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

3
4 Pejman Alanjari¹
5 SeyedReza RazaviAlavi*²
6 Simaan AbouRizk³

7
8 **Abstract**

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

¹ Graduate Student, Hole School of Construction Engineering Department of Civil and Environmental Engineering
University of Alberta 5-080 Markin CNRL Natural Resources Engineering Facility Edmonton, Alberta, Canada T6G
2W2, alanjari@ualberta.ca.

*² Corresponding Author: PhD Candidate, Hole School of Construction Engineering Department of Civil and
Environmental Engineering University of Alberta 5-080 Markin CNRL Natural Resources Engineering Facility
Edmonton, Alberta, Canada T6G 2W2, reza.razavi@ualberta.ca, Phone: 1-780-200-2808.

³ Professor, Hole School of Construction Engineering Department of Civil and Environmental Engineering
University of Alberta 5-080 Markin CNRL Natural Resources Engineering Facility Edmonton, Alberta, Canada T6G
2W2, abourizk@ualberta.ca

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

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

30 **Introduction**

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

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

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

59 Although warehousing and material distribution are some of the main functions in
60 material management systems (Bell and Stukhart 1986), and improper storage is recognized as
61 one of the deficiencies of material management (Thomas et al. 2005), few researchers focused on
62 how to distribute materials on yards and plan material layouts in order to have efficient storage.
63 This problem is escalated in the material laydown areas of the fabrication shop. Song et al.
64 (2006) reported that the uncertainty in material management of fast track industrial projects,
65 particularly pipe spool fabrications, leads to delivering the materials 5 to 6 months prior to the
66 installation schedule. Maintaining and managing the materials stored for a longer period of time
67 in laydown yards need a sophisticated planning system. To plan material yard layouts, it is
68 necessary to capture the effect of material consumption, material size and density, capacity of
69 laydown areas and number of available equipment resources on the reduction of the throughput
70 time. In particular, the dynamic nature of material handling should be considered in terms of

71 changes, disruptions and delays in material delivery and consumption plans. To reflect these
72 factors, two primary material placement policies in large construction yards can be identified:

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

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

84 **Proactive Versus Reactive Material Placements**

85 To further highlight the differences between proactive materials placement approach and
86 reactive approach, two methods of materials placement are discussed, as shown in Figure 1.
87 Since most construction companies use yard segmentations and a defined grid location system as
88 a map to efficiently find a place for positioning materials and track their locations in practice, it
89 is assumed that the map of the yard is given in nine cells where two of them are available for
90 placing the materials. In Figure 1, two situations have been compared: in the first one (a), 20
91 batches of iron angle ($20 \times L8 \times 8 \times 1/8$) would be stocked on the laydown space on the far right,
92 and 1 day after, 65 batches of W section ($65 \times W14 \times 43$) will be placed on the available space on
93 the far left. The second situation (b) illustrates a swapped situation in which W-sections go to the
94 right laydown and iron angles go to the left. Generally, the rule of thumb for decision-making on

95 where to place materials is the availability of free laydown area and proximity to the
96 consumption unit. Based on these rules and the reactive material placement policy, on day 1, the
97 layout planner looks for the closest possible laydown to the exit point and proceeds with the
98 placement. Thereby, the placement policy, given in Figure 1(a), would be automatically
99 prioritized and implemented. Proactive materials management, however, has the schedules
100 available, and makes holistic decisions on the basis of consumption demands as well as
101 proximity. The work suggests that proactive material handling will give freedom to the
102 purchasing manager to procure materials based on demands, and place them appropriately on the
103 material stock yard so that the overall haulage time/cost during the project life-time can be
104 minimized. Figure 1(b) is based on this placement mentality, in which iron angles are placed on
105 the far left laydown space, even though these spaces are farther from the exit point. The reason
106 for this arrangement is that there would be 4 trips for iron angles and 10 trips for W-sections, as
107 of day 2, until day 12. Thus, it would be more reasonable and cost-effective to place iron angles
108 on the left-side laydowns. It is seen in this case that the consumption demand criterion has
109 superseded the proximity preference for the iron angles. It should be noted that in this
110 comparison, consumption of W-sections has started 1 day after that of the iron angles. On day 2,
111 10 closer trips for W-sections would take less time than 4 farther trips for iron angles. As such,
112 the proximity criterion still holds, but it is applied in combination with consumption demands.

113 <Figure 1>

114 For the reasons mentioned above, a proactive material placement policy is proposed, in
115 which a placement schedule is presented and material batches are destined to be placed on
116 particular cells days before arrival at the yard. In order to implement a proactive material
117 placement strategy, the time span for material flow to and from the yard shall be expanded to
118 cover a reasonable material flow process. Promoting an accurate change management program

119 can help managers achieve the proactive material placement plan. Table 1 summarizes the
120 differences between these two approaches. In order to improve adoption of the proactive
121 placement approach and achieve the optimum material layout, a hybrid optimization method is
122 proposed. The theory of the optimization development is discussed in the next section.

123 <Table 1>

124 **Hybrid Optimization Development**

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

139 In this research, fitness function, which plays an important role in GA, is defined as the
140 total haulage time, since reduction in haulage time could lead to improving material handling
141 productivity and cost. At this stage, simulation is implemented and integrated with GA.
142 Simulation can model the material handling process, resource interactions and corresponding

143 haulage time measurements. Simulation ensures the right trade-off between distance and
144 resource availability to supply the consumption unit efficiently. GA generates material placement
145 configurations in terms of chromosomes, and sends them to the simulation engine. Simulation,
146 on the other hand, measures the haulage time on the basis of the received information and sends
147 it back to GA as the fitness function output (Figure 2 (a)).

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

157 <Figure 2 >

158 It is important to note that some hard constraints, such as cell capacity and material
159 consistency constraints, may exist, and material placement should comply with them. However,
160 these constraints are not fixed throughout the project and may change daily. For instance, on day
161 1, there could be several placement arrangements considering the yard hard constraints. By
162 choosing one of the arrangements, the yard inventory is changed for the next day. In addition,
163 consuming some materials on day 1 will change the inventory. As a result, the yard inventory is
164 updated daily based on the incoming and outgoing materials, which suggests that hard
165 constraints of the yard change continually. These dynamic changes are sophisticatedly modeled
166 in GA for proposing the material placement layout day by day.

167 **Case Study**

168 In this section, a case study, inspired from a real material yard of a steel fabrication
169 company located in Edmonton, Alberta, Canada, is presented. As shown in Figure 3 (a), the yard
170 has 20 cells numbered consecutively and divided by 2 separate south and north yards. Two cells,
171 #7 and #9, are indicated as “reserved for special jobs,” and no material can be placed in these
172 cells. Two overhead cranes with the capacity of 15 tons spanning the south and the north yards
173 are deployed to load the materials in 20 s, haul them from the yard cells to a car with an average
174 speed of 5 km/h, and unload them in a car in 20 s. The car and rail system are used to transport
175 materials from the point of crane delivery to the point of exit at the speed of 4 km/h and unload
176 them at the fabrication shop entry in 200 s. The crane-car interaction poses a challenge in linear
177 computation of haulage time. Both cranes are using the same car, so that the availability of the
178 car can influence the productivity of the cranes. When the car is serving a crane, another crane
179 should wait for it. This waiting time reduces the productivity of the crane. Hence, modeling the
180 interaction of the cranes and the car is crucial, which further highlights the significance of
181 simulation in modeling the complicated resource interactions. Since the position of the material
182 specifies which crane is to be utilized, the material layout affects the productivity of the system
183 and transportation time, which is measured by simulation. The material handling process was
184 modeled in the Symphony (Hajjar and AbouRizk 1996) environment.

185 The yard hard constraints are as follows: 1) reserved cells, i.e. materials are not allowed
186 to be placed in the cells reserved for specific jobs, 2) material compatibility constraint, i.e.
187 placing different types of materials in a cell are not allowed, and 3) cell capacity constraint, i.e.
188 the cells do not receive materials more than their capacities due to safety concerns. A coordinate
189 system assigned to the yard was used to determine the haulage distances. For selecting the
190 materials to be consumed, the proximity criteria to the point of exit based on Euclidean distance

191 was used because in reality, the closest material to the consumption unit is visually selected. That
192 is, the closest available material to the exit point was selected to be hauled there. As illustrated in
193 Figure 3 (b), a 30-day schedule was considered for incoming and outgoing materials. In Figure 3
194 (b), each individual blue cell represents one incoming batch of materials and each individual red
195 cell shows one outgoing batch. The numbers in these cells also represent the number of material
196 pieces of the corresponding batch. It is seen that the total number of incoming batches is 71, and
197 the total number of outgoing batches is 271. Figure 3 (c) shows the inventory on day 1. The GA
198 parameters used in this case study are 80%, 5%, 200 and 2000 for the crossover probability,
199 mutation rate, population size, and number of generations, respectively.

200 <Figure 3>

201 **Analysis and Results**

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

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

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

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

254 <Figure 4>

255 <Table 2>

256 **Summary and Conclusions**

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

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

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

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

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332

333

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

334

335

336

Table 2 (a) Proposed placement plan

337

338

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 °	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 ∨	10
3	6	10×L6×4×3/8	15 ×	10
4	7	10×L6×6×3/8	20 ∨	10
4	8	10×L6×4×3/8	8 ~	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 ∨	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 ∨:				30
Total L6×4×3/8 placement on cell # 15 ×:				10
Total L6×6×3/8 placement on cell # 8 *:				10
Total L6×4×3/8 placement on cell # 8 ~:				10
Total L6×4×3/8 placement on cell # 3 °:				10

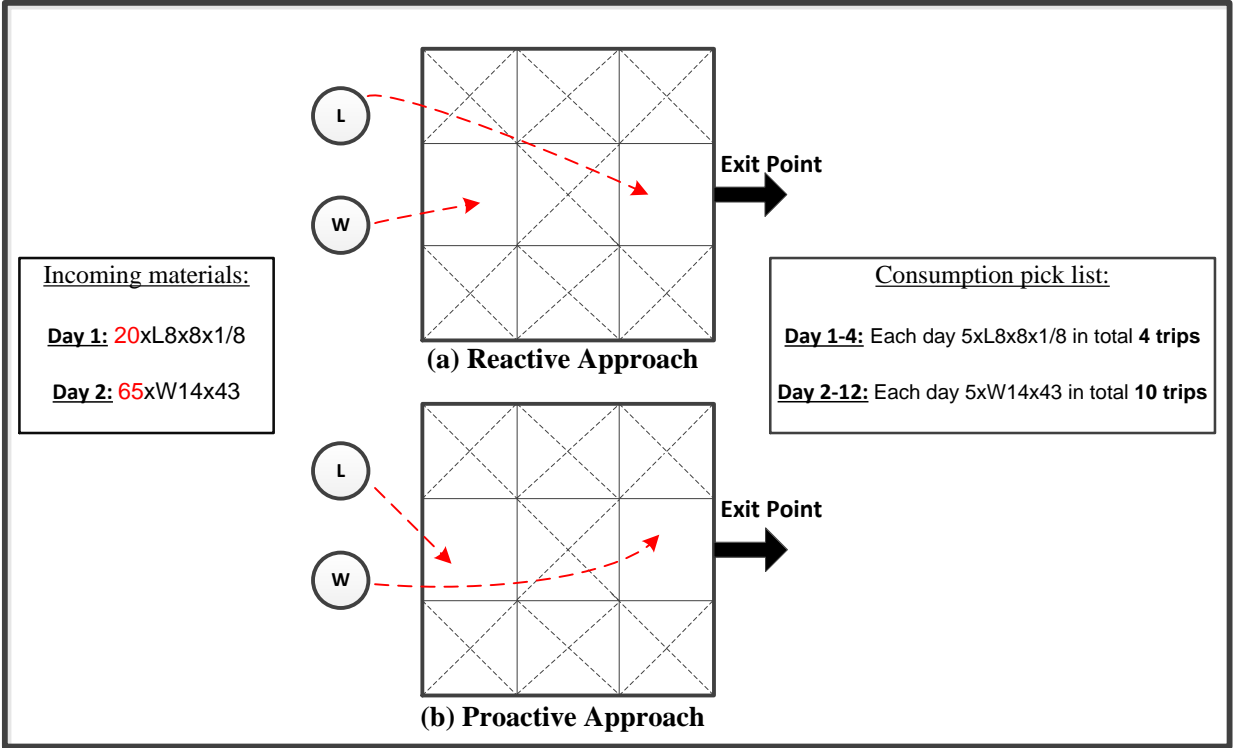
339
340

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 °	5
3	18	5×L6×6×3/8	8 *	5
3	19	5×L6×4×3/8	3 °	5
4	27	5×L6×6×3/8	20 ∇	5
4	28	5×L6×4×3/8	15	5
5	36	5×L6×6×3/8	20 ∇	5
5	37	5×L6×4×3/8	15 ×	5
6	45	5×L6×6×3/8	20 ∇	5
6	46	5×L6×4×3/8	8 ~	5
7	54	5×L6×6×3/8	20 ∇	5
7	55	5×L6×4×3/8	8 ~	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 ∇	5
9	73	5×L6×4×3/8	14	5
10	81	5×L6×6×3/8	20 ∇	5
10	82	5×L6×4×3/8	14	5
Total L6×6×3/8 take off from laydown# 20 ∇:				30
Total L6×4×3/8 take off from laydown# 15 ×:				10
Total L6×6×3/8 take off from laydown# 8 *:				10
Total L6×4×3/8 take off from laydown# 8 ~:				10
Total L6×4×3/8 take off from laydown# 3 °:				10

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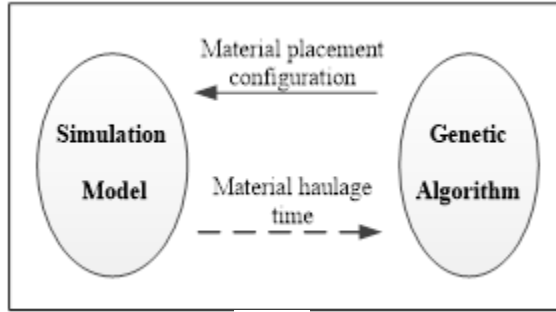


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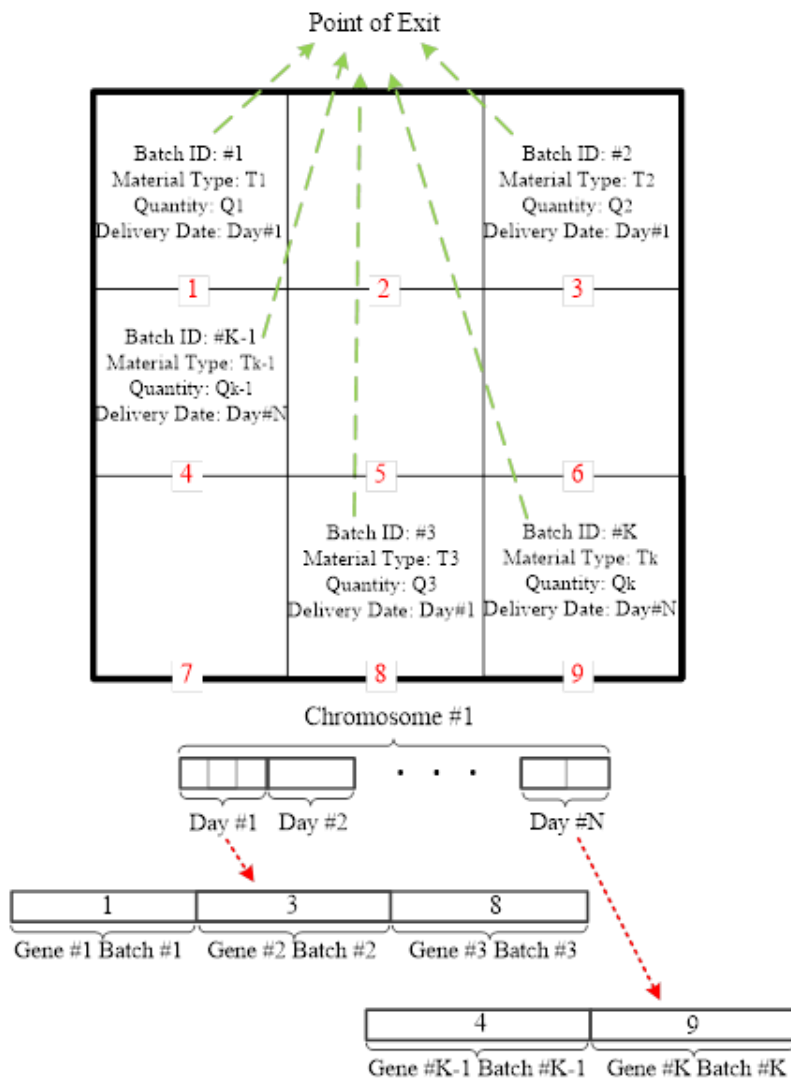
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(a)

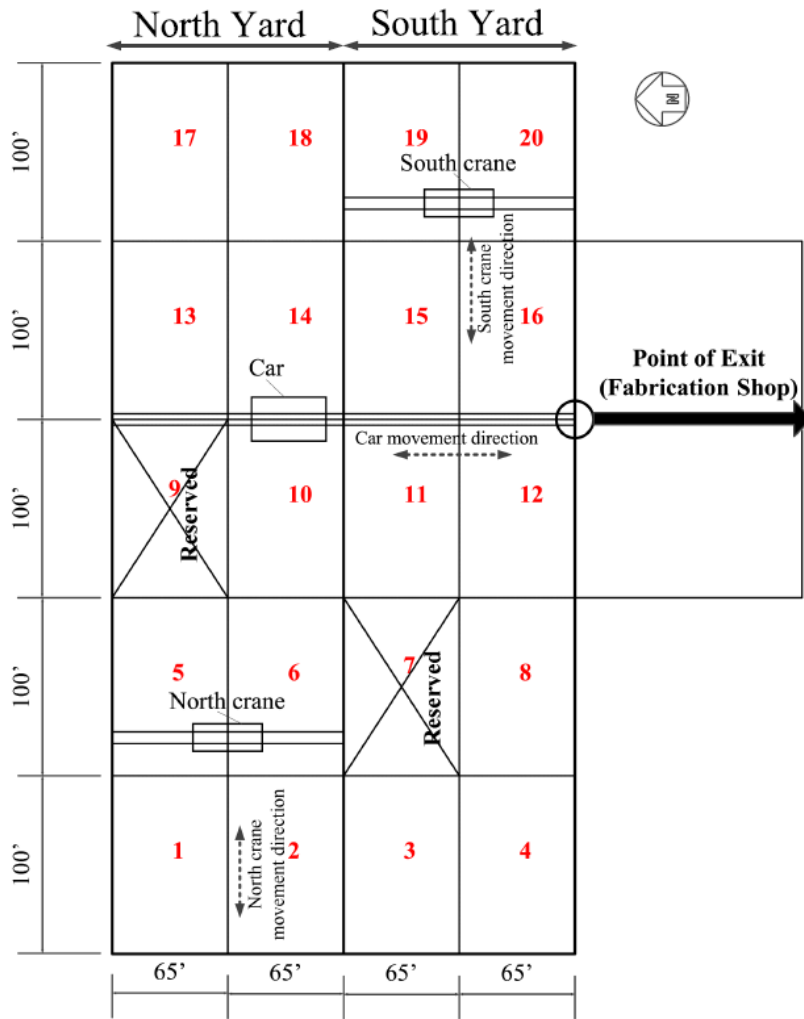


(b)

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350

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



(a)

Material type	I/O	One month duration of material flow on the yard																													
		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
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																					
	Outgoing	5	5	5	5	5	5	5	5	5																					
L6x4x3/8	Incoming	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		
	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		
W10x30	Incoming																				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	20	20	20	20	20	20	20	20		
W14x43	Incoming										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		
C10x15.3	Incoming																			50				50							
	Outgoing										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
C8x13.75	Incoming																			50				50							
	Outgoing										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
C15x50	Incoming																			50				50							
	Outgoing										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
PL3/8	Incoming																														
	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		
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		
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		

(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

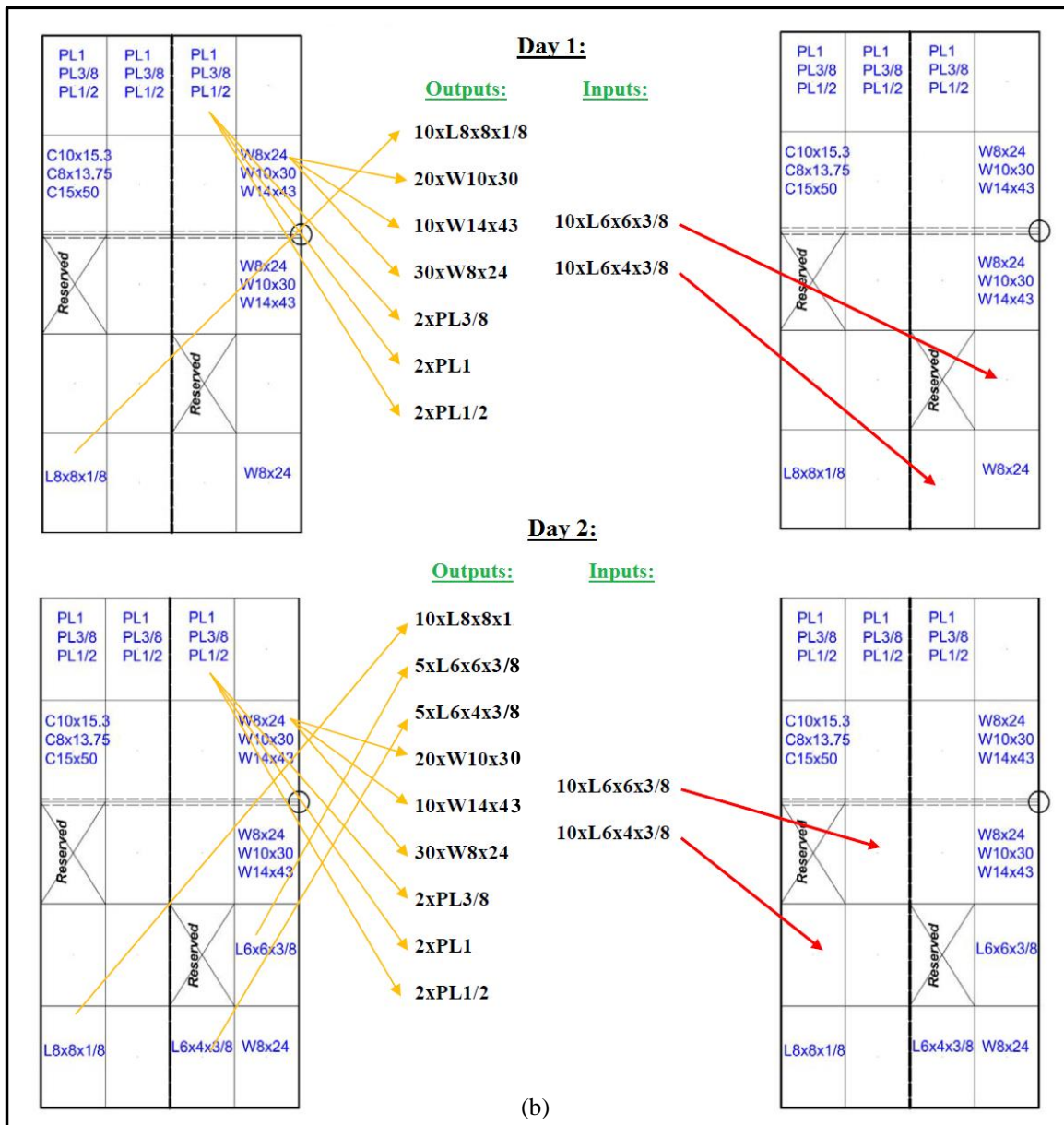
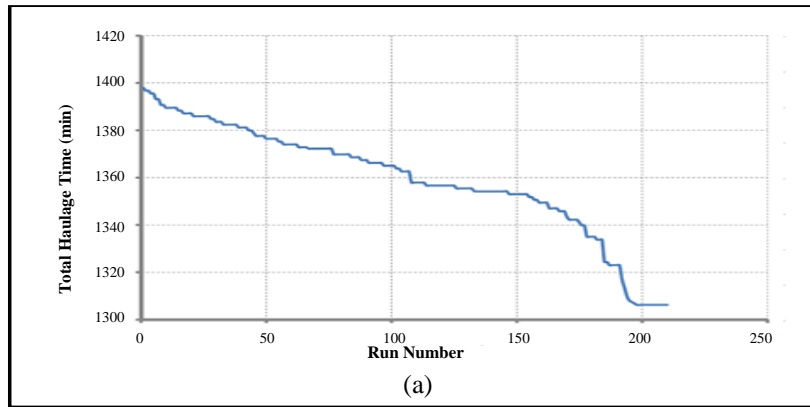
(c)

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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



356

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