CONSIDERING ACTIVITY CONFLICTS IN TOWER CRANES LAYOUT PLANNING USING AGENT-BASED SIMULATION

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Abstract: Tower cranes are considered to be one of the most important equipment in large construction projects. The layout planning of tower cranes that defines the types, the quantities and the positions of the tower cranes, has a significant impact on the overall productivity and cost effectiveness of construction projects. Previous research utilized either mathematical methods, or visualization tools to find an optimal tower crane layout plan. But such methods and tools are not adequate to evaluate the effect of conflict among tower cranes in terms of time and cost calculations. Moreover, they don't assure the maximum efficiency of tower crane layout to fulfill the needs of crane-based executed activities. This research develops an Agent Based Simulation (ABS) model to overcome the limitations of previous research. It calculates the time and the cost of tower cranes operation cycles, taking into account the potential conflict among the working tower cranes. A case study is provided to demonstrate the capabilities and contributions of the developed ABS model.

1   INTRODUCTION

There is a need to incorporate Agent-Based (AB) technologies with significant construction operations such as tower crane operations. Most previous work is based solely on mathematical or discrete event simulation technique. Previous models often lack dealing with conflict effect between tower crane, which is the key of time and cost calculation. In addition, they didn't focus on the ability of tower cranes layout to comply with the time schedule. The main objective of this research is to develop an ABS model to solve the multi tower crane location problems and to overcome the limitations of the previous research work. To achieve this main objective, the following sub-objectives are carried out:

1. Study tower crane operations to describe the interaction between tower cranes and other tower crane layout objects; supply points, demand points and site requests. Also, study conflicts between tower cranes and how to solve the conflicts.

2. Build calculations which represent tower crane movements, conflict between cranes and cost calculations.

3. Develop an agent based simulation model based on external MS Excell database for input data entry to show the real time of tower crane operations. The model should be able to capture the dependencies and interactions of the model elements; tower cranes, supply points, demand points and site requests. Also, the model is designed to collect data from tower cranes to estimate the time and cost of tower crane operations.

4. Design user interface to facilitate exploring the expected time/cost for different scenarios to help decision maker to choose the appropriate combination of tower crane.

2   LITERATURE REVIEW

The ABS applications in construction management focused on supply chain management, construction claims management, infrastructure management, procurement, construction site safety and construction workers' behavior. Shehwaro et al. (2016) used ABS to simulate the effect of learning on labor productivity in the construction industry. Where agents interact with each other and their surroundings thereby creating an adaptive environment open for learning and improvement. Jabri and Zayed (2017) applied Agent-Based Modeling and Simulation as an effective bottom-up tool to model earthmoving operations.

Previous research efforts have been developed to optimize the locations of tower cranes, based on different criteria that mainly focus on minimizing both time and cost. Zhang et al. (1999) developed a mathematical model to optimize the location of a group of tower cranes using Monte Carlo simulation. Abdel-Khalek et al. (2013) used Genetic Algorithms optimization technique to select the type and location of tower crane to be used in a construction site. The objective was to minimize the total transportation time. Marzouk and Abubakr (2016) utilized Genetic Algorithm (GA) and Building Information Modeling (BIM) for tower crane planning. This BIM-based model was used to verify the locations of cranes, by applying clash detection and developing a 4D plan. Yeoh and Chua (2017) showed that neglecting the impact of multiple construction stages leads to suboptimal crane deployment costs. The proposed model was able to provide better solutions when multiple stages were considered. Monghasemi et al. (2016) developed an approach which manage the waiting times, of the service request instead of minimizing the total travel time of tower cranes. This is done by prioritizing service request sequence using a least deviation method based on the pending time for each requested crane service. Wang et al. (2014) integrated Building Information Modelling (BIM) and firefly algorithm to find the optimum tower crane layout. This model used BIM technology to calculate the quantities of transported materials. The tower crane layout was then determined using firefly algorithms.

3   RESEARCH METHODOLOGY

A flowchart of the proposed methodology is depicted in Figure 1. The first step in the proposed model is determining its inputs that represent the supply points, demand points, possible tower crane locations, and tower crane-based work tasks. The second step is defining the service request list that is the list of work tasks, paired with its adequate tower cranes. Then a sequence of ordering, based on the work task priority and crane availability, is followed to assign each crane to the appropriate work task. A conflict check is done before crane assignment and before every crane movement, to avoid conflict and determine how to deal with the potential conflicts. The process continues until all work tasks are accomplished. Afterwards, the proposed model was tested by examining a case study to demonstrate the model capabilities.

4   TOWER CRANE OPERATIONS

Figure 2 illustrates the three-dimensional crane geometries and the hook movements of T and luffing tower crane types. To model the tower crane operations, each lifting cycle is divided into four actions:
1. Moving the hook from the previous location (the last demand point or idle state) to the location of the supply point.
2. Loading the target load.
3. Moving the loaded hook to the location of the demand point.
4. Unloading the target load and repeating the cycle or going to the idle state.

The cycle time of tower crane is calculated based on prior works. However, the equations, applied in (Zhang et al., 1999), have been modified and summarized as follows:

[1] $T = max(T_h, T_v) + \beta * min(T_h, T_v) + T_L + T_u$

Where;
T_v = time for vertical hoisting of hook (min)
T_h = time for horizontal movement of hook (min)
T_L = time for loading

T_u = time for unloading

β = hook simultaneous movement parameter (degree of coordination of hook movement in vertical and horizontal planes)
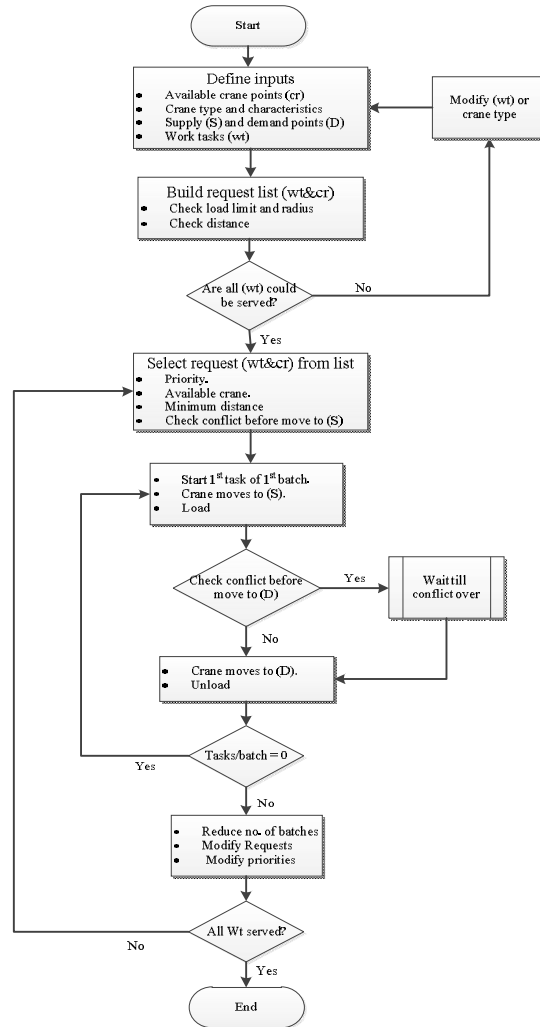

Figure 1: Flow chart of the proposed ABS model

5   AGENT BASED MODEL

The proposed AB model consists of a number of agents that represent the key influencing elements of the tower crane operations. Figure. 3 illustrates the interaction between such agents. Detailed description of the model can be found in (Younes and Marzouk 2018).

5.1   Supply and Demand points agents

These agents contain the locations of supply and demand points, in terms of their coordinates. The locations of supply points are determined by the construction site team, according to the site conditions and space availability. On the other hand, the locations of demand points are represented with the coordinates of construction elements, such as columns and concrete slabs that should be served by tower cranes. The coordinates of these two agents can be fed from an external or internal database.
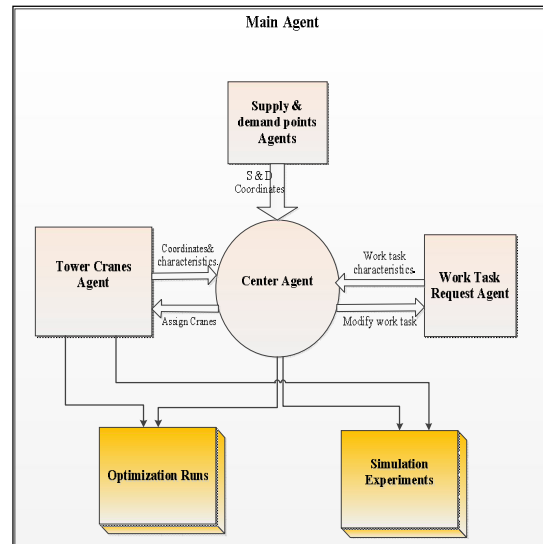
Figure 3: Interactions of the model agents

5.2 Work task requests agent

This agent represents the characteristics of work tasks that are determined in two steps. The first step is selecting a short duration (one day) from the project time schedule. The one-day time schedule should represent the largest number of daily activities that depend on the tower cranes. Also, a list of tower crane-based activities is extracted from this one-day duration time schedule. The second step is to describe each crane-based activity in detail, and to list the description in a work task requests table. This description is obtained from the site, depending on its characteristics. Each request includes Supply point (S), Demand point (D), Number of batches, Max load, Work task priority, loading time and unloading time.

5.3 Tower crane agent

This agent consists of three parts. The first part includes all possible crane location coordinates that are linked to the database sheet. The second part includes the tower crane characteristics. These characteristics vary according to the crane type and site conditions. The third part is the state chart that describes the tower crane hook movement between different states and how it moves between them to perform the required tasks. Figure 4 illustrates the tower crane state chart. The crane hooks remain in the *Idle state,* waiting for a task assignment message that comes from the *center* agent. When a crane is selected, to perform a certain task, it *moves to the supply point*. Then, the crane *loads* the target load at the supply point. After loading and before moving to the demand point, a *conflict check* is carried out, using (Anylogic) programming, to assure that there is no conflict with any other working cranes. If a conflict takes place, then the crane hook waits until the other crane moves. After that, the crane hook *moves to the demand point* and *unloads* the transported load. The crane hook repeats this cycle, moving between the supply and demand points, until finishing off the work tasks within a certain batch. Then, it moves to the *Idle state* position, waiting for another work task assignment, released by the *center* agent.

5.4 Center agent

The center or control agent, acts as a play maker or a control room that interacts with other agents and directs the process. The center agent state chart, shown in Figure 5, depicts the control steps to govern the tower crane operations as follows:

1. The locations of tower cranes are determined by one of two methods: The first method sets the number of cranes, where their locations are randomly determined, based on the available

locations that are defined by the crane agent. The second method sets the state of each available crane location; whether to be occupied by a crane or not.

2. Build a service request list: Each item in this list is a pair of work task and tower crane location, depending on two conditions: a) the distance between the supply or demand points and the crane point should be less than the crane jib length. b) The work task load should be less than the load, obtained from the tower crane load chart that depends on the type of the tower crane and its radius, for lifting. The load chart provides the load capacity of the tower crane and the corresponding maximum lifting radius of the crane. It is worth noting that the allowable lifting radius is extended when the lifting load is reduced. If a work task can't be served by a crane, then either a distance reason or a load limit reason is determined. Hence, the decision maker can take action by changing the crane location or the crane type. To choose a service request from the list, to start, a sequential methodology is set as explained below.

3. *Select a service request* from the service request list, based on its priority, under the condition that its paired crane is in the idle state. However, if no crane is in the idle state, then the model waits until a crane enters the idle state.

4. If more than one crane can serve the selected work task, then the center agent *selects the crane* that has the minimum distance to the supply/demand points of the selected work task.

5. The *conflict check* is an important and repetitive process that aims at avoiding conflict between the selected service request crane and any other working crane. The proposed ABS model deals with the conflict three times: 1) before starting the crane cycle, by checking the conflict possibility of the crane hook with any other working crane, 2) before the crane hook movement from the supply point to the demand point and 3) before the crane hook movement from the demand point to the supply point, to repeat the cycle. Figure 6 shows the conflict resolution stages, where Figure 6-a illustrates the potential conflict, if Crane 2 moves to its supply location, Point 2, while Crane 1 is in the working state at its supply location, Point 1. When Crane 1 moves to the demand Point 1, the conflict is over and Crane 2 can move to supply Point 2, as shown in Figure 6-b. If the selected service request has a conflict with a working crane, then the control state chart goes back to select another service request.

6. After selecting the service request, its selected crane is assigned to start the work, serving the specified work task, as explained in the crane agent clause. Each crane notifies the center agent with its state and availability, after finishing its work task.

7. The center agent state chart returns to Item 3 to select a new service request. The process continues until finishing all work tasks listed in the service request list.

5.5   Model Outputs

The developed ABS model could be utilized either for simulation experiments or for optimization runs, depending on the required target. Throughout the simulation experiments, different combination scenarios can be examined, by varying the model inputs, to help the decision maker to review several scenarios of the whole operation and their outcomes. All the model outputs are defined, such that they serve the main goal of the model, which is planning of the tower crane layout. The model outputs can be defined as follows:

1. Tower cranes consumed times in different states; working, idle and conflict. These times show the operation efficiency and the time consumed in different states. Also, one of the model outputs represents the overall time required to execute the whole operation that should be compared to the planned time schedule.
2. The tower cranes costs that are divided into fixed cost and running cost, for each single crane and for the whole operation. The tower cranes costs should also be compared to the planned costs.
3. Whenever the work task cannot be served by any crane, the model feeds back with reasons, either for a distance reason or a load limit reason.
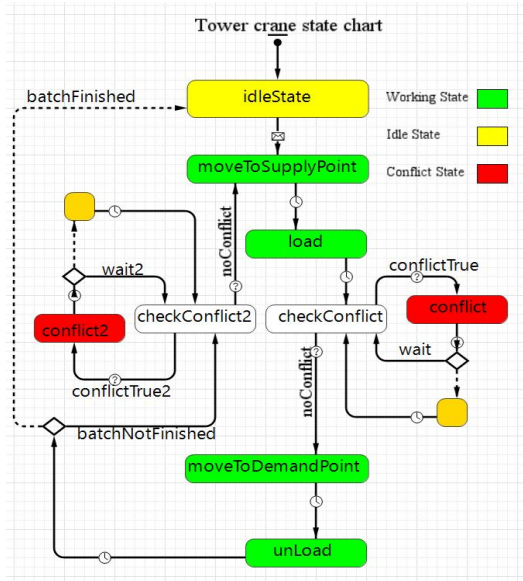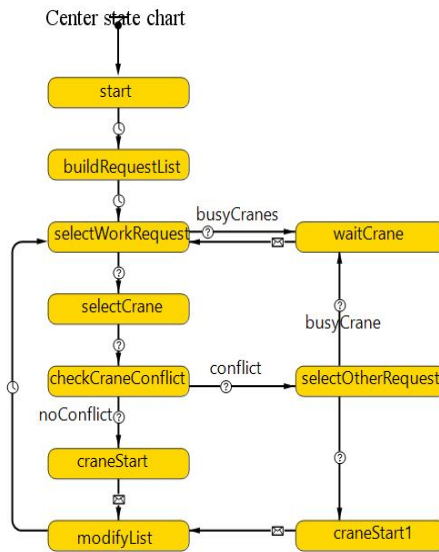
Figure 4: State chart of the tower crane agent Figure 5: State chart of the center agent
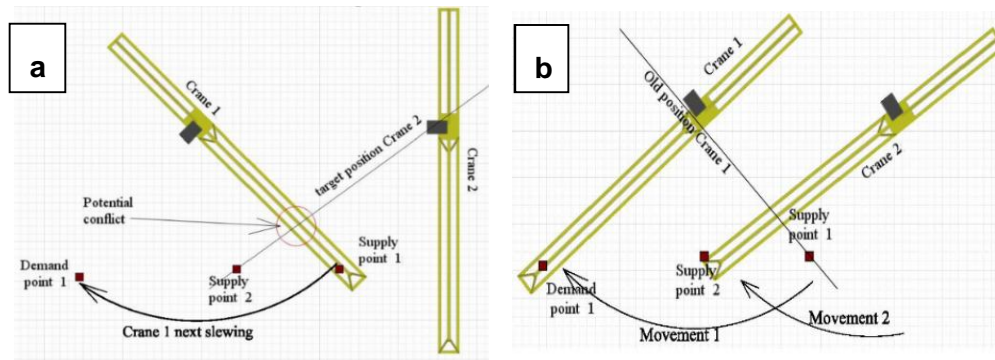

Figure 6: Conflict resolution stages

6   CASE STUDY

The proposed ABS has been applied in the construction of the extension of Madinah mosque expansion – El-Madinah City, Saudi Arabia. The case study focused on the construction of the ground floor of a part of Zone 1 of the project. The main tower crane-based activities are lifting formwork panels, reinforcing steel bars, steel cages and fresh concrete. Figure 7 shows the case study zone. Detailed description of the case study and the results can be found in (Younes and Marzouk 2018).

6.1   Identify/Define Model Inputs

Model inputs are linked with the model database via four main excel sheet tables. The first two tables contain the locations of supply and demand points, expressed with coordinates, as shown in Table 1. The location of supply points are determined by means of the construction site team, according to the site conditions and space availability. On the other side, the locations of demand points represent the coordinates of the construction elements such as columns and slabs. The third table lists all available positions to locate the tower cranes as shown in Table 2. It should be mentioned that the available locations of tower cranes are determined according to several factors: the time schedule, structural design, space availability, and the architectural design. Nevertheless, other factors, such as the requirements of heavy

loads and project large area, push towards locating the tower cranes inside the structural skeleton. The work task requests are extracted from two sources; the time schedule and construction site conditions. The fourth table lists a defined data of one day crane-based work tasks, as shown in Table 3, where the uniform probability distributions were considered to estimate the durations of loading and unloading times. Besides, the distance (Δ) is assumed to be 10 m to represent the increase in the hook vertical movement between the supply and demand points, as described in the tower crane operations section.
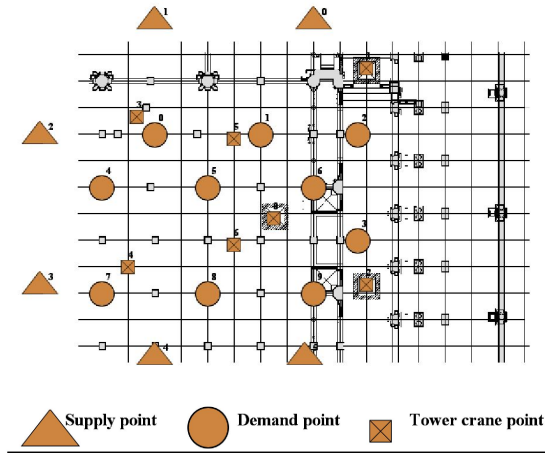

Figure 7: Top view of supply, demand and possible tower crane points

Table 1: Case supply points & demand points Table 2: Coordinates of tower crane points (Cr)

	Number	X	Y	Z
Supply (S)	1	72	10	0
	2	36	10	0
	3	10	36	0
	4	10	70	0
	5	36	86	0
	6	70	86	0
Demand (D)	1	36	36	19
	2	60	36	19
	3	82	36	19
	4	82	60	19
	5	24	48	30
	6	48	48	26
	7	72	48	26
	8	24	72	30
	9	48	72	34
	10	72	72	30

	Number	X	Y	Z
Crane points	Cr1	63	55	70
	Cr2	84	21	55
	Cr3	84	70	70
	Cr4	32	32	55
	Cr5	30	66	70
	Cr6	54	37	55
	Cr7	54	61	70

Table 3: Work task requests for the case study

Number	D	S	Number of Batches	Tasks/ Batch	Max Weight (ton)	Priority	Load Time (min.)	Unload Time (min.)
1	1	2	3	4	3	1	Uni. [2, 4]	Uni. [3, 5]
2	1	2	2	4	3	2	Uni. [2, 4]	Uni. [3, 5]
3	2	1	3	6	2	1	Uni. [1, 3]	Uni. [2, 4]
4	2	1	3	6	2	2	Uni. [1, 3]	Uni. [2, 4]
5	3	1	4	5	1	2	Uni. [1, 3]	Uni. [2, 4]
6	4	6	3	4	3	1	Uni. [2, 5]	Uni. [3, 6]
7	4	6	2	4	3	2	Uni. [2, 5]	Uni. [3, 6]
8	5	3	1	2	1	1	Uni. [3, 6]	Uni. [5, 8]
9	5	3	1	2	1	2	Uni. [3, 6]	Uni. [5, 8]
10	6	3	1	2	1	3	Uni. [3, 6]	Uni. [5, 8]
11	7	6	1	1	8	1	Uni. [4, 7]	Uni. [17, 23]
12	7	6	1	1	8	2	Uni. [2, 4]	Uni. [3, 5]
13	8	5	2	2	1	1	Uni. [3, 5]	Uni. [5, 8]
14	8	5	1	2	1	3	Uni. [3, 5]	Uni. [5, 8]
15	9	6	2	3	6	3	Uni. [4, 7]	Uni. [17, 23]
16	10	6	2	3	6	3	Uni. [4, 7]	Uni. [17, 23]
17	10	6	2	3	6	3	Uni. [2, 4]	Uni. [3, 5]

6.2   Simulation experiments

The model has run several times under various tower crane combinations and configurations (different crane types and jib lengths). In addition, each run has been repeated without taking into consideration the conflict effect, to highlight the advantage of the proposed model. Figure 8 shows a snapshot of the model, while running.

Figure 9-b depicts the tower crane utilization ratio of a single run of the model, whereas Figure 9-a depicts the total time and cost of the operation, divided into three portions: working, idle and conflict. Such outputs aid the decision maker to realize the overall efficiency of the operation and suggest the corrective action to enhance the operation outcomes.

As mentioned previously, it is assumed that the project can use four types of tower cranes where seven locations of the tower crane points, are available to be occupied by any tower crane. Each tower crane location has two alternatives, either occupied or free. This generates 512 combinations which are individually running. Four groups of combinations are selected. Each group represents a certain number of tower cranes (3, 4, 5 and 6). Each group includes four simulation runs; one simulation for each crane type. These results are in 16 combinations that can widely demonstrate the capabilities of the proposed model throughout diverse input data and facilitate the comparison between different output combinations. Table 4 lists the configurations of the 16 combinations, alongside their outputs, the total cost and time. In addition, for each combination, a separate run has been executed, without taking into account the conflict effect. To analyze the results, briefly, the following notices have been extracted from Table 4:
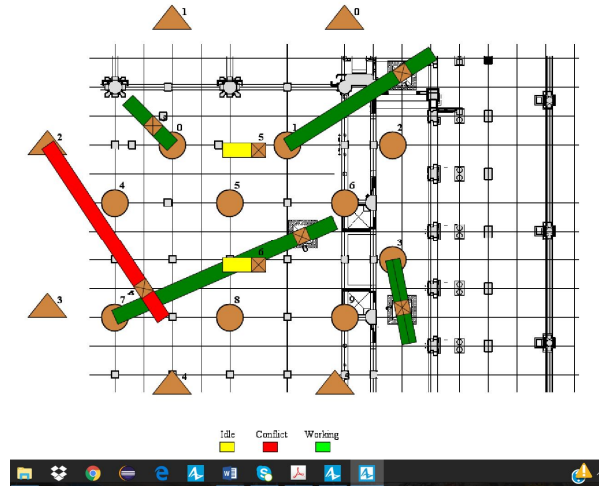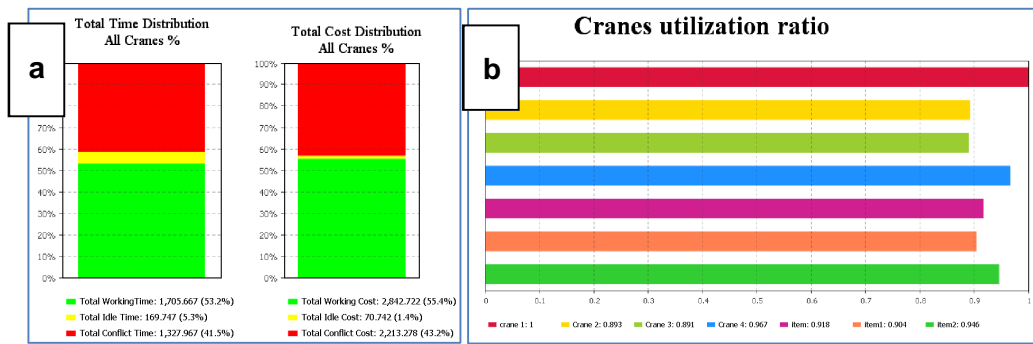
Figure 8: Running of simulation experiments

Figure 9: Generated outputs of the simulation experiments

Table 4: Sample of the simulation outputs

Comb.	Type	Cranes number	Crane Positions							Conflict		Neglect Conflict		Difference	
			1	2	3	4	5	6	7	Time (min)	Cost ($)	Time (min)	Cost ($)	Time (%)	Cost (%)
1	Type 1	4			*	*	*		*	469	2878	418	2552	10.8%	11.3%
2	Type 2	4			*	*	*		*	Work tasks 2,3 and 4 are not served due to load limit					
3	Type 3	4			*	*	*		*	899	3846	451	1909	49.8%	50.4%
4	Type 4	4			*	*	*		*	Work tasks 2, 3 and 4 are not served due to load limit.					
5	Type 1	5	*	*		*	*		*	546	3367	348	2549	36.2%	24.3%
6	Type 2	5	*	*		*	*		*	577	2399	575	2298	0.3%	4.2%
7	Type 3	5	*	*		*	*		*	Work tasks 10 and 4 are not served due to load limit.					
8	Type 4	5	*	*		*	*		*	Work tasks 10 and 4 are not served due to load limit.					
9	Type 1	3			*	*			*	731	3110	563	2657	23.0%	14.6%
10	Type 2	3			*	*			*	Work tasks 2, 3 and 4 are not served due to load limit.					
11	Type 3	3			*	*			*	972	4278	563	2618	42.1%	38.8
12	Type 4	3			*	*			*	Work tasks 2, 3 and 4 are not served due to load limit.					
13	Type 1	6		*	*	*	*	*	*	421	3231	297	2577	29.5%	20.2%
14	Type 2	6		*	*	*	*	*	*	611	2599	359	2236	41.2%	14.0%
15	Type 3	6		*	*	*	*	*	*	1009	4481	384	1909	62.0%	57.4%
16	Type 4	6		*	*	*	*	*	*	732	2821	368	1865	49.7%	33.9%

1. It can be noticed that combinations 2, 4, 7, 8, 10, 11 and 12 are not feasible, since some work tasks were not served because of the load limit of tower cranes. Consequently, these combinations are either excluded or applied under their defined shortage.

2. Neglecting the conflict effect results in less time and cost outputs. The difference ranges between (0.3% - 41.2%) and between (49.8% - 62%) for the luffing type and T type, respectively. That means, omitting the conflict constraints leads to misleading results and therefore leads to a false tower crane layout.

7   CONCLUSION

The proposed ABS model simulates the tower crane operation cycles, where the tower cranes and other agents that influence the whole operation are interacting. Based on the model inputs, the model outputs, in terms of cost, time and utilization ratios are determined. This helps the decision maker to compare between alternative scenarios, based on the site conditions and available resources. Also, the model quantitatively evaluates the conflict effect on the whole tower crane operation Simulation revealed the effect of conflict on the time and cost. Also, the simulation results show the advantage of the luffing type tower cranes that always has a total time less than that of T type tower cranes. This is because of the high maneuverability of luffing cranes to avoid conflicts.

REFERENCES

Abdel-Khalel, H., Shawki, K. and Adel, M., 2013. A computer-based Model for optimizing the location of single tower crane in construction sites. *International Journal of Engineering Science and Innovative Technology*, **2**(2), pp.438-446.

Jabri, A. and Zayed, T., 2017. Agent-based modeling and simulation of earthmoving operations. *Automation in Construction*, **81**, pp.210-223.

Marzouk, M. and Abubakr, A., 2016. Decision support for tower crane selection with building information models and genetic algorithms. *Automation in Construction*, **61**, pp.1-15.

Monghasemi, S., Nikoo, M.R. and Adamowski, J., 2016. Sequential ordering of crane service requests considering the pending times of the requests: An approach based on game theory and optimization techniques. *Automation in Construction*, **70**, pp.62-76.

Shehwaro, H., Zankoul, E. and Khoury, H., 2016. An Agent-Based Approach for Modeling the Effect of Learning Curve on Labor Productivity. *The First European and Mediterranean Structural Engineering and Construction Conference*, Istanbul, Turkey (ISBN: 978-0-9960437-2-4).

The AnyLogic company. Online: https://www.anylogic.com, accessed: 14 May 2017.

Wang, J., Liu, J., Shou, W., Wang, X. and Hou, L., 2014, July. Integrating building information modelling and firefly algorithm to optimize tower crane layout. In *The 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014)*.

Yeoh, J.K. and Chua, D.K., 2017. Optimizing Crane Selection and Location for Multistage Construction Using a Four-Dimensional Set Cover Approach. *Journal of Construction Engineering and Management*, **143**(8), p.04017029.

Younes, A. and Marzouk, M., 2018. Tower cranes layout planning using agent-based simulation considering activity conflicts. *Automation in Construction*, **93**, pp.348-360.

Zhang, P., Harris, F.C., Olomolaiye, P.O. and Holt, G.D., 1999. Location optimization for a group of tower cranes. Journal of construction engineering and management, **125**(2), pp.115-122.