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A Simulation-Based Approach for Material Yard Laydown Planning

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Abstract

This paper describes a simulation-based approach for planning material laydown yards for steel fabrication projects. The classic approach to material placement is the "reactive approach," whereby as material arrives, the yard foreman decides, based on few rules and his/her past experience, where to place everything. It's often fraught with uncertainty resulting from imprecise and difficult-to-forecast construction consumption schedules, resource interactions, and supply chain issues, especially in material delivery. This paper outlines an approach to optimize reactive placement policy using heuristics, genetic algorithms and simulation to model material movement from laydown areas to the consumption unit. The novel approach combines analytical tools and heuristics to model the dynamic nature of material management. The paper compares this integrated approach with commonly-used optimization techniques which use weighted target functions based on rule of thumb. A case study demonstrates the suitability and efficiency of the proposed optimization method in reactive laydown yard management.

Key words: material management; laydown planning; material handling; simulation; genetic algorithm

1. Introduction

Materials handling is a part of the broader domain of materials management. Materials handling can be defined as "the art and science of conveying, elevating, positioning, transporting, packaging and storing of materials" (Ray 2007). Applying the right material handling methodology in construction projects would result in real savings in the project time and cost, improved labor productivity and reduced surplus.

Due to inefficiency of operations for places and methods that materials are handled and stored (Tommelien 1994), researchers have, in the past, formulated materials placement and handling approaches for planning construction yards. Crainic et al. (1993) investigated space allocation by studying the space and time dependency of events. They proposed a space optimization method based on event handling of the incoming materials (container being the materials) on terminals. Gambardella et al. (1998) addressed spatial allocation of containers on terminal yards, and presented a decision support system for the management of an intermodal container terminal. Zhang et al. (2003) also studied the storage space allocation problem in storage yards of terminals. In another study, Shen and Khoong (1995) established a decision support system to solve a large-scale planning problem concerning the multi-period distribution of empty containers for a shipping company. To improve material transportation cost on site, Cheung et al. (2002) developed a genetic algorithm (GA) model to determine the near optimal layout of facilities on concrete precast yards.

Wenzel et al. (2010) demonstrated that simulation can connect the planning stage to operation to reduce costs in production and logistic systems. Marasini and Dawood (2002) developed a process model for evaluation of stockyard layouts for standard precast concrete products, and provided some promising results presenting reduced throughput times once they used GA in collaboration with simulation. Zhou (2006) developed a GA-based site optimization algorithm and incorporated it in a simulation model which used the optimized site-layout as the starting point of simulation.

Despite the considerable number of studies conducted on construction material handling and layouts, organization of laydown areas, which directly affects material handling costs, remains a challenge in practice.

The goal of this study is to determine a dynamic, optimum storage yard layout for improving material handling cost and time using simulation tools integrated with an optimization engine. Our main focus is on utilizing a “reactive approach” strategy for allocation of incoming material. A comparison between the proposed methodology and the other existing approaches, which try to optimize material handling costs by reducing haulage distances, is presented.

2. Reactive Placement Approach

Material handling is greatly dependent on other processes such as planning, estimating, drafting, purchasing, installing and commissioning, etc. Changes, disruptions and delays in any of the other processes naturally impacts material management and handling. For instance, Figure 1 demonstrates a typical drafting procedure and its interaction with purchasing and consumption of the material in a steel fabrication company. Once a steel fabrication company wins a job, it receives the design drawings from the client (IFC drawings). In most cases, after developing the reserved bill of material and preparing detail drawings, the approval of the customer (which adds several time-consuming activities when the customer asks for revisions, as shown in Figure 1) is required. The incorporation of a customer’s feedback time into the baseline schedule provides space for proactive material handling and management, in which purchase lists and pick lists are known in advance, and leaves room for further implementation of best practices to pursue continual improvement in a construction company. However, a slight change in meeting the milestones generally affects the predictability of the process. Some of these unwanted changes include: late delivery of design drawings and revised drawings, change orders, and mistakes and errors in drafting. In response to such changes, yard management policies, as part of the overall material handling program, react accordingly, and change reciprocally. The approach for dealing with this challenge is called ‘reactive placement policy’ in this study. In the reactive placement policy, the receiver (the person who receives the material from the supplier/vendor/mill or any other material provider) does not have the arrival schedule for a specific period of time informing him what material arrives at site on the days ahead. The receiver also does not know what material will be consumed and leave the yard in a timely manner (for a specific period of time). The only information the receiver has is the daily pick tickets from the consumption unit required for that day, and the material arrival list from purchasing containing what material is arriving that day. For these reasons, the receiver has to react to daily incoming batches for placement on the laydown areas. For placing the material, the receiver can be given a daily schedule in advance providing the information regarding which grid the material should be stocked. For example, if a batch of material arrives at the yard containing twenty different material types to place in twenty different laydown areas, the receiver knows where to place them on the yard grid network, as each material type has a tag with that information.

3. Research Methodology

This research initially attempted to identify current practice of yard foremen when faced with daily incoming batches to the yard. As a result, the following factors were found to be involved in common practice of material laydown planning for steel fabrication projects:

- dynamism of the material flow in and out of the yard,
- material transfer time/distance from the yard to the consumption schedule,
- space availability of the laydown areas,
- special provisions such as laydown occupancy due to reserved spaces for special jobs,
- logistics of the yard (yard dimensions, transfer lines to consumption unit, permanent and temporary hauling equipment on the yard), and

- hard and soft yard constraints such as material compatibility constraints (materials of the same type can be stacked in one laydown area).

On steel fabrication yards, equipment units such as overhead cranes, forklifts and carts are deployed to transfer the key material from the laydown areas on the storage yard to the consumption unit. Under a tight schedule, it would be paramount that the right materials are delivered in a timely manner. Moreover, the use of equipment should be minimized to reduce costs as hourly rate of equipment use could be very high.

In the next step, efforts are made to help the yard foreman place the materials on the laydown areas in a more sophisticated manner considering the abovementioned factors.

Simulation, which is one of the mathematical tools that has been widely used in academia, and very recently in practice, can be of great assistance to serve this purpose, as it can model resource interactions intelligently. Pristker (1986) defines simulation as “the process of devising a mathematical model of an actual world system and experimenting with the model on a computer.” Hence, the material handling process is modeled using a simulation tool to evaluate the efficiency of the material laydowns from the material handling time/cost point of view.

Moreover, to propose an optimum or near-optimum solution, all possible placement combinations must be examined, which is impossible due to the great number of laydown areas and variety of material types. As a result, genetic algorithm, which lends itself to examining cases and discovering the optimum or near-optimum solution through iterations within the algorithm, is implemented to determine the optimized layout. Another advantage of genetic algorithm is that it works properly in conjunction with simulation as used in various instances e.g. in facility layout planning (Azadivar and Wang 2000), resource optimization (Hegazy and Kassab 2003) and optimizing the cost of steel production line (Paul and Chanev 1998).

Simphony (Hajjar and AbouRizk 1996) is used as the simulation environment for this study because it has flexible programmable core services that can be easily accessed, developed and customized. It also provides an interactive graphic user interface, where models can be easily created and then run in a computer program. *Simphony* as a simulation tool will interact with genetic algorithm. This interaction is explained with further details in the following section.

4. Integrated Model for Material Yard Optimization

Simulation and genetic algorithm are integrated to optimize the material layout. It should be emphasized that GA is not used separately from simulation. Conversely, a framework has been established in this research where a continuous information exchange is maintained throughout the analysis, in which simulation and GA help find the optimum solution step-by-step up to the final results.

GA is based on biology, and the fact that natural selection is made to present better populations in consecutive generations. As species evolve, the new attributes are encoded in the chromosomes of individuals. Within this process, evolutionary development such as combination, swap and mutations can occur during breeding. GA then proceeds with survival of the fittest (best) chromosomes over sequential generations. In GA, a gene is a single encoding of part of the solution space, i.e. either single bits or short blocks of adjacent bits that encode an element of the candidate solution. A chromosome is a string of genes that represents a solution, and population is the number of chromosomes available to test. Candidate solutions to the optimization problem play the role of individuals in a population. Crossover operator recombines the selected parent chromosomes. Mutation operator is designed to avoid falling into local maxima or minima. It is very likely that without mutation, the population would rapidly become uniform under the effect of selection and cross over operators (Coley 1999). The GA maintains balance between crossover and mutation operators (Melanie 1999).

In GA, fitness function is the measure of goodness of the candidate solution. In this study's particular problem, simulation of construction processes and activities is useful as it enables the user to incorporate resource allocation in problem solving. In fact, simulation can easily model the laydown placement operation, and material haulage from laydowns to consumption units no matter how many transfer lines exists. It is also capable of reporting the time or the cost of the material haulage to the point of exit. Therefore, it could be a perfect candidate for evaluating different placement arrangements which would make the simulation itself a fitness function.

Figure 2 shows the flowchart of simulation and GA interactions and demonstrates how simulation can help GA evaluate the fitness of a generated population. This model is adopted based on the features of GA and the requirements of the optimization problems. As depicted in Figure 2, once the model is initialized by the required information, the goodness of the generated material arrangements by GA is examined by simulation. Then, based on the results of the simulation, GA performs its operators and generates new solutions to satisfy the termination criteria. In this research, the focus is time of material haulage, since cost information cannot be easily acquired, though a separate study for haulage distance determination is also conducted. It should be noted that simulation can effectively process time of material haulage considering resources available for material transportation, whereas distance determination is trivial given the geometry of the yard and simulation may not be necessary for processing haulage distance. In fact, complications such as queue time, waiting time and idleness of equipment (equipment utilization) necessitates and justifies the use of simulation for fitness evaluation of the problem in question. In particular, once the laydown yard is large, containing a multitude of cells and several types of hauling and handling equipment such as forklifts, loaders, gantry and overhead cranes, etc., simulation can readily and sufficiently model the resources, and provides the haulage time and the end of the analysis. Without use of simulation, consideration of the items such as loading/unloading/travel time of equipment, equipment competition over resources (e.g. material and other equipment) and equipment capacity consideration would be very difficult to model.

In the integration process as illustrated in Figure 3, GA sends chromosomes containing placement arrangement, yard and incoming material information to simulation, and on the other hand, simulation models the yard and resource conditions and analyzes the material transportation problem, and provides GA with time/cost of material haulage to the point of exit. GA receives this information and uses it as fitness data by which it can evaluate the current population. In other words, simulation in this study plays the role of fitness function in the overall structure of GA. Technically; the simulation model is accessed through .Net capabilities and run as many times as required inside the C# program developed by the authors.

To clearly show what chromosomes are contained in the proposed model, Figure 4 shows an imaginary laydown yard with 9 cells, which is hosting incoming materials with four different batches. There is equipment such as forklifts and loaders to transport materials from laydowns to the point of exit (consumption unit). Assuming an arbitrary arrangement of these four batches in yard cells # 2, 7, 6 and 4, a chromosome whose genes represents cell numbers can be formed. Gene #1 has stored the value 2 which is the number of the cell on which material batch #1 has been stacked. Gene #2 stores the value 7 which represents the cell number on which batch #2 has been placed, and so forth. Figure 4 also shows that each laydown area (cell) accommodates a specific material type, with a specific quantity. In the following section, a case study is presented to demonstrate the suitability and efficiency of the proposed optimization method.

5. Case Study

In this section, a sample material handling process in the steel fabrication industry has been modeled using the developed program and simulation. This case study is based an actual laydown yard feeding a steel fabrication shop located in Edmonton, Alberta, Canada. The dimensions of the yard are approximate. Steel materials are transported and delivered to the yard by trains and trucks, and unloaded by forklifts and placed on different segments on the laydown yard. Figure 5 illustrates the stock yard of the fabrication shop having 20 segments divided by two separate south and north yards. The dimensions of the yard are approximate. Two overhead cranes span the south and the north yards, and haul material from the yard cells to the point where a car and rail system transports the material to the point of exit. As shown in Figure 5, two cells have been reserved for special jobs, and no material can be stocked in these laydown areas. The cells are numbered consecutively to facilitate the modeling process. Crane and car travelling speeds, as well as loading and unloading times, are given in Table 1. The same data that is given in the table has been used in the simulation model of the material haulage. A coordinate system can be assigned to the yard to represent its position with respect to the point of exit. This coordinate system will be used frequently in the program to determine the distances from the cells to the rail-car system and the car to the exit point. Simulation models the work process, required resources and interaction between resources. Figure 6 depicts the crane-related activities and car-related activities along with their sequences and the required resources. The work flow for the material handling is the accommodation of the material by the receiver and the haulage of them to the car, which subsequently carries the steel pieces to the fabrication shop. These activities are repeated to provide all the materials needed by the fabrication shop. As shown in Figure 6, for the activity of "loading the car" two resources, i.e. the crane and the car, are required and interact with each other. It should be noted that the existence of one car, which serves two overhead cranes, poses a challenge to the receivers if they want to utilize the cranes productively. That is, the cranes and the car should work in some form of harmony where cranes do not wait in a queue to be served by the car as it poses safety issues for hoisted load that should not be hanging over the workers on the yard. If the workload is heavy, though, this might be inevitable due to unavailability of the car for the cranes.

In addition to the described information required for building the simulation model, the following information is needed to complete the model:

- Information on incoming materials to the laydown yard.
- Information on outgoing materials from the laydown yard.
- Information on materials in the yard inventory as an initial condition of the materials in the laydown yard.

Table 2 gives information on a sample of incoming materials to the yard. The selected incoming materials are taken off an actual purchase order to a steel production facility for the fabrication job and the selected sections are commonly-used section types, usually circulated on a shop yard. Table 3 shows a sample daily consumption schedule and bill of materials that are requested by the fabrication shop. It should be noted that consumption bill of materials could be totally independent of incoming materials on the same day. In fact, except for a very few cases where rush jobs require the availability of some materials for the rush production, the incoming and outgoing materials are independent from one another.

In Table 4, quantity and type of materials in the yard inventory are shown. The quantities are selected in such a way that some cells will reach their maximum capacities once excessive placement is imposed upon them. As for the capacity of the cells, an ad-hoc capacity determination has been adopted on the basis of interviews conducted with experienced yard foremen in steel fabrication companies. The rule of thumb is not to stack steel pieces (e.g. iron angles, W-sections, channels, plates) more than 2 meters high, as safety regulations would not allow further material stacking, assuming a neatly-arranged stack.

Having run the model with the given GA parameters, as presented in Table 5, the optimum layout of materials to achieve the least haulage time was determined as illustrated in Figure 7. GA inputs were selected based on several trial and error runs to maintain accuracy and reasonable run-time speed.

6. Discussion

There are approaches for defining the objective function other than using simulation, as follows:

- Simulated arrangements using radial distance (SARD): SARD evaluates the distance between the stocked materials and exit point using Euclidean distance function. This is often the approach that the material receiver applies to estimate the proximity of the placed batches to the consumption unit. The objective function is $\sum_{i=1}^{n} d_i$ where d_i is the Euclidian distance of laydown number 'i' to the exit point, and n is the number of the cells that materials are placed.
- Simulated arrangement using perpendicular distance (SAPD): This approach calculates the actual material haulage route within the yard, that is, the cranes traverse along the yard and the car carries the materials afterwards across the yard. The objective function is

$\sum_{i=1}^{n} d_i$ where d_i is the perpendicular distance of laydown number 'i' to the exit point, and *n* is the number of the cells that materials are placed.

- Simulated arrangements using weighted perpendicular distance (SAWPD): This method takes into consideration the fact that material haulage time is dependent not only upon the distance to the exit point, but also on their volumes. That is, transferring a batch with greater volume to the consumption unit would naturally take more time than a batch with lesser volume. The objective function is $\sum_{i=1}^{n} d_i \times V_i$ where d_i is the perpendicular distance of laydown number 'i' to the exit point, V_i represents the volume of the material batch number 'i', and *n* is the number of cells in which materials are placed.

By comparing the results that have been given by GA-simulation interaction and GA based on evaluation of distance, the significance of simulation incorporation and its integration with GA can be highlighted. Given the same input data as the simulation model, these objective functions were examined and different results were obtained. In order to further highlight the differences between optimization analyses by using distance and simulation as fitness functions, we simulated the arrangements obtained by distance optimization approach. To this end, we imported those arrangements into the simulation model and measured the haulage time. Then, we compared and contrasted the results to discover whether or not the resulting placement arrangements can minimize the haulage time as efficiently as simulation can. Figure 8 shows a comparison between four series of analysis results. As observed in Figure 8, neither of the distance-generated results can offer optimized haulage time given by simulation. The least haulage time of the optimized arrangements from distance evaluator fitness functions is 17% more than that of the simulation model. Although improvements can be seen once perpendicular and weighted perpendicular distance fitness functions are used, inconsistencies in optimization trend, fluctuations and excessive overtime compared to the simulation-based results are observed. The following two main reasons can be stated as the root cause of such incompatibilities of the results:

- Distance determination (or weighted distance determination) ignores the capacity of the hauling equipment (cranes and car). The crane could work with its full capacity or a portion of its capacity based on the volume of the material batches. It is very likely that small chunks of materials are hoisted by the crane either due to the original volume of the batch or due to the remaining portion of the materials on a laydown area hauled by the last travel of the crane.
- Distance determination approaches ignore the waiting time of the cranes in south and north yards waiting for the car to serve them. In other words, resource interaction (in particular equipment interaction) is simply disregarded in such analyses whereas simulation can readily incorporate resource interaction through accurate resource modeling.

In order to observe the difference between simulation method and distance related methods, the trend of placement arrangement improvement layout resulted from SARD method using GA was exhibited in Figure 9 as an example. To this end, three arrangements (a, b, and c) were selected randomly during the run-time and portrayed along with the optimum layout (d). SARD model allocates the materials to the cells in such a way that they stay within a certain radius from the exit point, as depicted in Figures 9 (a) through (d). The reason for this layout of the incoming material placement is the simple fact that chromosomes are ranked with respect to their Euclidian distance to the exit point.

The same series of post-processing can be carried out once the fitness function is set to use simulation, as illustrated in Figure 10. In contrast with SARD, the simulation-based method tries to position the materials on the south yard so that they can be served by the south overhead crane and minimize the travelling time of the car, as depicted in Figures 10 (a) and (b) for batches 4 and 9, respectively. In Figure 10 (c) and (d) also, materials are displaced along the yard to account for different volumes that they have and their impact on the working cycle of the south crane.

This comparison demonstrates that if all the material batches are nested in the south yard, they are served by the south crane which is itself served by the car with shorter travelling time to the exit point. As a result, use of the south crane at all times guarantees smoother work process and interaction between the crane and the car, as the crane itself does not remain idle and always works, since mostly it has to span a wider distance in comparison with the car. The closeness of the travelling speeds of the crane and the car helps prove this fact.

7. Summary and Conclusions

The reactive placement policy is most commonly adopted in the steel fabrication industry, for laying out materials on yards, because of the dynamic nature and innate uncertainties involved in material management. In the reactive placement approach, yard personnel have no prior information in regards to the consumption schedule; instead, they react to daily incoming batches for placement on the laydown areas. In this study, the challenges of reactive placement approach were analyzed, and simulation integrated with GA was proposed as a solution to improve this approach and identify an optimum incoming material layout to minimize material transportation time and costs. The reduction in time and cost can improve labor productivity, and also create a better yard-consumption schedule. An optimum arrangement can assist the receiver in making better placement decisions for the incoming batches, considering the yard's hard constraints.

The proposed simulation-based approach was compared against other identified approaches using the distance evaluator fitness functions. The results of the analyses led to the following conclusions:

- The distance evaluator fitness functions model what the receiver would usually perceive as the closest laydown to place the material. However, the results of this study revealed that reduction in haulage distances does not necessary lead to lower haulage time, so this method is not ideal.
- Simulation models work processes and resource interactions, which further facilitate the accurate fitness evaluation of the proposed material laydown, within GA. Continuous information flow between simulation and GA brings about a more realistic model of material handling and placement and helps present a more accurate optimization result.
- The more complicated the resource interaction is on a laydown yard, the more effective and useful simulation can be for a GA-based optimization problem.
- In this research, the approach was applied to steel fabrication projects; it is reproducible, and therefore, could be applied to other problems of a similar nature.

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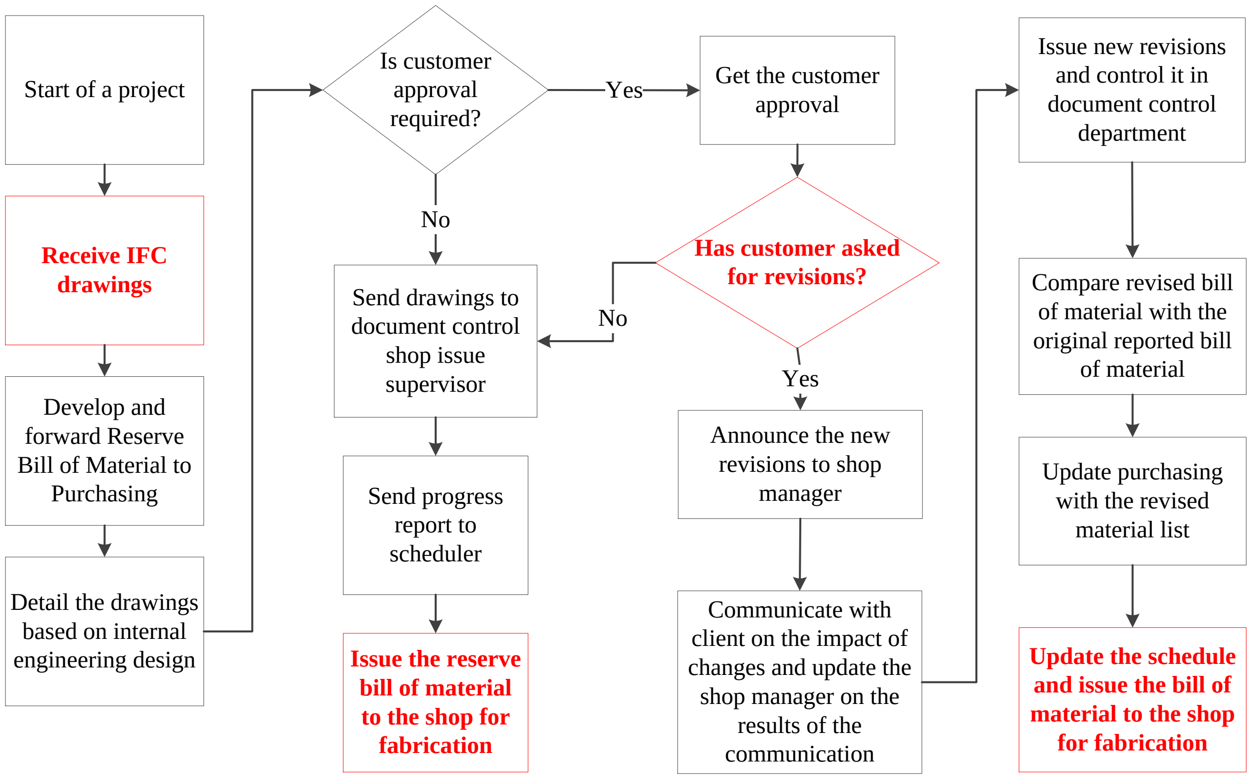

Fig. 1: Drafting procedure and its interaction with purchasing and consumption of the material.

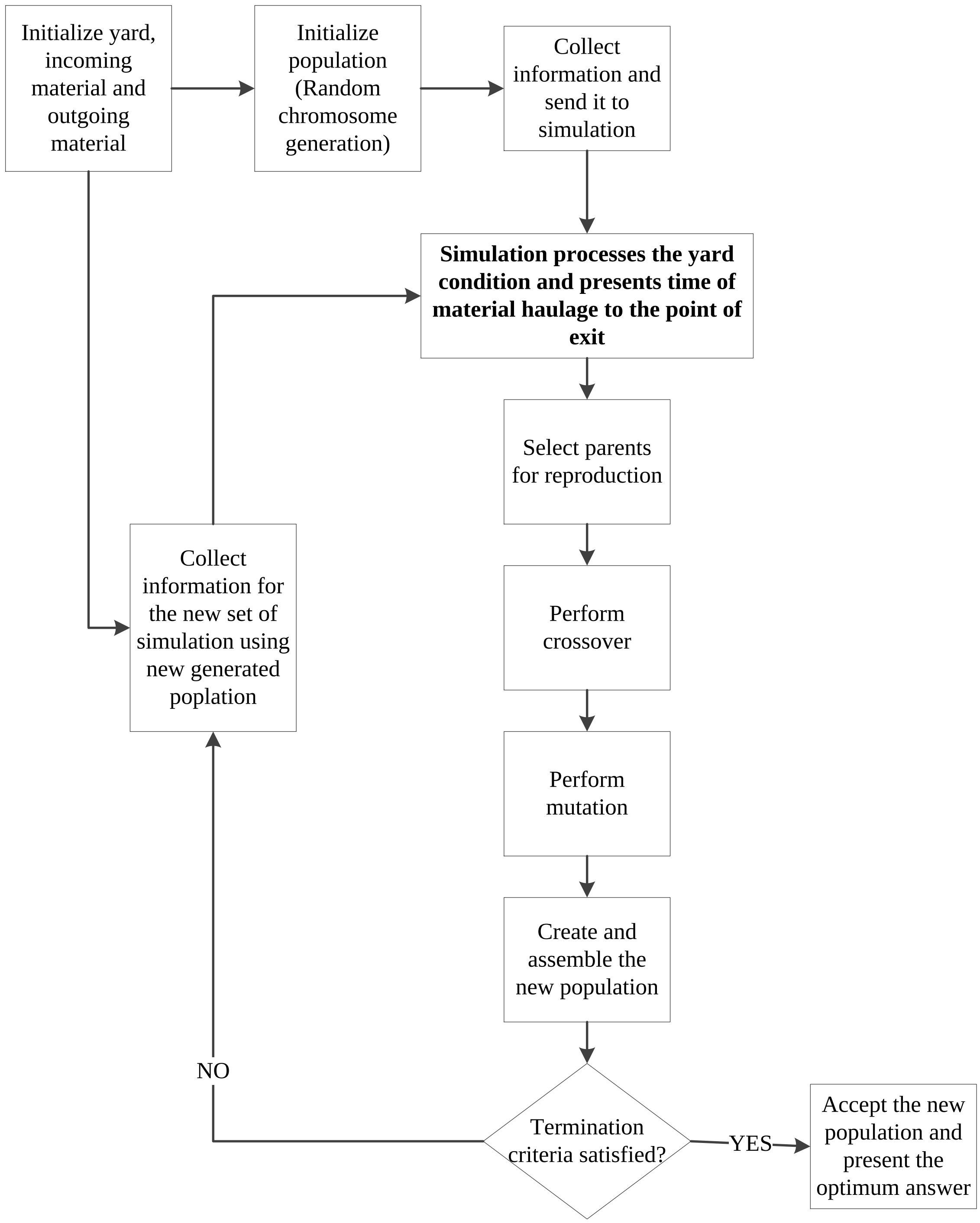

Fig. 2. Simulation and genetic algorithm interactions.

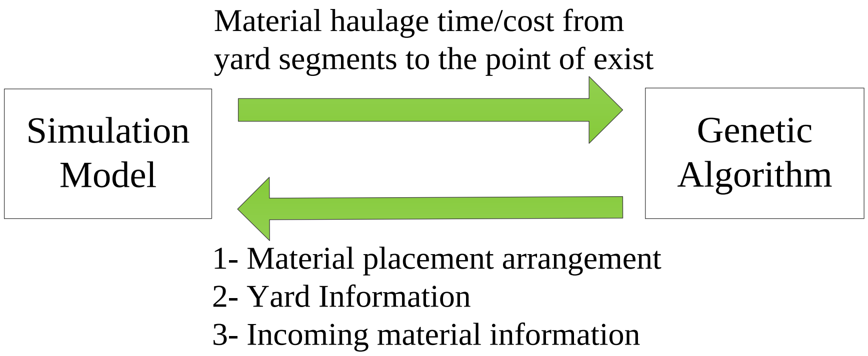

Fig. 3. Integration of simulation and genetic algorithm.

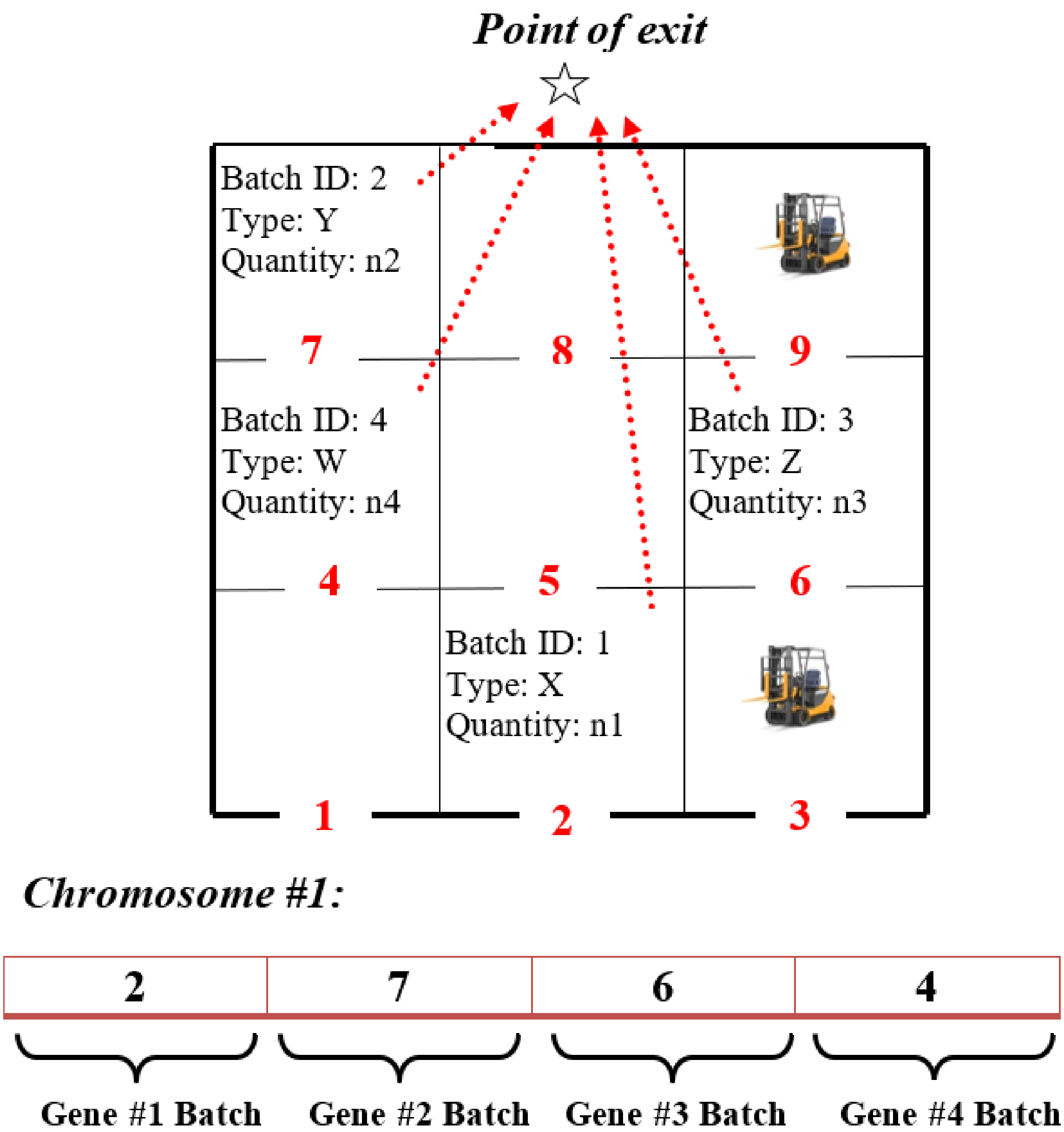

Fig. 4. Chromosome representations in the GA model.

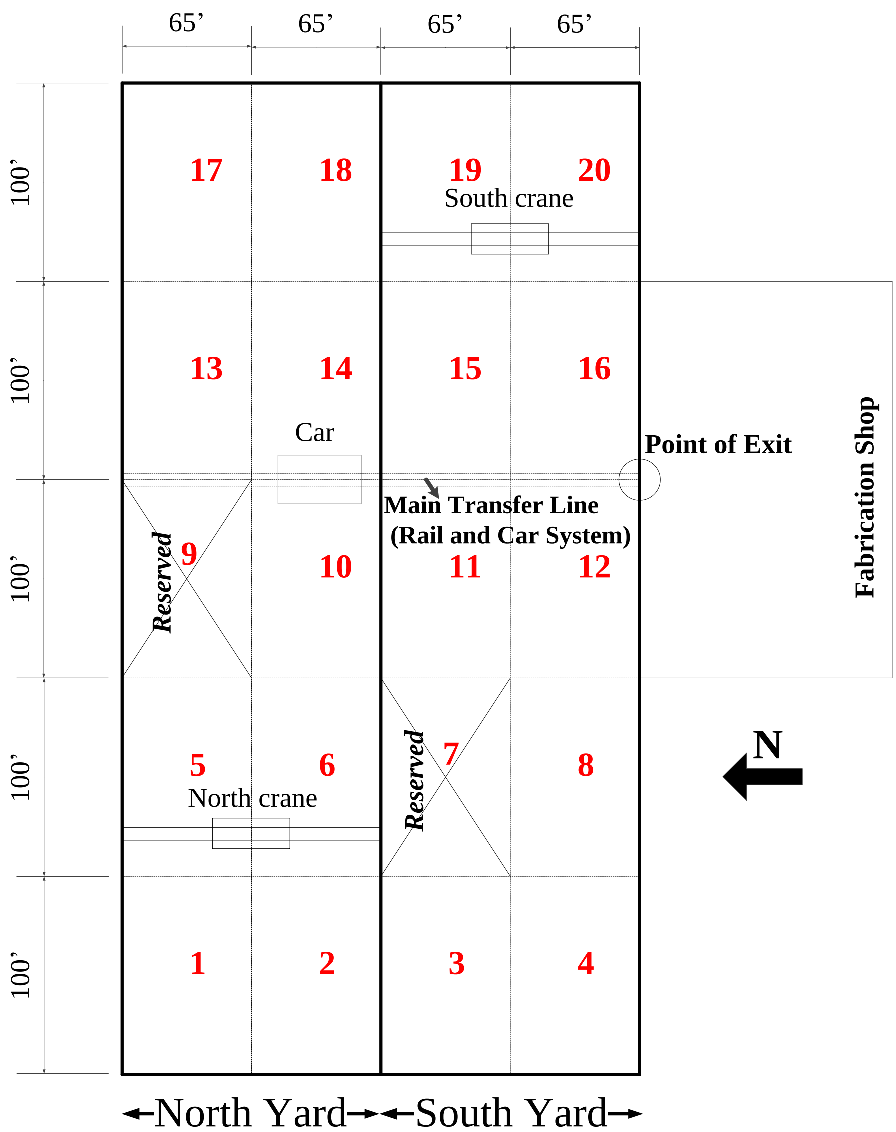

Fig. 5. The map of the material yard.

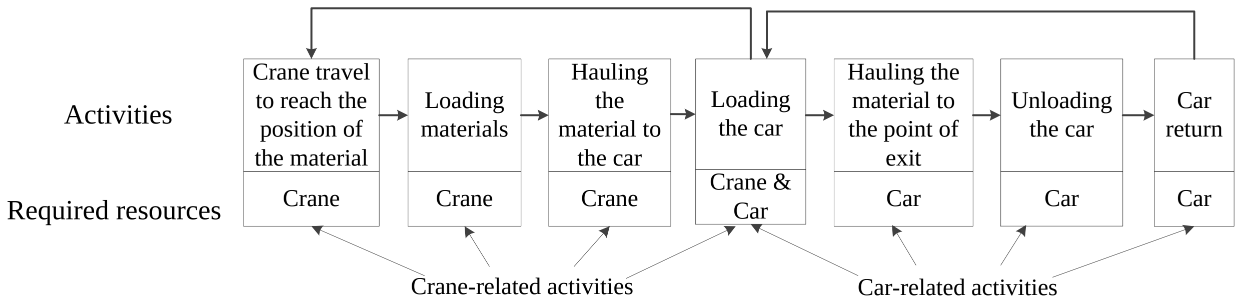

Fig. 6. Activities and required resources in the case study.

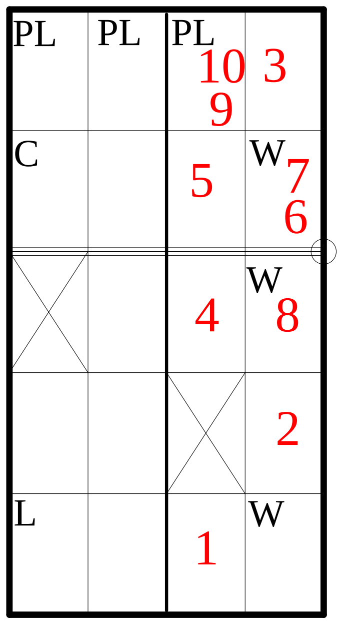

Fig. 7. Optimum material layout based on simulation.

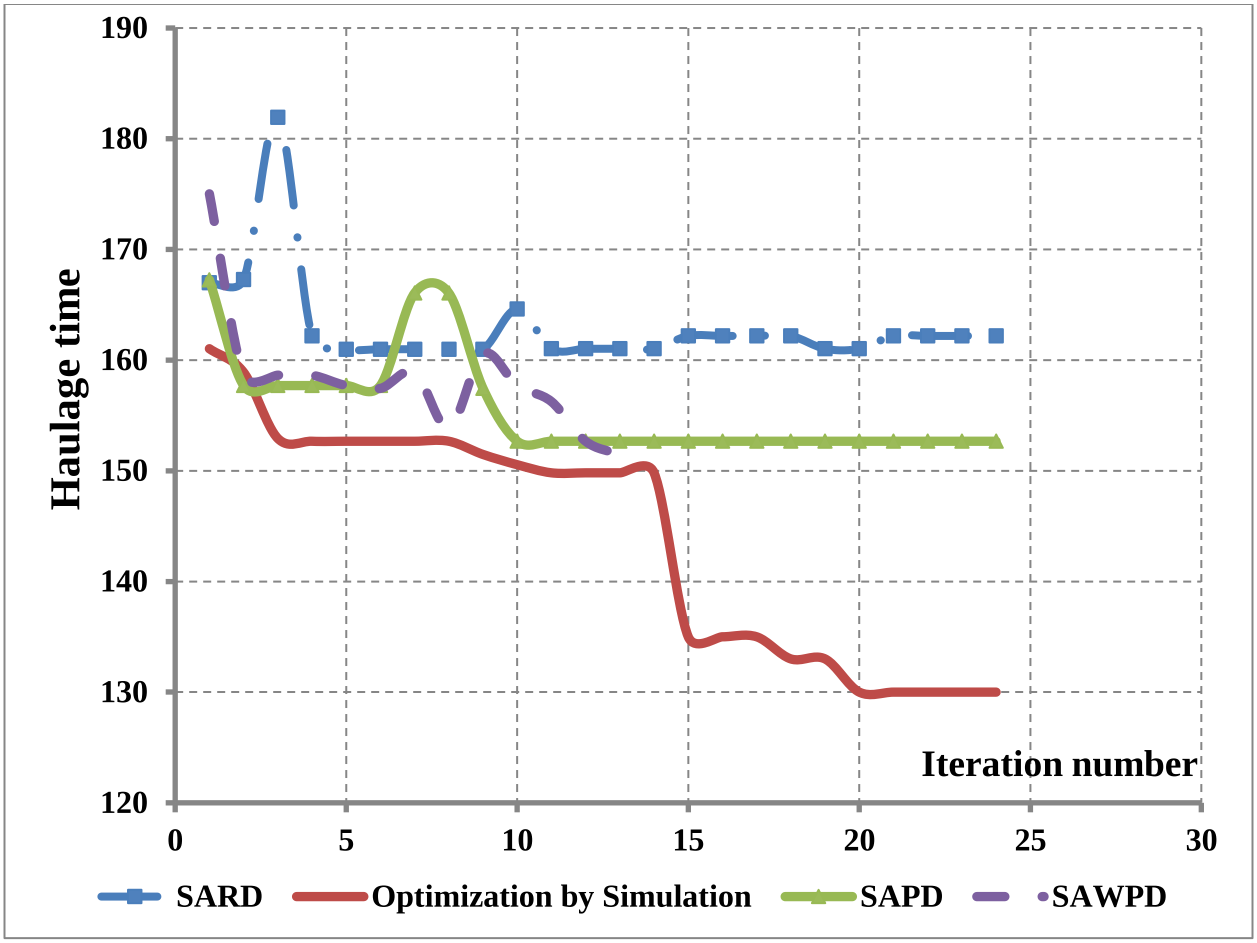

Fig. 8. Comparison of simulated placement arrangements obtained by different optimization fitness evaluations.

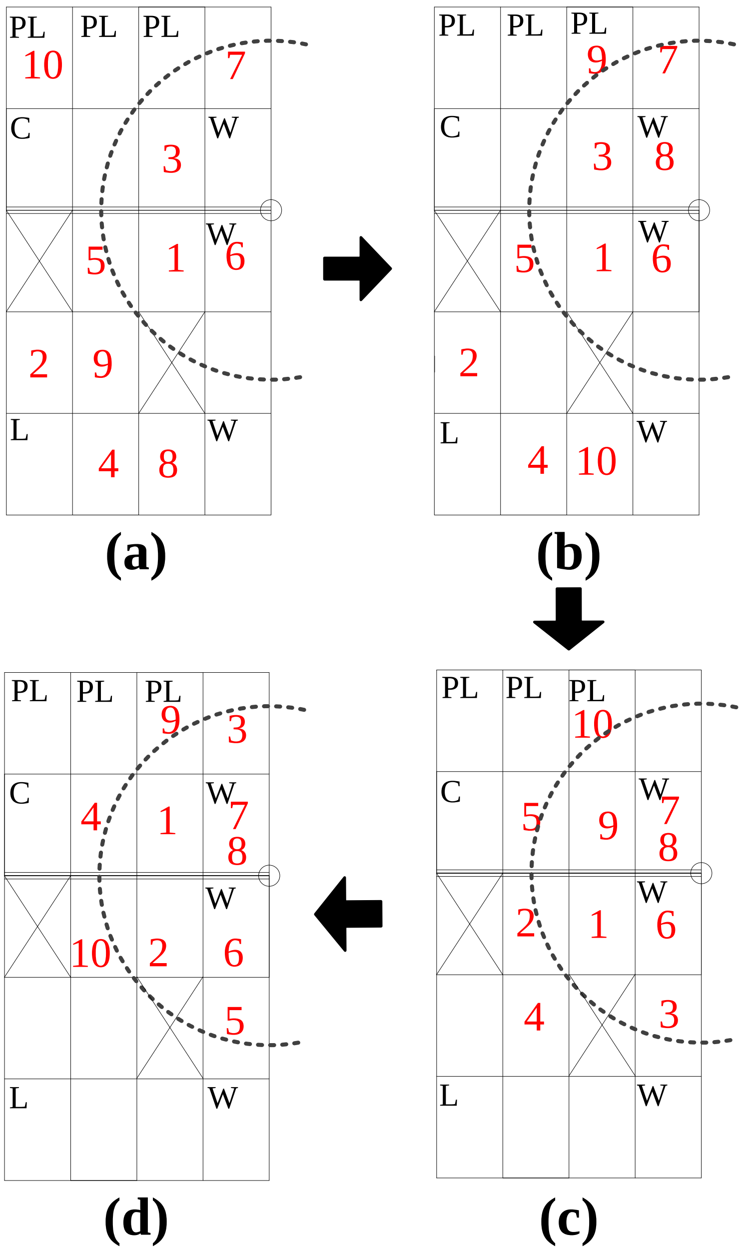

Fig. 9. The trend of optimizing material layout by SARD method.

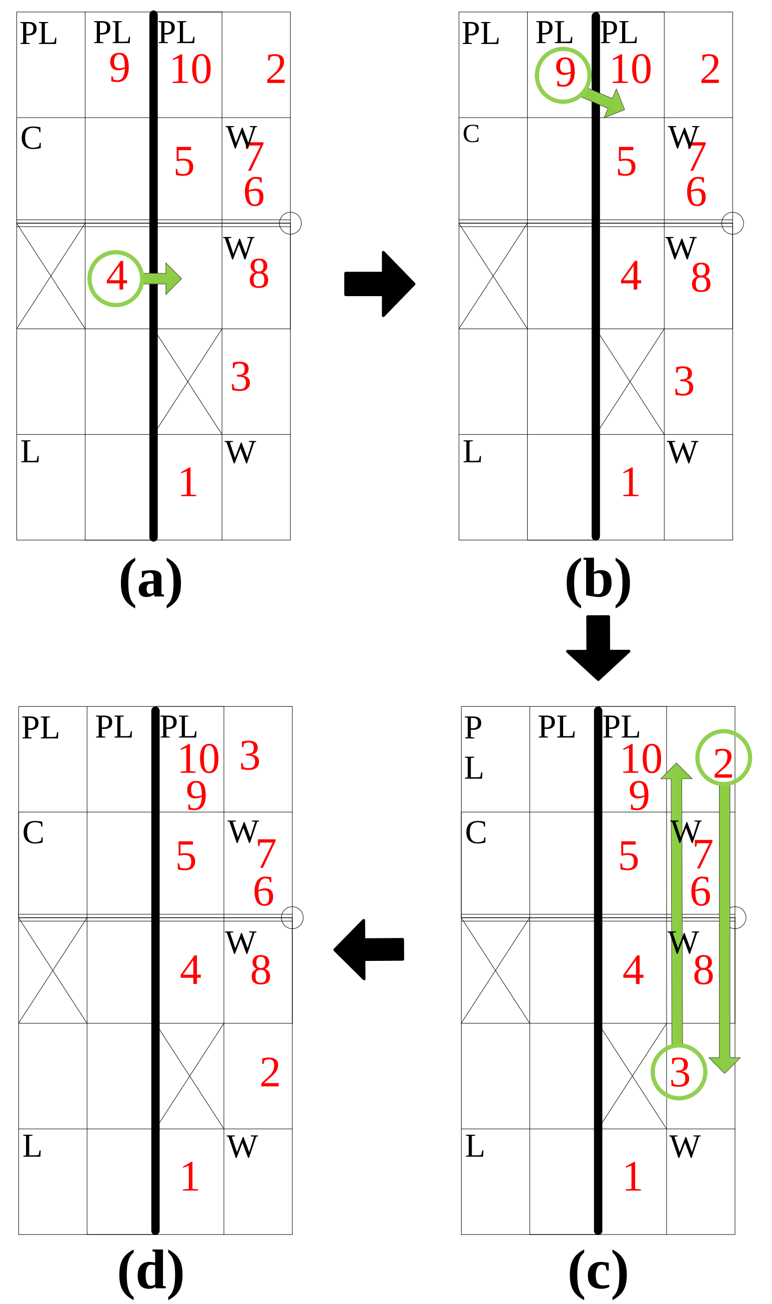

Fig. 10. The trend of optimizing material layout by the simulation-based method.

Table 1: Loading and unloading times and traveling speed of the cranes and of the car

Parameter	Value
Crane Capacity	15 tons
Crane Travelling Speed	5 Km/h
Crane Loading Time	20 s
Crane Unloading Time	20 s
Car Travelling Speed	4 Km/h
Car Unloading Time	200 s

Table 2: The list of incoming materials to the yard

ID	Type	Quantity	Length
1	L6×4×3/8	5	60
2	L6×6×3/8	20	50
3	L8×8×1/8	15	60
4	C10×15.3	200	60
5	C8×13.75	300	40
6	W8×24	50	60
7	W10×30	50	60
8	W14×43	50	35
9	PL3/8	10	8
10	PL1/2	15	8

Table 3: The list of outgoing materials to the fabrication shop

ID	Type	Quantity	Length
1	L6×4×3/8	10	60
2	C10×15.3	300	60
3	C8×13.75	450	40
4	W8×24	10	60
5	W10×30	10	60
6	W14×43	10	35
7	PL3/8	10	8
8	PL1/2	15	8
9	PL1	5	8

Table 4: Quantities and types of materials in the yard inventory

Cell #	Quantity × (Material)	Cell #	Quantity × (Material)
1	215×(L8×8×1/8)	11	Empty
2	Empty	12	102×(W8×24)+400×(W10×30)+400×(W14×43)
3	Empty	13	350×(C10×15.3)+500×(C8×13.75)+500×(C15×50)
4	170×(W8×24)	14	Empty
5	Empty	15	Empty
6	Empty	16	300×(W8×24)+158×(W10×30)+500×(W14×43)
7	Reserved	17	88×(PL3/8)+30×(PL1)+20×(PL1/2)
8	Empty	18	100×(PL3/8)+20×(PL1)+12×(PL1/2)
9	Reserved	19	33×(PL3/8)+50×(PL1)+55×(PL1/2)
10	Empty	20	Empty

Table 5: GA internal parameters

Parameter name	Parameter value
Crossover probability	80%
Mutation rate	5%
Population size	100
Number of generations	2000
Number of genes in a chromosome	10