Iranian Journal of Operations Research
Vol. 12, No. 1, 2021, pp. 49-63

Delay scheduling based on discrete-event simulation for construction projects

M. Abolghasemian[1,*], A. Pourghader Chobar[2], M. AliBakhshi[3], A. Fakhr[4], S. Moradi Pirbalouti[5]

Following the increasing growth of urbanization in recent decades in Iran, housing has become one of the most critical issues in the country. In this regard, mass production of housing has received more attention, and residential complexes can be considered a physical manifestation of the idea of mass housing in cities. Operational efficiency in residential construction production systems is evaluated based on average house completion time, the number of houses under construction, and processing time of activities. However, these systems are prone to non-uniformity problems and suspensions resulting from different variables, such as adverse weather conditions, workplace accidents, fluctuations in house demand, and rework. The purpose of this research is to show the effect of reprocessing on the manufacturing process. In this study, the rework parameter and the variables of frequency, duration, and time of call-back have been considered. Also, the effects of these parameters on tangible performance criteria have been investigated. In this regard, we apply the combined approach of discrete-event simulation and computational modeling; then, we compare the results. Measurements show that the systems fragmented by repeated and short repetitions while referring to early are in optimal performance.

***Keywords**: Discrete-event Simulation, Computational Modeling, Rework, Call-back duration, Rework frequency and time*

Manuscript was received on 10/12/2021, revised on 11/14/2021 and accepted for publication on 12/26/2021.

Introduction

The success of a project depends on many factors. In the meantime, the quality of the project schedule and control of the project phases is very important. In project management, scheduling is one of the most significant factors because it determines the time of completion of the project. In addition, the credibility of project managers is closely linked to the schedule because the deadline must be estimated. If the project is not completed on time, project costs will increase, and profit margins will decrease [17]. For this purpose, Hosseinabadi and Tirkolaee [26], propose a new local search algorithm for task scheduling in multi-agent system. An acceptable approach to project planning and control is to use network-based tools such as the critical path method and the project

[*] Corresponding Author.
[1] Faculty of engineering, Industrial engineering department, Islamic Azad University, Branch of Lahijan, Lahijan, Iran , m.abolghasemian.bt@gmail.com.
[2] Department of Industrial Engineering, Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran , apourghader@gmail.com.
[3] Department of Industrial Engineering, Tarbiat Modares University, Tehran, Iran , Mehdi.alibakhshi@modares.ac.ir.
[4] Master graduate Executive Management, Islamic Azad University, Branch of Sanandaj, Kordestan, Iran, awrinfakhr@gmail.com.
[5] School of industrial engineering, College of engineering, University of Tehran, Tehran, Iran , Samaneh_moradi@ut.ac.ir

evaluation and review. The critical path method has a significant weakness. In this method, before starting the project, the duration and start time of activities are deterministic. If the scheduling program is more realistic based on the time, its effect will be evident over the project. Also, evaluating and reviewing projects is associated with network events integration results and cannot model the correlation between project activities [13]. Recently, Golpîra and Tirkolaee [27], due to the special importance of management in construction projects, studied an overview of the construction management concept. In traditional project planning, the critical path method is used as the primary tool. However, in the management of interrelated construction processes, the capacity and capability of this method are questionable [19]. Residential construction operations involve interconnected processes, so contractors regularly release their resources and use them in the following construction. Under such situations, the weakness of traditional project management tools such as the critical path method, earned-value analysis, and cost-estimating is entirely apparent. To address these issues, a global production planning in construction, inspired by the production section, focuses not only on individual activities but also on interconnected resources. This concept has emerged in construction management based on the theory of hierarchical construction operations. Production management uses discrete-event simulation for modeling and planning [3]. By using a discrete-event simulation model, interruptions in the workflow can be explored [2]. In construction operations, reprocessing disrupts the construction process in several ways. Supervisors inspect defects in contractors' performance, and the contractor is called upon to correct the defect. Reprocessing is usually done between two manufacturing processes. However, it is often prioritized and considered an activity that must be done immediately [18].

According above mentioned, in this research the rework factor in the presence of three variables, named length of interruptions caused by rework, rework frequency, and timeframe of call-backs for rework, have been considered. Then, to show the effect of reworking on the construction process, a hybrid approach of discrete-event simulation and computational modeling has been used. Computational modeling is performed separately for process contractors, and then the construction steps of multi-story residential houses are modeled using discrete-event simulation tools. The building-housing sector has been chosen as the case study of this research because mass builders usually systematically record data of construction. Important questions of the paper are as follows:

Q1: How can the length of interruptions caused by rework, the frequency of rework and timeframe of call-backs for rework be measured for construction projects?

Q2: How can scheduling rework on performance metrics be considered?

Main objective of the paper is as follows:

O1: developed a hybrid approach using discrete-event simulation and computationally modelling for showing rework effects.

This article is organized as indicated: In Section 2, a theoretical background and review of the relevant literature are provided. In Section 3, the research method is presented. In Section 4, the application of the proposed method for the case study is shown. Finally, In Section 5, the conclusion and future study are presented.

2. Theoretical background

2.1. Production system of residential buildings

Construction environments are dynamic, and construction processes are usually modeled into interconnected precedents and continuations. The workflow is hand-in-hand between different contractors, and construction supervisors are responsible for managing the flow. At the end of each process, the contractor will release his resources and use them again in the following work. The project goes on as usual when each process starts and finishes on schedule. According to the schedule, there are two main preconditions for starting a process: 1) timely completion of previous processes and 2) providing high-quality work without the need for a call-back [2]. For example, the building skeleton contractor relies on the quality of the building foundation as a prefabricated process. If there is a deficit in the foundation, the skeleton process does not begin, and the foundation contractor is called in to correct the defect.

2.2. Modeling interruptions from reprocessing

Production cycle time is usually considered one of the project's main performance criteria [7]. In practice, the frequency and duration of reprocessing, among other parameters, can affect the completion time of the house. The interval in which the rework call-back occurs, changes the duration and effects of the interruptions. In the following, three periods for requesting re-employment, as stated by Arshpour et al. [2], will be presented.

2.2.1. On-time call-back for rework before releasing resources

Reworking is usually requested when a specific manufacturing process has been completed. Supervisors of builders and construction supervisors carry out relevant inspections to identify any defects. If there is a defect, the contractor will be called to that process to correct the mistake. Once the necessary rework has been completed, the following contractor can begin work. Figure (1) shows a schematic interpretation of an on-time call-back. As can be seen from the figure, after the completion of process a, the inspectors noticed a defect in completing this process. Therefore, a rework call-back is made before releasing the resources. Reworking also delays the completion of process b. In other words, the reprocessing factor causes the process not to be completed on time and to be delayed.

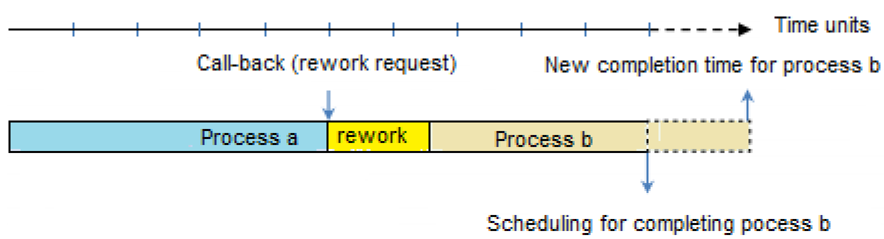


Figure 1. On-time call-back structure

2.2.2. Late call-back for rework after releasing resource

Sometimes defects are discovered after the manufacturing process has begun. So, a call-back for rework is made after the responsible contractor has left the site and released the resources. In this case, reprocessing is a priority for the responsible contractor. Figure (2) shows a schematic interpretation of the late call-back. As can be seen from the figure, the late call-back for reprocessing has split process b into separate parts. Therefore, it has the potential to cause long delays.

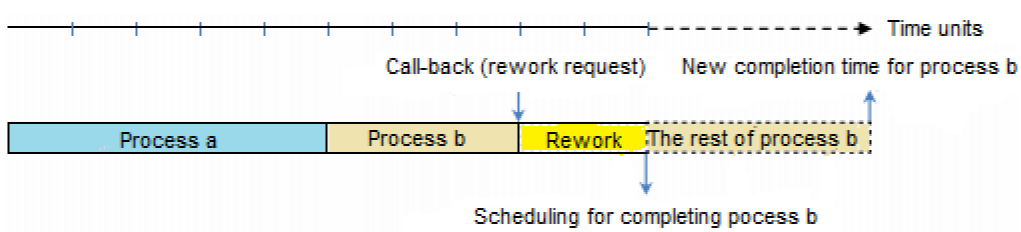


Figure 2. Late call-back structure

2.2.3. Early call-back for rework before completion

Close and public monitoring of construction can lead to a call-back for rework during a process. Under such situations, the reworking contractor can use the resources already used to correct the defect. Due to sufficient resources, the contractor can complete the rework using some labor while others have moved on to the subsequent work. Figure (3) shows a schematic interpretation of this call-back method.

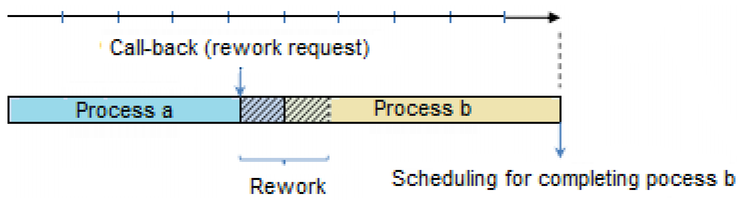


Figure 3. Call-back structure during processing

2.3. Related studies

This section examines the concept of rework and previous research that has focused on modeling of construction reworking.

In this study, field of construction management is considered from the point of view of reworking computational modelling and discrete-event simulation. Because, reworking in construction projects refers to unnecessary activities related to a process that has not been done correctly from the beginning [9]. The nature of reworking can be considered an activity that must be done due to non-compliance with the requirements by completing or correcting at least one more time [14]. So far, many researchers have investigated the causes of reworking in the field of construction. For example, Fayek et al. [4] presented a precise model to the Construction Owners Association of Alberta (COAA) to provide a standard method for measuring and classifying construction reworking. It consists of five broad areas of reworking, and each of these areas includes four possible causes. The five broad areas are: 1) human resource capability, 2) leadership and communications, 3) engineering and surveillance, 4) construction planning and scheduling, and 5) supply of materials and equipment. Excessive overtime is often used when the project is behind schedule. Fayek [4] stated that this excessive overtime causes fatigue to the workers and reduces productivity resulting in low quality of work and so reworking. Palaneeswarn et al. [16] identified the lack of managerial and supervisory skills as the main factor causing rework. They showed that the skills of supervisors and the workforce are fundamental requirements for every construction project. Huang et al. [6] showed that poor leadership and communication and ineffective decision-making lead to reworking. Low et al. [11] stated that the main factors of reworking are: poor leadership, strategic decisions made by senior managers or key decision-makers, processes, practices, and technologies for the project. Lopez et al. [10] cited a change in design as one of the most important factors in reworking and increasing costs. They identified the factors that cause design errors, such as inadequate design consultants, inefficient computer-aided automation, insufficient quality assurance, and poor design team integration. Josephson et al. [8] investigated the causes of rework in construction planning, scheduling, and the supply of materials and equipment. They showed that changes due to improper planning have a significant impact on the cost of reprocessing. They showed that non-compliance with specifications and untimely delivery of materials lead to reworking in the Swedish construction industry. They stated that prefabricated parts with the wrong dimensions and quantities are not uncommon in the construction industry and cause rework. They also pointed out that the unavailability of materials in the right place at the right time is a factor leading to rework. Simultaneous project implementation is another reason to rework. Mobini et al. [15] pointed out that concurrence in project implementation is one of the reasons for reworking. Also, they stated that since fast delivery to the market is becoming an important issue in the construction industry, pre-construction processes start before the previous ones finish entirely. So more market share is gained, but the cost of redevelopment is imposed on the construction project, leading to decreased profits and productivity.

Another factor in rework in the construction industry is customers. Huang et al. [7] identified reprocessing as an important challenge in construction projects. Their research focused on exploring customer-related rework in Singapore construction projects. To achieve this goal, they collected information on 381 construction projects from 51 construction companies. Out of them, 41 companies and 226 construction projects were involved in customer-related rework. Their results showed that changes in raw materials and project scope from the customer will be the main factors in increasing rework and costs. In other words, the intervention of customer tendency in the project leads to rework. Recently, relevant studies have predicted delays in construction projects using meta-heuristic methods to identify the factors influencing project delays. For example, Zhao et al. [20] predicted delays in prefabricated projects using neural networks to consider the effects of risk on these types of projects. Overall, they aim to provide a model of delay prediction for construction applications, providing key information for controlling the delay effects of risk-related factors in construction planning. Goodarzizad et al. [21] examined the prediction of construction efficiency using an artificial neural network and Grass Hopper optimization algorithm. Their research aims to measure the construction efficiency of concrete pouring operations related to commercial-office complex projects in Iran. They identified 19 important factors that significantly affected construction efficiency and classified them into five groups: personal, managerial, economic, technical, and environmental. Then, a hybrid model based on an artificial neural network (ANN) and Grass Hopper optimization algorithm (GOA) is proposed to determine the most influential factors and increase the accuracy of the proposed model. Ebrahimi et al. [22] presented a novel approach, using hybrid feature selection (HFS), machine learning (ML), and particle swarm optimization (PSO) to predict and optimize construction labor productivity (CLP). HFS selects factors that are most predictive of CLP to reduce the complexity of CLP data. Guido et al. [23] studied the evaluation of the effective factors in accidents using machine learning techniques. For this purpose, in this research work, two machine learning algorithms including the group method of data handling (GMDH)-type neural network and a combination of support vector machine (SVM) and the grasshopper optimization algorithm (GOA) are employed for evaluating the number of vehicles involved in the accident based on the seven factors affecting transport safety including the Daylight (DL), Weekday (W), Type of accident (TA), Location (L), Speed limit (SL), Average speed (AS) and Annual average daily traffic (AADT) of rural roads of Cosenza in southern Italy. Kazerooni et al. [24] proposed a model applied to determine CLP improvement strategies for concrete pouring activities in building projects. This study contributes to the body of knowledge by providing a systematic approach for selecting appropriate CLP improvement strategies based on interrelationships among the factors affecting CLP and the impact of such strategies on CLP.

According to above mentioned main contribution of the research are as follows:

- Effect of the length of interruptions caused by rework, the frequency of rework and timeframe of call-backs for rework were measured and analyzed for construction projects.
- A computationally approach was used to analytically model the performance of project construction.
- Then, a discrete-event simulation was developed to modelling and analyzing the process of the construction project to be solved analytically problem.

3. Research method

In this paper, we aim to investigate the effects of call-back intervals and the frequency and duration of rework on the performance of the whole mass-scale housing process. In this regard, the hybrid approach of computational modeling and discrete-event simulation has been used to accurately model the volume of residential buildings in Mehr housing complex in Rasht city. For this purpose, in the first stage, production data such as process time and available resources were collected from companies active in constructing Mehr Rasht residential complex. In this step, input analyzer tool of Arena 14.0 was applied to fit the probability distribution with the rework data. Because, the input analyzer automatically checks the data for all acceptable distributions and finds the best fit based on test statistics and minimum squared values. Then, in the second stage, computational modeling was employed. The Availability of Contractors (A), as the primary source in residential buildings, has been calculated using computational models developed by Little [9] and improved by Hopp and Spearman [5].

$$A = \frac{RI}{RI + DOR} \tag{1}$$

In equation (1), RI indicates the rework interval, and DOR indicates the duration of rework. Reworking leads to delayed and sequential processes. The well-known logic of work processes in the construction is first in first out (FIFO), and its parameters can be calculated as equations (2) to (5).

$$t_e = \frac{t}{A} \tag{2}$$

$$\mathrm{Q} = \mathrm{DOR} * \mathrm{TH} \tag{3}$$

$$QDR = \frac{1}{t} - TH = \frac{1}{t} - \frac{1}{t_e} \tag{4}$$

$$QDT = \frac{Q}{QDR} \tag{5}$$

In the above equations, t represents the process time, and t_e represents the effective process time. TH is Throughput of the Process, and QDR indicates the Queue Depletion Rate, and QDT is Queue Depletion time. In other words, to calculate the depletion time of a process queue, it is sufficient to form the ratio of the queue length of that process to its depletion rate. In the Third step, discrete-event simulation model is built, and construction processes of a residential building is presented in ARENA 14 software. Then, in the Fourth step, for assess accuracy of the simulation model 12 experiments were performed so that three call-back time frames with different durations and intervals were combined. The combined use of computational modeling and discrete-event simulation strengthens the research reported in this paper, and then the results are compared and adapted. In Figure (4) shown the research methodology framework.

The application of a combined methodology, in which both computational and simulation modeling are conducted, suggests a robust research approach in the field of construction engineering and management. Simulation has been recommended as a decision support tool (DSS) that is able to predict the physical behavior of the system in the long-term periods Abolghasemian et al [25]. In addition, comparison analysis both of simulation and computational models provides a measure of validation and accuracy of the built models.

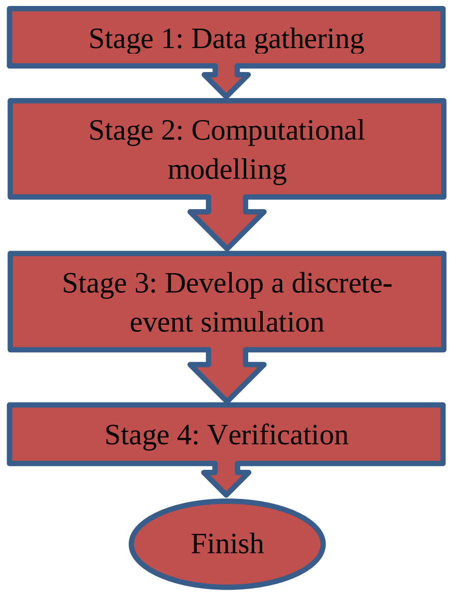


Figure 4. Framework of the research

4. Results

4.1. Description of the system

The residential buildings section was selected as the research area of this article, as this section usually records good documentation of construction data. Mehr residential complex in Rasht city is a case study of this article. Construction data was collected from a company active in the field of housing construction. The information received is related to a 5-storey building that includes 10 residential units with 100 to 120 square meters. Figure (5) presents the conceptual model of residential construction operations.

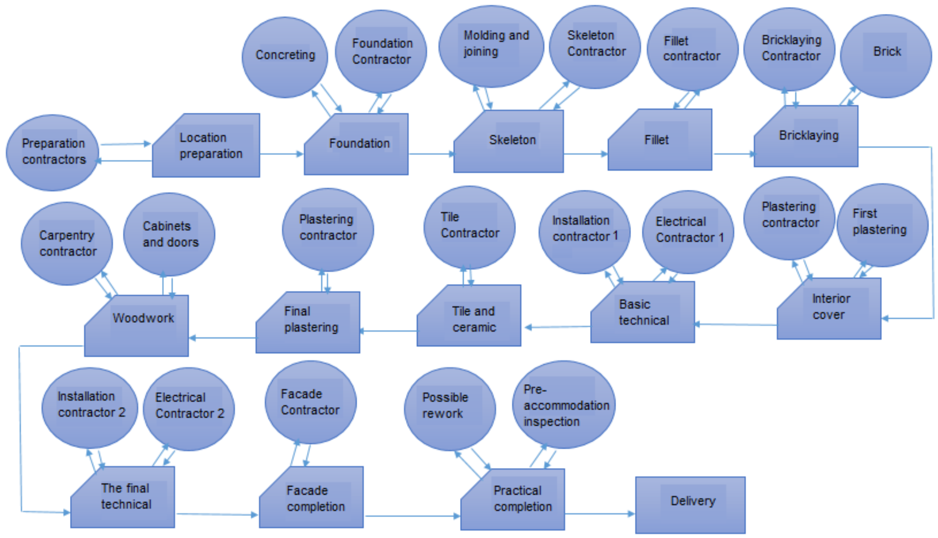


Figure 5. Conceptual model of residential house construction operations

As the conceptual model shows, construction processes are modeled in an interdependent network of precedents and continuations. Accurate modeling was done so that the resulting model reflected the complex interrelationships at construction sites and workflows within the interconnected network of contractors. Workflow varies between different contractors. If the construction project goes through its normal direction, each contractor will start their work and delivers it to the contractor of the following process on time, without any breaks. If there is a break in a process, the relevant contractor will be called to correct the defect. Since contractors do not act independently in construction operations, the activity of the previous job must be completed to continue the project path.

4.2. Development of the computational model

Firstly, for development of the computational model is necessary define different types of rework. In Table 1, frequency and duration in the different types of rework are shown that are likely to occur in a construction project are presented by Arshpour et al. [2].

Table 1. Different types of rework

Type of rework	Frequency of Rework	Duration time of rework
Very frequent - very short	Exponential,7	Exponential,1
Frequent –short	Exponential,14	Exponential,2
Infrequent-long	Exponential,21	Exponential,3
Very infrequent-very long	Exponential,28	Exponential,4

Very frequent-very short rework occurs on average once a week and disrupts the project for one day. Frequent-short rework occurs on average once every two weeks, interrupting the project for two weeks. Infrequent-long rework occurs on average once every three weeks and interrupts the construction project for three days, and finally, very infrequent-very long rework occurs on average once every four weeks and keeps the construction project suspended for four days. As mentioned earlier, reworking leads to delayed and sequential processes. The purpose of computational modeling is to calculate the production parameters in the presence of reworking with different intervals and periods. The building foundation process, which has a statistical distribution of 19.5 +

Erlang [0.792, 2], was analyzed using the principles of queue theory. Table (2) shows the results of computational modeling for the foundation process.

Table 2. Computational modeling results of the foundation process

Parameter	Very frequent-Very short	Frequent- Short	Infrequent-Long	Very infrequent-Very long
Duration of Rework	Exp,1	Exp,2	Exp,3	Exp,4
Availability level	87.5	87.5	87.5	87.5
Throughput of the Process	0.041	0.041	0.041	0.041
Queue length	0.041	0.082	0.123	0.164
Queue Depletion Rate	0.006	0.006	0.006	0.006
Queue Depletion Time	6.83	13.66	20.5	27.33

The computational modeling results of processes prone to reworking show the effect of rework frequency and duration on tangible performance criteria. Although project managers have accepted long breaks between rework and are reluctant to have the work process suspended frequently, the results show that periodic and short weekly rework is better in terms of performance metrics. Comparison of four different frequency and duration modes for the foundation process shows that the working lines are shorter in the presence of very frequent and very short rework. Therefore, to deplete these queues, less time is spent. In other words, by decreasing the frequency and increasing the reworking time, we will observe a significant increase in the values of queue length and queuing time for construction processes. These results confirm that by reducing the changes in the workflow within the interconnected network of contractors, it will be possible to reduce the duration of the construction project.

4.3. Developing discrete-event simulation model and designing experiments

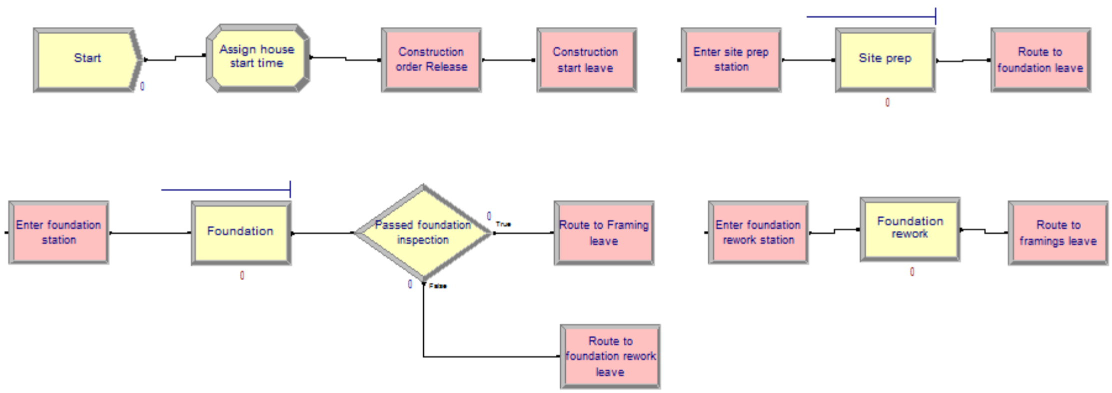
The conceptual model of residential construction operations was presented in Figure (4) and mentioned in the previous sections. The analytical solution of such a model is very complex. Tangible performance metrics such as; the number of completed buildings, the number of buildings under construction, and the average cycle time of the building cannot be calculated analytically; therefore, simulation modeling is required. The discrete-event simulation model of construction operations is designed in Arena 14 software. It is necessary to run the model for a long time to measure the steady-state of the system. Therefore, the construction of residential houses is simulated in 1500 working days, which includes four days of the warm-up period. An essential part of simulation studies is the validation of the simulation model because it allows the analyst to ensure the accurate design of the model. Validation is usually achieved by comparing the results obtained from the implementation of the simulation model with the actual results. Due to the lack of significant differences between these two series, the validity of the simulation model can be concluded. Figure (5) shows part of the software modeling window. According to this figure, after each stage of the construction process, an inspection is performed to obtain approval. If it is approved, the following contractor can start the work process; otherwise, the need for rework will be considered for the process. Simulation experiments are designed to analyze the "what-if" questions so that each scenario has different levels of workflow variability. 12 experiments are designed by combining three call-back time frames and four items for rework frequency and duration. Table (3) shows the simulation results in the form of 12 experiments. The simulation results show that the time frame of the call-back has a significant effect on the criteria. This means that an early call-back for rework significantly increases the number of completed buildings. At the same time, it reduces the completion time and the number of houses under construction. Optimal form occurs when rework is a very frequent-very short type and referred to early. Experiment 9 shows that the number of completed units is maximized, and the number of units under construction and completion time is minimized. On the other hand, the worst-case scenario occurs when rework is a very infrequent-very long type and is referred to late. Experiment 8, in which the number of completed units is minimized and the number of units under construction and completion time reach their maximum values.

Table 3. Discrete-event simulation results

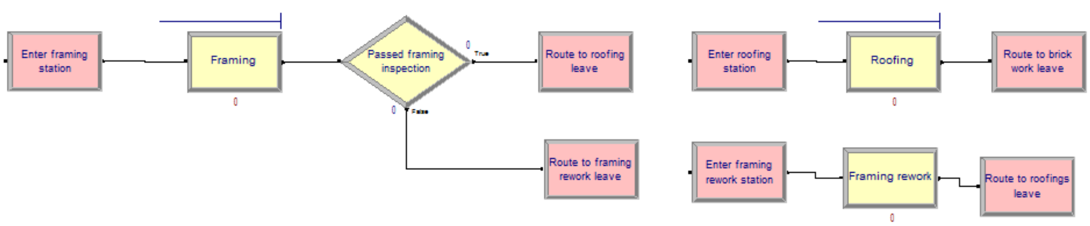
Experiment No.	Rework call-back framework	Rework frequency	Rework duration	The number of completed units	The number of units under construction	Completion time
1	On- time	Very frequent	Very short	49	33	418
2	On- time	frequent	Short	44	36	438
3	On- time	infrequent	Long	42	38	451
4	On- time	Very infrequent	Very long	40	40	471
5	late- time	Very frequent	Very short	39	37	441
6	late- time	frequent	Short	35	39	462
7	late- time	infrequent	Long	32	42	479
8	late- time	Very infrequent	Very long	29	44	498
9	early- time	Very frequent	Very short	63	27	376
10	early- time	frequent	Short	60	29	379
11	early- time	infrequent	Long	55	31	411
12	early- time	Very infrequent	Very long	53	34	425

4.4. Comparing the results of the computational model and discrete-event simulation model

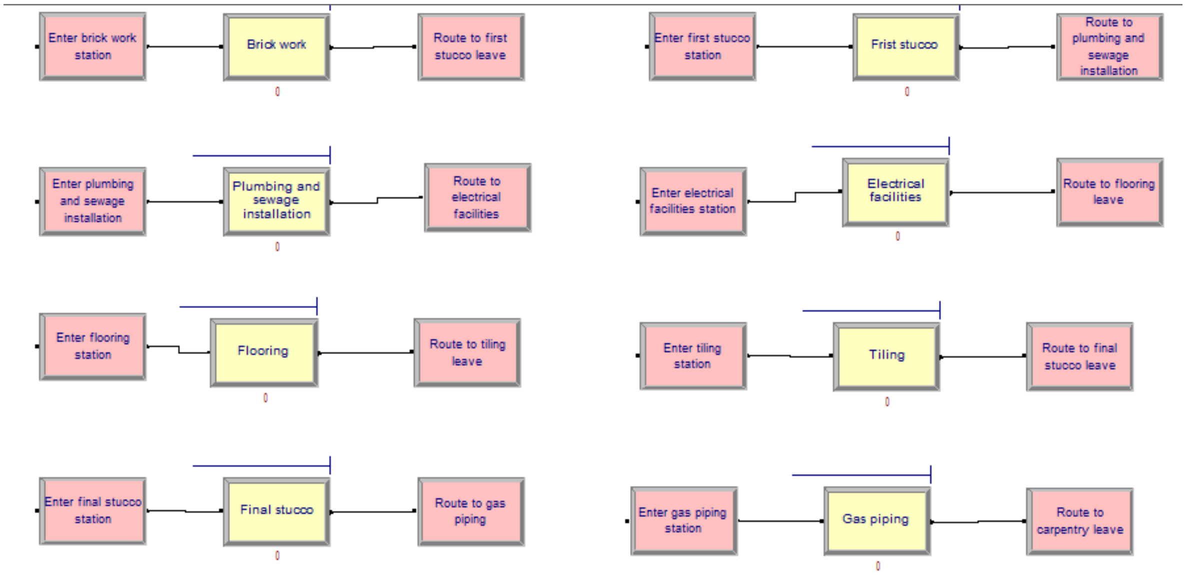
As stated in the computational modeling results, although project managers often prefer longer intervals between their processes, the number of queues is much less in the presence of very frequent-very short rework. Consequently, the depletion time is less in this type of queue. According to the 12-experiment discrete-event simulation model results, the number of completed buildings reaches its maximum when the rework is very frequent-very short under any call-back framework for rework (early, on-time, or late). In this case, the number of units under construction and completion time is minimized. It is clear that the results of the computational model and the discrete-event simulation model are equal and supportive of each other.



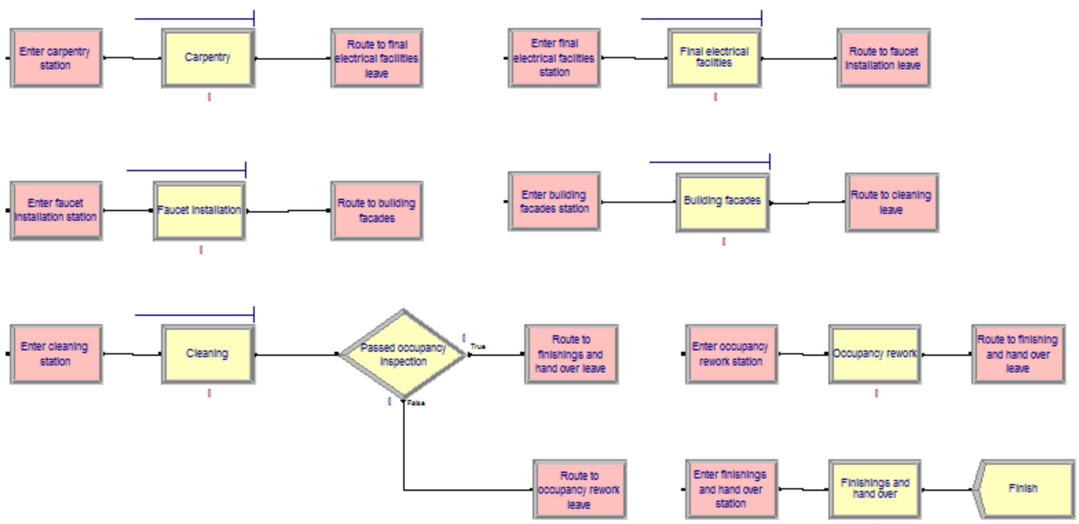
(a)



(b)



(c)



(d)

Figure 5. (a;b;c;d) Simulation model designed in ARENA 14.0 software

4.5. Managerial insights and practical implications

Previous works have demonstrated the negative impact of variability on performance metrics of construction projects. For this purpose, in this study quantitatively analyzed the impacts workflow variability on tangible performance metrics in several construction production scenarios. To this end, proposed a framework in four steps. In proposed framework computational and discrete-event simulation modeling are two basic element of the research methodology. The results obviously show that construction performance and productivity are very sensitive to the interval of activity starts, especially when workflow is subject to variability caused by factors such as rework. According to the results it is suggested that project managers avoid assigning excessive levels of work quantities to trade contractors when the workflow is subject to variability.

5. Conclusion

This study focused on residential construction prone to rework. The rework factor with three call-back variables of duration, frequency, and time framework was studied. Quantitative analysis of computational model and discrete-event simulation model showed that effective construction criteria are directly related to rework variables. Infrequent but long reworking has a more negative impact rather than frequent but short reworking. Compared to different time frameworks, the worst-case scenario occurs in late call-back because the contractor has moved its staff and resources to another location. The results of the computational model and the simulation model confirmed each other. They showed that the frequency and duration of rework along with the time framework for call-back are a significant combination of variables affecting the completion time and the number of completed units. Therefore they should be considered in construction scheduling. Main limitation of the research are: (1) due to the fact that the rework is done by the supervising engineers, therefore, in terms of the various number of engineers, pressure is applied to the owner. Also, (2) in many countries there are strict rules for the timing of construction projects, in which case the development of a general timeline framework can help amateur builders. Interesting topics to suggest future study for further work include as: consider more random variables in the problem and examine the rework factor in other areas of construction such as tunneling and road construction.

Acknowledgment

The authors would like to make special thanks to the two anonymous reviewers for their useful comments that helped us improve the manuscript.

References

[1] Akhvian, R. and Behzadan, A. H. (2011). Dynamic Data Driven Simulation of Ongoing Construction Process. Proc., Annual Conf. of the Canadian Society for Civil Engineering, QC, Canada.

[2] Arashpour, M., Wakefield, R., Blismas, N. and Lee, E. W. M.(2014).Analysis of disruptions caused by construction field rework on productivity in residental projects.140(2), 1-13.

[3] Bashford, H. H., Walsh, K. D. and Sawhney, A. (2003). Relationships between system loading and cycle time in a residental construction production system. Proc., *construction research congress. 1-8.*

[4] Fayek, A. R., Dissanayake, M. and Campero, O. (2003). Measuring and classifying construction field rework: A pilot study, Research report, Construction Owners Association of Alberta (COAA), The University of Alberta, Edmonton, Canada.

[5] Hopp, W. J. and Spearman, M. L. (2008), Factory physics, McGraw-Hill, New York.

[6] Hwang, B., Thomas, S., Hass, C. and Caldas, C. (2009). Measuring the impact of rework on construction cost performance. *Journal of Construction Engineering and Management.* 13(4). 187-198

[7] Hwang, B., Zhao, X. and Goh, K. (2014*). Investigating the client-related rework in building projects. The case of Singapore. International Jornal of Project Management.* 32(4). 698-708.

[8] Josephson, P.E., Larsson, B. and Li, H. (2002), Illustrative benchmarking rework and rework costs in Swedish construction industry, *ASCE Journal of Management in Engineering,* 18(2), 76-83

[9] Little, J. D. C. (1961). A proof for the queuing formula: *Oper.Res.,* 9(3), 383-387

[10] Lopez, R., Love, P.E.D., Edwards, D.J. and Davis, P.R. (2010), Design error classification, causation, and prevention in construction engineering, *ASCE Journal of Performance of Constructed Facilities*, 24(4), 399-408

[11] Love, P. E. D. (2002), Auditing the Indirect Consequences of Rework in Construction: A Case Based Approach, *Managerial Auditing Journal*, 17(3), 138-146

[12] Love, P.E.D., Edwards, D. J., Irani, Z. and Walker, D.H.T. (2009). Project pathogens: The anatomy of omission errors in construction and engineering projects, *Journal of IEEE Transactions on Engineering Management*, 56(3), 425-435

[13] Martinez, J. C. and Photios, G. I. (1997), State-based probabilistic scheduling using STROBOSCOPE'CPM Add On, proceedings, *construction congress*, 438-445.

[14] McDonald, R. (2013), Root Causes and Consequential Cost of Rework, XL Group Insurance North America Construction.(accessed 30 March 2014)

[15] Mobini, M. D. M., Rabbani, M., Amalnik, M. S., Razmi, J. and Rahimi-vahed, A. R. (2009), Using an enhanced scatter search algorithm for a resource-constrained project scheduling problem, 13(6), 597-610

[16] Palaneeswarn, E., Kumaraswamy, M., Ng, T. and Love, P. (2005). Measuring of rework in Hong Kong construction project, Proceedings of the Queensland University of Technology Research Week International Conference, Australia 04-08 julay 2005.

[17] Sawhney, A., Walsh, K. D., Bashford, H. H. and Palaniappan, S. (2009). Impact of inspected buffers on production parameters of construction process, *Journal of construction engineering and management*,319-329

[18] Suri, P.K., Bhushan, B. and Ashish, J. (2009). Time estimation for project management life cycle: A simulation approach, *international journal of computer science and network security, 9(5), 211-215*

[19] Tommelein, I., Riley, D., and Howell, G. (1999). Parade Game:Impact of work flow variability on trade performance, 304-310

[20] Zhao, Y., Chen, W., Arashpour, M., Yang, Z., Shao, C. and Li, C. (2021). Predicting delays in prefabricated projects: SD-BP neural network to define effects of risk disruption. Engineering, Construction and Architectural Management.

[21] Goodarzizad, P., Mohammadi Golafshani, E. and Arashpour, M. (2021). Predicting the construction labour productivity using artificial neural network and grasshopper optimisation algorithm. *International Journal of Construction Management*, 1-17.

[22] Ebrahimi, S., Fayek, A. R., & Sumati, V. (2021). Hybrid artificial intelligence HFS-RF-PSO model for construction labor productivity prediction and optimization. *Algorithms*, *14*(7), 214.

[23] Guido, G., Haghshenas, S. S., Haghshenas, S. S., Vitale, A., Astarita, V., Park, Y., & Geem, Z. W. (2021). Evaluation of Contributing Factors Affecting Number of Vehicles Involved in Crashes Using Machine Learning Techniques in Rural Roads of Cosenza, Italy.

[24] Kazerooni, M., Nguyen, P., & Fayek, A. R. (2021). Prioritizing Construction Labor Productivity Improvement Strategies Using Fuzzy Multi-Criteria Decision Making and Fuzzy Cognitive Maps. *Algorithms*, *14*(9), 254.

[25] Abolghasemian, M., Ghane Kanafi, A., & Daneshmandmehr, M. (2020). A Two-Phase Simulation-Based Optimization of Hauling System in Open-Pit Mine. *Iranian Journal of Management Studies*, *13*(4), 705-732.

[26] Hosseinabadi, A. A. R., & Tirkolaee, E. B. (2018). A gravitational emulation local search algorithm for task scheduling in multi-agent system. *International Journal of Applied Optimization Studies*, *1*(01), 11-24.

[27] Golpîra, H., & Tirkolaee, E. B. (2021). Optimization for Construction Supply Chain Management. In *Application of Mathematics and Optimization in Construction Project Management* (pp. 165-183). Springer, Cham.