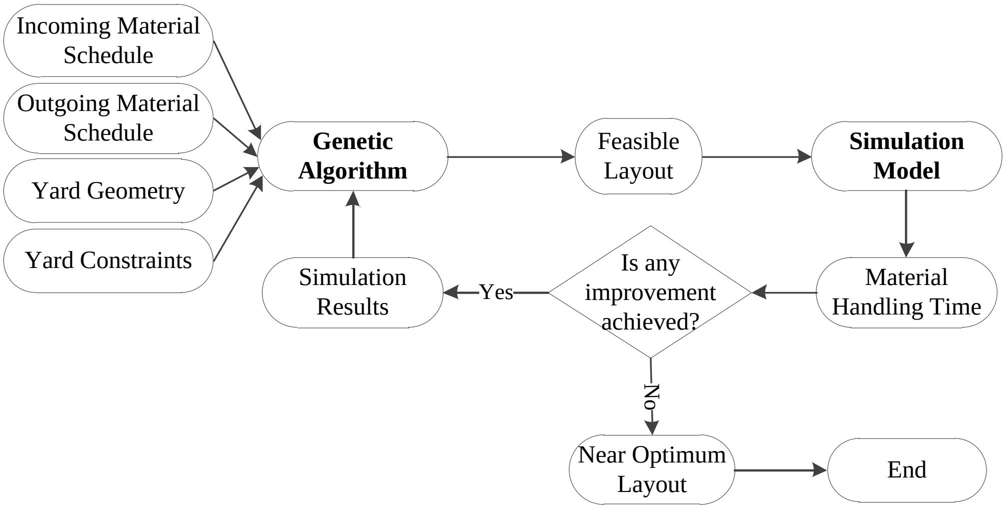

Figure 1: Interaction of simulation and GA

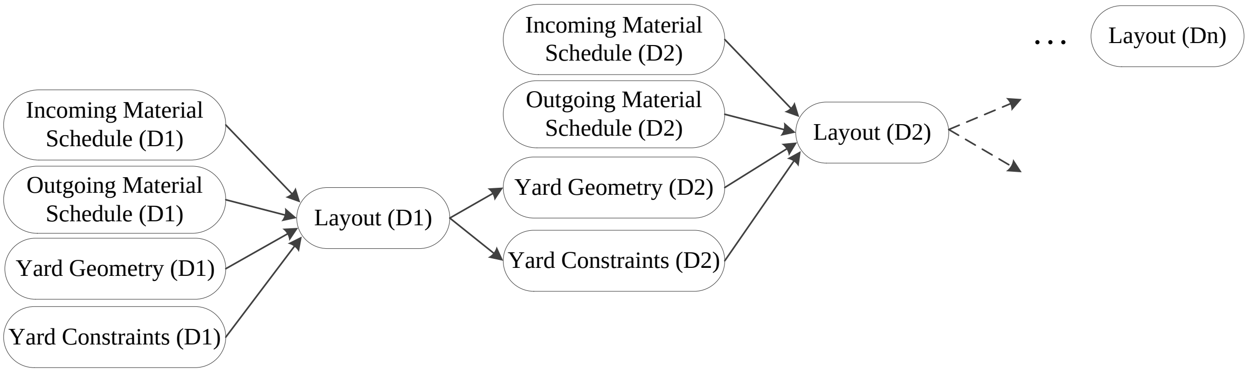

Figure 2: Producing feasible layout for the proactive placement approach in GA

5 CASE STUDY

In this section, implementation of the proposed model for MLP of the yard laydown area in a steel fabrication project is studied. Figure 3 exhibits the geometry of the yard and its initial conditions at the beginning of the study. The yard consists of 20 cells divided into north and south yards for accommodating the steel materials. In each side of the yard, one overhead crane is working: the north crane and south crane. The capacity of each crane is 15 tons. The cranes are responsible for transporting materials from the corresponding yard to the rail and car system located in the middle of the yard. The travelling speeds of the crane and car are 5 and 4 km/h, respectively. The cranes offload the materials in the car and the car transports them to the point of exit to feed the fabrication shop. The crane loading time and unloading time is 20 seconds. In the described material handling process, there is an interaction between the cranes and the car. Since there is only one car available, a crane cannot offload the material in the car when the car is serving another crane or travelling. As a result, that crane should wait until the car is available. This waiting time prolongs the transportation time. As shown in Figure 3, two cells reserved for a specific job are not available for placing the material. The initial condition of the yard includes the yard inventory presented in Table 1, also shown in Figure 3. Compatibility of the material should also be applied as a constraint in placing the material in cells, which means that materials of the same type can be positioned in one cell. Implementing the proposed integrated model, GA and simulation are interacting to find the near optimum material layout stored in the vacant cells. In this interaction, GA produces feasible solutions (i.e. the position of the incoming materials) for simulation. Simulation evaluates the total material transportation time of those solutions and returns the results to GA. Resuming this cycle, GA-simulation model attempts to produce better solutions to minimize the transportation time.

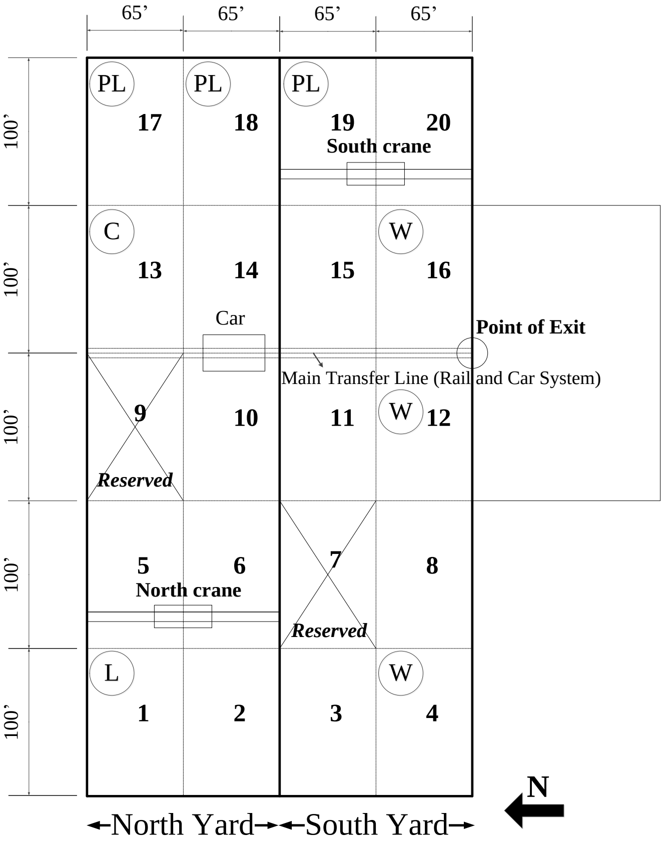

Figure 3: Yard geometry and initial conditions

In this case study, initially, the reactive placement policy approach is adopted for placing 10 batches incoming on one day and 9 outgoing batches, as presented in Table 2. It should be noted that the outgoing materials are selected based on the closeness of the available material to the point of exit, which is a common industry practice. That is, the outgoing material can be independent from the incoming material and the outgoing materials are selected from the existing material on the yard, not the new arrival materials. This independency is further discussed in the proactive approach.

To demonstrate the superiority of the simulation-based method over optimizing the sum of weighted distance function (SWDF), the layout is also optimized using Equation 1, where w represents the weight of the incoming batches, d is the perpendicular distance of the material position to the exit point, and n is the total number of the incoming batches. The enhanced layout from optimizing the sum of weighted distance function is also simulated to measure the haulage time. Table 3 shows the haulage time of the simulation-based result and SWDF result. Comparing these results proves that simulation-based method could reduce the haulage time by about 16%.

Table 1: The yard inventory

Cell #	**Quantity ×(Material)**
1	215×(L8x8x1/8)
4	170×(W8x24)
12	102×(W8×24)+400×(W10×30)+50×(W14×43)
13	100×(C10×15.3)+100×(C8×13.75)+100×(C15×50)
16	300×(W8×24)+158×(W10x30)+50×(W14x43)
17	88×(PL3/8)+30×(PL1)+20x(PL1/2)
18	10×(PL3/8)+10×(PL1)+10×(PL1/2)
19	10×(PL3/8)+10×(PL1)+10×(PL1/2)

Table 2: Incoming and outgoing materials and material layout in the reactive placement approach

Incoming Material			**Outgoing Material**	
Type	**Quantity**	**Placement cell #**	**Type**	**Quantity**
L6x4x3/8	5	3	L6×4×3/8	10
L6x6x3/8	20	8	C10×15.3	300
L8x8x1/8	15	20	C8×13.75	450
C10x15.3	200	11	W8×24	10
C8x13.75	300	15	W10×30	10
W8x24	50	16	W14×43	10
W10x30	50	16	PL3/8	10
W14x43	50	12	PL1/2	15
PL3/8	10	19	PL1	5
PL1/2	15	19	-	-

Table 3: Material haulage time comparison using two optimization methods

Material haulage time (min)	
Simulation-based method	SWDF method
130.0	151.5

For the proactive approach, a 30-day period is studied. During this time, 71 batches are coming to the yard and 271 batches are going out. For brevity, Figure 4 illustrates a comparison chart between total volumes of the inputs, and outputs, and volume of the available materials on the yard on day 1. It is seen in this chart that the inventory cannot meet the material needs of the fabrication shop, i.e. L6×6×3/8 and L6×4×3/8. On the other hand, for some materials, such as PL1 and PL1/2, it is supplied from the inventory and the incoming material. It should be emphasized that planning for the purchasing department takes place as discussed above, and often times, the material flow on the yard and its logistics might not be accounted for meticulously. It is the job of the receiver or material handling manager to decide which laydown spaces would be the best places to stock material on, given this holistic purchasing plan, which is directly impacted by the fabrication shop demands.

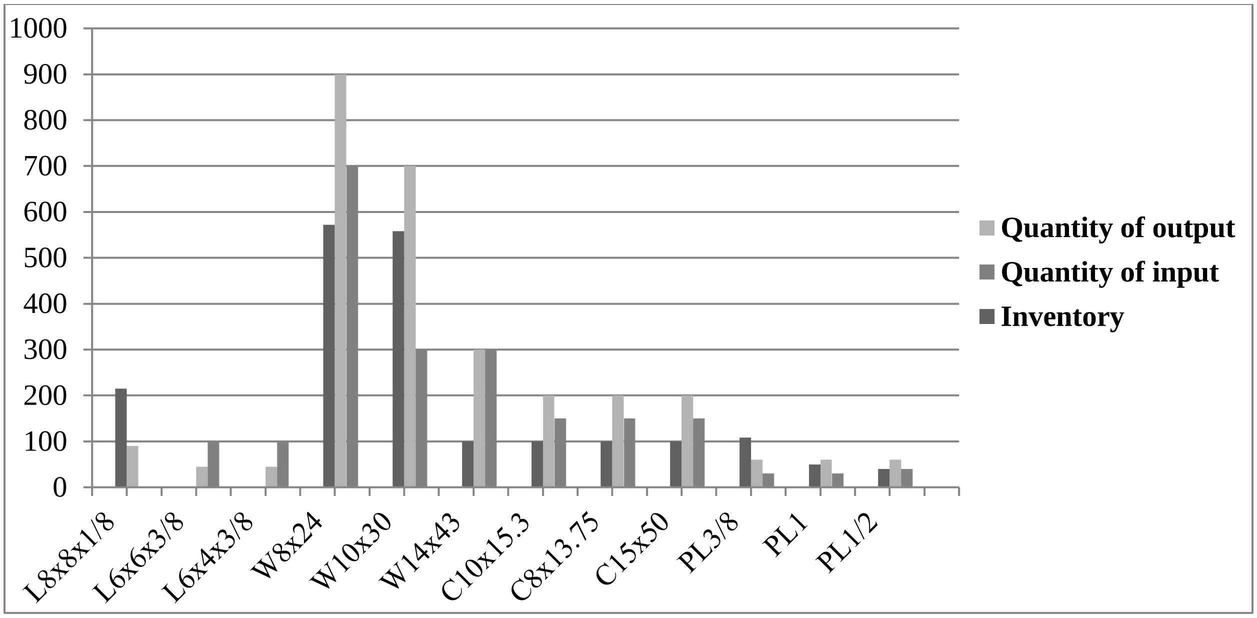

Figure 4: Total volume comparison between inputs, outputs and inventory on day 1

Similar to the reactive approach, the developed model determined the optimum position of the material batches on the yard based on the cell number. To further highlight the significance of simulation, one can delve a little deeper into simulation capabilities in modeling the resource interaction on the yard. It would be noteworthy to determine the waiting time of the cranes for the car. Simulation can provide the total waiting time of the cranes as the car is the key resource during the material haulage operation serving the two cranes. The amount of waiting time for the car may reveal how important resource interaction could be in the entire optimization process. Table 4 shows total simulation time of 7 selected layouts through optimization where layout #7 is the optimum layout. It is observed that the amount of waiting time could go in excess of 1% of the entire haulage time. It is also seen in this table that as the optimization progresses from layout #1 to #7, the waiting time decreases significantly, which further underlines the role of simulation in optimization.

Additionally, simulation can readily present the utilization time of the cranes, which reveals how equipment resources are used during the placement operation. Table 4 shows utilization percentage for the north crane, proving that the optimum layout is the one that strives to stock the materials on the south yard as much as possible. The utilization data shows the optimization is more resource-oriented than distance-oriented, as the utilization of the north crane decreases as the fitter solutions are introduced. Smooth interaction of the south crane and the car, without having to wait for the north crane to be served, would be a good leading roadmap for the optimization process. This can be further proven by separating the waiting time of the south crane from that of the north crane. It is seen that as the utilization of the north crane decreases, the waiting time of the south crane also decreases, which would ultimately lead to a more optimized layout. However, it is understood that once the yard is more congested, the north crane would have to be utilized to serve the materials on the north yard. The discussions given above would merely highlight the significance of the simulation in constantly evaluating the proposed layout. The merits that can be brought upon the GA optimization problems in construction should not be ignored in favor of the more simplified SWDF method. It should also be emphasized that by incorporating stochastic data into the simulation model due to uncertainties in the input data, the accountability of the model can be promoted.

Table 4: Crane utilization and waiting time for the car

Layout #	**Total Haulage Time (HT)**		**North Crane**		**South Crane**	**Total Waiting Time (WT) (min)**	**WT/HT (%)**
	Hour	Minute	Waiting Time for Car (min)	Utilization (%)	Waiting Time for Car (min)		
1	23.2781	1396.686	4.29	63	10.3	14.59	1.04
2	23.079	1384.74	4.41	59	9.4	13.81	1
3	22.979	1378.74	4.3	57	8.9	13.2	0.96
4	22.4718	1348.308	4.17	49	7.4	11.57	0.86
5	22.2529	1335.174	4.16	45	6.86	11.02	0.83
6	21.8946	1313.676	4.09	39	6.05	10.14	0.77
7	27.7951	1307.706	4.11	37	5.77	9.88	0.76

6 CONTRIBUTION OF THE DEVELOPED MODEL TO FLP AND CONCLUSION

As discussed earlier, MLP and FLP have some similarities. First, the main objective of both tasks is to minimize the transportation time/cost. In MLP, only material transportation time/cost is considered, while in FLP material, workers and equipment transportation time/cost should be accounted for. In the proposed method, simulation was utilized to evaluate material transportation time. As such, simulation can be used to evaluate the transportation time of the other resources, i.e. workers and equipment. In addition, in MLP, the constraints are applied in GA while producing a feasible layout. As mentioned earlier, FLP has similar constraints, particularly safety constraints, which can be modeled as hard constraints. As in MLP, these hard constraints can be considered in GA while creating feasible facility layouts. Then, the feasible facility layouts are evaluated by simulation for measuring transportation time/cost. That is, the developed model for MLP can be adopted for FLP with slight adjustments. Furthermore, two identified approaches for placing material, i.e. the reactive and proactive policies, are similar to static, dynamic and global optimum facility layout. In the reactive approach, the material layout is designed for a short period of time, which is similar to static facility layout. Both consider a snapshot of the layout and try to optimize it without any changes over the designed period. If the reactive approach is replicated for sequential periods, it will be similar to dynamic site layout planning where the project time is divided into some time spans and the facility layout for each span is optimized sequentially. This method ignores the influence of each layout on the successor layouts. The proposed proactive approach can consider this influence by changing the layouts for all designed days and minimize the total haulage time. Hence, a similar approach to proactive approach can be implemented in FLP for finding the global optimum facility layout.

The superiority of the model developed in MLP is proven in this research, as follows:

- Simulation can model the material handling process and consider resource interactions, which is not possible in other methods.
- The developed model can minimize material handling time, while minimizing transportation distance does not necessarily lead to minimum haulage time under a tight schedule and close interactions of the resources.
- Integration of simulation with GA aids in the search for the near optimum layout.
- The yard geometry and constraints can also be considered in GA when producing a feasible layout.

- The reactive and proactive approaches can be modeled for the projects with different levels of uncertainties in material delivery and consumption schedule.

Exploiting the findings of this study, the proposed research methodology is tailored to solving the facility layout planning in the future studies.

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