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Site pre-cast yard layout arrangement through genetic algorithms

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Abstract

The use of modular construction has gained wide acceptance in the housing sector. Standardized modular units are often pre-cast on site. The establishment of site pre-cast yard, in particular arranging the pre-cast facilities within the compound, presents real challenge to site management. This complex task is further aggregated with the involvement of several resources with different transport cost. A GA-model is developed for the search for a near optimal layout solution. The fitness function is to minimize the total transport cost for a pre-determined daily output. The use of the model is illustrated by an example. When compared with the best solution within the initial population, 18.45% reduction in cost for resources flow was achieved by the near optimal layout arrangement arrived at the 673rd trial. It is also suggested that the model can be extended to other layout problems such as warehouse and production line.

Keywords: Genetic algorithms; Order chromosome; Site pre-cast yard

1. Introduction

The use of modular construction has gained wide acceptance in the housing sector. Standardization enables wider use of pre-cast technique, as well as facilitating production under controlled environment. The gain in quality and less reliance on skilled labor help to reduce the overall production cost. With a planned annual output of around 35,000–50,000 units, the Hong Kong Housing Authority took the lead to pioneer the use of standardized components some 20 years ago. The scope of application has expanded ever since. The production of pre-cast units within a pre-cast yard involves repeated movements of resources between the essential facilities needed for production. The layout of these facilities directly affects the magnitude of the resources flow cost factor. This paper presents the use of GA to handle a site pre-cast yard layout problem. The problem can cater for variations in flow and transport cost respective to the types of resource.

2. Genetic algorithm

A genetic algorithm is a computational method modeled on biological evolutionary process [1]. It can be used to find a near optimal solution to a problem that may have many solutions. The search process is independent to the problem and the search can be performed under many types of fitness function, be it discrete or continuous, linear or non-linear. Furthermore, wide flexibility is accorded to the

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construction of the fitness function to suit a wide range of problem [2].

2.1. Applications of genetic algorithms

In the past decade, the application of genetic algorithms increased significantly. GA can be applied to a wide range of problems in various industries. For example, in biochemistry industry, GA has long been used in genetic engineering. Before actual laboratory testing, a conceptual idea represented by mathematical model(s) is encoded. Computerized simulation would then be carried out to obtain preliminary test results. This saves both time and cost for the whole genetic engineering process. In the manufacturing industry, GA has been commonly used in many processes like design of workshop layout plans [3], arrangement of departments with unequal area requirements [4], cost optimization in manufacturing process [5], production scheduling of grouped jobs [6,7].

Mathematically, GA transforms a population of individual mathematical objects, each with an associated fitness value, into a new population using operations patterned after the Darwinian principle of reproduction and survival of the fittest.

The following summarizes the essential of a GA operation:

1. Establishment of a representation of the problem.
2. Setting values for the various parameters that the genetic algorithm uses.
3. Creation of an initial population of potential solutions.
4. Rating the population in terms of their fitness.
5. Population evolution through genetic operators.

Al-Tabtabai [8] suggests that the use of GA methodology is appropriate in the following circumstances:

(a) conventional statistical and mathematical methods are inadequate;
(b) the problem is very complex because the possible solution space is very large to analyze in a finite time;
(c) the additional information available to guide the search is absent or not sufficient so that the use of conventional methods is not practical;
(d) the solution to the problem can be coded in the form of a string of characters;
(e) the problem is large and poorly understood; and
(f) there is a need for near optimal solutions quickly for use as starting points for conventional optimization methods.

Construction problems typically involve multiple objectives with decision to be sought through optimization within certain constraints. The application of GA in construction has gained popularity in recent years. Notable examples include site layout optimization [9,10], scheduling [11], resources allocation [12], equipment selection [13], and determination of laying sequence for a continuous girder reinforced concrete floor system [14], fuzzy rule determination and fuzzy membership tuning [15] and optimization of layout of tower cranes on construction sites [16].

3. Site pre-cast yard study

As mentioned in Section 1, the increase in use of site pre-casting in the public housing sector in Hong Kong is self-evidencing. In this regard, a methodology that assists layout planning of a site pre-cast yard would therefore be of value to project planners. The efficiency of a site pre-cast yard is very much affected by the positioning of the various facilities within the yard compound. A GA is used in this

Table 1
Facilities within a pre-cast yard

Facilities
Main gate
Side gate
Batching plant
Steel storage yard
Formwork storage yard
Bending yard
Cement/sand/aggregate storage yard
Curing yard
Refuse dumping area
Casting yard
Lifting yard

Table 2
An example of an order chromosome

One chromosome		
Gene number	Location number	Facilities (number)
Gene (1)	$L_1(XL_1,YL_1)$	Side gate (2)
Gene (2)	$L_2(XL_2,YL_2)$	Formwork storage area (5)
Gene (3)	$L_3(XL_3,YL_3)$	Main gate (1)
Gene (4)	$L_4(XL_4,YL_4)$	Casting yard (10)
Gene (5)	$L_5(XL_5,YL_5)$	Lifting yard (11)
Gene (6)	$L_6(XL_6,YL_6)$	Curing yard (8)
Gene (7)	$L_7(XL_7,YL_7)$	Batching plant (3)
Gene (8)	$L_8(XL_8,YL_8)$	Cement, sand and aggregate storage area (7)
Gene (9)	$L_9(XL_9,YL_9)$	Bending yard (6)
Gene (10)	$L_{10}(XL_{10},YL_{10})$	Refuse dumping area (9)
Gene (11)	$L_{11}(XL_{11},YL_{11})$	Steel storage area (4)

study to obtain a near optimal location arrangement for the pre-cast facilities through minimization of transport cost of resource flow among the facilities.

It is assumed that the geometric layout of available locations is predetermined and fixed. Each of the predetermined is further considered to be capable of accommodating the largest one among the facilities. If the number of locations is more than that of facilities, dummy facilities can be added for computation purpose. The coordinates ($L_i = (XL_i,YL_i)$) identify the locations within the yard area. The facilities listed in Table 1 are to be located within the yard area.

The travelling distance (for resources) between the locations i and j is given by D_{ij}. Rectangular distance is used as opposed to diagonal distance as the physical sizes of the facilities prohibit diagonal movement of resource between locations. The use of rectangular distance between locations resembles the actual resource movements.

With the coordinates, a matrix of distance $\mathbf{D}_L$ can be constructed.

$$D_{ij} = |XL_j - XL_i| + |YL_j - YL_i| \tag{1}$$

$$\mathbf{D}_{L(q\times q)} = \begin{bmatrix} D_{1,1} & D_{1,2} & \cdots & \cdots & D_{1,q} \\ D_{2,1} & \cdots & \cdots & & \vdots \\ \vdots & & & & \\ \vdots & D_{i,j} & & & \\ D_{q,1} & \cdots & \cdots & & D_{q,q} \end{bmatrix}$$

Where D_{ij} = the rectangular distance between locations i and j; $L_i = (XL_i,YL_i)$ the coordinates of the locations within the yard area.

With the daily anticipated output, the frequencies (per day) of trips for resources flow between the facilities can be calculated and presented in a frequency matrix, $\mathbf{F}_{Mk(q\times q)}$, for all Mk in $[1,n]$, n is number of types of resource flow.

$$\mathbf{F}_{Mk(q\times q)} = \begin{bmatrix} F_{Mk1,1} & F_{Mk1,2} & \cdots & \cdots & F_{Mk1,q} \\ F_{Mk2,1} & \cdots & \cdots & & \vdots \\ \vdots & & & & \\ \vdots & F_{Mkr,s} & & & \\ F_{Mkq,1} & \cdots & \cdots & & F_{Mkq,q} \end{bmatrix}$$

The cost per unit distance for the n types of resources flow is given by C_{Mk}, for all Mk in $[1,n]$.

3.1. Setting values for the various parameters

The setting of population size, probability of crossover and mutation is a trial and error process.

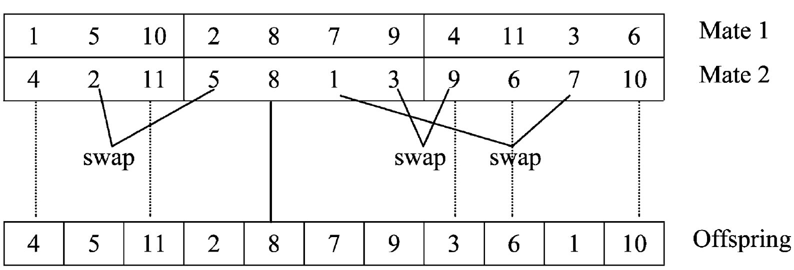

Fig. 1. Crossover of order chromosome.

			swap								
2	6	3	1	8	10	4	11	7	5	9	Before mutation
2	6	3	11	8	10	4	1	7	5	9	After mutation

Fig. 2. Example of the mutation operator for 11-gene order chromosome.

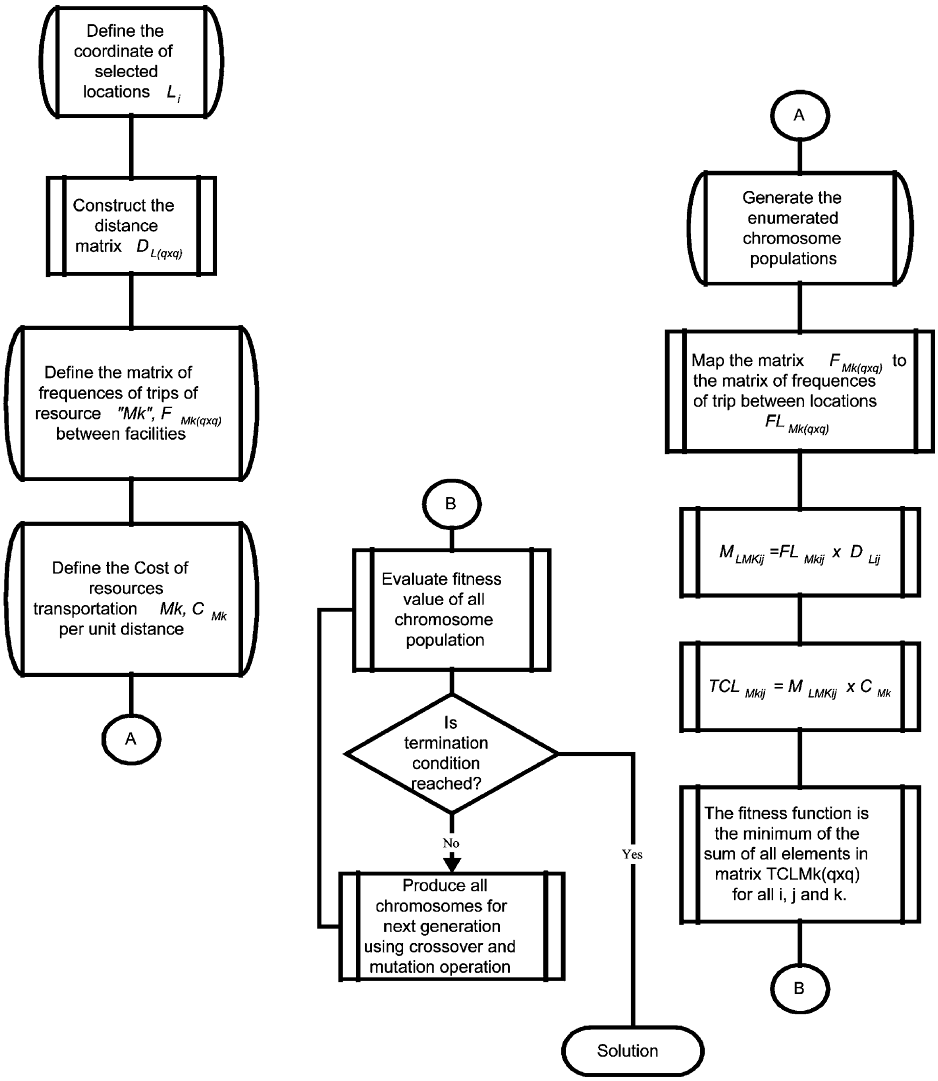

Fig. 3. Flows of the GA operations for site pre-cast layout study.

3.2. Initial population

The type of chromosome used in Evolver™ is called the order chromosome. This type of chromosome is normally used in solving sequencing problems. The pre-cast yard layout can be reduced to a traveling salesman problem. The facilities numbers are arranged into the location numbers, in which, each facility is unique. In a similar context, no duplicate is permitted for locations of the facilities within a site pre-cast yard. Hence, order chromosome with unique genes is suitable for the site pre-cast yard study. Table 2 shows an example of an order chromosome. For example, in Table 2, the batching plant (facility no. 3) is placed at location no. 7 and the corresponding gene position within the chromosome is seven (Fig. 1).

The function of the GA is to find the optimal order of the facilities in the 11 genes within the chromosome. Fifty chromosomes were generated as the initial population.

3.3. Rating the population in terms of their fitness

In this study, the fitness of the chromosome is assessed by the total cost per day for transporting all resources necessary to achieve the anticipated output. The objective function is therefore given by,

$$\text{Total cost} = \min\left(\sum_{k=1}^{n}\sum_{i=1}^{q}\sum_{j=1}^{q}\mathrm{TCL}_{Mk,i,j}\right). \qquad (2)$$

Where

$$\mathbf{TCL}_{Mk(q\times q)} = \begin{bmatrix} \mathrm{TCL}_{Mk1,1} & \mathrm{TCL}_{Mk1,2} & \cdots & \cdots & \mathrm{TCL}_{Mk1,q} \\ \mathrm{TCL}_{Mk2,1} & \cdots & \cdots & & \vdots \\ \vdots & & & & \\ \vdots & \mathrm{TCL}_{Mki,j} & & & \\ \mathrm{TCL}_{Mkq,1} & \cdots & \cdots & & \mathrm{TCL}_{Mkq,q} \end{bmatrix}$$

$$\mathrm{TCL}_{Mkij} = M_{LMij} \times C_{Mk} \qquad (3)$$

$$M_{LMkij} = \mathrm{FL}_{Mkij} \times D_{ij} \qquad (4)$$

$$\mathbf{FL}_{Mk(q\times q)} = \begin{bmatrix} \mathrm{FL}_{Mk1,1} & \mathrm{FL}_{Mk1,2} & \cdots & \cdots & \mathrm{FL}_{Mk1,q} \\ \mathrm{FL}_{Mk2,1} & \cdots & \cdots & & \vdots \\ \vdots & \mathrm{FL}_{Mkr,s} & & & \\ \mathrm{FL}_{Mkq,1} & \cdots & \cdots & & \mathrm{FL}_{Mkq,q} \end{bmatrix}$$

$\mathbf{D}_{L(q\times q)}$	the distance matrix between different locations
D_{ij}	the distance between location i and j
$\mathbf{F}_{Mk(q\times q)}$	the frequency matrix of resource *Mk* flow between different facilities per unit time
$F_{Mkr,s}$	the frequency of resource *Mk* flow between facilities r and s per unit time
C_{Mk}	the cost per unit distance for resources *Mk* flow
$\mathbf{TCL}_{Mk(q\times q)}$	the total cost matrix of resource *Mk* flow between different locations
$\mathrm{TCL}_{Mki,j}$	the total cost of resource *Mk* flow between locations i and j
M_{LMkij}	the total distance traveled of resource *Mk* flow per unit time between locations i and j
$\mathbf{FL}_{Mk(q\times q)}$	the frequency matrix of resource *Mk* flow between different locations per unit time
$\mathrm{FL}_{Mki,j}$	the frequency of resource *Mk* flow between location i and j per unit time.

Table 3
Facilities to be located in a site pre-cast yard

Number	Facilities
1	Main gate
2	Side gate
3	Batching plant
4	Steel storage yard
5	Formwork storage yard
6	Bending yard
7	Cement and sand and aggregate storage yard
8	Curing yard
9	Refuse dumping area
10	Casting yard
11	Lifting yard

Table 4
Coordinates of the locations

Location number	*X*	Y
1	15	40
2	13	30
3	22	30
4	25	20
5	20	10
6	12	10
7	40	10
8	48	20
9	48	35
10	5	20
11	32	42

It is noted that the frequency matrix, $\mathbf{F}_{Mk(q\times q)}$, of resource *Mk* flow between different facilities should be mapped into the frequency matrix, $\mathbf{FL}_{Mk(q\times q)}$, of resource *Mk* to reflect the flows of resources between the various locations respective to the different combination of facility locations generated by GA. This is necessary as for each generation, a new set of locations will be assigned for the facilities, with the flow between the facilities being governed by the production logistic, the frequency flow of resources between the locations will be recalculated. It can be done by mapping the row index and column index from the frequency matrix, $\mathbf{F}_{Mk(q\times q)}$, to the frequency matrix, $\mathbf{FL}_{Mk(q\times q)}$, through the combinations between facilities number and location number generated by the chromosome. The mapping can be implemented by the "index" function in Microsoft Excel™.

Table 5
Distance between the locations

$i \setminus j$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	0	12	17	30	35	33	55	53	38	30	19
2	12	0	9	22	27	21	47	45	40	18	31
3	17	9	0	13	22	30	38	36	31	27	22
4	30	22	13	0	15	23	25	23	38	20	29
5	35	27	22	15	0	8	20	38	53	25	44
6	33	21	30	23	8	0	28	46	61	17	52
7	55	47	38	25	20	28	0	18	33	45	40
8	53	45	36	23	38	46	18	0	15	43	38
9	38	40	31	38	53	61	33	15	0	58	23
10	30	18	27	20	25	17	45	43	58	0	49
11	19	31	22	29	44	52	40	38	23	49	0

Table 6
Frequency of resources flow between facilities per day

$r \setminus s$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
(a) Aggregate, sand and cement											
1							20				
2							15				
3							35			35	
4											
5											
6											
7	20	15	35								
8											
9											
10			35								
11											
(b) Reinforcement											
1				30							
2				20							
3											
4	30	20				50					
5											
6				50						50	
7											
8											
9											
10						50					
11											
(c) Formwork											
1											
2											
3											
4											
5										48	
6											
7											
8											
9											
10					48						
11											
(d) Complete pre-cast units											
1											28
2											20
3											
4											
5											
6											
7											
8										48	48
9											
10								48			
11	28	20						48			

Table 7
Transport cost per unit distance between facilities for the four types of resource

Mk	C_{Mk}
1	5
2	4
3	8
4	8.5

3.4. Population evolution through genetic operators

Crossover and mutation are used as genetic operators for the evolution of the population. Evolver™ [17], the GA package used in this study, employs a steady-state approach. This means that only one organism is replaced at a time, rather than an entire “generation” being replaced. To obtain the equivalent number of “generations” before convergence, divide the number of individual trials explored by the size of the population.

The order solving method performs crossover using a similar algorithm to the order crossover operator described by Davis [18]. This selects items randomly from one parent, finds their place in the other parent, and copies the remaining items into the second parent in the same order as they appear in the first parent. This preserves some of the sub-orderings in the original parents while creating some new sub-orderings.

To preserve all the original values, the order solving method performs mutation by swapping the

Table 8
One chromosome in the initial population

Location number	Facilities number	Facilities
1	6	Bending yard
2	4	Steel storage yard
3	10	Casting yard
4	8	Curing yard
5	11	Lifting yard
6	1	Main gate
7	7	Cement and sand and aggregate storage yard
8	3	Batching plant
9	9	Refuse dumping area
10	2	Side gate
11	5	Formwork storage yard

Table 9
Frequency of resources flow between locations

i \ ***j***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
(a) Aggregate, sand and cement											
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	35	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0		0	0	0	0	0	0
6	0	0	0	0	0	0	20	0	0	0	0
7	0	0	0	0	0	20	0	35	0	15	0
8	0	0	35	0	0	0	35	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	15	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
(b) Reinforcement											
1	0	50	50	0	0	0	0	0	0	0	0
2	50	0	0	0	0	30	0	0	0	20	0
3	50	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	30	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	20	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
(c) Formwork											
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	48
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	48	0	0	0	0	0	0	0	0
(d) Completed pre-cast units											
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	48	0	0	0	0	0	0	0
4	0	0	48	0	48	0	0	0	0	0	0
5	0	0	0	48	0	28	0	0	0	20	0
6	0	0	0	0	28	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	20	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0

Table 10
Transport cost units for resources

Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
(a) Aggregate, sand and cement											
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	6300	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	2800	0	0	0	0
7	0	0	0	0	0	2800	0	3150	0	3375	0
8	0	0	6300	0	0	0	3150	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	3375	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
(b) Reinforcement											
1	0	2400	3400	0	0	0	0	0	0	0	0
2	2400	0	0	0	0	2520	0	0	0	1440	0
3	3400	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	2520	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	1440	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
(c) Formwork											
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	8448
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	8448	0	0	0	0	0	0	0	0
(d) Completed pre-cast units											
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	5304	0	0	0	0	0	0	0
4	0	0	5304	0	6120	0	0	0	0	0	0
5	0	0	0	6120	0	1904	0	0	0	4250	0
6	0	0	0	0	1904	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	4250	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0

positions of some variables in the organism. For example, in Fig. 2, genes 1 and 11 swap their positions to form a new chromosome. The number of swaps performed is increased or decreased proportionately to the increase and decrease of the mutation rate setting (from 0 to 1).

In Evolver™, parents are chosen with a rank-based mechanism. Instead of some genetic algorithm systems, where a parent's chance to be selected for reproduction is directly proportional to its fitness, a ranking approach offers a smoother selection probability curve. This prevents good organisms from completely dominating the evolution from an early point. The flows of the GA operations for the Site Pre-cast yard layout study are presented in Fig. 3.

4. Illustration

The GA model so described was applied to a site pre-cast yard of size 50 × 50 m. The facilities to be positioned in the yard together with their designated numbers are given in Table 3. For example, the main gate and the lifting yard are designated as Facility 1 and 11, respectively.

The eleven locations were also determined with the coordinates given in Table 4.

With the coordinates, the rectangular distance matrix ($\mathbf{D}_{L(q \times q)}$) for the locations were then calculated and presented as Table 5.

The next step involved the researchers determining the logistic of resources flow between the facilities. The four types of resource considered are:

1. aggregate, sand and cement/concrete ($Mk = 1$);
2. reinforcement bars ($Mk = 2$);
3. formwork ($Mk = 3$);
4. completed pre-cast units ($Mk = 4$).

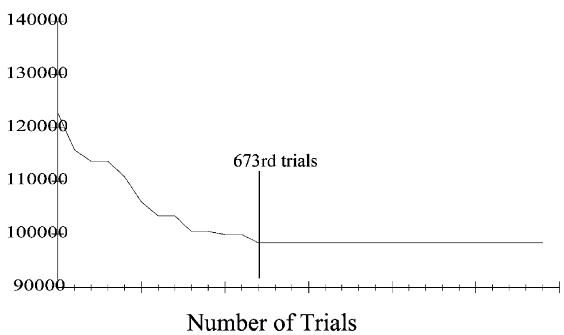

Fig. 4. Fitness of trials.

Table 11
The near optimal layout

Location number	Number	Facilities	*X*	Y
1	1	Main gate	15	40
2	11	Lifting Yard	13	30
3	8	Curing yard	22	30
4	10	Casting yard	25	20
5	6	Steel storage yard	20	10
6	4	Bending yard	12	10
7	9	Refuse dumping area	40	10
8	5	Formwork storage yard	48	20
9	3	Batching plant	48	35
10	2	Side gate	5	20
11	7	Cement and sand and aggregate storage yard	32	42
Total transport cost: 99,788				

The flow logistic for the resources is somewhat dictated by the production process. Cement, sand, aggregate, reinforcement bars and formwork materials are stored in their respective storage areas before they are transported to their production units (batching plant, bending yard and casting yard, respectively). Concreting of the pre-cast units is carried out at the casting yard. The concreted units will undergo the curing process in the curing yard before being placed in the lifting yard. The flow pattern is shown

Table 12
Result from Evolver™

Results	
Trials	1673
Recalcs	1673
Original Value	122,362
+ soft constraint penalties	0
= result	122,362
Best Value Found	99,788
+ soft constraint penalties	0
= result	99,788
Occurred on trial number	673
Time to find this value	00:01:43
Stopped because	No improvement for 1000 trials
Optimization started at	PM 12:30:30
Optimization finished at	PM 12:34:22
Total optimization time	00:03:52

in Fig. 5. Table 6 gives the trip frequency of the four types of resource between the facilities.

In addition, the cost units per distance for each type of resources (C_{Mk}) were determined and the results are given in Table 7.

The initial population was now ready to be generated. Table 8 gives one chromosome of the initial population.

With the chromosome as shown in Table 8, the corresponding frequency matrices between locations for the four types of resources, resulting from the assignment of the facilities to gene positions, were calculated and presented in Table 9.

The distance matrix for the four types of sources were given by,

$$M_{LMkij} = \mathrm{FL}_{Mkij} \times D_{ij}. \tag{4}$$

Applying $\mathrm{TCL}_{Mkij} = M_{LMkij} \times C_{Mk}$ (Eq. (3)), the transport cost units for the four types of resources with location arrangement as shown in Table 8 were obtained and given in Table 10.

Using the layout arrangement in Table 8, the following illustrates the calculation for the transport cost for transporting aggregate, cement and sand ($Mk = 1$) from the storage area (facility no. 7) to the batching plant (facility no. 3). From Table 8, the resource movement shall then be between locations 7 and 8. According to the Eqs. (3) and (4), the transport cost between locations 7 and 8 can be expressed as follows: Transport cost = distance between locations 7 and 8 (from Table 5) × frequency of movements between facility locations 7 and 8 (from Table 9) × transport cost per unit distance (from Table 7) = 18 × 35 × 5 = 3150 (Table 10).

Similar operations were applied to all chromosomes within the population. The objective function (Eq. (2)) was used to assess the fitness. Evolutions were performed by the Evolver™ software. The genetic operators performed crossover and mutation. The probability of crossover and mutation were set at 0.5 and 0.06, respectively. The initial population size was 50. For each generation, the above opera-

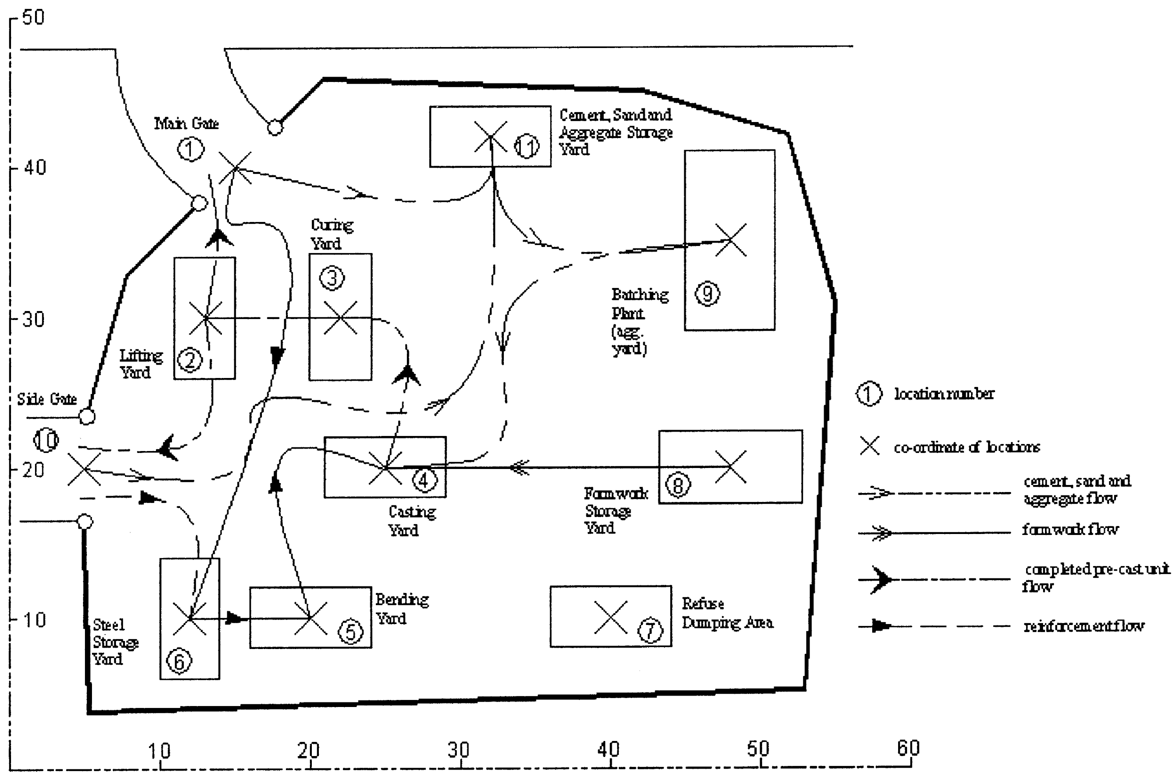

Fig. 5. Site pre-cast yard layout arrangement plan for the near optimal solution.

tions were repeated so that the fitness of all chromosomes within the trials assessed. The transport cost for resource flow remained constant as from 673rd trials, that is, 13.46 generations (Fig. 4) and the near optimal solution was shown in Table 11. Table 12 summarizes the results from the GA operations performed by Evolver™. Fig. 5 presents the site pre-cast yard layout as plotted from Table 11, the flow of the resources is also indicated.

5. Discussions

The illustration example demonstrates the searching ability of GA. Time-wise, with an initial population of 50, the near optimal solution was obtained in 1 min 43 s. The search space is calculated by,

$$P_{k,n} = \frac{n!}{(n-k)!}. \tag{5}$$

Where $P_{k,n}$ is the number of permutations for k facilities to be located in n locations.

In the example, $n = k = 11$, hence, the possible layout arrangements are given by 11! (39,916,800). The attainment of the near optimal solution at the 673rd trial represents only a coverage of 0.001686% of the search space.

As for the transport cost, the daily transport for resource movements to achieve the planned output reduced from 122,362 cost units (based on the best layout within the initial population) to 99,788 cost units (based on the near optimal solution). A 18.45% reduction was achieved through the use of the GA model. The GA model can be extended to other situation sequencing problems exhibiting a patterned flow of resources, e.g. warehouse and supermarket layouts.

6. Concluding remarks

Genetic algorithms are suitable for tackling combinatorial problems involving large search space. Near optimal solution for this type of problem is often obtained through evolution. Order chromosome representation neatly fills this need. This research takes full advantage of this salient feature of order chromosome and applies to a site pre-cast yard layout problem. The methodology so described in this paper, through the use of an illustration example, is shown to be an efficient method to obtain a near 'optimal' solution. Efficiency is achieved in terms of the small population size and relatively short convergence process.

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