Genetic Algorithms for Construction Site Layout in Project Planning

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Abstract: Construction site layout is concerned with the existence, positioning, and timing of the temporary facilities that are used to carry out a construction project. Typically these problems are very complicated to formulate and difficult to solve. They are, however, very important to virtually any construction project, since the site layout can significantly affect the cost of the project. This paper describes the general site layout problem from both a theoretical and a practical point of view. It proposes genetic algorithms as a possible solution technique and includes a theoretical example of positioning temporary facilities. This is extended to a practical problem in which the cost of movement is modeled realistically using an augmented genetic algorithm. Some preliminary conclusions are drawn for the application of genetic algorithms to construction site layout problems.

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Introduction

The objective of site layout is to determine what temporary works are required and to position them in space and time throughout the project in such a way as to improve the construction process. This will be reflected in one, some, or all of the following:

- A reduction in the project cost,
- An improvement in the quality of the work,
- An improvement in safety of operations on the project, and
- An improvement in the environmental aspects of the work.

It can be seen that these features are closely related to the objectives of project planning (Mawdesley and Askew 1991), and indeed the whole problem can be seen as being very closely related to project planning.

One of the main ways in which a site layout can achieve the objectives is by the minimization of travel times and the removal of unnecessary movement of resources and handling of materials. A good site layout should save a considerable amount of nonproductive time that can arise from poor planning and coordination of the work of the various resources employed.

Construction site layout is essential to any project and has a significant impact on the economy, safety, and other aspects of the project. Despite this, in practice, the site layout plan is often not made with the same thought as is given to the production of the project plan itself—and, indeed, sometimes there is no specific site layout plan. This leads to some decisions being delayed and made only when absolutely necessary. For example, in extreme cases, the decisions as to where to store materials on some projects might only be made when the materials have been transported to the construction site and must be taken off the delivery vehicles.

Site layout is also a dynamic problem because of the constantly changing nature of a project. This makes it slightly different from static problems such as the layout of factories and electronic components. The problem is therefore practically important and theoretically challenging.

Genetic algorithms have recently emerged as a robust search procedure for complicated problems, and many successful applications to practical scheduling have been reported (e.g., Syswerda and Palmucci 1991; Lee and Kim 1996; Al-Tabtabai and Alex 1997). In this paper, the application of genetic algorithms to construction site layout problems is explored and some models of the construction site layout problems are proposed and investigated.

Construction Site Layout Problems

As an initial part of this work, practicing engineers and other construction personnel were interviewed to determine the importance of the overall problem. In addition to verifying the significance of the topic, several factors were identified as being generally of importance. These are listed below together with a short description of why they were considered so.

1. Access and traffic routes: Generally, all construction sites require resources (labor, equipment, and material) to be brought onto site, taken off site, and moved around site. The movement onto and off sites is here termed ‘‘access,’’ while the movement around the site is called ‘‘traffic routes.’’ Obviously, both access and traffic routes will vary depending on the project type and the specific project. A road construction project over virgin ground will have different problems from a city center redevelopment project, but in both the ability to move onto, off, and around the site will affect the cost of the

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project. In both cases, the positioning will also affect safety and may affect the environmental impact. As a general rule, construction professionals suggest that access and traffic routes should be positioned in such a way as to avoid service lines and to link work areas without crossing them.
2. Material storage and handling: Materials brought onto a project are often not used immediately. In this case, they need to be stored. Some materials are valuable and have to be protected from theft; others are dangerous and people have to be protected from them; while still others are neither ‘‘valuable’’ nor dangerous and can be stored unprotected. These three types give rise to the need for several different storage facilities, with different costs involved in their construction and maintenance. Handling of construction materials is often expensive, with large pieces of equipment being required. The construction professionals suggested that material storage should be positioned to avoid double handling and unnecessary movement.
3. Administration buildings and welfare facilities: Almost all construction projects require administration buildings and welfare facilities for the workers. Administration buildings should have a good view of the works and be free from noise. Other facilities, such as toilets, should be placed to cause as little disruption to the project as possible.
4. Equipment, workshops, and services: On those projects that require them—large road construction projects, for example—these facilities are very important. Workshops must be located so as to ease access and create short routes to the scene of construction with the necessity to avoid site congestion.

The overriding message that came from the construction professionals was that, in general, construction site layout problems are very complicated. They considered them to be:

1. Very difficult to specify: Just as it is difficult to define the best plan for a construction project, so it is very difficult to define the best site layout. What is of vital importance on one project may be of little importance at all on another. In fact, even within one project, what is important one day may not be important on the next (see the following).
2. Interrelated with other management tasks: The development of a site layout is closely linked with other planning tasks and highly dependent on the construction methods employed and other site related factors. The site layout can not be decided before other planning tasks are determined and, conversely, some planning tasks are affected by the site layout. Thus, for example, different operational sequences of the same construction work (the schedule) may need different site layouts, but without settlement of the construction schedule, it will be very difficult, if not impossible, to determine an appropriate site layout.
3. Highly dynamic: As a construction project progresses, the requirements of the construction work will change and site layout may need to be altered or improved. Because this change may involve the whole construction project, any site layout which is ‘‘optimal’’ at a specific period may not be so during other periods. Thus, obtaining the ‘‘optimal’’ site layout for the whole project is actually a process that is continuous throughout the project’s duration.
4. Underresearched: Considerable research has been done into facilities layout, but very little has been done into general site layout. The particular features described in 1–3 above mean that methods developed for use in other situations are not directly applicable to this problem.

A complete site layout should include the following aspects:

- The temporary facilities that need to be established,
- The geographic layout of the temporary facilities, and
- The timing of the establishment and removal of specific facilities during the project.

Therefore, site layout problems are about what temporary facilities are needed and where and when they should be set up.

Related Work on Layout

Site layout problems have long been recognized as being of importance, but while they have been written about (e.g., Twort and Rees 1995), there have been no complete solutions proposed.

The nature of the problem means that no well-defined method can guarantee a solution. At best, guidelines point out the issues that field managers must consider while laying out their project sites (Rad and James 1983). Layout problems have, however, been treated using operations research (Seehof and Evans 1967) and artificial intelligence (Hamiani 1989; Tommelein et al. 1991).

These all have similar drawbacks; namely:

- They rely on the generation of a knowledge base that will allow choice between various geographical layouts. This has proved very difficult to produce for real projects.
- The integration of the scheduling procedures with the geographical aspects to generate the site layout has proved difficult.

The positioning of major pieces of equipment might be considered a subset of the general site layout problem. Several authors report research into this topic by various methods. For example, Warszawski and Peled (1987) describe techniques for positioning cranes on a building site. These employ knowledge-based systems. They are not dynamic and do not look at all aspects of the positioning, although it might be possible to extend them to do so.

Yeh (1997) and Zouein and Tommelein (1999) identified a construction site layout problem. In Yeh’s problem, there are n resources to be positioned, n available positions, and all the information about operation and setup cost is known. An assignment of resources to positions is searched to minimize the whole cost. A neural network was used to solve the assignment type of construction site layout problem in which the problem is formulated as a discrete combinatorial optimization problem. This is a static and special case of more general construction site layout problems.

A class of similar but different problems is facility layout problems in manufacturing industries and very large scale integration in electronics, which have been studied extensively. The facility layout problem is concerned with finding the most efficient arrangement of several indivisible departments with unequal area requirements within a facility. The objective of facility layout problem is to minimize the material handling cost or resource movement cost inside a facility.

In facility layout problems, there are in general two sets of constraints considered:

1. Department and floor area requirements; and
2. Department location restrictions (departments cannot overlay, departments must be placed within the facility, and some must be fixed to a location or cannot be placed in specific regions).

Floor loading and floor-to-ceiling clear-height constraints also exist in multiple-floor facilities, in which the vertical distances between departments are considered in addition to the horizontal distance.

Two sets of solution methods are employed in attacking facility layout problem: heuristics and exact methods. Exact algorithms are developed to obtain, in theory, optimal solutions, but because of the combinatorial nature of the problem, they are only applicable for small-scale problems.

Heuristic methods are usually used for larger problems. The current trend in research for facility layout problems is concentrated in four areas: (1) developing more suitable models; (2) extending existing models to include a time element (dynamic layout); (3) adding uncertainty (stochastic layout); or (4) adding multiple criteria for evaluation. There are also special cases for specific types of problems. A review of the facility layout problem can be found in Russell and Gau (1996).

Genetic Algorithms

Genetic algorithms are modeling techniques based on biological behavior (Wilson 1997). They rely on the speed of computers either to combine elements from two solutions (or parents) or to mutate a single solution to a complex problem to produce a third solution (or child) and evaluate it. If the third solution is ''better'' than one of the others, then it ''survives'' and the worst one ''dies''—along the lines of ''survival of the fittest'' in Darwin's theory of evolution. The process continues through a number of iterations or ''generations,'' with each solution contributing to the next generation in proportion to its ''goodness.'' Random factors ensure that the solution space is adequately covered. [See Dowsland (1996) for a brief introduction to genetic algorithms and a discussion on their possible use to assist managers.]

Since genetic algorithms are generic and flexible and need little knowledge and information about the problem domain, they have found wide application in diverse areas (Proudlove et al. 1998). There have been many applications of genetic algorithms in civil engineering. Soh and Yang (1996) used a genetic-based search technique for shape design of structures in civil engineering in the least weight design of a truss structure. Navon and McCrea (1997) established a genetic algorithm to optimize a robot's kinematics based on collision avoidance, percentage of coverage, dexterity, unit cost, and total cost. Al-Tabtabai and Aux (1997) applied a genetic algorithm to manpower scheduling. There are also many other application cases for using genetic algorithms in scheduling, planning, and management.

The main aspects to be considered in the development and use of genetic algorithms are encoding, fitness function, the selection procedure, crossover, mutation operations, and termination.

Encoding

Fundamental to any genetic algorithm structure is the encoding (representation) mechanism for representing a solution of the problem to be solved. Such a representation is referred to as a chromosome. The encoding mechanism depends on the nature of the problem's variables. Conventionally, a solution is represented by binary strings, although this is rather limiting for the site layout problem.

Fitness Function

A fitness function must be devised for each problem to be solved. Given a particular chromosome, the fitness function returns a numerical ''fitness'' value, which is supposed to be proportional to the ''utility'' or ''ability'' of the individual that particular chromosome represents.

Selection

This models nature's survival-of-the-fittest mechanism. Fitter solutions survive, while weaker ones perish. Through selection, a chromosome survives to the next generation and produces offspring according to its relative fitness.

There are different ways to simulate the natural selection procedure, for example, proportionate selection, ranking selection, tournament selection, and truncation selection. Among all the selection schemes, proportionate selection is probably the most widely used and can be implemented by the Roulette wheel technique, as described by Goldberg (1989).

Crossover

This is the operation for searching the solution space. Pairs of chromosomes are picked at random from the population to be parents and subjected to crossover. Crossover is a procedure of exchanging the information of both parent chromosomes and making up offspring with mixed genes.

Mutation

After crossover is continuously used for some generations, some genetic information may be lost. The mutation operation is used to restore this. In many applications, mutation is only treated as a secondary operator after the crossover operator.

Termination Criterion

Equipped with all the components, genetic algorithms can operate continuously until prespecified termination conditions are satisfied. Some of the most widely used termination criteria are maximum number of generations, maximum nonimprovement generation numbers, and convergence rate of the population. In practice, other termination criteria are also possible.

Formulation of Site Layout Problems

This section describes the theoretical definition of the layout problem in genetic algorithm form.

Problem Specifications

Site Area and Coordinate System

Consider a rectangular site area depicted as in Fig. 1. If a coordinate system is established with one corner of the area as its origin, then the area can be described by the coordinates (X,Y) of its opposite corner, where X=width and Y=height of the site area. Any locations on the site can be specified and identified by their coordinates.

Temporary Facilities

Temporary facilities, such as workshops and site offices, can be any shape and be positioned in any orientation. For simplicity, assume that facility shapes are rectangular and their sides are parallel with the coordinate system axes. Each facility needs a certain area, and the location of a facility can be represented by the coordinates of its two opposite corners [for example, (x_1,y_1) and (x_1',y_1') for facility 1 in Fig. 1].

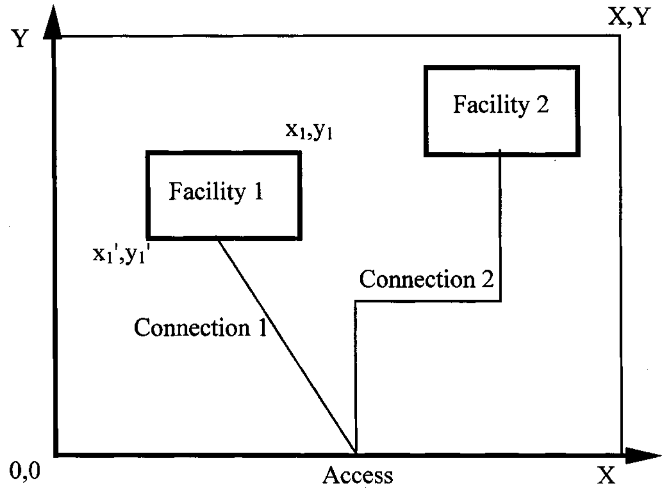

Fig. 1. Rectangular site area

Accesses

A site area is usually not completely open for access from all directions. Entrances or gates are the main accesses for materials and personnel. Positions of accesses can also be specified by their coordinates.

Connections

Transport is required between facilities and between facilities and building sites. The distances can be Manhattan (rectilinear) (connection 1 in Fig. 1) or Euclidian (connection 2 in Fig. 1).

Genetic Algorithm Formulation

Suppose that there are M facilities to be positioned and set up within the site area; here, facilities include both temporary and permanent ones. The only difference between them is that the former can float around the site and their locations need to be determined, while the latter have been positioned already and will not change during the project duration.

It is assumed that, for facility i, the required area is a_i and the coordinates of its opposite corners are (x_i, y_i) and (x_i', y_i'); thus $|(x_i - x_i')(y_i - y_i')| = a_i$.

The distance between facilities i and j is

$$d_{ij} = \surd[(x_i - x_j)^2 + (y_i - y_j)^2] \qquad (1)$$

Based on the initial interviews with engineers and the reviews of the layout literature, the fitness or objective function for the site layout problem can be expressed as

$$\begin{aligned}\text{Fitness} = f(&\text{material transport cost} + \text{facilities setup cost}\\ &+ \text{facilities removal cost}\\ &+ \text{work site personnel visit cost} + \text{others})\end{aligned}$$

which, for most practical situations can be written as

$$\begin{aligned}\text{Fitness} = &\Sigma_i \Sigma_j [d_{ij} \Sigma_k (p_{ijk} q_{ijk})] + \Sigma_i s_i(x_i, y_i) + \Sigma_i r_i(x_i, y_i)\\ &+ \Sigma \Sigma u_{ij} f_{ij} d_{ij} \qquad (2)\end{aligned}$$

where d_{ij}=distance between facility i and facility j; q_{ijk}=quantity of material k required by work site j from facility i (quantity of material k transported from facility i to facility j); p_{ijk}=transport price of unit quantity of material k from facility i to facility j; $s_i(x_i, y_i)$=setup cost of facility i at location (x_i, y_i) [this cost is a function of location (x_i, y_i)]; $r_i(x_i, y_i)$=removal cost of facility i at location (x_i, y_i) [this cost is a function of location (x_i, y_i)]; f_{ij}=frequency visits of personnel from facility i to facility j; and u_{ij}=utility value of a personnel visit from facility i to facility j. There will generally be constraints on the position of facilities. Some of these can be modeled by changing the values of the costs [$s_i(x_i, y_i)$, etc.], while others require mathematical formulation.

Exclusion of Some Facilities for Some Areas

Certain areas are not suitable for positioning some facilities. For example, it may be that the engineer wishes to avoid placing a material store in an environmentally sensitive area. This kind of constraint can be realized by increasing the setup cost for an area, thereby preventing the facilities from being positioned there in "good" solutions.

Overlap Conditions

For a specific area, not more than one facility can be set up on it to avoid overlapping.

If a facility is represented by using the coordinates (x, y) of one of its corners, the required area for the facility is A, and the width of the facility area is z, then the nonoverlapping constraint between blocks B_i and B_j can be expressed as

$$\begin{aligned}\max\{&[x_j - (x_i + z_i)][(x_j + z_j) - x_i], [y_j - (y_j + A_i/z_i)][(y_j\\ &+ A_j/z_j) - y_i]\} \geqslant 0 \qquad (3)\end{aligned}$$

Interfacility Distance

Some facilities can not be positioned within a given distance of each other. For example, it is better not to position a noisy workshop close to an office for health and safety reasons. This kind of constraint can be represented as

$$d_{ij} \geqslant D_{\min}$$

where $D_{\min}$=minimum distance allowed between particular facilities.

Some facilities may need to be positioned near each other or within some distance. For example, a crane must be placed close to the building it serves. This kind of constraint can be represented as

$$d_{ij} \leqslant D_{\max}$$

where $D_{\max}$=maximum distance allowed between particular facilities.

The formulation above is a general model for site layout problems. To find solutions, genetic algorithms will be applied to them.

Chromosome and Operations

An array of the real values of coordinates of facilities is used as a chromosome in this work.

Suppose there are two parent chromosomes:

$$P_1 = (X^{p^1}, Y^{p^1})$$

$$X^{p^1} = (x^{p^1}_1, x^{p^1}_2, x^{p^1}_3, \ldots, x^{p^1}_i, \ldots, x^{p^1}_N)$$

$$Y^{p^1} = (y^{p^1}_1, y^{p^1}_2, y^{p^1}_3, \ldots, y^{p^1}_i, \ldots, y^{p^1}_N)$$

$$P_2 = (X^{p^2}, Y^{p^2})$$

$$X^{p^2} = (x^{p^2}_1, x^{p^2}_2, x^{p^2}_3, \ldots, x^{p^2}_i, \ldots, x^{p^2}_N)$$

$$Y^{p^2}=(y^{p^2_1},y^{p^2_2},y^{p^2_3},\dots,y^{p^2_i},\dots,y^{p^2_N})$$

where: $X^{p^i}(Y^{p^i})$ is an array of $x(y)$ coordinate values for all the facilities for chromosome I and, because there are two parents, $i=1$ or 2. So $(x^{p^1_3},y^{p^1_3})$ are the coordinates for facility 3 in chromosome 1; and N=number of facilities to be positioned

With this chromosome, the traditional operations are not suitable, and specific genetic operations have been developed.

Crossover Operator

This operator is to make a child chromosome

$$C_1=(X^{c1},Y^{c1})\quad\text{from}\quad P_1\quad\text{and}\quad P_2 \tag{4}$$

Arithmetic Combination Crossover Operator

This algorithm can be described as follows:

- Step 1: Randomly generate an integer number m, $1<m<N$.
- Step 2: Randomly generate m integer numbers i_k, $1<i_k<N$ and $1<k<m$.
- Step 3: for $j=i_k$, $1<i_k<N$ and $1<k<m$

$$x^{\mathrm{c1}}_{\mathrm{j}}=\alpha x^{\mathrm{p1}}j+\beta x^{\mathrm{p2}}j$$

$$y^{\mathrm{c1}}_{\mathrm{j}}=\alpha y^{\mathrm{p1}}j+\beta y^{\mathrm{p2}}j$$

where α and β=randomly generated real numbers.

The rest of the coordinate values of C_1 are directly copied from P_1.

If the position of P_1 and P_2 is exchanged, the application of the algorithm above can make another child chromosome in a similar manner.

In this crossover, the coordinate values of child chromosomes are obtained by arithmetic combination of parent chromosome coordinates. If $\alpha+\beta=1$, then the crossover operator above is a weighted average of two parent chromosomes and will make the corresponding coordinate value of the child chromosome stay between its two parents. Specifically, if $\alpha+\beta=1$ holds for both x and y coordinates, then the children made will be between the two parents on the line that links them.

If there are constraint intervals for any coordinate, modulo operation can be applied to make sure the corresponding coordinates of the child chromosomes do not violate the constraint. With different α and β values, the children produced can be distributed differently around the connection line between two parents.

For example, let $P^1=[(1,2),(2,3)]$ and $P^2=[(5,8),(4,2)]$. This means that there are two facilities, and in P^1 their positions are (1,2) and (2,3), respectively. If random number $m=1$, $i_k=1$ and the crossover operation happens to the x coordinate, $\alpha+\beta=1$, and $\alpha=0.5$, a child can be made as $C^1=[(0.5\times1+0.5\times5,2),(2,3)]=[(3,2),(2,3)]$. Only the position of the first facility has been changed, and the second facility stays where it was.

Coordinate Swap Crossover Operator

This operation is the same as the conventional binary crossover operator, which can be implemented as 1-point, 2-point, multiple-point, or uniform crossover operations. In this operation, one or several coordinates of one parent chromosome are swapped with the corresponding ones of the other parent chromosome. Alternatively, the whole chromosome can be divided into several subsections and subsection(s) swapped instead of individual coordinates. The decision on which coordinate(s) will be exchanged can be determined randomly.

For the example above, if the x coordinate of facility 1 is randomly selected for swapping, the child chromosome will be $C^1=[(5,2),(2,3)]$.

Mutation

As for crossover operators, different mutation operators can be developed. Two are described in the following.

Random Offset Mutation Operator

In this operator, a random number is added to a coordinate that is randomly selected from a randomly chosen chromosome P so that the original position of a facility is moved. Different implementations can be applied. For example, several facilities can be selected for this mutation operation and random positions can be assigned to some facilities instead of adding offsets to their coordinates.

To guarantee that valid positions are generated or assigned, modulo operation may be applied to keep the obtained results within specific intervals.

Swap Mutation Operator

Another mutation operation can be produced by randomly swapping x and y coordinates for a facility or swapping corresponding coordinates of different facilities. Once again, modulo operation may be necessary to satisfy any boundary constraint.

Based on the principle and nature of crossover and mutation operations, other implementations are possible and different operations can be developed and applied.

Site Area Cost and Shortest (Least Cost) Route

In facility layout problems, distances are usually considered as Manhattan (rectilinear) or Euclidian. In a real construction site, partial or complete road connections between facilities may exist. It may be necessary to build whole roads for travel and transport between facilities, or it may be possible to build links between existing pieces of roads to form the necessary connections. Whichever approach is actually taken, it should generate the shortest or least cost route between two facilities. The travel cost may be different due to the different landscape or surface conditions. To represent the cost distribution, the construction site is divided into small grids, within which the cost can be assumed uniform. Based on the site cost distribution information, a least cost route can be established and used as a criterion for the facility configuration.

Site Cost Distributions

To reflect the geographic difference of the site area, the whole site area is divided into small grids. Because of the position, preference, and uneven surface of the site area, the cost distributions vary from grid to grid. There are basically three different costs: setup, removal, and travel. In addition to cost, the preference and constraints can be considered and combined into the aggregated cost or fitness function. This simplifies the consideration of constraints and other factors that impose restrictions on the possible position. The data required can be obtained from site surveys and/or based on the opinions of site staff.

Set-up cost: This is the cost for setting up the facilities. The whole area can be considered for temporary facility positioning; this includes all the locations, such as the location of permanent facilities and any occupied area. For the unavailable area, the cost can be chosen to be arbitrarily large to deter any consideration of setting up a facility there.

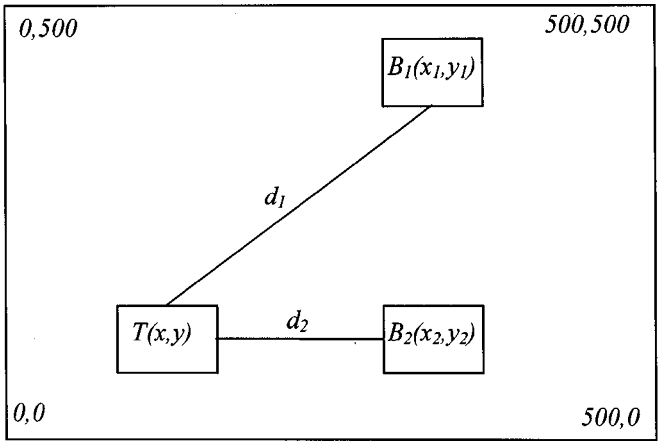

Fig. 2. Example site

Travel cost: This is the cost of transport passing through a grid. To reflect a situation such as an edge of the road or grass or a river bank, the costs in different directions can be considered to be different. It is possible that, for a grid, the setup cost is very high but the travel cost is very low. This is the situation for a road where travel is permitted and nothing should be set up. On the other hand, the travel cost may be very high but the setup cost can be low. A traffic restrained area is an example of such a situation.

Through adjustment of costs (setup or travel), both preferences and constraints can be imposed.

The minimum travel cost between two points on a rectangular grid can be determined using graph theory for Manhattan costs and by geometry for Euclidean costs.

Numerical Example

The theories described in this paper have been applied to many problems. Two are given here as examples. The first is a small example to illustrate experiments carried out to prove that the methods work. The second example is more realistic and is included to illustrate the use of the technique in practical situations.

Example 1

Suppose there is a construction site as shown in Fig. 2. There are two buildings $B_1(x_1,y_1)$ and $B_2(x_2,y_2)$ to be constructed in the rectangular work site area defined by (0,0) and (500,500); here, x_i and y_i are the coordinates for the two buildings. A temporary service facility $T(x,y)$ needs to be established somewhere to deliver the same service in the same quantity of that service (material, labor, etc.) to both work sites.

The question is where to position the facility $T(x,y)$; i.e., the coordinates x and y are to be determined so that the transportation cost of the service is minimized. Only two dimensions are considered here for simplicity, but the problem does not change if three are used. All facilities are assumed to have unit size.

This problem is selected for solution as a demonstration so that it can easily be checked and verified by other, more conventional, methods.

Representation of Problem

The specific position of a facility in the layout is defined by the coordinates of the location of the facility with respect to a properly established coordinate system. Different positions will correspond to different layouts, so the coordinate (x,y) $(0 \leqslant x \leqslant 500$ and $0 \leqslant y \leqslant 500)$ of the temporary facility can be used as a gene for the problem. Different (x,y) coordinates mean different positions of the facility and hence different site layouts.

Table 1. Range of Values Used in Experiments

Item	Minimum	Maximum
Population size	20	100
Crossover rate	0.3	0.8
Mutation rate	0.01	0.3

Evaluation and Fitness Values

To simulate the problem, it is necessary to establish a fitness or objective function. Initially it is assumed that the unit cost of delivering the service is proportional to the delivery distance and it is necessary to deliver the service to both sites with minimum total cost. In this example, the Euclidean distance is used.

This objective can be written mathematically as

$$\text{Minimize the cost} = p_1 q_1 d_1 + p_2 q_2 d_2 \tag{5}$$

where p_i=price of delivering a unit quantity of material to site i per unit distance; q_i=quantity of service required by site i; and d_i=distance between the temporary facility and site i.

Because the fitness of a genetic algorithm is normally in the form of a maximum, this is changed to

$$\text{Fitness} = k/\text{Cost} \tag{6}$$

where k is a constant and $k > 0$.

Simulation Framework

The site considered is shown in Fig. 2. Building 1 is positioned at (0,400) and building 2 at (400,0). Each building requires 100 units of the service to be delivered through the site access.

A generational simulation scheme is applied in which, at each generation, an intermediate population is produced for reproduction, crossover, and mutation operations. The termination criterion is the maximum number of generations. All the other components are the same as in a typical genetic algorithms.

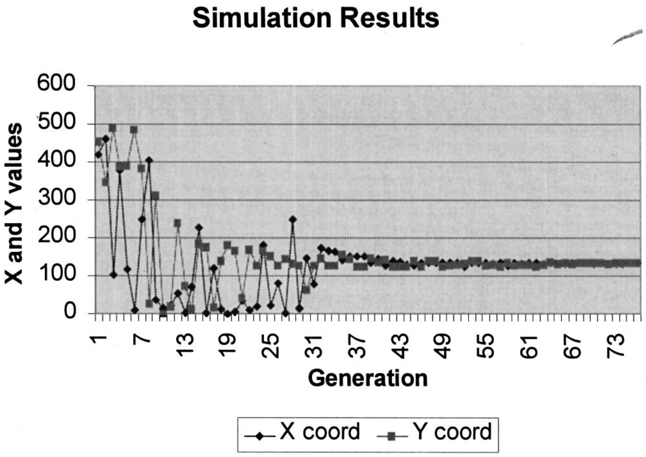

Fig. 3. Convergence of coordinates

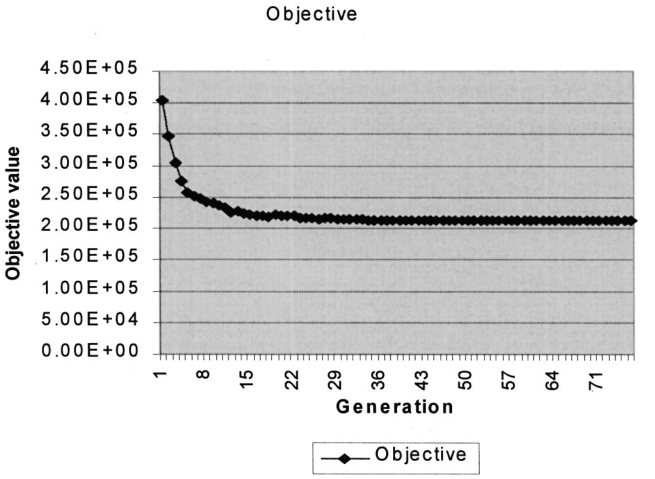

Fig. 4. Convergence of objective value

The range of values used in testing the genetic algorithm is shown in Table 1.

Using any of the combinations of these parameters, the genetic algorithm finds the optimal solution for the problem in fewer than 100 generations. For small population sizes (less than 20), there is a distribution of solutions around the optimum due to errors. For larger populations, the algorithm finds the optimal solution very accurately. The simulation results are shown in Figs. 3–5.

Fig. 3 shows the change of coordinate *x* and *y* values of the facility to be positioned over the generations in the simulation. From this it can be seen that, with the simulation, the location of the facility converges to a specific location and the values of the coordinates become increasingly stable. The cost decreases with the increase in simulation generations, as shown in Fig. 4, and is stable, in this example, after 40 generations. The geographical convergence is shown in Fig. 5. It can be seen that the facility is positioned over most of the site area at some stage of the simulation. This ensures that a local optimum is not found in preference to a global one. In fact, with all combinations of the parameters in Table 1, the location converges to the optimal one that, in this simple example, can be calculated as (133.3,133.3).

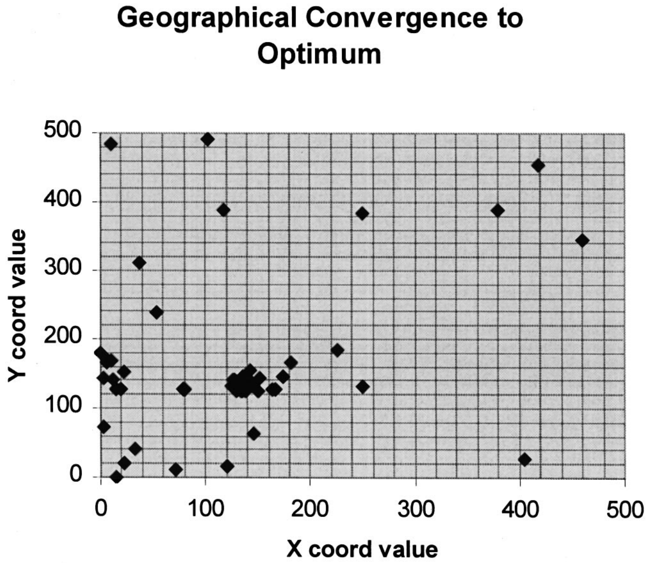

Fig. 5. Coverage of site by simulation

In this example, only one facility is considered. The technique can be used for more than 100 facilities and the optimal solution can still be found without significant increase in computational effort.

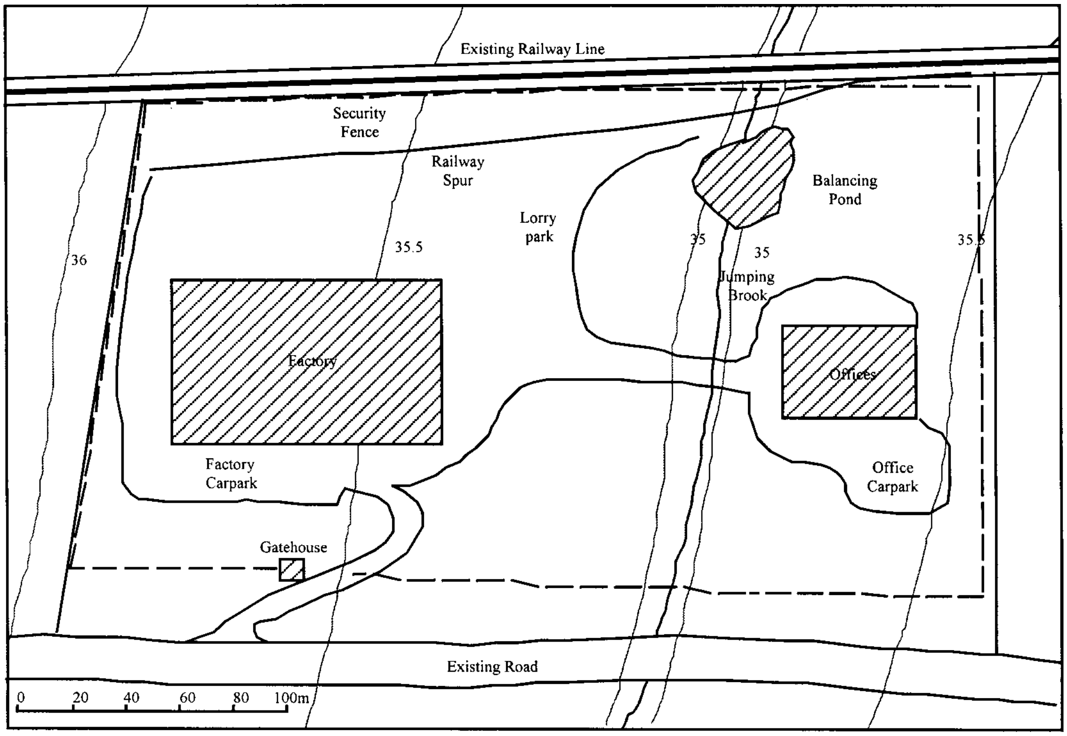

Fig. 6. Site layout for factory project

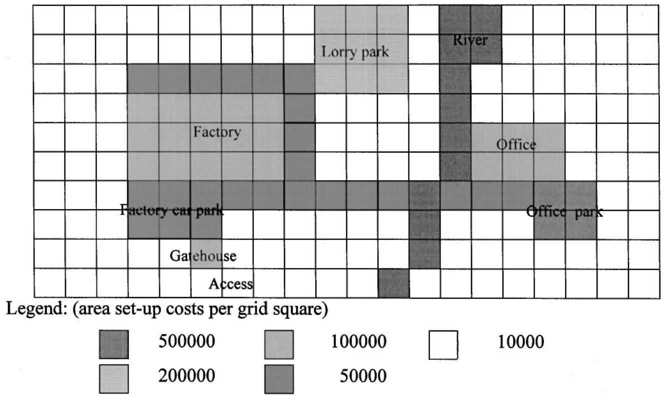

Fig. 7. Site layout and setup cost distribution for factory project

Example 2

In this section, a more practical example is described. This is based on a real project. The general layout of the permanent facilities and geography of the site is shown in Fig. 6. The permanent facilities considered are a factory, factory car park, factory lorry park, offices, and an office car park. The problem is to set up temporary facilities on the site to supply services to the project. The temporary facilities considered in the example are a site office, a reinforcement store, a concrete batching plant, and a general store.

The layout in Fig. 6 is simplified as shown in Fig. 7, in which the positions and areas of all the six permanent facilities are shown in grid form. The grid size is 20 m. The genetic algorithm is applied to this layout as a sufficiently accurate model of reality. If greater accuracy were required, the grid could be made smaller.

The transport and traffic needed by facilities can be divided into two types: those between temporary facilities and those between temporary and permanent facilities. The transport and traffic requirements between temporary facilities and permanent facilities are shown in Table 2. Table 3 shows the transport and traffic requirements from temporary to temporary facilities.

Fig. 7 also shows the cost of setting up temporary facilities on the site. Fig. 8 shows the distribution of transport costs to be considered. The high cost areas for setting up facilities include roads where only traffic is allowed. The car and lorry parks are the next highest cost areas. Ideally, no facilities would be placed in these areas, so the cost is set high to avoid it occurring. No facilities are allowed on the grass, so the setup cost there is therefore set arbitrarily high. In this example, the travel cost, shown in Fig. 8, is the same in all directions for any given grid element. The model allows different costs in the north-south, south-north, east-west, and west-east directions. Using the data above, the genetic algorithm produces a layout solution as shown in Fig. 9.

Table 2. Unit Resource Requirement of Permanent Facilities to be Supplied from Each Temporary Facility

	Permanent Facility					
Temporary facility	Lorry park	Road	Office	Gate house	Car park	Factory
Office	60	20	800	100	20	1,200
Reinforcement store	200	0	200	10	0	700
Concrete batching plant	100	0	50	10	0	150
General store	0	10	500	50	0	200

Table 3. Unit Resource Requirement of Temporary Facilities to be Supplied from Each Temporary Facility

	To Temporary Facility			
From temporary facility	Office	Reinforcement store	Concrete batching plant	General store
Office	0.0	100.0	100.0	150.0
Reinforcement store	0.0	0.0	0.0	0.0
Concrete batching plant	0.0	0.0	0.0	0.0
General store	50.0	50.0	100.0	0.0

The example of the factory project shows that the technique is able to place multiple facilities on a complex site, but it does not show its full power. By adjustment of the various parameters in the model, many different scenarios can be described. For example, if there is a requirement to avoid disturbing the environment in a particular area, the setup and transport costs can be increased and the method will leave the most sensitive areas undisturbed.

Other aspects of site layout require different modeling techniques, and several of these have been incorporated into the model and tested. In some situations, it might be advantageous to ensure that facilities are either placed close together or kept apart. The former can be modeled by increasing the amount of resource to be transported between the facilities under consideration, the latter by including a constraint in the system.

Other practical aspects have also been modeled. The site layout problem is often considered different from other layout problems because of its dynamic nature. In this formulation, the changing nature of the site has been modeled by enabling the system to produce different site layouts at different phases of construction and assigning removal costs to temporary facilities.

Limitations of System

The system has been tested with a range of parameters and with a range of site configurations. It has been found that the optimization procedure is sensitive to the relative costs assigned to setup and transport. In particular, care has to be taken if the surface of the fitness function is relatively flat over a large area of the site.

In addition, the dynamic nature of a project has been modeled by considering the site layout to be associated with phases of the work. While giving answers that are practical, they cannot be

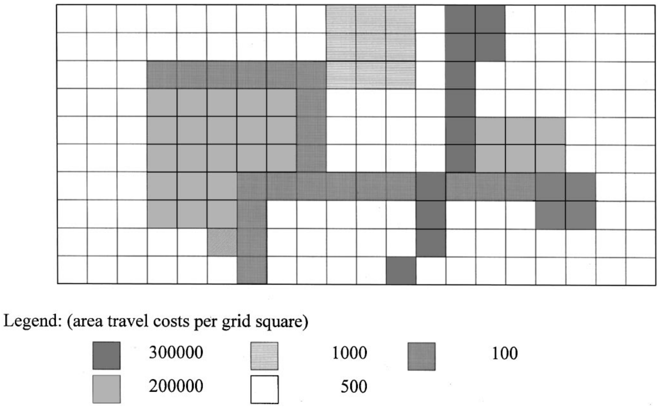

Fig. 8. Site travel cost distribution for factory project

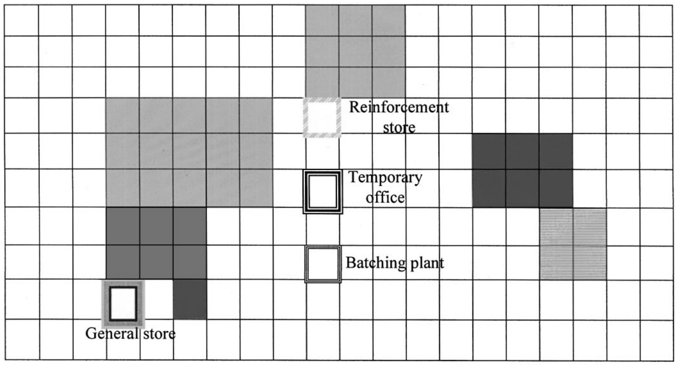

Fig. 9. Site layout solution for factory project

proved to be optimal. Indeed, the determination of layout and the scheduling procedure would need to be carried out concurrently to demonstrate optimality. Work is continuing in these two areas.

Conclusions

This paper has described the formulation of the problem of positioning temporary facilities on a construction site as a genetic algorithm. It has provided crossover and mutation operators to allow the operation of the genetic algorithm.

The fitness function can be drawn up to include a range of measures of the layout offering the ability to include transport, setup, and removal costs. It can also include other less tangible measures such as environmental and safety aspects. Constraints on the solution can be included in the problem.

The proposed methods have been illustrated by means of two examples. These show that the technique is able to find solutions to the problems in a small number of generations and hence a reasonably small computational time. Without actually saying so, they also reinforce the necessity of researching the ''front end'' data input problem, the time involved, the level of detail, the development and use of relevant databases, etc.

The use of a rectangular grid has made the problem easy to specify and solve. The smaller the grid size, the more accurate the solution but the greater the computational effort required.

Further work is being carried out to fully integrate the site layout and scheduling operations.

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