BIM-Integrated Construction Operation Simulation for Reliable Production Management

SooWon Chang, soowonch@gmail.com
Ewha Womans University, Seoul, Korea

JeongWook Son*, jwson@ewha.ac.kr
Ewha Womans University, Seoul, Korea

WoonSeong Jeong, tamu.wsj@gmail.com
Ewha Womans University, Seoul, Korea

June-Seong Yi, jsyi@ewha.ac.kr
Ewha Womans University, Seoul, Korea

Abstract
As construction projects become larger and more complex, traditional construction planning based on historical data and heuristic adjustment can no longer incorporate all managerial details such as productivity dynamics. The fluctuation between plan and execution, by traditional planning method, brings cost overruns and duration extension on construction site. In this regard, to minimize these differences, this paper presents a BIM-integrated simulation framework that can predict productivity dynamics by considering factors affecting productivity at the operational level. We developed APIs for the framework 1) preparing a BIM model to produce input data for the simulation; 2) composing construction simulation in operational level; 3) obtaining productivity predicted by running BIM-integrated simulation. This framework was tested with a steel-structured model. The results show that we can expect significant improvement of predicting dynamic productivity. The reliable productivity can contribute to optimized resource allocation, schedule reliability increase, storage cost saving, and material loss reduction.

Keywords: Dynamic productivity, Computer Simulation, BIM

1 Introduction
As construction projects become larger and more complex, traditional construction planning and control practice can no longer produce a plan that incorporates all the project details such as design complexity, work difficulty, learning curve, and coordination process. Thus, on construction site, construction managers go through many problematic situations such as lack of materials, error of inputting resources, and wastes of resources. These problems of excessive or lack of materials usually happen because actual productivity are subject to be deviated from the original plan.

While predicting reliable productivity at operational level is important as many aspects such as minimizing uncertainties, accomplishing the expected efficiency, and decreasing waste of time, cost, and materials, it is difficult for construction managers to predict reliable productivity dynamics. First, construction projects have unique characteristics: construction projects differ in location, design, level of labor skill, and project team composition. The new setup and environment of the project adds more uncertainties to the planning process, so that planning based on historical data can no longer guarantee the expected performance. Second, a variety of operational and managerial factors influence on construction productivity. Since current planning practice does not consider all the operational and managerial details, managers' heuristic adjustment cannot incorporate all the details.

In this regard, this paper introduces our continuing research endeavor to develop a simulation framework that can predict reliable productivity dynamics by considering factors affecting on productivity at the operational level. To accomplish reliable prediction, Building Information Model

(BIM) is integrated with construction operation simulations. By using BIM, we could reflect projects' uniqueness to planning process. Also, through simulation, we could consider diverse factors synthetically and operate construction works repeatedly in a virtual space without risks. In integration of BIM and Simulation, simulations were fed data of the building elements, which was already generated in the BIM. The developed BIM-integrated simulation performed construction operations in a virtual world and generated forecasted productivity dynamics.

2 Lessons Learned

Until now, when construction managers establish a plan, they refer to historical data first. And then, they adjust somewhat by their own experiences. However, construction productivity changes dynamically every day. The fluctuation between a plan and execution brings cost overruns and duration extension on construction site, which is shown in Figure 1. If production is greater than the expected, resources such as labors and equipment will be wasted and materials will be scarce. Thus, this situation leads to waste money from inputting unused resources such as labors, equipment, and time. On the other hand, if production is lesser than the expected, it also leads to problematic situations on construction site; materials will be remained, managerial cost from unused materials will increase, and delay will happen. Therefore, to decrease cost overruns and delay extension, the reliable prediction of productivity is required in construction management field.

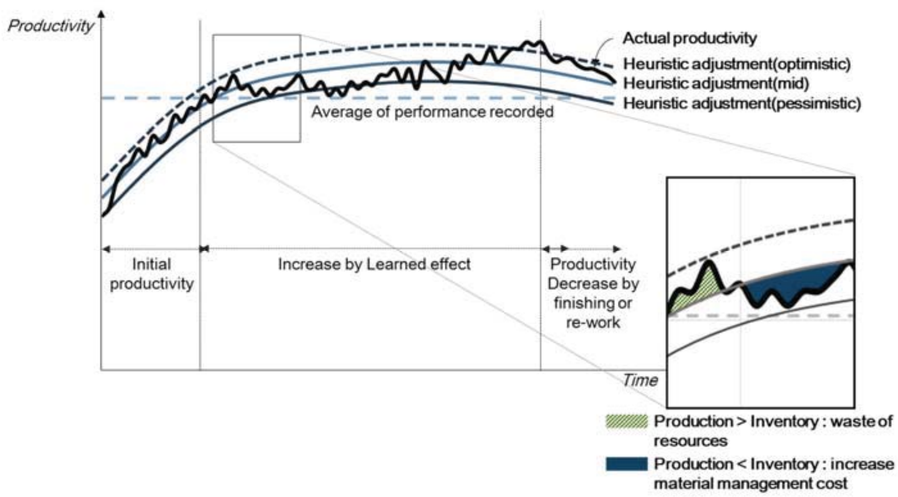

Figure 1 Impact of fluctuation between execution and forecast

2.1 Computer simulation in construction

Though computer simulation has been introduced in construction field to improve estimating, planning, and control (AbouRizk & Mohamed 2002), it has not been widely used in the industry due to low generality and difficulties of development. Also, since simulation factors are mostly quantified based on historical average value (Al-Jibouri et el 2004), simulation input values are still questionable whether those consider unique and capricious construction conditions. In order to supplement theses defects of simulation method, some research tried to integrate between simulation methods or integrate simulation with other database systems (Alvanchi et el 2011). In this respect, this research suggests new methodology making simulation development process convenient and realistic to promote the use of computer simulation for construction management.

2.2 Application of building information modeling

The rapid progress of BIM technology made building performance evaluation quicker and easier. Building performance analysis tools such as energy efficiency (Azhar & Brown 2009) and structural analysis extract required data from BIM and reuse them to produce outcomes. However, in construction management domain, BIM data are only used for simple purposes; for example, automated generation of schedules based on just material quantity-takeoff (Mikulakova et al 2010).

Although current usable range of BIM data is still limited, the usability needs to be extended because reusing BIM data can significantly reduce time and effort for reproduction of building data. It could be a breakthrough to improve efficiency and reliability of construction management and performance analysis.

2.3 Lean construction

The primary goal of lean production is to avoid waste of time, money, equipment, etc.; everything is focused on productivity improvement and cost reduction (Melles 1997). One of the most important instruments of lean production is Just-in-time (JIT) delivery. It reduces the stocks of materials through the concept that new subassemblies are made only immediately before they are actually needed (Melles 1997), so that the implementation of JIT needs reliable production (Melles 1997).

According to the Parade game theory in construction (Tommelein et al 1999), the more variability between supply and demand, the much more inventory buffers in lower providers' storage. High level of variability decreases the efficiency of the whole supply chain by adding waste of time and money from unnecessary inventory management. For minimizing the waste of the whole construction process, it is important to reliably predict productivity for end-demander. Reliable productivity dynamics prediction for end-demander contributes to decrease the difference between a plan and execution. In this regard, by achieving reliable productivity prediction on construction site, we aim to accomplish the expected level of efficiency of the whole supply chain and contribute to minimize waste of time, cost, and materials.

3 BIM-integrated simulation for reliable production prediction

3.1 BIM-integrated construction operation simulation framework

Authors have developed a simulation framework that can predict productivity dynamics by considering factors affecting on productivity at the operational level for reliable production management. This framework is provided in Figure 2. The simulation model was integrated with BIM: it extracts necessary input from a pre-built BIM model like geometry. And then, we could obtain output expected as work productivity as a result of running the simulation incorporating all operational and managerial details to estimate work productivity.

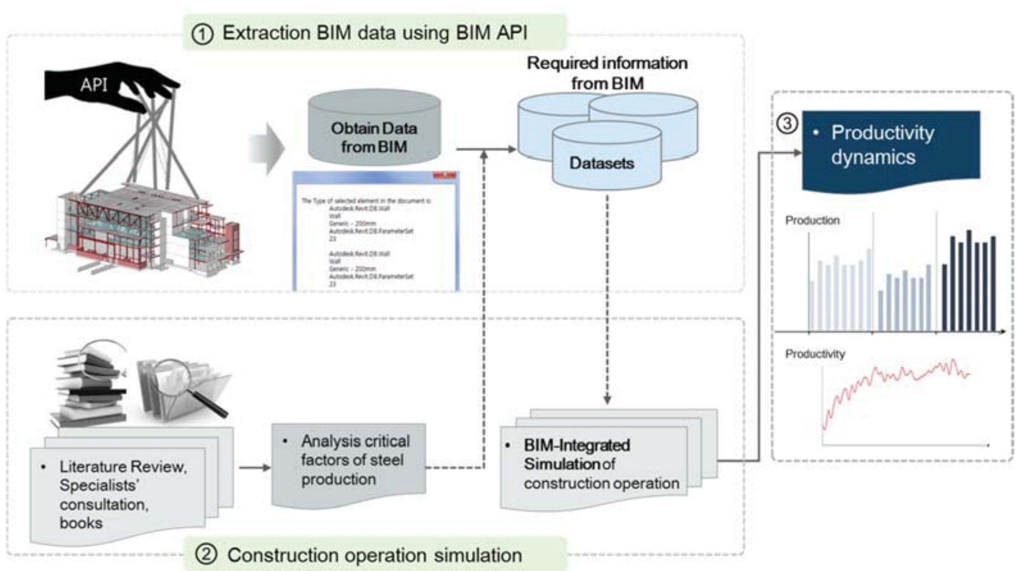

Figure 2 BIM-integrated simulation framework diagram

3.2 BIM2SIM approach

We developed commands to interchange data between the simulation and a BIM model. We used Autodesk Revit, which provides an Application Programming Interface (API) to utilize data. The

BIM2SIM approach is provided in Figure 3, and the following procedures are needed for extracting BIM data required:

- Preparing a pre-built BIM model
- Building a code which can extract data in BIM
- Constructing Dataset sorted for simulation
- Translating dataset into input data for utilizing simulation

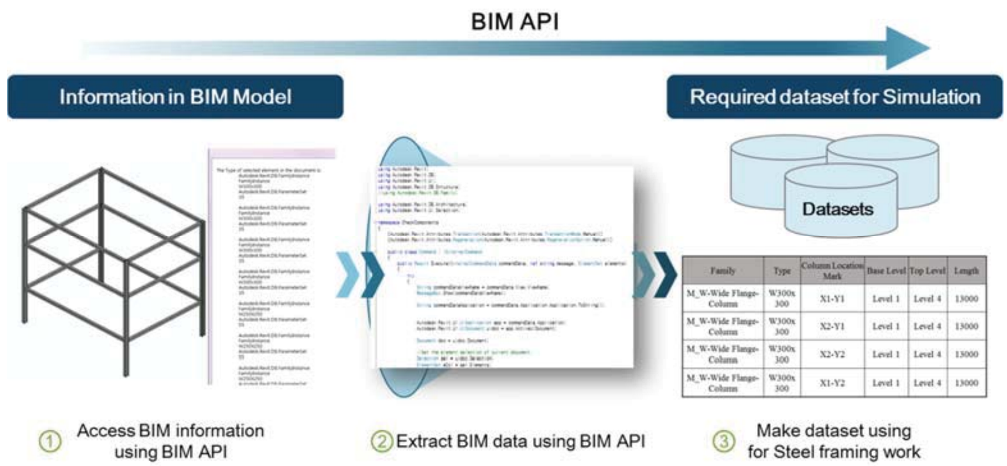

Figure 3 Command implementation using Autodesk Revit APIs

3.3 Construction operation simulation with BIM data

We developed construction operation simulations. Authors scrutinized construction processes thoroughly by reviewing literatures and interviewing experts to build reliable simulation. First, we drew a conceptual model as a blueprint to develop simulations. Then, factors affecting on work productivity were listed. Based on the collected information, we developed construction operation simulations using Anylogic software. The process is shown in Figure 4, and the following tasks are required for developing and conducting computer simulation:

- Organizing work procedures of construction operation
- Finding factors affecting on work productivity
- Developing a simulation
- Extracting data regarding a building from BIM
- Implementing computer simulations
- Run the computer simulations and collect results

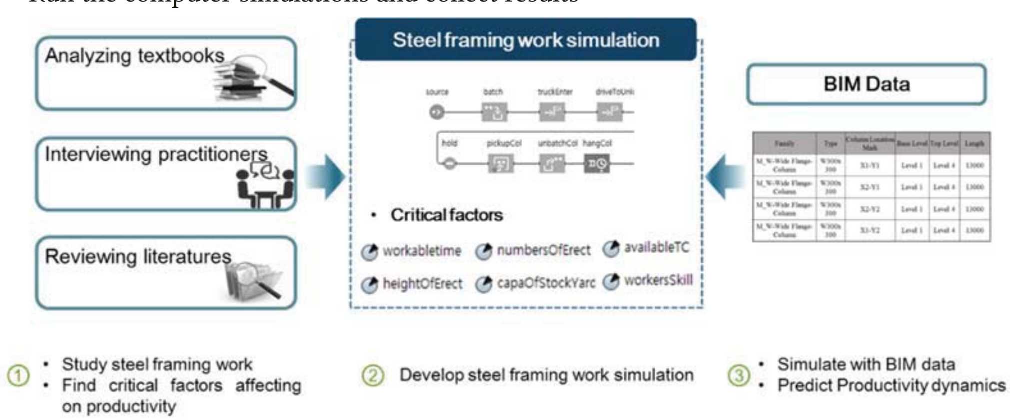

Figure 4 Simulation development process

4 Application to a steel erection case

The developed BIM-integrated simulation framework was applied to steel framing work. Steel framing work was chosen as a case because it is one of the most critical process which influences on the total project cost and time in South Korea. Also, steel work productivity can vary depending on work conditions. We built steel framing work simulation as Discrete Event Simulation approach because steel works are performed as a sequence of events in time. Tested model is provided in Figure 5. The model is quite simple, but we can find an applicability of the framework presented in this research. Plus, we will apply the framework to more complex model in the future.

Structural Column Schedule					
Family	Type	Column Location Mark	Base Level	Top Level	Length
Level 1					
M_W-Wide Flange-Column	W300x300	X1-Y1	Level 1	Level 4	13000
M_W-Wide Flange-Column	W300x300	X2-Y1	Level 1	Level 4	13000
M_W-Wide Flange-Column	W300x300	X2-Y2	Level 1	Level 4	13000
M_W-Wide Flange-Column	W300x300	X1-Y2	Level 1	Level 4	13000

Structural Framing Schedule				
Family	Type	Reference Level	Beam Location Mark	Length
Level 2				
M_W-Wide Flange	W250X250	Level 2	Y2-X1X2	12000
M_W-Wide Flange	W250X250	Level 2	X1-Y1Y2	9000
M_W-Wide Flange	W250X250	Level 2	Y1-X1X2	12000
M_W-Wide Flange	W250X250	Level 2	X2-Y1Y2	9000
Level 3				
M_W-Wide Flange	W250X250	Level 3	Y2-X1X2	12000
M_W-Wide Flange	W250X250	Level 3	X1-Y1Y2	9000
M_W-Wide Flange	W250X250	Level 3	Y1-X1X2	12000
M_W-Wide Flange	W250X250	Level 3	X2-Y1Y2	9000
Level 4				
M_W-Wide Flange	W250X250	Level 4	Y2-X1X2	12000
M_W-Wide Flange	W250X250	Level 4	X1-Y1Y2	9000
M_W-Wide Flange	W250X250	Level 4	Y1-X1X2	12000
M_W-Wide Flange	W250X250	Level 4	X2-Y1Y2	9000

Figure 5 Tested steel-structured model

4.1 Pre-processing a BIM model and producing input data

We created a steel-structured BIM model to demonstrate our framework. The BIM model has the required information for the construction simulation model including the number of columns and beams, the size, and type of each columns and beams. After creating the BIM model, the developed commands using BIM APIs. APIs enable engineers to obtain the required information from the BIM model. The commands translated the extracted data into input data for resource information in the simulation model. Figure 6 shows the required information retrieval process from the BIM model and the data translation between the BIM model and the simulation model.

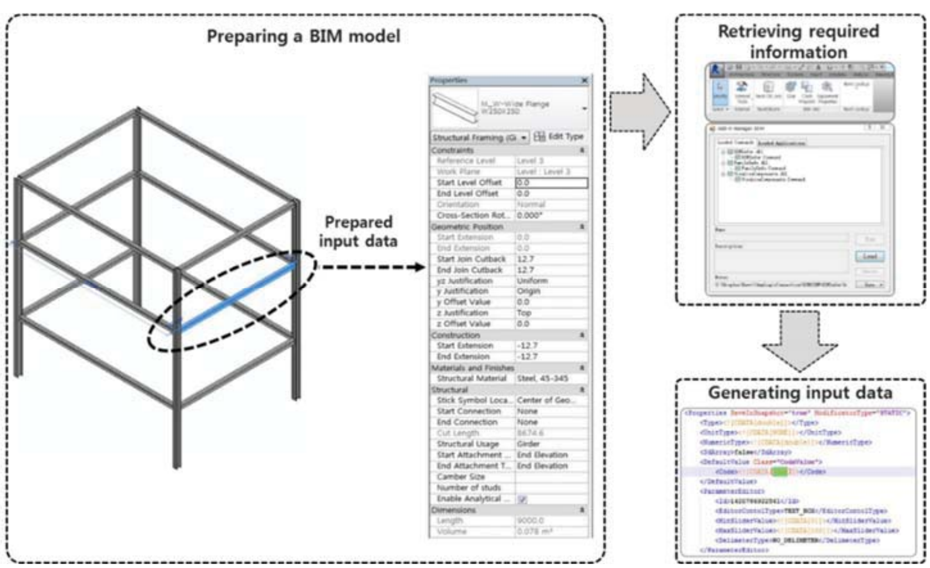

Figure 6 Data retrieval process from a BIM model and input data preparation process

4.2 Developing steel erection work simulation

By reviewing literatures and interviewing experts, we scrutinized steel framing work processes at operational level, and then we expressed these work processes as a drawing to develop simulation. Afterward, we composed simulation model using Anylogic software, which is shown in Figure 7. Additionally, we came to know that workable days, the number of materials, stockyard space, height of working, utilization of tower crane, and skill of workers are critical factors determining work productivity in steel framing work. In order to incorporate those factors in the simulation, we used schedule and parameters in Anylogic software, which is provided in Figure 7. In Table 1, specific simulation blocks and names are described.

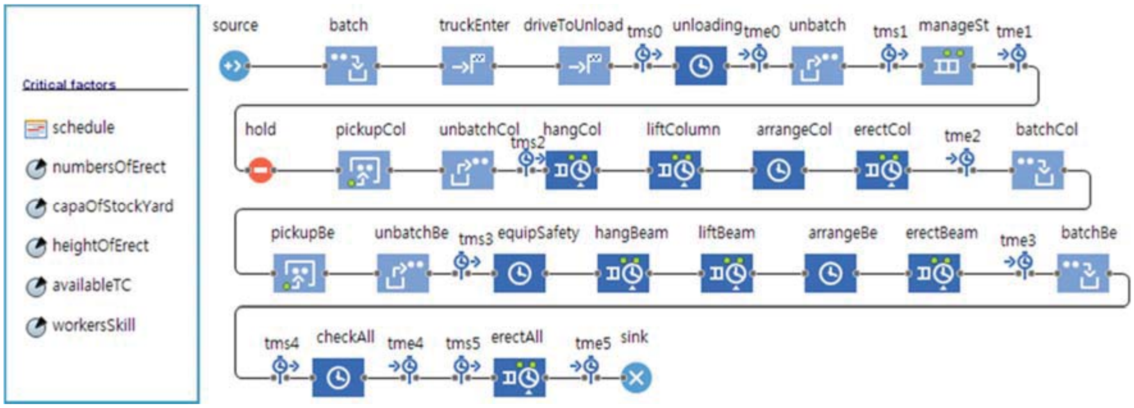

Figure 7 Steel framing work simulation model in Anylogic

Table 1 Specific simulation steps of steel framing work

Simulation blocks	Naming	Description
Source	source	This is a starting point of the process model.
Batch	batch	Requested steels are entered in one truck, so batch is needed semantically to bind steels to one entity.
MoveTo	truckEnter	This means a step entering a truck.
MoveTo	driveToUnload	This means a step moving truck to a stockyard space.
Delay	unloading	This means an unloading step.
Unbatch	unbatch	This means a step detaching steels from a truck.
Queue	managSt	This means a stockyard; steels are remained in this step.
Hold	hold	Holding steel entities to pass to erecting beams before erecting columns are completed
Pickup	pickupCol	Selecting the number of columns planned to be erected
Unbatch	unbatchCol	Selected one entity is divided to individual columns.
Service	hangCol	Pre-processing to erect columns on ground
Service	liftColumn	Lifting columns one by one
Delay	arrangeCol	Arranging columns on right point
Service	erectCol	Erecting columns roughly
Batch	batchCol	When columns stretched to three stories are erected, this step binds erected columns as one entity to move on next step.
Pickup	pickupBe	Selecting the number of beams planned to be erected
Unbatch	unbatchBe	Selected one entity is divided to individual beams.
Delay	equipSafety	Preparing safety materials
Service	hangBeam	Pre-processing to erect beams on ground
Service	liftBeam	Lifting beams one by one
Delay	arrangeBe	Arranging beams on right point
Service	erectBeam	Erecting beams roughly

Batch	batchBe	When beams are erected, this step binds erected beams as one entity to move on next step.
Delay	checkAll	Checking the vertical and horizontal states of roughly erected materials
Service	erectAll	Erecting all erected materials definitely
Sink	sink	This is an ending point of the process model.

5 Results and discussion

Among critical factors affecting on steel work productivity, we could reflect two factors; the number of materials and capacity of stockyard. The number of materials are the sum of the number of columns and the number of beams. These two data are extracted from the BIM model by using commands built at 4.1 phase. And then, capacity of stock yard is one of the managerial factors, so we enabled the value changeable on simulation environment even the simulation is running.

We supposed there are four individual models and erection works are performed as a sequence. Figure 8-10 provide the results of running steel work simulation based on BIM Data. The simulation results shows that productivity decreased at the point transferring from erecting columns to erecting beams. This might be because alienation of work occurs at that point.

Furthermore, among beam erections, erection work is the most productive in second time. Compared Figure 8 and 9, we could figure out the productivity of erecting beam is greater than that of erecting column. From this comparison, we could assume that the level of erecting beams is easier than that of erecting columns. This is might be because columns are erected without supports, on the other hand, columns would be able to buttress for erecting beams.

Among beam erections, the difference between the greatest productivity and the lowest productivity became smaller and productivity of beam erection itself became also smaller. Moreover, we could test the methodology using BIM-integrated simulation. The framework can predict more dynamic productivity rather than traditional method based on historical data and heuristic adjustments.

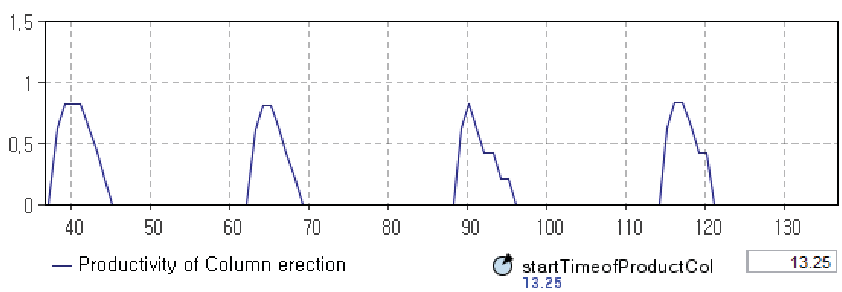

Figure 8 Productivity of Column erection (units/hour*worker*equipment)

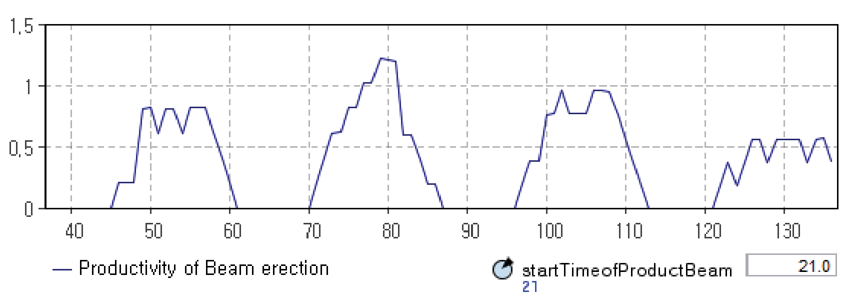

Figure 9 Productivity of Beam erection (units/hour*worker*equipment)

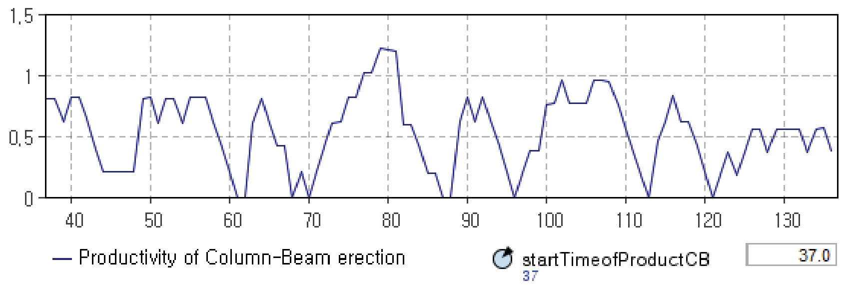

Figure 10 Total Productivity of steel framing work (units/hour*worker*equipment)

6 Conclusion

In this research, we presented the methodology predicting reliable productivity dynamics in construction operation level. Additionally, we could check that BIM-integrated simulation framework is plausible methodology to predict productivity dynamic in construction field. In this research, expanding usability of BIM data for planning construction management is particularly contributable in construction management field. Moreover, construction managers can reduce efforts for reproduction of building information by reusing BIM data. Also, by reusing BIM data and considering many critical factors in simulation, we would be able to reduce uncertainties and waste on construction site.

On the other hand, there are some limitations of this research. This framework is only evaluated about a simple steel structure model, so we will apply this framework to a more complex structure model to evaluate the applicability. In addition, to check and visualize the results of simulation faster, we reduced the simulation time by second time level. At this procedure, the observation error might be generated. For these reasons, we are evaluating all values of each simulation. Although we could extract much information from BIM, we couldn't be sure how the data can be reflected to simulation steps. Therefore, we are studying connection between factors and simulation steps, or relation between diverse factors in simulation to increase reliability of simulation results. In the future, authors plan to study this framework further in order to support construction managers' decision-making. To support decision-making for construction managers, we need to suggest more intuitive results.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Science, Future Planning and LCA (No. NRF-2013R1A1A1010562 and No. NRF-2013R1A1A2A10008723)

References

AbouRizk, S. (2010). Role of simulation in construction engineering and management. Journal of Construction Engineering and Management, 136(10), p. 1140-1153.

AbouRizk, S., & Mohamed, Y. (2002). Optimal construction project planning. Paper presented at the Simulation Conference, San Diego, California, U.S.A., December 2002. p. 1704-1708.

Al-Jibouri, S. H., Mawdesley, M. J., Askew, B. H., & Patterson, D. E. (2004). A computer system for modelling the process of earthwork planning in linear construction projects and applying preferred techniques. International Journal of Computer Applications in Technology, 20, p. 90-101.

Alvanchi, A., Lee, S., & AbouRizk, S. (2011). Dynamics of working hours in construction. Journal of Construction Engineering and Management, 138(1), p. 66-77.

Azhar, S., & Brown, J. (2009). BIM for sustainability analyses. International Journal of Construction Education and Research, 5(4), p. 276-292.

Azhar, S., Brown, J., & Farooqui, R. (2009). BIM-based sustainability analysis: An evaluation of building performance analysis software. Paper presented at the Proceedings of the 45th ASC Annual Conference.

Azhar, S., Brown, J., & Sattineni, A. (2010). A case study of building performance analyses using building information modeling. Paper presented at the Proceedings of the 27th international symposium on automation and robotics in construction (ISARC-27), Bratislava, Slovakia.

Cho, C.-S., Chen, D., & Woo, S. (2011). Building information modeling (BIM)-Based design of energy efficient buildings. Paper presented at the Proc. of 28th International Symposium on Automation and Robotics in Construction.

Mao, X., & Zhang, X. (2008). Construction process reengineering by integrating lean principles and computer simulation techniques. Journal of Construction Engineering and Management, 134(5), p. 371-381.

Melles, B. (1997). What do we mean by lean production in construction? Paper presented on the 2nd workshop on lean construction. Catholic University of Chile, Santiago, Chile, 1994. p. 11-16.

Mikulakova, E., König, M., Tauscher, E., & Beucke, K. (2010). Knowledge-based schedule generation and evaluation. Advanced Engineering Informatics, 24(4), p. 389-403.

Tommelein, I. D., Riley, D. R., & Howell, G. A. (1999). Parade game: Impact of work flow variability on trade performance. Journal of Construction Engineering and Management, 125(5), p. 304-310.

Tommelein, I. D., & Weissenberger, M. (1999). More just-in-time: location of buffers in structural steel supply and construction processes. Paper presented at the Proceedings IGLC. University of California, Berkeley, California, U.S.A., July 26th – 28th 1999. p. 110-120.

Wang, W.-C., Weng, S.-W., Wang, S.-H., & Chen, C.-Y. (2014). Integrating building information models with construction process simulations for project scheduling support. Automation in construction, 37, p. 68-80.