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CONSTRUCTION SITE LAYOUT FOR MINIMIZATION OF TRANSPORTATION COST: STEP-BY-STEP TEACHING APPROACH

Wen YI [a], and Shuaian WANG [b], and Maria ATTARD[c]
[a] *School of Engineering and Advanced Technology, College of Sciences, Massey University, Auckland, New Zealand*
[b] *Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hong Kong*
[c] *Department of Geography, Faculty of Arts, OH132, University of Malta, Msida MSD2080, Malta*
Email: wenyi96@163.com, hans.wang@polyu.edu.hk, maria.attard@um.edu.mt

ABSTRACT

Construction site layout concerns the choice of locations for temporary facilities (e.g., fabrication shops, staging areas, tower cranes) and construction waste. Construction site layout affects the transportation cost of materials and wastes in the site and hence is a key factor in construction management. Construction site layout involves complex decision processes that are usually formulated as optimization models. We propose a step-by-step teaching approach to facilitate students' learning. In the approach, students first learn static site layout with only temporary facilities. Next, we teach dynamic site layout with only temporary facilities. Finally, dynamic site layout with both temporary facilities and waste is delivered. This step-by-step teaching approach alleviates the learning burden for students.

Keywords: Transportation cost; Construction site layout; Construction management.

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Construction site layout concerns the choice of locations for temporary facilities (e.g., fabrication shops, staging areas, tower cranes) and construction waste. Construction site layout affects the transportation cost of materials and wastes in the site and hence is a key factor in construction management. Construction site layout involves complex decision processes that are usually formulated as optimization models. We propose a step-by-step teaching approach to facilitate students' learning. In the approach, students first learn static site layout with only temporary facilities. Next, we teach dynamic site layout with only temporary facilities. Finally, dynamic site layout with both temporary facilities and waste is delivered. This step-by-step teaching approach alleviates the learning burden for students.

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1. INTRODUCTION

Construction site layout concerns the choice of locations for temporary facilities and construction waste. Construction site layout affects the transportation cost of materials and wastes in the site and hence is a key factor in construction management. Construction site layout involves complex decision processes that are usually formulated as optimization models. However, students in construction management/built environment are generally not equipped with optimization knowledge. As a result, it is a challenging task to teach students the rationale behind construction site layout models and decision support systems.

In this paper, we propose a step-by-step teaching approach to facilitate students' learning. In the approach, students first learn static site layout with only temporary facilities. Next, we teach dynamic site layout with only temporary facilities. Finally, dynamic site layout with both temporary facilities and waste is delivered. This step-by-step teaching approach alleviates the learning burden for students.

2. STATIC SITE LAYOUT FOR TEMPORARY FACILITIES

A static construction site layout problem assumes that all the temporary facilities are set up and removed at the same time (Yeh, 1995; Li and Love, 1998; Yi et al., 2018); as a result, a temporary facility cannot overlap spatially with fixed facilities or other temporary facilities.

In a static construction site layout problem, we have a construction site with a given area. The area can be e.g. a rectangle. In the construction site, there are fixed facilities, for example, the buildings to be constructed. Sometimes the entrance to and exit from the construction site are also fixed, and they and their adjacent road inside the site can also be treated as fixed facilities. The fixed facilities are the "obstacles" in construction site, meaning that no other facility can overlap with them.

There are a number of temporary facilities in a construction site, for instance, fabrication shops, staging areas, and tower cranes. In contrast to fixed facilities whose locations are determined, the choice of locations for the temporary facilities has some flexibility. For instance, the location of a tower crane can be flexible as long as the tower crane is capable of working on the building; the location of a fabrication shop is even more flexible. In theory, the size and shape of a temporary facility are also flexible, at least to some extent. However, in reality, redesigning a temporary facility simply for the purpose of saving transportation cost is generally not worth the time and effort. As a result, for instance, the size of a fabrication shop is determined by the total workload in the construction site and the shape of the fabrication shop is simply one from the standard designs. Therefore, in construction site layout, it is usually assumed that the size and shape of a temporary facility is fixed. However, the direction of a temporary facility can be rotated for 90 degrees. For instance, a 3m×4m fabrication shop can be 3m long in the west-east direction and 4m long in the north-south direction, or 4m long in the west-east direction and 3m long in the north-south direction.

2.1 Calculate the Total Transportation Cost

We first ask students to calculate the transportation cost for a fixed construction site layout plan. A fixed construction site layout plan generally has a set of fixed facilities, and a set of temporary facilities whose locations are given. The location of a fixed or a temporary facility is usually represented by its centroid. All the materials transported to the fixed or temporary facility are assumed to be transported to its centroid; all the materials transported from the fixed or temporary facility are assumed to be transported from its centroid.

<i> Distance between two facilities. The distance between two facilities is usually calculated based on the Euclidian distance or Manhattan distance; in some elaborated calculations, the distance is based on the shortest path between the two facilities, taking into account the obstacles between them. We use Euclidian distance. We provide students with Table 1, and ask students to fill in Table 2. Students are first required to calculate the distances in Table 2 using calculators and then using Microsoft Excel.

Table 1. Centroids (x, y) of the fixed facilities and temporary facilities

Facilities	Centroid (unit: m)
Fixed facility 1	(20, 20)
Fixed facility 2	(50, 40)
Temporary facility 3	(5, 10)
Temporary facility 4	(35, 50)
Temporary facility 5	(35, 42)

Table 2. Euclidian distance (m) between any two facilities

Distance	facility 1	facility 2	facility 3	facility 4	facility 5
Fixed facility 1	0				
Fixed facility 2		0			
Temporary facility 3			0		
Temporary facility 4				0	
Temporary facility 5					0

<ii> Calculate the total transportation cost. The total transportation cost is expressed in terms of the amount of materials to transport multiplied by the transport distance. Therefore, we need to provide students with the amount of materials to transport between two facilities, as shown in Table 3. It should be noted that we did not specify the unit used in Table 3. In fact, the unit, depending on the context, can be ton/day, ton/week, truck/day, truck/week, etc. The key issue is to make sure that all the numbers in Table 3 have the same unit. It should also be noted that Table 3 is not symmetric, e.g., the amount of materials transported from fixed facility 1 to temporary facility 3 may not be the same as the amount from temporary facility 3 to fixed facility 1. Students are required to calculate the total transportation cost based on Table 2 and Table 3, using Microsoft Excel.

Table 3. Amount of materials to transport between two facilities

From / To	facility 1	facility 2	facility 3	facility 4	facility 5
Fixed facility 1	0	0	0	2	4
Fixed facility 2	0	0	1	1	1
Temporary facility 3	6	10	0	3	4
Temporary facility 4	8	12	2	0	1
Temporary facility 5	9	15	0	4	0

2.2 Compare Different Layout Plans

We provide students with more than one construction site layout plan for temporary facilities and ask students to compare their total transportation costs. For instance, we provide three construction site layout plans in Table 4 to students and ask students to compare the plans. It should be noted that in the three construction site layout plans the centroids of the fixed facilities are the same. By calculating the total transportation costs for the three plans and identify the one with the lowest total transportation cost, students can identify the best plan.

Table 4. Centroids of the fixed facilities and temporary facilities in three layout plans

Facilities	Layout plan 1	Layout plan 2	Layout plan 3
Fixed facility 1	(20, 20)	(20, 20)	(20, 20)
Fixed facility 2	(50, 40)	(50, 40)	(50, 40)
Temporary facility 3	(5, 10)	(15, 10)	(5, 10)
Temporary facility 4	(35, 50)	(35, 50)	(30, 50)
Temporary facility 5	(35, 42)	(35, 42)	(30, 40)

We further ask students to form groups of three persons and ask each group to design, based on its experience and visual observation, a good construction site layout plan. Note that at this stage, for simplicity, we let the directions of the temporary facilities be fixed. We will first check whether the construction site layout plan designed by a group is feasible, that is, whether there is spatial overlap between a fixed facility and a temporary facility or between two temporary facilities. If the construction site layout plan is feasible, we will then calculate its total transportation cost. To accelerate the process, we ask group 2 to check whether group 1's construction site layout plan is feasible and if yes, calculate the total transportation cost. It is possible that zero, one, or more than one group will be the winner. (Note that "zero" means all construction site layout plans are infeasible; "more than one" means at least two groups come up with construction site layout plans with the same lowest total transportation cost.)

2.3 Model Static Site Layout

We will teach students to model static site layout of a discrete nature. "Discrete" means the number of candidate locations of a temporary facility is finite. For instance, we may discretize the construction site into grids of squares, each of which is 1m×1m, and require that the centroid of a temporary facility must be at the center of a square.

Since students have no prior optimization modeling background, we show students how to model the static site layout problem as follows.

<i> The directions of the temporary facilities are fixed. To formulate an optimization model, we show students the decision variables: for each temporary facility, which candidate location to choose; these decision variables can be represented by binary variables. We then ask students to formulate the total

transportation cost using the decision variables. Finally, we guide students to formulate the constraints one by one: exactly one candidate location for each temporary facility must be chosen; no two facilities can overlap; the whole of a temporary facility must be within the area of the construction site.

<ii> The directions of the temporary facilities can be rotated for 90 degrees. We then show students that we add a “mirror facility” for each temporary facility, representing the one that is rotated for 90 degrees. Then we need to add decision variables representing whether the mirror facility is chosen (and then the original temporary facility is not chosen) and if yes, which candidate location is chosen.

A natural question for students is how to solve the optimization model. It is impractical to teach students commercial optimization solvers such as CPLEX or GUROBI, because they may not be free, they may be complex to use, and they may require plenty of programming techniques. Instead, we teach students to use Microsoft Excel to solve the models. Although Microsoft Excel is much slower, it is very easy to learn because students are all familiar with Microsoft Excel.

3. DYNAMIC SITE LAYOUT FOR TEMPORARY FACILITIES

A dynamic construction site layout problem accounts for the time dimension (Elbeltagi et al., 2004; Xu and Li, 2012; Said and El-Rayes, 2013). Not all temporary facilities are constructed or demolished at the same time. It is possible that a temporary facility is removed once it has completed its tasks and a new temporary facility is constructed at the same location.

We first ask students to brainstorm to come up with some solutions. For instance, students may come up with solutions based on their visual observation. Of course, treating the dynamic site layout problem as a static site layout problem is also a possible approach. However, it is possible that the static site layout problem is infeasible, while the dynamic site layout problem is feasible.

We share with students that dynamic construction site layout needs to balance the trade-off not only spatially, i.e., between the choices of locations for different temporary facilities, but also balance the trade-off temporally, that is, between the choice of location for a temporary facility during different times (e.g., different days or different weeks). This problem is very challenging for site managers to make decisions manually. Hence, optimization models are also required. Similar to the static one, we will show students the solution process for the optimization models using Microsoft Excel. It should be noted that we will also show students a rolling-horizon solution approach. For instance, the whole construction process may take 20 weeks. We first solve the dynamic construction site layout problem for the first five weeks by assuming there is no material to transport in week 6 to week 20; we then fix the location of the temporary facilities that are setup in week 1, and solve the dynamic construction site layout problem for week 2 to week 6 by assuming there is no material to transport in week 7 to week 20, etc. Although the solution obtained by this rolling-horizon solution approach is generally not optimal, it has two apparent advantages: first, the computation time is much shorter than solving the overall dynamic model; second, in practice there are plenty of uncertainties and this approach can use updated parameters once we learn more information about the uncertain input parameters.

4. DYNAMIC SITE LAYOUT FOR TEMPORARY FACILITIES AND WASTE

In the construction process a lot of wastes will be generated. These wastes will be temporary stored within the construction site and then be transported periodically to dump. Therefore, we need to allocate some areas within the construction site to temporarily store the wastes. Different from temporary facilities that have pre-designed shapes and sizes, the size of a waste pile is dependent on the amount of waste generated, and the shape of a waste pile is generally free but is usually rectangular. Therefore, to account for waste piles in dynamic construction site layout, we further need to decide (a) when an area is allocated for a waste pile and when that area is no longer used for waste storage, (b) the location of the area, and (c) the shape and size of the area.

It is generally beyond the capacity for the students to model waste piles in construction site layout because the models are too complex. Similar to the way we handle temporary facilities, we ask students to propose a few possible locations, shapes and sizes of the waste piles, based on their experiences and visual observation, and then develop optimization models that are solved by Microsoft Excel.

5. CONCLUSION

This paper has proposed a step-by-step teaching approach to facilitate students' learning of construction site layout to minimize transportation costs. In the approach, students first learn static site layout with only temporary facilities. Next, we teach dynamic site layout with only temporary facilities. Finally, dynamic site layout with both temporary facilities and waste is delivered. This step-by-step teaching approach alleviates the learning burden for students. In the future, we will develop an interactive special-purpose software for students to better visualize, try, compare, and appreciate construction site layout models.

6. REFERENCES

Elbeltagi, E., Hegazy, T., Eldosouky, A. (2004). Dynamic layout of construction temporary facilities considering safety. *Journal of Construction Engineering and Management*, 130(4), pp. 534-541.

Li, H., Love, P. E. (1998). Site-level facilities layout using genetic algorithms. *Journal of Computing in Civil Engineering*, 12(4), pp. 227-231.

Said, H., El-Rayes, K. (2013). Performance of global optimization models for dynamic site layout planning of construction projects. *Automation in Construction*, 36, pp. 71-78.

Yeh, I. C. (1995). Construction-site layout using annealed neural network. *Journal of Computing in Civil Engineering*, 9(3), pp. 201-208.

Yi, W., Chi, H. L., Wang, S. (2018). Mathematical programming models for construction site layout problems. *Automation in Construction*, 85, pp. 241-248.

Xu, J., Li, Z. (2012). Multi-objective dynamic construction site layout planning in fuzzy random environment. *Automation in Construction*, 27, pp. 155-169.