Potential Application of GIS to Layout of Construction Temporary Facilities

M. H. Sebt[1], E. Parvaresh Karan[2], M. R. Delavar[3]

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Abstract: *Geographic information systems (GIS) are one of the fastest growing computer-based technologies of past two decades, yet, full potential of this technology in construction has not been realized. Based upon GIS capabilities, construction site layout is one of the areas that GIS could be applied. The layout of temporary facilities (TFs) such as warehouses, fabrication shops, maintenance shops, concrete batch plants, construction equipments, and residence facilities has an important impact on the cost savings and efficiency of construction operations, especially for large projects. The primary objectives of this paper are to describe GIS technology and to present application of GIS technology to construction site layout. The study also delineated the methods of location TFs in construction site. An example application of GIS to location optimization of tower crane and concrete batch plant is provided to demonstrate GIS capabilities as compared with previous models. The spatial and nonspatial data which used in construction site layout process are analyzed and arranged on GIS environment and results showed the GIS can solve site layout problem. Finally, areas of additional research are noted.*

Keywords: *GIS, Construction Site Layout, Temporary Facilities.*

1. Introduction

Geographic information systems (GIS) are one of the fastest growing computer-based technologies of past two decades. They are being used in diverse application areas related civil engineering, such as: disaster management systems, environmental problems, hydrologic, Infrastructure management systems, Irrigation and drainage, transportation, and urban planning. Directions magazine estimated that there was over 1$ billion in GIS software sales alone in 2001, with additional billion spent for services, hardware, and related activities (DeMers 2002). Although GIS technology has more capabilities on construction, such as network functions that assists in scheduling methods like CPM and PERT, full potential of this technology has not been realized. Some applications of GIS related construction has been addressed in the literature. Jeljeli et al (1993) used a GIS technology to construction contractor prequalification.

Oloufa et al (1994) developed an integrated GIS that aids managers in activities related to on-site soil condition. Cheng and Yang (2001) presented the system, MaterialPlan, which integrated GIS-based cost estimates with construction scheduling to automate planning tasks required for materials layout. Li et al (2003) investigated the roles of internet-based GIS in E-commence systems and used of GIS capability to integrate, to manage, and to analyze spatial information. Zhong et al (2004) integrated GIS with visualization techniques for planning and visualizing of dam construction processes. Poku and Arditi (2006) developed a system called PMS-GIS (Progress Monitoring System with Geographical Information Systems) to represent graphical construction progress.

Cheng and O'Connor (1996) developed an automated system for construction temporary facilities. The system, ArcSite, including a GIS integrated with database management system (DBMSs). ArcSite is a useful tool for construction site layout but has not been used properly GIS capabilities. Also, the location of construction equipment, as an important factor, is not considered in the system and the resulting layout of facilities may not arrive at the optimal solution (Elbeltagi et al. 2004). It is evident that with passing of about fifteen year from presenting the system, changes are required. GIS

[1] Associate Professor, Dept. of Civ. And Environ. Engrg., amirkabir Univ., Tehran, Iran. E-mail: sebt@aut.ac.ir
[2] Graduate Research Assistant, Dept. of Civ. And Environ. Engrg., amirkabir Univ., Tehran, Iran. Email: p.karan@aut.ac.ir
[3] Assistant Professor, Dept. of surveying., College of Engrg., Tehran Univ., Tehran, Iran. E-mail: mdelavar@ut.ac.ir

have not been used, however, to solve the site layout problem as defined in this paper.

The primary objectives of this paper are: (1) To present a brief description of GIS technology; (2) to describe the circumstances (methods) of carrying out the layout of construction temporary facilities; (3) to explore potential GIS application to the construction site layout; (4) to identify areas of additional research.

2. Description of GIS Technology

Among different descriptions have presented about GIS, Dueker and Kjerne (1989) defined proper one as "GIS are a system of hardware, software, people, organization and institutional arrangement for collecting, storing, analyzing, and disseminating information about areas of the earth". In this section a brief description of this technology is provided.

To work with GIS, like other systems, familiar with database structure is required. Three basic types of database structures which more common are: hierarchical data structures, network systems, and relational database structures. Data in hierarchical data structures have one-to-many or parent-child relationship. In the hierarchical system, each relationship be explicitly defined before the structure and its decision rules are developed. Network systems are an improvement over hierarchical structures for GIS work because they are less rigid and can handle many-to-many relationships. This structure allows users to move from data item to data item through a series of pointers. Many GIS databases have many-to-many relationship, for this reason network systems recognized as a proper structure. Relational database structures, on the other hand, obviated the network systems shortcoming to used large numbers of pointers. The database structure stored data as ordered records or rows of attribute values called tuples.

The data included on life cycle of a facility can be categorized as spatial and nonspatial. As much as 75% of the spatial data pertaining to a facility are common to all phases of the facilities delivery process (Foster et al 1989). GIS, on the other hand, provide capabilities for spatial and nonspatial data to be collected from different sources, stored, analyzed, and presented systematically. Spatial data have four basic components that significantly differentiate them from any type of data: (1) Geographical positions; (2) descriptive attributes; (3) spatial relationships, i.e, topography; and (4) temporal relationships (Jeljeli et al 1993).

GIS recognize three primitive types of spatial objects: points, lines, and areas. Vector and raster data models are two alternate models for representing these objects. The basic logical units of the vector model are points, lines, and polygons. A point is stored as a single X, Y-coordinate pair, a line as a series of X, Y-coordinates, and a polygon (area) as a closed loop of X, Y-coordinate pairs defining the boundaries of the area. The basic units of the raster model are individual cells. The raster space is subdivided into cells (usually square in shape). Each cell is referenced by a row and column number. Additional attribute information concerning a given cell is stored with the data record for that cell. In this model, a point is represented by a single grid cell, a line by a number of consecutively neighboring cells, and an area by a cluster of neighboring cells.

The selection of a data model, vector or raster, depends largely on the selected construction application. Advances in hardware and software technologies, however, have gradually made the differences between them less significant. Raster model has advantages such as simplicity, low cost, ease of data collection, and image interpretive aspect, and for vector model could be pointed some advantages such as high accuracy and topological capabilities. To extract meaningful information from the GIS data base, appropriate functions must be performed. This process is commonly referred to as data manipulation and analysis.

According to condition of problem, various types of GIS analysis functions can be performed. Some of the most important functions of GIS include overlay operations, neighborhood functions, and connectivity functions, such as proximity and network operations.

Overlay operations involves the integration of multiple layers to create a new data set. The overlay functions can perform simple operations such as laying a road map over a map of local wetland. Resultant layer contains new spatial objects with different attribute and topological information. Neighborhood function analyzes the relationship between an object and similar surrounding object. This function idea is to characterize each object as part of a larger neighborhood of objects based on some shared attribute. All neighborhood processes require three parameters: (1) the location of one or more target areas, (2) the size of the neighborhood surrounding the target area, and (3) a function to perform in the defined neighborhood and assigned to the targeted area.

The main role of proximity functions is to determine if a given point, line, or area lies within a certain distance of another point, line, or polygon. Network functions, on the other hand, can be used to allocate a given resource, such as construction material, or to determine the minimum cost path through a given network between an origin and destination. They are commonly used for moving resource from one location to another. Network analysis entails four components: (1) set of resources; (2) one or more locations where the resource are located; (3) an objective to deliver the resources to a set of destinations; and (4) set of constraints that places limits on how the objective can be met.

Data output is the procedure by which GIS results are displayed in a form suitable to the user. The most common output products generated by GIS are maps of various kinds, such as thematic maps, choropleth maps, isorithmic maps, dot maps, line maps, animated maps, landform maps, and cartograms. For applications such as engineering, other nonmap graphics may be preferred. GIS have the capability to generate several graphic formats. These graphics include: bar charts, pie charts, scatter plots, and histograms.

3. Construction Site Layout

Site layout planning is an important task that involves identifying the temporary facilities (TFs) needed to support construction operations, determining their size and shape, and appropriately positioning them within the boundaries of a construction site (Tommelein et al. 1992a). Temporary facilities range from simple lay-down areas to warehouses, fabrication shops, maintenance shops, concrete batch plants, construction equipments, and residence facilities (Yeh 1995).

Various approaches have been described in the literature to deal with the facility layout problem from different perspectives. Heuristic, as opposed to optimum, solutions refer to solutions that are based on heuristic rules, experience, and simplified approaches. Due to the complexity of the construction site layout problem, mathematical optimization was only successful for a single or very limited number of facilities. The majority of researchers, however, have used heuristic approaches and knowledge-based systems to place the facilities on a construction site in a loosely packed manner. A loosely packed arrangement of facilities, as opposed to a tightly packed one, refers to the situation when spaces are permitted between facilities. Loosely packed arrangements are most suitable for laying out construction sites (Hegazy and Elbeltagi, 1999).

According to methods of location temporary facilities, writers considered these facilities as three parts; tower cranes, concrete batch plant, and temporary buildings (e.g. office, parking, storage, shops and etc). In the next sections each of parts are described.

3.1. Tower Cranes

Tower cranes are the most expensive and frequently shared resources on building construction sites. Efficient utilization of tower cranes greatly depends on type, number, and also location of tower crane(s). As the number of work tasks and the demand for tower cranes increase, planners may be required to make bold decisions on job conditions for a particular situation. A poor decision is likely to have significant negative effects, which will lead to additional costs and possible delays (Al-Hussein et al, 2006).

On large construction projects several cranes generally undertake transportation tasks, particularly when a single crane cannot provide overall coverage of all demand and supply points, and/or when its capacity is exceeded by the needs of a tight construction schedule. Many factors influence tower crane location. In the interests of safety and efficient operation, cranes should be located as far apart as possible to avoid interference and collisions, on the condition that all planned tasks can be performed. However, this ideal situation is often difficult to achieve in practice; constrained work space and limitations of crane capacity make it inevitable that crane areas overlap. Subsequently, interference and collisions can occur even if crane jibs work at different levels (Zhang et al, 1999).

Crane lift capacity is determined from a radius-load curve where the greater the load, the smaller the crane's operating radius. Assuming a load at supply point (S) with the weight *w*, its corresponding crane radius is *r*. A crane is therefore unable to lift a load unless it is located within a circle with radius *r* [Fig. 1(a)]. To deliver a load from (S) to demand point (D), the crane has to be positioned within an elliptical area enclosed by two circles, shown in Fig. 1(b). This is called the feasible task area. The size of the area is related to the distance between S and D, the weight of the load, and crane capacity .The larger the feasible area, the more easily the task can be handled.

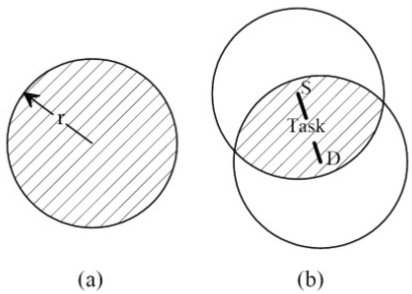


Fig. 1. Feasible Area of Crane Location for Task

Zhang et al (1999) determined three geometric relationships for any two feasible task areas, as illustrated in Fig. 2; namely, (a) one fully enclosed by another (tasks 1 and 2); (b) two areas partly intersected (tasks 1 and 3); and (c) two areas separated (tasks 2 and 3). As indicated in cases (a) and (b), by being located in area A, a crane can handle both tasks 1 and 2, and similarly, within B, tasks 1 and 3. However, case (c) shows that tasks 2 and 3 are so far from each other that a single tower crane is unable to handle both without moving location; so more than one crane or greater lifting capacity is required.

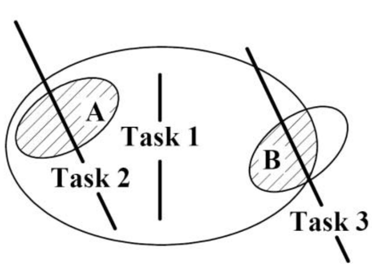


Fig. 2. Task "Closeness".

The closeness of tasks can be measured by the size of overlapping area, e.g., task 2 is closer to task 1 than task 3 because the overlapping area between tasks 1 and 2 is larger than that for 1 and 3.

This concept can be extended to measure closeness of a task to a task group. For example, area C in Fig. 3(a) is a feasible area of a task group consisting of three tasks, where task 5 is said to be closer to the task group than task 4 since the overlapping area between C and D is larger than that between C and E. If task 5 is added to the group, the feasible area of the new group would be D, shown in Fig. 3(b).

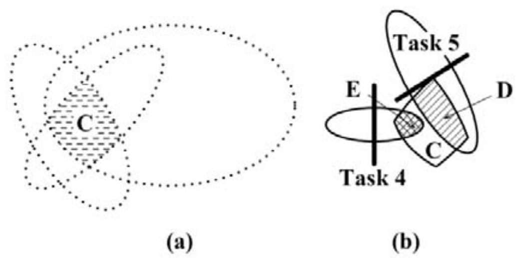


Fig. 3. Grouping Tasks.

Layout of tower cranes begins with determining initial tasks. These initial tasks are assigned respectively to different (crane) task groups as the first member of the group, and then all other tasks are clustered according to proximity to them. Obviously, tasks furthest apart are given priority as initial tasks. When multiple choices exist, tasks with smaller feasible areas selected as initial tasks. After assigning an initial task to a group, the model searches for the closest remaining task by checking the size of overlapping area, then places it into the task group to produce a new feasible area corresponding to the recently generated task group. The process is repeated until there are no tasks remaining having an overlapping area within the present group. Thereafter, the model switches to search for the next group from the pool of all tasks, the process being continued until all task groups have been considered.

Previous models mainly used two criteria to location optimization for tower cranes; balanced workloads in terms of respective transportation time for each crane, and lowest possibility of conflict. Severity of conflicts can be determined with number of intersections between two triangles with apexes representing the supply point, demand point, and crane location (Fig. 4).

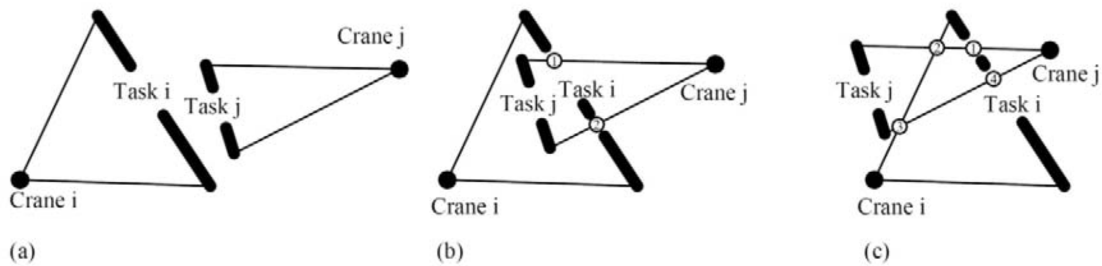


Fig. 4. Severity of conflicts.

Obviously the more intersections the more likely are conflicts. If two triangles are apart as in 4(a), no conflict happens. Hence, conflict in 4(c) is more probable than in 4(b). To use mathematical equations and know severity of probable conflicts, models calculated lowest possibility of conflict as optimization criterion.

Transportation time for each crane could be another criterion for tower crane optimum location. Some researches have been done about tower crane location which time is major factor. Leung and Tam (1999) developed linear multiple regression models aiming at modeling the hoisting time prediction. By doing so, the resultant models can serve two objectives: predict the hoisting times; and determine the optimal position of cranes or select the optimum sitting positions of cranes in terms of hoisting time. Tam et al (2002) developed traditional linear regression models and nonlinear neural network models for predicting hoisting times of a tower crane. Number of lift in tasks, hook travel time, supply and return time are variables that applied for tower crane location optimization in this matter.

3.2. Concrete Batch Plants

A concrete batch plant is an important element in any concrete construction process, whether it is working as a central mixing plant onsite or is offsite supplying ready mixed concrete to a project. The concrete can be mixed in a batch plant offsite or in a batch plant onsite and then transported by transit mixers (Zayed and Minkarah 2004). The major decision variables that influence management decisions of the concrete batch plant location are the volume of concrete consumption and the time of transportation between concrete batch plant and demand place.

Demand places are permanent facilities which designed before construction begins. Therefore their required concrete and their location have been defined. The objective function for batch plant location optimization was defined as minimum time-amount of concrete delivery. Whatever time-amount of concrete delivery is shorter the concrete transportation cost is smaller. Since concrete carrying machines (i.e., transit mixers) are similar in individual project, "time" replace with "distance". Application of distance as criterion of objective function increased possibility of using more models. Whatever distance of concrete delivery is larger the transportation time is greater and vice versa. Similarity of concrete carrying machines concludes linear relation between "time" and "distance".

One simple model to determining optimum location for concrete batch plant in site, minimize product of amount by distance. Between locations which could use for batch plant location, the model should find one that has minimum amount of required concrete multiplied by distance.

3.3. Temporary Buildings

This part of TFs involved warehouses, residence facilities, office, parking, fabrication shops, maintenance shops and labs. Finding optimize location for temporary buildings (TBs) depend on facilities that TBs supported them. Because of increasing productivity, minimizing travel time and also improving safety some relations between permanent facilities and their support facilities has been developed.

We could categorize these relations as "close to", "far from", "within specified distance of", "next to" and "visible from". Most TBs needed to "close to" their supported PFs. For example the warehouse should be located close to entrances to ease deliveries (Sadeghpour et al, 2006). In practice, material storage yards and warehouses are located as close as possible to the work areas to reduce excess on-site transportation. "Far from", as opposed to close to, used in situation that something endanger TBs. For example, OSHA standard 1926.407 recommends storage facilities of electrical equipment and possible sources of sparks are located far from flammable material (OSHA 2003). Similar condition exists for hazardous material. These materials include (1) explosives and blasting devices used in rock excavation; (2) flammable material such as fuel used by construction equipment; (3) toxic substances such as asbestos, coal tar pitch volatiles, cadmium, benzene, formaldehyde, methyl chloride among other materials including 13 carcinogens identified by OSHA (OSHA 2003); It is better to locate site offices and residence facilities outside the range of crane operations whenever possible (El-Rayes and Khalafallah, 2005).

Closeness sometimes represent quantitative. In this situation, one facility should be located "within specified distance of" another. The best example of the former state is for tower crane and supply point. It is necessary the supply point within operating radius of tower crane. Some facilities have joint operations. These facilities should be located next to each other, like steel storage and wedding shop. For maintaining security, finally, some facilities should be located visible from another, like warehouse from office. Table 1 is shown some TBs and their relation to another.

Table 1. Temporary facilities relations

Number	Temporary Buildings (TBs)	Relation	Related Facility/Area
1	Residence facilities	Far from	Operating Area
		Far from	Crane's opeating raduis
		Close to	Site entrance
2	Lavatory and washroom	within d of	Operation Area
			Office
			Residence facilities
3	Dinning hall	Far from	Operating Area
		Close to	Lavatory and washroom
4	Parking	Next to	Office
		Close to	Car entrance
		Far from	Operating Area
5	Office	Next to	Site entrance
		Close to	Car entrance
		Far from	Welding Shop
		Far from	Electrical shop
		Far from	Access road
6	Soil and concrete test labs	Close to	Garage
		Close to	Electrical shop
7	Fuel storage	Far from	Welding shop
		Next to	Garage
8	Warehouses	Close to	Site entrance
		Close to	Car entrance
		Visible from	Office
		Next to	Garage
9	Garage	Within d of	Car entrance
		Far from	Office
10	Welding shop	Next to	Plumbing workshop
		Far from	Office
		Far from	Formwork storage area
11	Plumbing workshop	Close to	Welding shop
		Far from	Office
12	Electrical shop	Close to	Plumbing workshop
		Far from	Office
13	Formwok storage area	Close to	Access road
14	Steel/Electrical storage area	Next to	Welding/Electrical shop

Note: d = distance specified by planner

Very likely satisfy one relation, invalidate another. For this reason planner should be make priority. After make priority and sometimes use affinity or proximity weights by the planner(s), different systems could be applied for solving site layout problem. Several approaches have been developed in the literature to deal with this problem by different AI techniques-such as knowledge-based systems (Tommelein et al. 1991, 1992b; Flemming and Chien 1995; Choi and Flemming 1996; Tam et al 2002), neural networks (Yeh 1995), and genetic algorithms (Philip et al. 1997; Li and Love 1998; Hegazy and Elbeltagi 1999; Harmanani et al. 2000; Mawdesley 2002; Zouein et al. 2002; Tam and Tong 2003; Elbeltagi et al 2004; El-Rayes and Khalafallah 2005)-were explored in the development of site layout systems. In another research Sadeghpour et al (2006) established assignment of priorities based on a satisfaction rate and weight of specified facility defined for another.

4. GIS Application to the Construction Site Layout

Inability to apply different shapes for site and facilities is one of the problems in previous models to construction site layout. In most efforts only a rectangular shape or group of unit areas, which take a rectangular shape, are used. Generally "closeness" criterion exists on the site layout models. GIS models, also, are not exception of this principle. According to type(s) and application(s) of facilities, the closeness can be determined by using quantitative or qualitative methods. Quantitative methods may consider the actual transportation cost per unit time or the amount of materials moved per unit time between shipping and demand areas on site. Alternatively, qualitative methods consider a subjective numerical proximity weight to express the desirability of having any two facilities close to each other on the site layout. Both methods could be used in the GIS models. Location optimization process for tower crane(s) mainly use spatial data. Feasible task area, in first, determines based on location of demand and supply points and crane's operating radius. These are spatial data. Proximity functions determine area lies within a certain distance of supply and demand points according to cranes type. Neighborhood function applied to grouping tasks. After determining initial tasks, GIS model assigns those respectively to different groups as the first member of the group, and then other tasks according to overlapping area with each group cluster to them by neighborhood function. This process require location of initial tasks and the size of overlapping area which determined by proximity functions. Finally overlay operations could be used to eliminate shortcoming of previous models. It was necessary to predetermine the type and geometric layout of all supply points in past models. Sometimes applied different type of cranes resulted in reduction cost or increase efficiency. Also supply point may change during construction phase. With aiding of overlay operation in GIS model, possibility of existence different crane types and supply point prepared. Each type of crane (or supply point) placed into different layer and with network systems this process could be made. Layout of tower crane(s) using GIS is illustrated in Fig. 5.

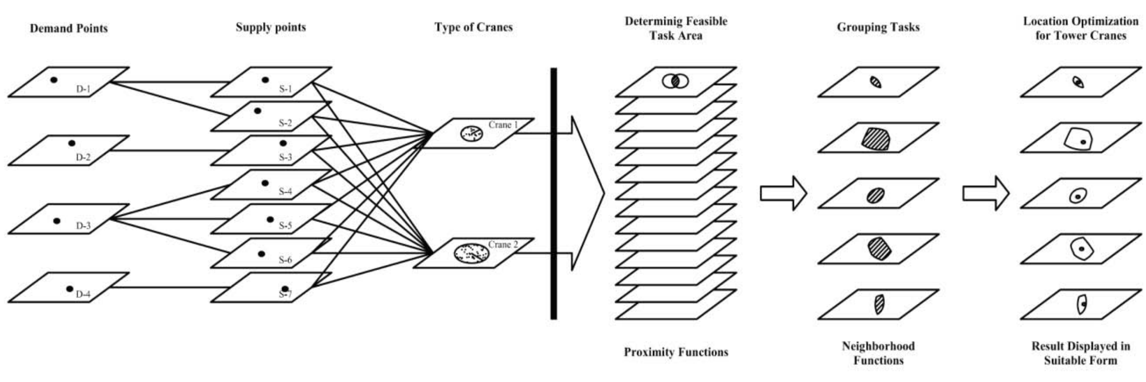
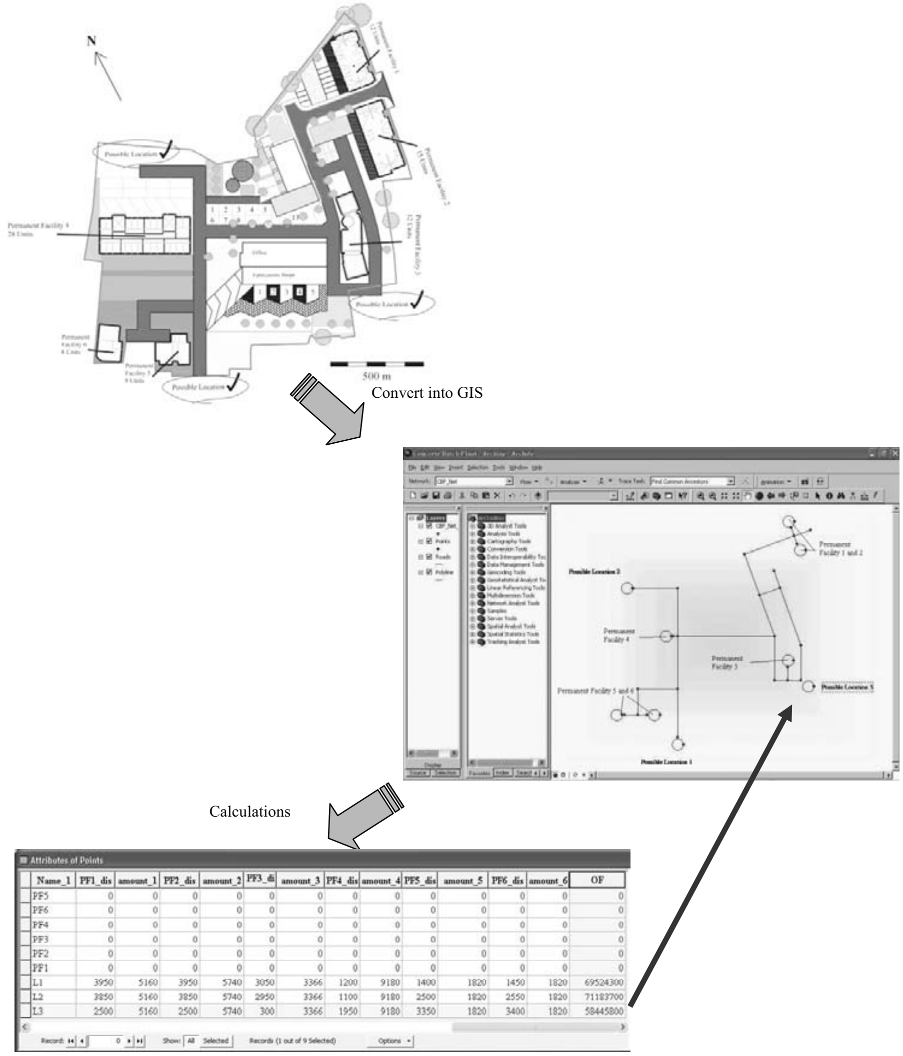


Fig. 5. GIS Based Layout of Tower Crane(s).

Concrete batch plant is one of the temporary facilities that shown potential application of GIS in site layout efficiency. As noted before, minimize transportation cost is a major factor in batch plant location optimization. Therefore the objective function was defined as minimum time-amount of concrete delivery. When time replaced with distance, GIS application made possible. Some similar application of GIS has been addressed in the previous researches. Locating fire stations, schools and other facilities according to shortest distance (or time) between them to supported place is a common application of GIS. Network functions can be used to allocate a concrete batch plant based on determining the minimum cost path through site roads between batch plant and demand points, i.e, permanent facilities. For this purpose one or more locations where the batch plant could be located must determined. Also set of constraints that places limits on how the concrete can be met and the objective function to deliver the concrete should be determined. GIS aided with amount of concrete required by permanent facilities, presented location which minimum distance multiple by amount of required concrete from demand points. This location refers as optimum location of concrete batch plant.

The following example contains six permanent facilities as demand points which their locations are shown in Fig. 6. Based on required space, the possible location for setting concrete batch plant divided into three locations (Possible Location 1 to 3). Also required concrete for each permanent facility (PF) and access roads were predetermined.



Name_1	PF1_dis	amount_1	PF2_dis	amount_2	PF3_di	amount_3	PF4_dis	amount_4	PF5_dis	amount_5	PF6_dis	amount_6	OF
PF5	0	0	0	0	0	0	0	0	0	0	0	0	0
PF6	0	0	0	0	0	0	0	0	0	0	0	0	0
PF4	0	0	0	0	0	0	0	0	0	0	0	0	0
PF3	0	0	0	0	0	0	0	0	0	0	0	0	0
PF2	0	0	0	0	0	0	0	0	0	0	0	0	0
PF1	0	0	0	0	0	0	0	0	0	0	0	0	0
L1	3950	5160	3950	5740	3050	3366	1200	9180	1400	1820	1450	1820	69524300
L2	3850	5160	3850	5740	2950	3366	1100	9180	2500	1820	2550	1820	71183700
L3	2500	5160	2500	5740	300	3366	1950	9180	3350	1820	3400	1820	58445800

Fig. 6. GIS Based Layout of Concrete Batch Plant.

Table placed below Fig 6 depicts the described procedure for determining optimum location. In this Table, distance between permanent facilities (PF1 to PF6) and possible locations (L1 to L3) are obtained from network analysis. Shaded column shows numeral sum for objective. As shown in this Table, Location3 (L3) is the optimum location for setting concrete batch plant because has a minimum of required concrete multiplied by distance.

Temporary buildings, finally, could be located with similar approach by GIS. After make priority by the planner, size and feasible location of temporary buildings should be determined. Then implementation of GIS technology results in solving construction site layout. Meanwhile visual presentation of the process, aided planner to understand errors in assumption or applied data and possibility of make changes on relation is provided. For these reasons we suggest GIS application to layout of construction site layout.

5. Areas for Future Research

Based on existing knowledge and understanding of GIS technology, several research areas about construction site layout can be identified. First, for proving GIS capability on tower crane locating, described procedure should be done by GIS technology. In addition to compare GIS result with results of previous models, different types of crane and also different layout of supply points added to GIS model. This act results in eliminating previous models shortcoming. For the reason that location optimization of concrete batch plant is different procedure and use another GIS analysis function, the next model allocated to this TF. This model is not new to GIS professional users but illustrate GIS capability efficiency.

Another model assigned to layout of temporary buildings. Similarities between GIS and other computer systems, such as computer-aided-design (CAD), project management (PM) systems, and facility management (FM) systems, the GIS could be applied in planning of construction site layout. Relation requirements between temporary buildings and their supported facilities, has an excessive impact on results. Finally, combine these models to a comprehensive model, implementation of all the layout process made possible. Thus, GIS is the only system which could be applied for locating whole of temporary facilities such as tower crane, concrete batch plant and temporary buildings.

6. Conclusion

This paper briefly described GIS technology and its analyses functions. Data required for layout of temporary facilities (TFs) has been gathered and according to methods of location, TFs categorized into three parts; tower cranes, concrete batch plant, and temporary buildings (e.g. office, parking, storage, shops and etc). The manner of locating for each part was described. Then potential applications of GIS technology in construction site layout were identified. Specific emphasis was placed on the spatial aspects of these applications as the justification for the use of the technology. Selected applications, location optimization of tower crane, concrete batch plant and temporary buildings, were used to highlight the strength of the technology. Suitable analysis functions, such as overlay operation, proximity and neighborhood function, suggested for each category of TFs. Writers attempted to show coordination of GIS technology with data required in construction site layout. For this reason allocated a section of the paper to explore potential of GIS application to the construction site layout. Finally, areas of additional research were identified.

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