MODELING AND TESTING OF A MAINTENANCE PROJECT USING SIMPHONY: CASE STUDY

Mubarak Al Alawi*, Mohammed Al Shahri, and Zainab Bacal
Department of Civil and Architectural Engineering, Sultan Qaboos University, Muscat, Oman

ABSTRACT: Unlike building a new project, the maintenance and rehabilitation of an existing project are complex. The complexity is driven by different factors such as limited access to the site, limited working hours, restricted storage area, a limited number of allowed crews to work simultaneously, etc. Considering all of these factors is essential for construction process planning. Hence, testing the maintenance project under different project scenarios will help to identify the optimum resources configuration. In this paper, we present a case study of a maintenance project located in Al Khodh, Oman. It is required to model and simulate the maintenance operation, given many client-based work constraints. The project was modelled using a Simphony simulation environment. The simulation model was tested in different resource configurations, including several floor accesses, other tiles breaking and tiles installation teams, and a different number of waterproofing teams. This study demonstrated that the tiles installation team is the most influencing resource in the project. Given one floor access at a time and using two tiles installation produces the most economical resources configuration. Three tiles installation teams are the best selection for two-floor accesses, and seven tiles installation teams selection is best for three floors.

Keywords: Construction Operation; Simulation; Simphony; Maintenance project; Discrete Event Simulation

نمذجة واختبار مشروع صيانة باستخدام **SIMPHONY**: دراسة حالة

مبارك العلوي* ومحمد الشحري وزينب بقال

الملخص: على عكس بناء مشروع جديد، صيانة وإعادة تأهيل مشروع قائم تعتبر عملية معقدة. يرجع التعقيد إلى عوامل مختلفة مثل صعوبة حركة المعدات الثقيلة في الموقع، وإلى ساعات العمل المحدودة، ومحدودية مساحة التخزين، وعدد أطقم العمل المسموح بها للعمل في وقت واحد وما إلى ذلك. يعتبر النظر في كل هذه العوامل ضروريًا لتخطيط وتقدير متطلبات مشروع الصيانة، وبالتالي من المهم اختبار مشروع الصيانة في ظل سيناريوهات عمل مختلفة. تبحث هذه الدراسة عملية نمذجة لمشروع صيانة منزل سكني يقع في مدينة الخوض في سلطنة عمان وتهدف إلى محاكاة عملية الصيانة في ضوء العديد من قيود العمل المحددة من قبل صاحب المشروع، وتسعى هذه الدراسة إلى تحديد خيارات الموارد البشرية المثلى لإتمام المشروع خلال فترة زمنية قصيرة وبتكلفة مالية مثالية. تم تصميم نموذج محاكاة المشروع باستخدام بيئة محاكاة Simphony وتم توفير مدخلات النموذج من قبل شركة البناء التي تعمل في المشروع. أيضا تم اختبار نموذج المحاكاة في ظل مدخلات مختلفة كعدد الطوابق المسموح العمل بها وعدد فرق إزالة وتركيب البلاط، وعدد مختلف من فرق العزل المائي. لقد وجد أن استخدام فريقين لتركيب البلاط هو أفضل اختيار في حالة السماح بالعمل في الطوابق بصورة متسلسلة ووجد أيضا استخدام ثلاثة فرق تركيب البلاط هي أفضل اختيار في حالة العمل في طابقين بصورة متزامنة ويفضل استخدام سبعة فرق تركيب البلاط في حالة العمل في ثلاث طوابق بصورة متزامنة.

الكلمات المفتاحية: أعمال بناء؛ محاكاة؛ سيمفوني؛ أعمال صيانة؛ محاكاة الأحداث المنفصلة.

*Corresponding author's e-mail: alawim@squ.edu.om

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1. INTRODUCTION

Construction activities pose complexity driven by the complex nature of the construction resources required. Construction productivity may be subjected to different factors that hinder the optimum uses of resources such as work environment, project nature, project resources, and project management (Al Alawi, 2021). Labour, material, equipment, and budget should be utilized efficiently to maintain the project milestones. Construction resources must work in harmony to achieve the projected cost, time, and quality defined for the project. Therefore, it is vital to understand the work of the construction activities, build a model, and simulate the construction operation to identify the optimum number of resources to utilize. Many optimization research studies covering different areas in construction were covered in the literature. For example, Osama and Alshibani (2009) optimized construction equipment using the genetic algorithm technique. Alavi and AbouRizk (2017) and Zhou *et al.* (2009) integrated genetic algorithms with simulation to optimize construction site layout variables. Al-Bataineh *et al.* (2013) used a scenario-based simulation analysis for project planning and decision support for a tunnelling construction project.

Lu *et al.* (2008) optimized the project schedule using a simplified simulation-based scheduling system. The system combined a discrete event simulation approach (SDESA) and particle swarm optimizer (PSO). It formulates resources scenarios and finds the shortest project duration. Zahraee *et al.* (2013) used discrete event simulation to model a concrete pouring process and identify the optimum resources. Similarly, Hassan and Gruber (2008) used discrete event simulation to model concrete paving operations. The model was used to study the impacts of the resources on the flow of operation and the construction process's cost-effectiveness. Al-Alawi, Bouferguene, and Mohamed (2018) applied distributed simulation with HLA to integrate weather effects in simulating earthmoving operations. Riga, *et al.* (2020) used mixed integer programming to optimize the tower crane and storage areas on construction sites. Yassin *et al.* (2020) used agent-based modelling to optimize the workflow of robotic steel and concrete 3D printers.

The selection of the best simulation method or the optimization algorithm to be used depends on many factors, such as the type of project, data availability, total operation time, and costs. The simulation allows replicating a system's behaviour, and forecasted changes may exert if tested under different testing scenarios. In this study, a maintenance project in Al Khodh Oman is modelled to find the optimum number of resources required to finish. Different work plans are to be tested and a different number of resources configurations. The project poses sequential nature, and thus discrete-event simulation has been selected to build the simulation model. A Symphony simulation environment was adopted in this study. The study starts by introducing a brief overview of the simulation. The maintenance project overview and its process description were presented. The testing scenarios were explained, and their results were discussed.

2. SIMULATION OVERVIEW

The simulation system can be either monolithic or distributed. The monolithic simulation models contain components that are executed and terminated simultaneously. Meanwhile, the simulation component in the distributed simulation model has its start and end simulation time. It interacts with the other simulation components by sharing information to replicate a real system (AbouRizk, Hague, and Ekyalimpa, 2016). In addition, depending on its characteristics, a real system can be simulated using different simulation techniques such as continuous simulation, time-based discrete simulation, and discrete event simulation. The difference between the discrete event simulation and the other two techniques is that the model's state is affected/changed by the state's change. Meanwhile, the continuous and time-based discrete simulation state of the model depends on the progress of time (Brito and Botrter, 2011).

Different simulation environments have been introduced and used in research; some are listed as follow:

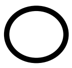
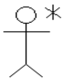
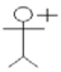
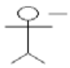
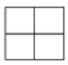
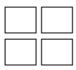
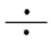
- ABC (Beaumont *et al.*, 2002)
- Symphony (AbouRizk and Hajjar, 1998)
- SLAM (Pritsker and O'Reilly, 1997)
- STROBOSCOPE (Martinez, 1996)
- Micro CYCLONE (Halpin, 1977)

Symphony is a simulation tool developed by AbouRizk and Hajjar (1998). It has built-in simulation elements, see Table 1, used to construct the operation flow of events. Furthermore, it allows system development to introduce simulation templates. A simulation model in Simphony starts with identifying and abstracting the case study and its overall process. Then the sequences diagram is plotted, and the time parameters for each event's duration are collected from the real operation. One of the main challenges in developing a reliable simulation model is collecting real-time data of the modelled process. However, most companies keep records of durations, productivity rate, and other information, which reduces the time required for model building. If no data exists, the studied problem shall be surveyed, and data recording tools such as cameras can collect the necessary data.

3. MAINTENANCE PROJECT OVERVIEW

The maintenance project scope of work is to change all the tiles, waterproof, and heat insulation for a villa located in a residential compound in Al Khodh city, Sultanate of Oman. The selected case study is situated within a residential compound with eight typical occupied villas, as shown in Fig. 1.

Table 1. Symphony simulation elements names and description.

Element	Name	Description
	"Create"	A "Create" element is responsible for creating entities and introducing them into the model
	"Resource"	A Resource element is responsible for defining a shared resource.
	"Preempt"	The Preempt element force capture the servers of a resource to an entity
	"Capture"	The Capture element is responsible for granting the exclusive use of one or more servers of a Resource to an entity
	"Release"	The Release element allows an entity to return servers it has previously captured to the pool of available servers.
	"File"	A File element is responsible for defining a queue in which entities wait for a shared resource.
	"Task	A Task element is responsible for modelling an activity. It achieves this by holding the entity for a while, as specified in its duration property"
	"Batch"	A Batch element aggregate n number of entities and release them as one entity
	"Unlatch"	The Unbatch element breaks down the entity to its original number of entities.
	"Generate"	A Generate element creates one or more clones of a passing entity.
	"Consolidate"	A Consolidate element blocks an entity arriving via the upper branch until one or more entities arrive via the lower branch.
	"Counter"	A Counter element is used to record important milestones in the lifecycle of an entity"

The project maintenance operation is conducted on all three floors of the project (ground floor, first floor, and roof floor). The complexity associated with this project is related to the operational constraints set by the client. The residential complex is fully occupied except for the studied villa. Time constraints such as the number of working hours and the start and end time of the workday have been set by the client. Due to limitations at the construction site, construction was allowed only during the daytime for eight hours. The project shall also be fully covered with a green mesh to protect the surrounding from dust pollution. The project's working clearance was set to be one meter from all sides except for the backside of the villa, which was set to be 2 meters to allow for construction waste storing before moving it outside of the residential compound, loading it on the hauling truck. The contractor decides to allocate a construction waste collection area on each floor, see Fig. 2 and fix a construction waste dumping tube extending from the roof floor to the ground floor. The contractor also decided to use part of the backside of the project to store some of the construction materials.

In addition to the constraints mentioned above, no trucks were allowed to enter the residential compound because of the client's request to provide minimum disturbance to the occupants and the limited manoeuvring area available on the project site. As a result, the contractor allocates another construction waste collection point for the trucks outside the project location. The construction waste transportation from the construction site to the landfill is subcontracted to a different contractor by the primary contractor. It is because of the limited accessibility of the truck to the site and to focus the contractor's resources in the maintenance operation only.

Figure 1. Top view of the residential compound (Google Earth-2021)

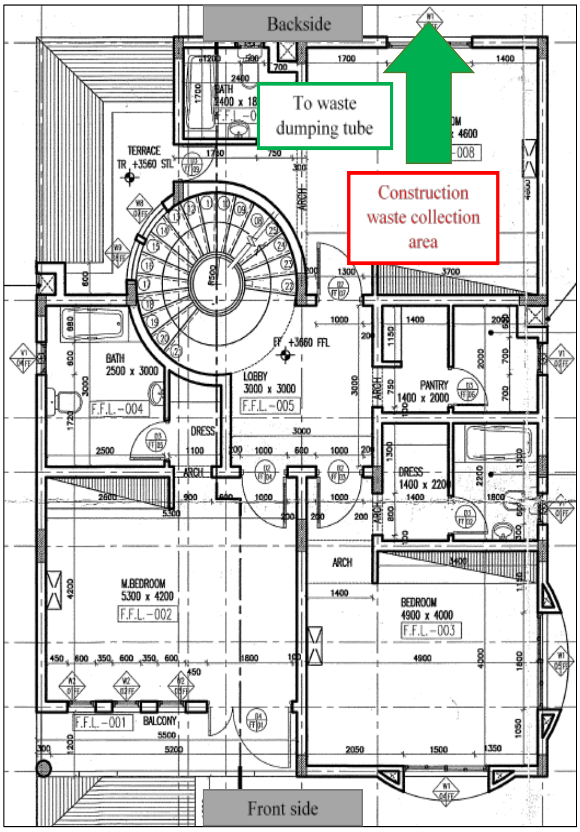


Figure 2. First-floor project layout

4. MAINTENANCE PROJECT PROCESS DESCRIPTION

The modelled maintenance operation is built in collaboration with the contractor's construction engineer. The maintenance operation is split into three sub-processes: roof floor process, first-floor process, and the second-floor process. This splitting process is mainly designed to allow the model to test the operation under different work start operations. For example, one floor at a time, two floors at a time, or three floors at a time scenarios. To achieve the flexibility to test the project operation under different work start times scenarios, a resource called "Floor Access" was created in the model.

The roof floor is the first to start the maintenance operation because the preempt element "Get Roof Floor Access", as shown in Fig. 3, is a higher priority than the same element in the first and ground floors sub-processes. Once the floor access is granted, the generated element "Generate 116 m^2" will generate the total area of the roof, 116 m^2. The 116 m^2 will undergo six significant activities, which are:

1. Breaking roof tiles
2. Transporting and dumping the construction waste through waste dump tube
3. Cleaning the roof to prepare for the waterproofing
4. Waterproofing
5. Waterproof testing
6. Heat boards and tiles insulation.

Three crews were added to the simulation model to perform the maintenance activities: the breaking team, waterproofing team, and tiles installation team. The selection of those three resources is based on the contractor request. It is worth mentioning that the local contractors classify their work according to the local construction trades in the market.

The definition of the breaking work role set by the contractor is that the breaking team shall stop breaking when four m^2 are completed and shall transport the construction waste to the dump pipe before starting the breaking work again. Once all tiles breaking is complete, the breaking team shall prepare the roof floor for waterproofing and clean and put concrete screeds on all edges. The waterproofing activity comes next and will acquire the waterproof crew to do the work. Once the waterproofing process is complete, the roof floor will be filled with water for 48 hours for testing purposes. Heat boards and tiles installation are combined in one task in the project and will be performed by the tiles installation team.

The first-floor maintenance operation is similar to the roof floors; however, the main difference is the resources' priority role. The model will test the operation under different resources and start work scenarios, and higher priorities are given to the upper floors. For example, if two-floor accesses are provided, the roof floor and first floor will start concurrently. If only one breaking team is available, it will be assigned to the roof floor because of its high priority. Although the project has rooms and bathrooms, which can be modelled individually, the construction engineer prefers to finish the task because of the limited workspace. The ground floor work is no different from the previous floors. However, the main difference is that no waterproofing is required, but concrete screeds on all ground floor areas will be added before the start of tiles works.

Table 2 shows all simulation elements' initial properties, such as individual task's duration and the number of crews in each element. The construction engineers specify the time of each task extracted from the historical database. A uniform distribution function for all activities durations was implemented. It is noteworthy that the contractor measures and records the productivity of the resources in a daily manner. However, this study is converted to an hourly rate by dividing the daily output by eight working hours. In addition, the waterproof installation and testing are considered constant because of the project's small scale, and their values are one day and two days, respectively.

5. DISCUSSION OF RESULTS

The maintenance project was tested under different testing scenarios. In the first scenario, the contractor has only one-floor access. The contractor shall perform the maintenance activities sequentially, starting from the roof and ending at the ground.

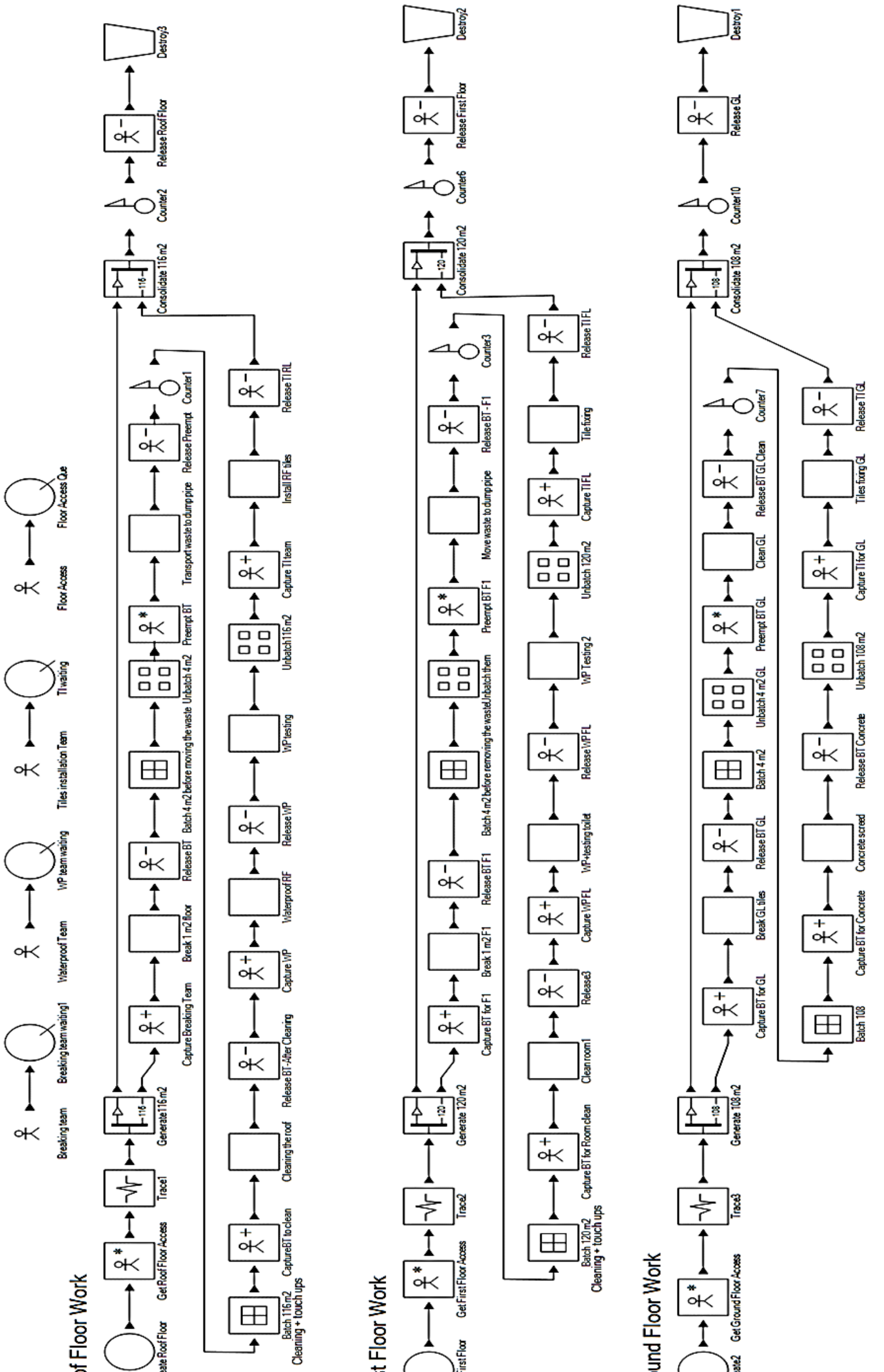


Figure 3. Maintenance project simulation model using Simphony.

Table. 2. Simulation processes and their initial parameters

Floor	Process	Time (min)
Roof floor	Breaking 1 m^2 of roof tiles	Uniform (19.5, 24)
	Transporting every 4 m^2 broken roof tiles to dump pipe	4
	Cleaning the roof	480 min (one day work)
	Waterproofing the roof	480 min (one day work)
	Testing the waterproof of the roof	2880 min (left for six days)
	Installation of roof tiles	Uniform (19.5, 24)
First floor	Breaking 1 m^2 of roof tiles	Uniform (12,16)
	Transporting every 4 m^2 broken roof tiles to dump pipe	4
	Clean all rooms	480 min (one day work)
	Waterproofing wet areas	1440 min
	Testing the waterproof of the roof	2880 min (left for six days)
	Installation of first-floor tiles	Uniform (30,40)
Ground floor	Breaking 1 m^2 of ground floor tiles	Uniform (12,16)
	Cleaning every 4 m^2	4
	Clean all floor	480 min (one day work)
	Concrete screed	480 min (one day work)
	Installation of ground floor tiles	Uniform (30,40)

Furthermore, a different number of resources were applied in this scenario to examine their sensitivity correlation with the project duration. For example, the tiles breaking team number of resources were increased by one resource in each simulation run, and the total project duration was recorded. Similarly, the total project duration was recorded when the same steps were repeated in the waterproofing and tiles installation teams.

In the second scenario, two roof accesses were granted to the contractor, which means that the contractor can work on two floors simultaneously conditioned by the availability of resources. Similarly, each type's number was increased by one, and the total project duration was recorded. The third testing scenario is similar to the second scenario. The main difference is that the third scenario allows the contractor to work on all floors simultaneously and is conditioned by resources' availability. Also, the priority of utilizing the resources is given in the following sequence: the roof floor has the highest priority, the first floor is the second, and the ground is placed last.

Figure 4 shows the maintenance total project duration based on one-floor access and a different number of resources. The total project duration has demonstrated a sensitivity to an increase in the number of resources except for the waterproofing team. This might be due to the fact that this team is called for a specific job task during the operation, and its work duration is generally constant. The original project duration was 58 days, given only one team is used for each process. However, it is reduced to 46 days if the breaking team number is increased to 6, and no more reduction in the duration can be achieved further. If the tiles installation team is expanded to seven, the project duration can be reduced to 39 days with no extra reduction if more tiles installation teams are employed.

Figure 5 shows the simulation model results when tested under two-floor accesses and a different number of resources. The original project duration was found in this case to be equal to 39 days. This means that the freedom to move from one floor to another has drastically improved the total project duration. Similar to the first testing scenario's findings, the increase in the waterproofing team number does not affect the project duration. The project duration can be reduced to 33 days if six tiles breaking teams are employed and can be reduced to 24 days if eight tiles installation teams are utilized. It is worth mentioning that the model is tested by fixing the number of resources of two teams and changing one team at a time.

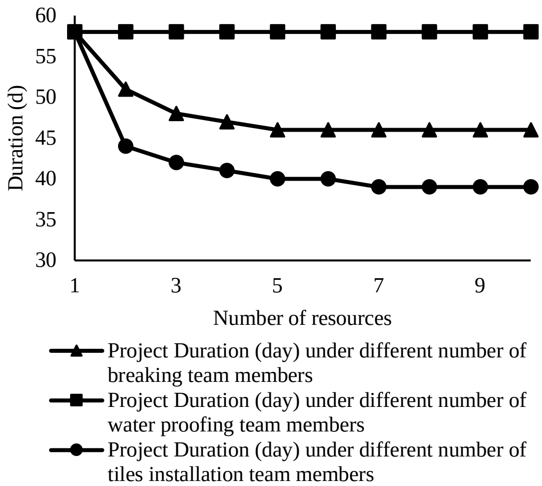


Figure 4. Project duration based on one-floor access and under different number of resources scenarios

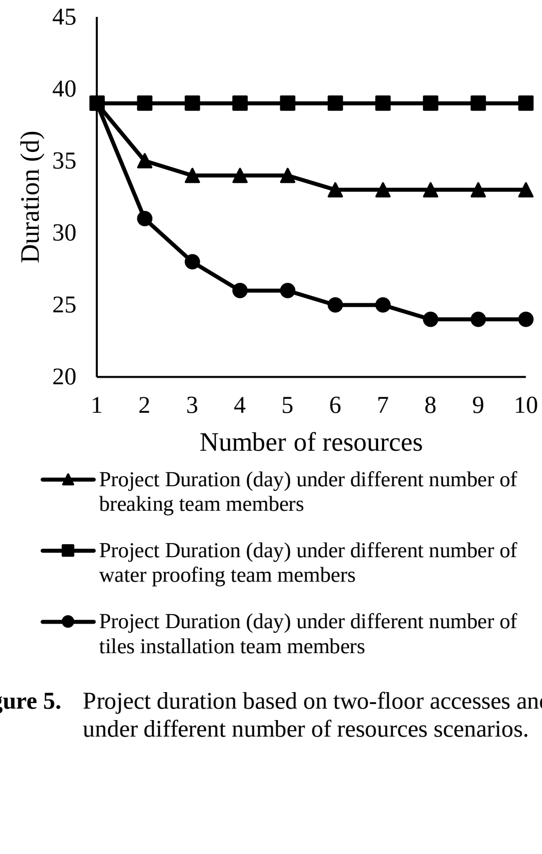


Figure 5. Project duration based on two-floor accesses and under different number of resources scenarios.

Figure 6 shows the third testing scenario results, which include three floors accesses. The original project duration in this scenario is 39 days. The project duration can be reduced to 11 days if nine breaking teams are employed and 19 days if seven tiles installation teams are utilized. Similar to the first two testing scenarios, no effect on the total project duration is reported despite more waterproofing teams being employed in the project. In addition to analyzing the project duration under different floor accesses and a different number of team numbers, the direct labour cost was also analyzed. The analysis investigated the direct labour cost's sensitivity under different floor accesses and different team numbers. The rate for each team is given by the contractor and listed in Table 3.

Figure 7 shows the total labour direct cost is given one-floor access and a different number of teams. The original total labour cost was OMR 1987, with a total project duration equal to 58 days. The minimum labour direct cost under a different number of breaking teams was OMR 1986. It was achieved by utilizing six breaking teams and resulted in a total project duration of 46 days. Using two tiles installation teams and one-floor access further reduced the direct labour cost to OMR 1864 and the project duration to 44 days.

Based on the above findings, the contractor recommended the following to achieve the lowest total direct cost given the construction works constraints defined by the client:

- One-floor access optimum: use two tiles, installation teams.
- Two floors access: use three tiles installation accesses.
- Three floors access: use seven tiles, installation teams.

Figure 8 shows the direct labour cost given two-floor access and under a different number of breaking and tiles installation teams. Like the previous testing scenario, employing six breaking teams will provide the minimum cost, OMR 1982, and allow the project to finish in 33 days. However, the project duration can be further reduced to 28 days with the exact cost if three tiles installation teams are utilized.

Figure 9 shows the total labour direct cost given three-floor accesses and under different teams numbers. The minimum labour cost can be reduced to OMR 847 from OMR 1991 if ten breaking teams are utilized, and it will allow the project to finish in 19 days. On the other hand, assigning seven tiles installation teams will result in a labour direct cost equal to OMR 1631 and allow the project to finish in 19 days.

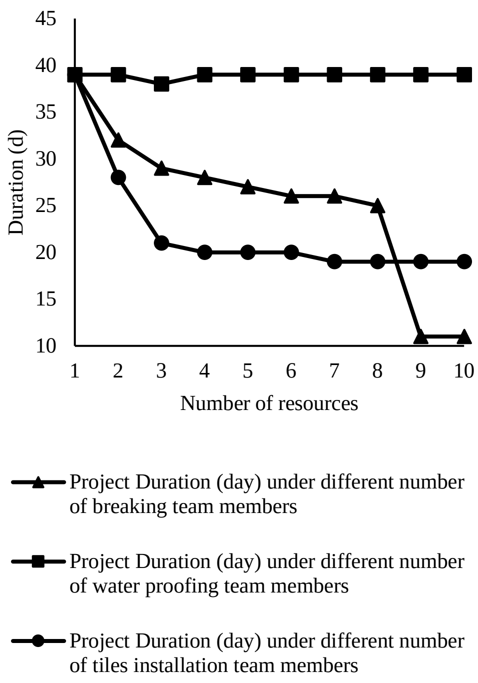


Figure 6. Project duration based on three-floor accesses and under different number of resources scenarios

Table. 3. Maintenance teams rates.

Maintenance activity	Price rate (OMR/h)
Mosaic tiles breaking (roof tiles)	5
Tiles breaking	5
Mosaic tiles installation (roof tiles)	3.375
Tiles installation	4.375
Waterproof operation	12

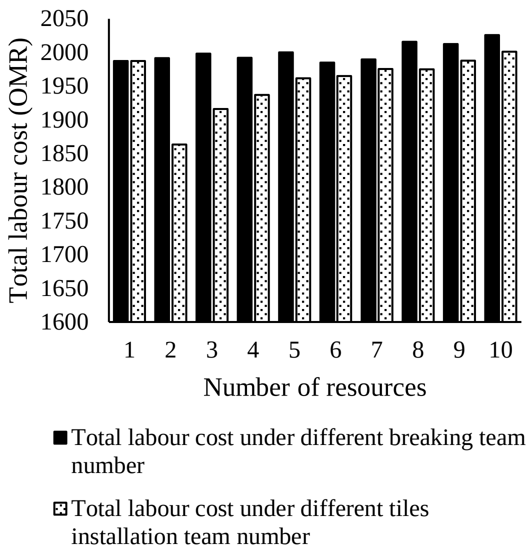


Figure 7. Total labour cost under different number of resources given one-floor access.

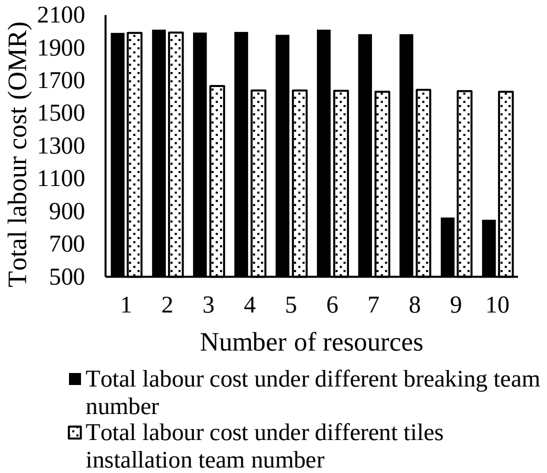


Figure 8. Total labour cost under different number of resources given two-floor accesses.

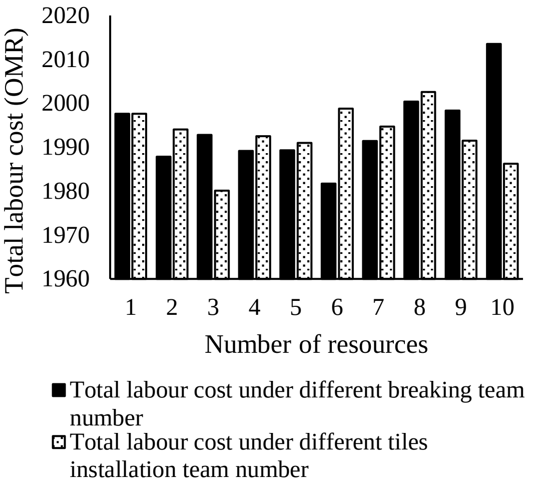


Figure 9. Total labour cost under different number of resources given three-floor accesses.

6. CONCLUSION

A maintenance project located in Al Khod was modelled using discrete event simulation. The model was built using the Simphony simulation environment. The simulation model was built using input given by the construction engineer of the maintenance project. The project was tested under different resource configurations, including floor accesses, other tiles breaking and tiles installation teams, and a different number of waterproofing teams. The total project duration was 58 days, given one resource in each resources category. It was found that the project duration was sensitive to the tiles breaking and tiles installation teams. The project duration can be reduced to 24 days in case of eight tiles installation teams, and two floors access are available to the contractor. Employing nine tiles breaking teams and allowing the contractor to work on all floors simultaneously can further reduce the total project duration. The total labour direct cost was also analyzed to select the optimum project duration. The analysis that using two tiles installation teams and given one-floor access will produce the optimum cost. Three tiles installation teams are the best selection for two-floor accesses, and seven tiles installation teams' selection is best for three floors. The project considered direct labour cost; however, the indirect cost may also influence the sensitivity analysis. Also, the time and cost analyses were performed independently from each other. Therefore, the future direction for the project is to perform a time-cost tradeoff analysis.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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