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A Hybrid Genetic Algorithm-Simulation Optimization Method for Proactively Planning Layout of Material Yard Laydown

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Abstract

This paper presents a hybrid optimization method combining genetic algorithm (GA) and simulation for planning the layout of material yard laydown areas. An optimized material yard layout entails efficiency in terms of time and cost for decision makers who seek increased performance in material handling, availability and accessibility. Laying out materials on yards is mostly performed reactively in current practice, where the planner decides daily where to position the incoming materials, based on the list of material arrival and required materials for consumption, received daily. This policy cannot account for dynamism of material flow in and out of the yard during a construction project. In contrast, a proactive materials placement policy can be used to address this concern based on incoming and outgoing material schedules for a certain period of time. This paper aims to evaluate the proactive material placement policy and present an integrated framework to determine the optimum layout for placing materials resulting in minimum material haulage time. To this end, a hybrid optimization is implemented through a case study from the steel fabrication industry, where an effective materials handling method could be of great significance. The major contribution of this work is development of an

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approach that performs dynamic layout optimization of materials arriving at construction yards, using GA to heuristically search for the solution, and use of simulation to model the material handling process and determine the material haulage time. Results of the analyses show clear merits of proactive material placement over the reactive strategy and demonstrate the importance of GA and simulation integration to obtain more realistic outcomes.

Key words: *material management, material handling, layout planning, simulation, genetic algorithm, hybrid optimization.*

Introduction

Having efficient materials management and materials handling systems is one of the key elements of successful completion of construction projects, while inefficiency of these systems adversely impacts project time and cost. Loss of productivity, delays, increase of indirect costs of delivery and use of material, re-handling and duplicate orders are among the consequences of poor material planning and management (Perdomo and Thabet 2002). Material management studies are widely published in the literature. Some researchers (e.g. Gambardella et al. 1998; Zhang et al. 2003; Crainic et al. 1993) have focused on various challenges in terminal yards such as allocation of resources and space, and scheduling of operations. Lee et al. (2006) developed a mixed integer-programming model for resolving yard storage allocation problem in a trans-shipment hub. For managing material storage and minimizing transportation costs, some studies such as Huang et al. (2010) and Fung et al. (2008) concerned different optimization methods for minimizing transportation distance in multi-story buildings.

Tommelein (1994) indicated that uncertainty existing during advanced planning is one of the root causes of inefficient material storing and handling. In projects where unique materials should be used in specific locations, the material supply uncertainties entail mismatching problems between materials and locations, resulting in loss of productivity (Tommelein 1998).

To take into account uncertainties in construction projects, experts have utilized simulation as a suitable planning tool for productivity measurements, risk analysis, resource planning, design and analysis of construction processes and methods, and minimization of project costs or duration (Sawhney et al. 1998, AbouRizk 2010). Simulation has shown to be effective in modeling of a number of situations that other tools fail to model, including examining the interaction between flow of activities, determining the idleness of productive resources, and estimating the duration of construction projects (Zhou 2006). It also provides a fast approach to experimenting with different scenarios without changing the systems themselves (Zhou 2006). Tommelein (1998) used simulation to examine different alternatives in material delivery schedule of pipe spool fabrications and address the mismatching problem. Marasini et al. (2001) focused on identifying the appropriate simulation-based approach for designing and managing the precast concrete stockyard layout that ensures efficient storage and dispatch of products.

Although warehousing and material distribution are some of the main functions in material management systems (Bell and Stukhart 1986), and improper storage is recognized as one of the deficiencies of material management (Thomas et al. 2005), few researchers focused on how to distribute materials on yards and plan material layouts in order to have efficient storage. This problem is escalated in the material laydown areas of the fabrication shop. Song et al. (2006) reported that the uncertainty in material management of fast track industrial projects, particularly pipe spool fabrications, leads to delivering the materials 5 to 6 months prior to the installation schedule. Maintaining and managing the materials stored for a longer period of time in laydown yards need a sophisticated planning system. To plan material yard layouts, it is necessary to capture the effect of material consumption, material size and density, capacity of laydown areas and number of available equipment resources on the reduction of the throughput time. In particular, the dynamic nature of material handling should be considered in terms of changes, disruptions and delays in material delivery and consumption plans. To reflect these factors, two primary material placement policies in large construction yards can be identified:

- Reactive placement policy, where the layout planners only receive daily lists of material arrival and required materials for consumption. Thus, they should react daily for positioning the incoming materials.
- Proactive placement policy, where the layout planners are given a material arrival schedule (as opposed to daily arrival list) informing them about the materials that will arrive at the site, for a certain period of time. That is, given a 10-day schedule, the planner knows precisely what material will come to the yard on the fifth day, for example, and what material is going to be used by the consumption unit on the same or a different day.

Alanjari et al. (2014) proposed a simulation-based approach to model reactive placement policy and optimize material yard layout. In light of that research, this study focuses on improving proactive placement policies.

Proactive Versus Reactive Material Placements

To further highlight the differences between proactive materials placement approach and reactive approach, two methods of materials placement are discussed, as shown in Figure 1. Since most construction companies use yard segmentations and a defined grid location system as a map to efficiently find a place for positioning materials and track their locations in practice, it is assumed that the map of the yard is given in nine cells where two of them are available for placing the materials. In Figure 1, two situations have been compared: in the first one (a), 20 batches of iron angle (20×L8×8×1/8) would be stocked on the laydown space on the far right, and 1 day after, 65 batches of W section (65×W14×43) will be placed on the available space on the far left. The second situation (b) illustrates a swapped situation in which W-sections go to the right laydown and iron angles go to the left. Generally, the rule of thumb for decision-making on where to place materials is the availability of free laydown area and proximity to the consumption unit. Based on these rules and the reactive material placement policy, on day 1, the layout planner looks for the closest possible laydown to the exit point and proceeds with the placement. Thereby, the placement policy, given in Figure 1(a), would be automatically prioritized and implemented. Proactive materials management, however, has the schedules available, and makes holistic decisions on the basis of consumption demands as well as proximity. The work suggests that proactive material handling will give freedom to the purchasing manager to procure materials based on demands, and place them appropriately on the material stock yard so that the overall haulage time/cost during the project life-time can be minimized. Figure 1(b) is based on this placement mentality, in which iron angles are placed on the far left laydown space, even though these spaces are farther from the exit point. The reason for this arrangement is that there would be 4 trips for iron angles and 10 trips for W-sections, as of day 2, until day 12. Thus, it would be more reasonable and cost-effective to place iron angles on the left-side laydowns. It is seen in this case that the consumption demand criterion has superseded the proximity preference for the iron angles. It should be noted that in this comparison, consumption of W-sections has started 1 day after that of the iron angles. On day 2, 10 closer trips for W-sections would take less time than 4 farther trips for iron angles. As such, the proximity criterion still holds, but it is applied in combination with consumption demands.

<Figure 1>

For the reasons mentioned above, a proactive material placement policy is proposed, in which a placement schedule is presented and material batches are destined to be placed on particular cells days before arrival at the yard. In order to implement a proactive material placement strategy, the time span for material flow to and from the yard shall be expanded to cover a reasonable material flow process. Promoting an accurate change management program can help managers achieve the proactive material placement plan. Table 1 summarizes the differences between these two approaches. In order to improve adoption of the proactive placement approach and achieve the optimum material layout, a hybrid optimization method is proposed. The theory of the optimization development is discussed in the next section.

<Table 1>

Hybrid Optimization Development

In this study, a combination of GA and simulation composes a hybrid optimization engine to determine the optimum material layout. GA, which is a search algorithm based on the philosophy of natural evolution and biogenetics introduced by Holland (1975), has been successfully applied to numerous areas in construction engineering and management [e.g. rehabilitation (Dandyand Engelhardt 2001) and resource scheduling (Chan et al. 1996)] as an effective heuristic method. In GA, a chromosome is a solution of the problem and includes a string of genes representing a single encoding of part of the solution domain. The population is a number of chromosomes existing to be examined. Selection and crossover are two operations in GA to search for the optimum result, and mutation operation is to avoid falling into local optima. To evaluate the goodness of the candidate solution, a fitness function is defined and measured in GA. Parameters including the population size (representing the number of chromosomes in the population), the crossover and mutation rates (representing the probability of performing crossover and mutation on the selected chromosomes), and the maximum number of generations are given by the user. See Mitchell (1999) for further information on developing GA.

In this research, fitness function, which plays an important role in GA, is defined as the total haulage time, since reduction in haulage time could lead to improving material handling productivity and cost. At this stage, simulation is implemented and integrated with GA. Simulation can model the material handling process, resource interactions and corresponding haulage time measurements. Simulation ensures the right trade-off between distance and resource availability to supply the consumption unit efficiently. GA generates material placement configurations in terms of chromosomes, and sends them to the simulation engine. Simulation, on the other hand, measures the haulage time on the basis of the received information and sends it back to GA as the fitness function output (Figure 2 (a)).

In this study, each gene in the chromosomes shows where the incoming material batch should be placed. The total number of genes in each chromosome equals the total number of batches in the studied period of time. Since segmentation is a general method for specifying the position of materials on large yards, genes would contain the cell numbers of the corresponding material batches, as illustrated in Figure 2 (b). In the example presented in Figure 2 (b), "K" is the total number of batches delivered during "N" days. Three batches: Batch #1, Batch #2 and Batch #3 are delivered on Day #1, and two batches: Batch #K-1 and Batch #K are delivered on Day #N. Chromosome #1 represents one of the possible solutions for all incoming batches from Day #1 to Day #N.

<Figure 2 >

It is important to note that some hard constraints, such as cell capacity and material consistency constraints, may exist, and material placement should comply with them. However, these constraints are not fixed throughout the project and may change daily. For instance, on day 1, there could be several placement arrangements considering the yard hard constraints. By choosing one of the arrangements, the yard inventory is changed for the next day. In addition, consuming some materials on day 1 will change the inventory. As a result, the yard inventory is updated daily based on the incoming and outgoing materials, which suggests that hard constraints of the yard change continually. These dynamic changes are sophisticatedly modeled in GA for proposing the material placement layout day by day.

Case Study

In this section, a case study, inspired from a real material yard of a steel fabrication company located in Edmonton, Alberta, Canada, is presented. As shown in Figure 3 (a), the yard has 20 cells numbered consecutively and divided by 2 separate south and north yards. Two cells, #7 and #9, are indicated as “reserved for special jobs,” and no material can be placed in these cells. Two overhead cranes with the capacity of 15 tons spanning the south and the north yards are deployed to load the materials in 20 s, haul them from the yard cells to a car with an average speed of 5 km/h, and unload them in a car in 20 s. The car and rail system are used to transport materials from the point of crane delivery to the point of exit at the speed of 4 km/h and unload them at the fabrication shop entry in 200 s. The crane-car interaction poses a challenge in linear computation of haulage time. Both cranes are using the same car, so that the availability of the car can influence the productivity of the cranes. When the car is serving a crane, another crane should wait for it. This waiting time reduces the productivity of the crane. Hence, modeling the interaction of the cranes and the car is crucial, which further highlights the significance of simulation in modeling the complicated resource interactions. Since the position of the material specifies which crane is to be utilized, the material layout affects the productivity of the system and transportation time, which is measured by simulation. The material handling process was modeled in the Simphony (Hajjar and AbouRizk 1996) environment.

The yard hard constraints are as follows: 1) reserved cells, i.e. materials are not allowed to be placed in the cells reserved for specific jobs, 2) material compatibility constraint, i.e. placing different types of materials in a cell are not allowed, and 3) cell capacity constraint, i.e. the cells do not receive materials more than their capacities due to safety concerns. A coordinate system assigned to the yard was used to determine the haulage distances. For selecting the materials to be consumed, the proximity criteria to the point of exit based on Euclidean distance was used because in reality, the closest material to the consumption unit is visually selected. That is, the closest available material to the exit point was selected to be hauled there. As illustrated in Figure 3 (b), a 30-day schedule was considered for incoming and outgoing materials. In Figure 3 (b), each individual blue cell represents one incoming batch of materials and each individual red cell shows one outgoing batch. The numbers in these cells also represent the number of material pieces of the corresponding batch. It is seen that the total number of incoming batches is 71, and the total number of outgoing batches is 271. Figure 3 (c) shows the inventory on day 1. The GA parameters used in this case study are 80%, 5%, 200 and 2000 for the crossover probability, mutation rate, population size, and number of generations, respectively.

<Figure 3>

Analysis and Results

Having run the model, it was found that the proposed hybrid optimization method was able to lower the haulage time in excess of 9% of the entire haulage time of 271 batches, as depicted in Figure 4 (a). In that figure, the values on the *y* axis represent the minimum haulage time of the chromosomes existing in the corresponding generation. The computational time of this model depends on many aspects, such as duration of the project, size of the simulation model (hauling equipment), number of cells, etc. For this case study, the analysis took about 30 minutes on a computer with a 3.2 GHz processor.

The GA-simulation engine determined the optimum arrangement of 71 incoming materials. To illustrate how the proposed solution has provided the planner with the optimized arrangement, material flow for only 2 days is shown in Figure 4 (b) for brevity. Starting from day 1, materials are removed from the yard based on the first day pick list. As discussed earlier, this process is performed on the basis of closest possible cells to the exit point. Then, it comes to the incoming materials for the first day, which are iron angles. They are placed on cells 3 and 8.

These cells are on the south yard. They are suitable places for the south overhead cranes to serve. On day 2, the shop needs 2 types of iron angles, namely, L6×6×3/8 and L6×4×3/8, which have been stocked on the yard the day before, thereby the shop can access them easily in little time. There are other materials on the list that are fed to the yard based on their proximity, as shown in Figure 4 (b), at the bottom right. On the same day, 2 more batches of iron angles arrive at the yard waiting to be placed. However, the program suggests placing them on the north yard on cells #5 and 14. One might inquire why the program does not suggest placing the iron angles on the south yard, preferably on the same spots or closer to the exit point, as the reactive approach would have proposed. Further search through the placement arrangement for all 30 days reveals that iron angles are variably placed on cells #1, 3, 5, 6, 8, 14, 10, 15, 18 and 20. Of these proposed placements, cells #3, 8, 15 and 20 are located on the south yards and the rest are on the north yard. The placement for iron angles continues until day 10, where there is no procurement of iron angles afterwards, due to sufficiency of the shop supply. Table 2 (a) highlights the proposed south laydowns and summarizes the quantities of the stocked iron angles on these spots. The sums of quantities for the iron angles stocked on south laydowns (cells #20, 15, 8, and 3) are presented at the bottom of the table. Table 2 (b), on the other hand, searches for the same iron angle types in the output plan proposed again by the program on the basis of closest possible cells to the exit point. The symbols in Table 2 are to facilitate identification and tracking of the material of the same types within incoming and outgoing steel. Adding all the quantities on the same south laydown cells (i.e. cells #20, 15, 8, and 3) reveals that the same amount of materials are removed from the yard by the shop, leaving the previously occupied south laydowns totally empty for the W-sections, channels and plates. The rationale behind this is that the program discovers that a great amount of W-sections and channels are coming to the yard from day 10 forward. As a consequence, it tries to place the iron angles based on the following principles:

- The south laydowns shall be emptied after day 10 so that W-sections and channels, which have higher flow volumes to the yard, as shown in Figure 3 (b), are placed closer to the exit point. If a higher amount of materials was placed on the south laydowns, there would be iron angles left over on the south yard, preventing the channels and W-sections from being placed close to the yard because of the hard constraints.
- Overall, 200 pieces of L6×6×3/8 and L6×4×3/8 come to the yard and 90 pieces are to be consumed. Of the 90 pieces, 70 pieces are taken from south laydowns and only 20 pieces are taken from the north laydown, which shows the suitability of the proposed placement for iron angles in terms of satisfying proximity criterion.
- Iron angles are not going to be used after day 10, thus it would be reasonable to stock the ones which are to be placed on the north yard as far as possible from the exit so that there would be room for other materials which may congest the yard in later days. For instance, cell #18, which is located on the north yard, and is considerably far from the exit point, contains plates. The optimization program waits for the day that plates are taken from cell #18, and quickly places the iron angles on day 10 in the farthest possible place.

<Figure 4>

<Table 2>

Summary and Conclusions

In this study, a sophisticated optimization computer program was developed to perform proactive placement on construction stock yards, which is capable of the following:

- Modeling the yard hard constraints including consistency and volume.
- Optimizing the placement based on consumption.
- Modeling the material removal process from the yard as close as possible to actual practice.

- Integrating the incoming and outgoing schedules of materials with the optimization engine to account for the dynamism of the yard material flow.
- Providing improved, built-in placement verification (satisfaction of hard constraints) to maintain the validity of the generated placement schemes.
- Incorporation of simulation into the optimization engine to evaluate the fitness of the generated chromosomes.

By using the developed solution in this study, each material batch would have a placement tag in advance to arriving at the yard, facilitating the material placement process for the yard foreman, and improving the material handling process for the materials management team. Results of the analyses show clear merits of proactive material placement over the reactive strategy described. It is understood that reactive techniques are practiced more frequently in construction stock yards due to unforeseen events and uncertainties in the incoming and outgoing material schedule, which is considered a limitation of the proactive approach. However, the advantages of proactive material handling would encourage decision makers to improve other pertinent processes to approach the ideals of proactive methods, so as to save as much time and money as possible.

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Table 1: The differences between the reactive and proactive approaches

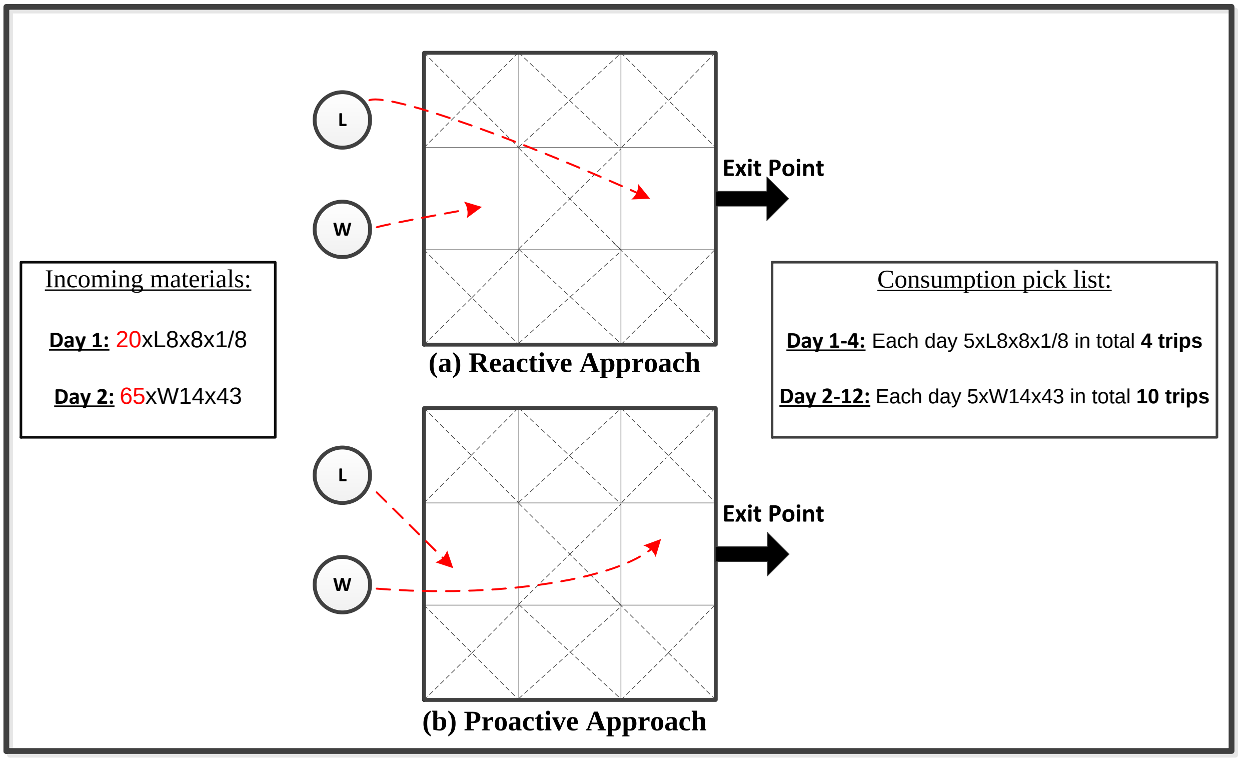
Material placement approach	Planning time span	Level of controlling changes in the incoming and outgoing material schedule
Reactive	Short (e.g. daily)	Low
Proactive	Long (e.g. weekly and monthly)	High

Table 2 (a) Proposed placement plan

Day No.	**Batch No.**	**Material type**	**Cell No.**	**Quantity**
1	1	10×L6×6×3/8	8 *	10
1	2	10×L6×4×3/8	3 ^{o}	10
2	3	10×L6×6×3/8	14	10
2	4	10×L6×4×3/8	5	10
3	5	10×L6×6×3/8	20 ^{v}	10
3	6	10×L6×4×3/8	15 $^{\times}$	10
4	7	10×L6×6×3/8	20 ^{v}	10
4	8	10×L6×4×3/8	8 $^{\sim}$	10
5	9	10×L6×6×3/8	1	10
5	10	10×L6×4×3/8	5	10
6	11	10×L6×6×3/8	5	10
6	12	10×L6×4×3/8	6	10
7	13	10×L6×6×3/8	6	10
7	14	10×L6×4×3/8	1	10
8	15	10×L6×6×3/8	20 ^{v}	10
8	16	10×L6×4×3/8	14	10
9	17	10×L6×6×3/8	14	10
9	18	10×L6×4×3/8	10	10
10	20	10×L6×6×3/8	18	10
10	21	10×L6×4×3/8	5	10
Total L6×6×3/8 placement on cell# 20 ^{v}:				**30**
Total L6×4×3/8 placement on cell # 15 $^{\times}$:				**10**
Total L6×6×3/8 placement on cell # 8 *:				**10**
Total L6×4×3/8 placement on cell # 8 $^{\sim}$:				**10**
Total L6×4×3/8 placement on cell # 3 ^{o}:				**10**

Table 3. Proposed Removal Plan for All the L6 × 6 × 3=8 and L6 × 4 ×3=8 Types of Iron Angles

Day No.	Batch No.	Material type	Cell No.	Quantity
2	9	5×L6×6×3/8	8 *	5
2	10	5×L6×4×3/8	3^{o}	5
3	18	5×L6×6×3/8	8 *	5
3	19	5×L6×4×3/8	3^{o}	5
4	27	5×L6×6×3/8	20^{v}	5
4	28	5×L6×4×3/8	15	5
5	36	5×L6×6×3/8	20^{v}	5
5	37	5×L6×4×3/8	$15^{\times}$	5
6	45	5×L6×6×3/8	20^{v}	5
6	46	5×L6×4×3/8	$8^{\sim}$	5
7	54	5×L6×6×3/8	20^{v}	5
7	55	5×L6×4×3/8	$8^{\sim}$	5
8	63	5×L6×6×3/8	14	5
8	64	5×L6×4×3/8	6	5
9	72	5×L6×6×3/8	20^{v}	5
9	73	5×L6×4×3/8	14	5
10	81	5×L6×6×3/8	20^{v}	5
10	82	5×L6×4×3/8	14	5
Total L6×6×3/8 take off from laydown# 20 ^{v}:				**30**
Total L6×4×3/8 take off from laydown# 15 $^{\times}$:				**10**
Total L6×6×3/8 take off from laydown# 8 *:				**10**
Total L6×4×3/8 take off from laydown# 8 $^{\sim}$:				**10**
Total L6×4×3/8 take off from laydown# 3 ^{o}:				**10**



(a) Reactive Approach

(b) Proactive Approach

Incoming materials:

Day 1: 20xL8x8x1/8

Day 2: 65xW14x43

Consumption pick list:

Day 1-4: Each day 5xL8x8x1/8 in total **4 trips**

Day 2-12: Each day 5xW14x43 in total **10 trips**

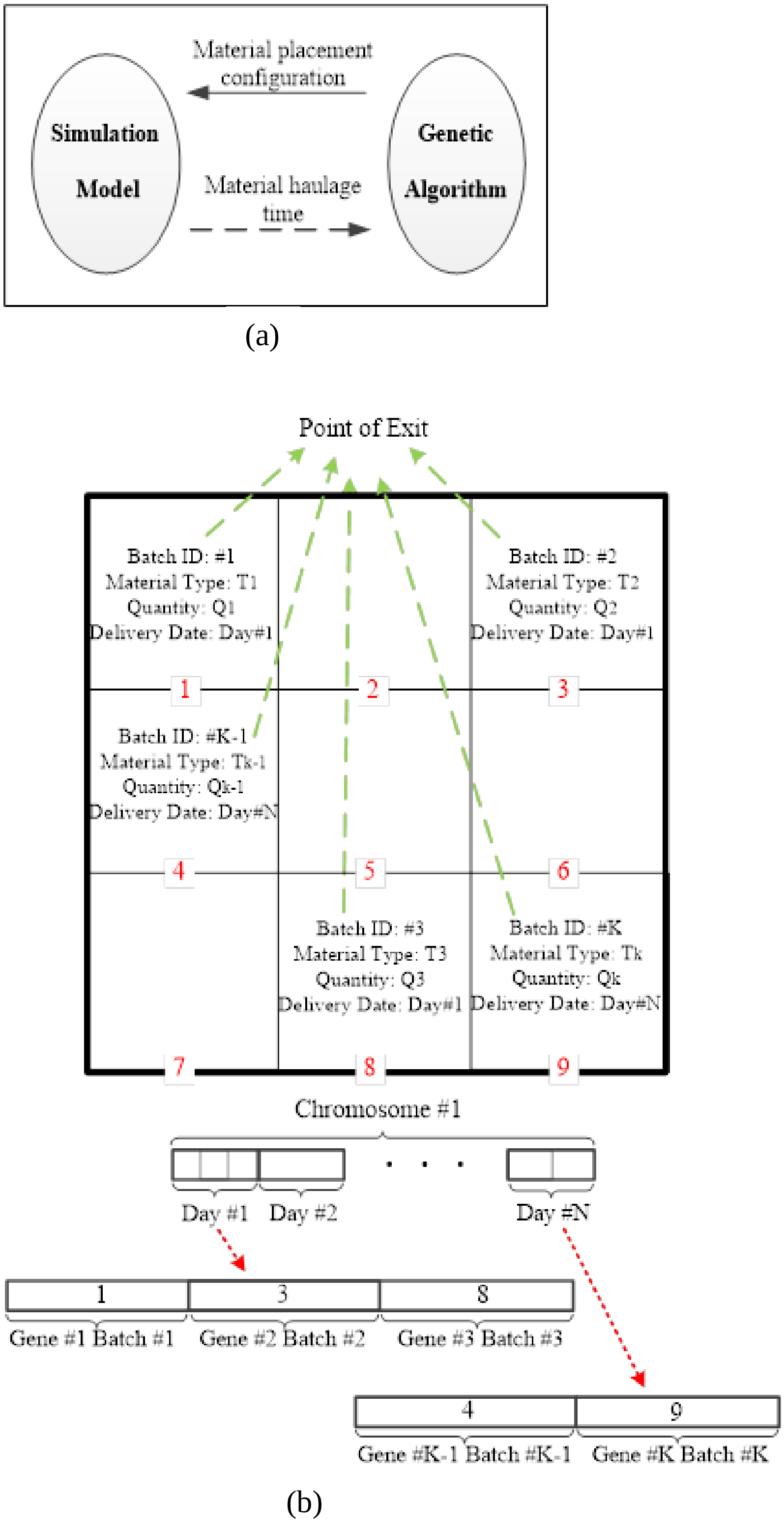
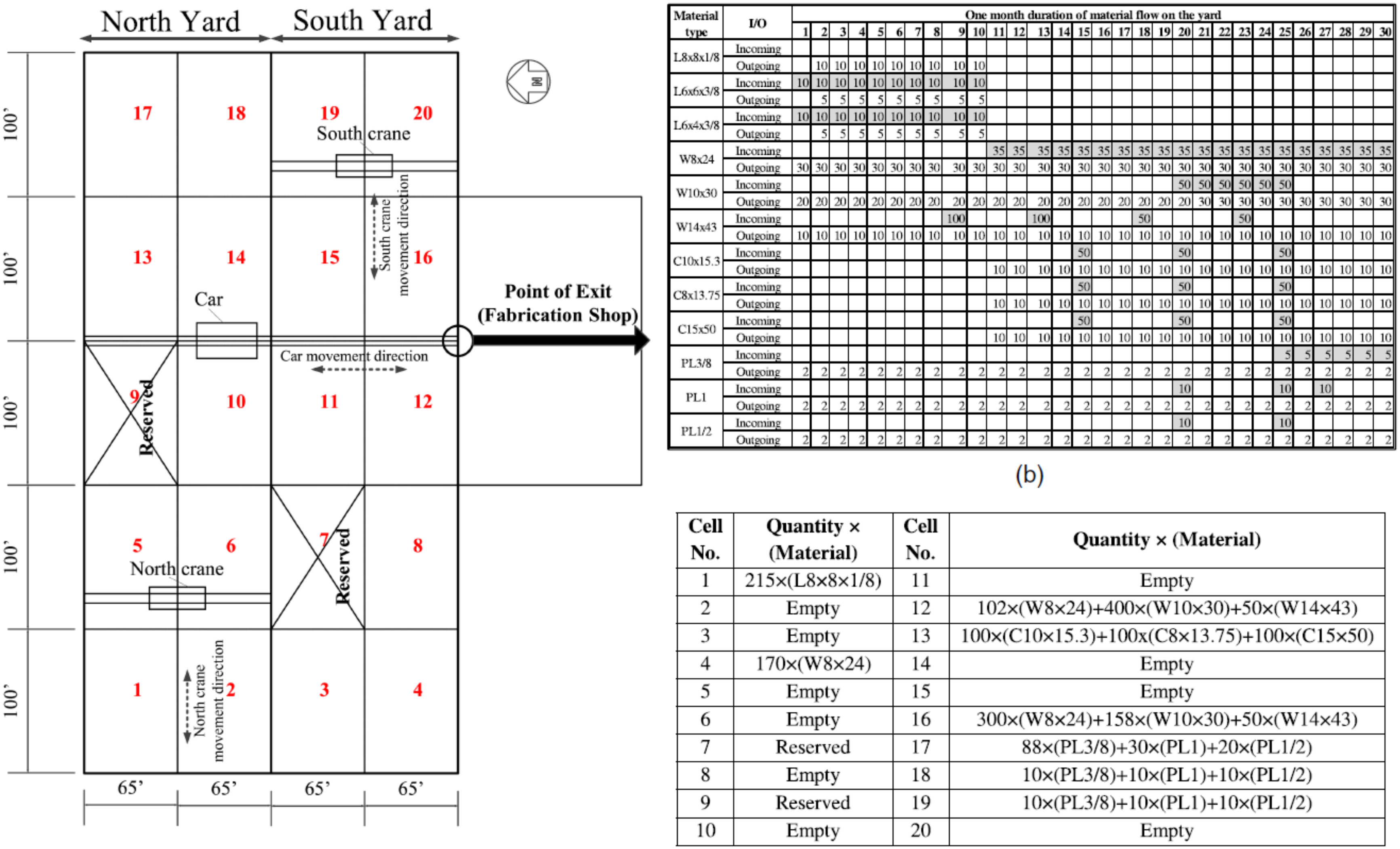


Fig. 2. Development of the hybrid genetic algorithm-simulation model: (a) genetic algorithm and simulation model interactions; (b) chromosome representation



Material type	I/O	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
		One month duration of material flow on the yard																													
L8x8x1/8	Incoming																														
	Outgoing		10	10	10	10	10	10	10	10	10																				
L6x6x3/8	Incoming	10	10	10	10	10	10	10	10	10	10																				
	Outgoing		5	5	5	5	5	5	5	5	5																				
L6x4x3/8	Incoming	10	10	10	10	10	10	10	10	10	10																				
	Outgoing		5	5	5	5	5	5	5	5	5																				
W8x24	Incoming											35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
	Outgoing	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
W10x30	Incoming																				50	50	50	50	50	50					
	Outgoing	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	30	30	30	30	30	30	30	30	30	30
W14x43	Incoming									100				100					50					50							
	Outgoing	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
C10x15.3	Incoming															50					50					50					
	Outgoing											10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
C8x13.75	Incoming															50					50					50					
	Outgoing											10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
C15x50	Incoming															50					50					50					
	Outgoing											10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
PL3/8	Incoming																									5	5	5	5	5	5
	Outgoing	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
PL1	Incoming																				10					10		10			
	Outgoing	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
PL1/2	Incoming																				10					10					
	Outgoing	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

(b)

Cell No.	Quantity × (Material)	Cell No.	Quantity × (Material)
1	215×(L8×8×1/8)	11	Empty
2	Empty	12	102×(W8×24)+400×(W10×30)+50×(W14×43)
3	Empty	13	100×(C10×15.3)+100×(C8×13.75)+100×(C15×50)
4	170×(W8×24)	14	Empty
5	Empty	15	Empty
6	Empty	16	300×(W8×24)+158×(W10×30)+50×(W14×43)
7	Reserved	17	88×(PL3/8)+30×(PL1)+20×(PL1/2)
8	Empty	18	10×(PL3/8)+10×(PL1)+10×(PL1/2)
9	Reserved	19	10×(PL3/8)+10×(PL1)+10×(PL1/2)
10	Empty	20	Empty

(c)

Fig. 3. Case study characteristics: (a) yard map schema; (b) incoming and outgoing schedule of materials in one view; (c) quantities and types of materials in yard inventory

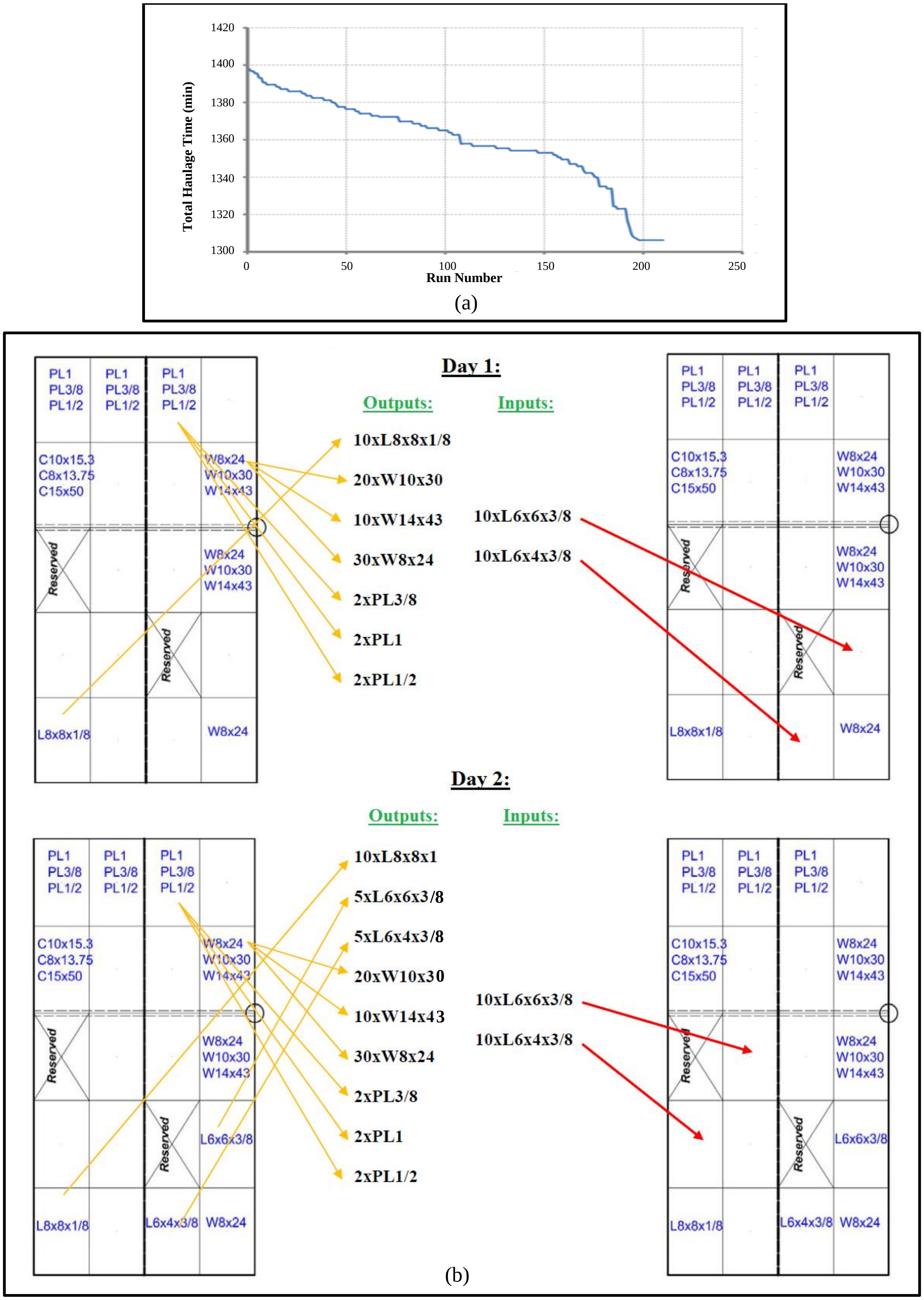


Fig. 4. Model results: (a) the reduction of total haulage time through optimization; (b) 2-day optimum material flow on the yard