# BIM Utilization for Design Improvement of Infrastructure

Keisuke Fujioka, Yuta Itoh, Masaru Minagawa, Shunji Kusayanagi

***Abstract*—**In this study, Building Information Models of the underground temporary structures and adjacent embedded pipes were constructed to show the importance of the information on underground pipes adjacent to the structures to improve the productivity of execution of construction. Next, the bar chart used in actual construction process were employed to make Gantt charts, and the critical pass analysis was carried out to show that accurate information on the arrangement of underground existing pipes can be used for the enhancement of the productivity of the construction of underground structures. In the analyzed project, existence of unexpected underground pipes did not cause significant construction delay, mainly because the construction manager properly dealt with the situations. However, in many cases of construction executions in the developing countries, the existence of unforeseeable embedded pipes often causes substantial delay of construction. Design change based on uncertainty on the position information of embedded pipe can be also important risk for contractors in domestic construction. So by using a project management software, CPM analyses were performed for virtual situations in which influences of delay-causing tasks were assumed more serious compared with the situation actually occurred. Through the analyses, the efficiency of information management on underground pipes and BIM analysis in the design stage for workability improvement was indirectly confirmed.

***Keywords*—**Building-information modelling, construction information modelling, design improvement, Infrastructure.

## I. Introduction

IMPROVEMENT of the productivity of execution of construction of infrastructures is an urgent issue for the construction industry. As one of effective measures to solve this issue, there is the use of BIM (Building Information Modeling) which integrally manages based on 3D model data in the design/construction process [1]. Also in Japan, BIM for social infrastructure development is called CIM (Construction Information Modeling), and the Ministry of Land, Infrastructure, Transport and has been leading the promotion of utilization of this technology [2].

Investigation of the workability and maintainability during designing using BIM is called front loading. As shown in Fig.1, front loading is a method to create BIM associated with information on scheduling and cost control in so-called upstream process up to the design and then reduce the risk of unexpected events in construction or maintenance phases with virtual construction simulation. However, due to contractual restrictions based on design-bid-build contracts, the effect of front loading is limited especially in public project projects [3]. Therefore, in this research, we will quantitatively evaluate the effect of virtual construction plan and front loading at the time of design to promote CIM used for social infrastructure development.

K. Fujioka is with Tokyo City University, Tokyo, Japan (phone: +81-3-5707-2226; fax: +81-3-5707-2226; e-mail: g1681724@tcu.ac.jp).

Y. Itoh is with Yachiyo Engineering Co.Ltd., Tokyo, Japan (e-mail: syuta0808@gmail.com).

M. Minagawa and S. Kusayanagi are with Tokyo City University, Tokyo, Japan (e-mail:minamasa@tcu.ac.jp, kusayanagi.shunji@kochi-tech.ac.jp).

The authors thank the financial support by Japan Construction Information Center Foundation for this research.

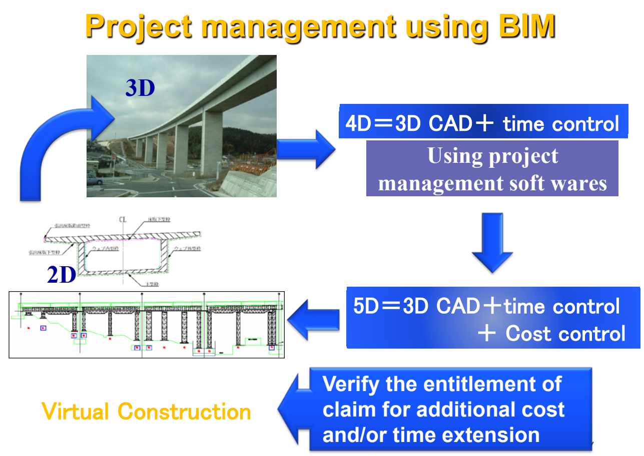


Fig.1 Front loading by using virtual construction with BIM [3]

Uncertainty of the position information of the buried underground pipes which is difficult to predict at the construction stage greatly affects the cost burden of the contractor. On the other hand, facility managers such as power companies, gas companies, water supply and sewage companies, etc. are managing using integrated information systems including three-dimensional models. However, the buried pipe information provided at the actual construction stage is only two-dimensional drawings. Therefore, the design change concerning the position information of the buried pipe can become a serious risk of contractors. Indeed, in construction work in overseas, especially in developing countries, the existence of buried pipes that are not foreseen at the time of design often causes a significant delay in construction. Meanwhile, for example, a construction company has developed a position detection system called Global Navigation Satellite System (GNSS), and technology capable of integrally and three-dimensionally managing position information of buried pipes is being established. Therefore, in this study, we analyze the improvement effect of BIM due to the delay of construction on the assumption that there is position information on the underground buried objects with high accuracy.

## II. Investigation Procedure

Three-dimensional modeling of temporary construction is carried out by using two-dimensional drawing of construction which has already been carried out. Then, the mismatch of the two-dimensional drawing at the pre-construction stage and the positional relationship between the temporary structure and the buried object are reproduced.

Next, based on the bar chart used in the actual construction, a Gantt chart is created using the project management software. And, the task that caused the delay of the construction period is been identified from the task group constituting the target project. Then, the situation where this task did not cause a delay is compared with the actual construction situation.

Next, it is assumed that the degree of influence of the task causing the delay of construction is virtually more serious. And we will analyze delay of construction against the situation. As a result, we evaluate the effect of improving the workability by accurately modeling the buried pipe information with BIM at the time of design.

*Target construction project*

The target construction is an underground railway-station building construction designed and constructed using a two-dimensional drawing without using BIM. An unexpected buried item was found in the process up to temporary lining, which caused a delay in construction. Targeted phase is the temporary construction of the underground railway-station project. Cost and construction period of these kinds of projects are usually affected by the uncertainty of the position information of underground buried objects. Also, for a long period of time and for a wide range of construction, we analyzed processes up to road covering in some sections.

- Contractor: Joint venture
- Construction Duration: From January 2005 to December 2014
- Provided data:
  - Two-dimensional design drawings (DWG format)
  - Monthly bar charts until December 2006
  - Cost Evaluation Table

*Three-dimensional modelling and Inconsistency between two-dimensional drawings*

General drawings of a temporary work, sectional views of water barrier walls, side views of vertical lines, plane views of cutting beams and road covering drawings were used to make a 3-dimensinal model. Fig.2 shows an example of 2-dimensional general drawings of a temporary work of the target underground railway station, and Fig.3 is its 3-dimensional model. A plurality of inconsistencies between drawings were confirmed with respect to existing or planned buried pipe positions from the created simple three-dimensional model. Fig.4 shows the inconsistency of the sewage trunk line position in the cross sectional view and the side view of the water barrier wall. Fig.5 shows another inconsistency in the position of the joint groove according to the plane view and the position according to the side view.

*Drawing Gantt charts from bar charts used by the contractor*

As shown by Fig.5, Gantt charts were constructed based on the bar charts actually used by the contractor. The Gantt charts used are two-year monthly schedules for the test drilling work, the obstacle removal work, and the temporary construction work.

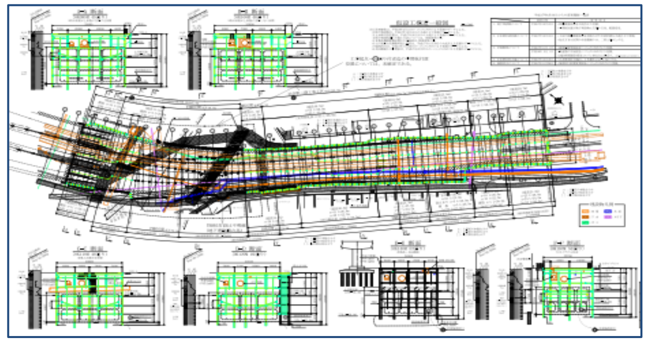

Fig.2 2-dimensional general drawings of a temporary work of the target underground railway station [4]

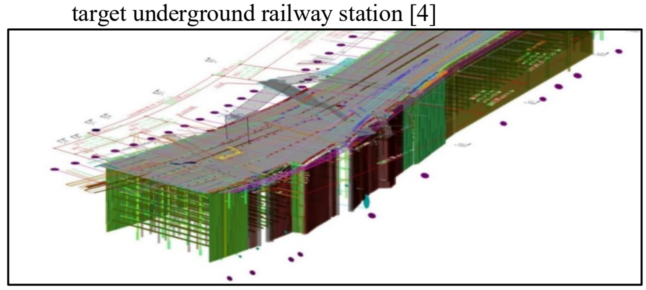

Fig.3 3-dimensional BIM model of the temporary work of the target underground railway station

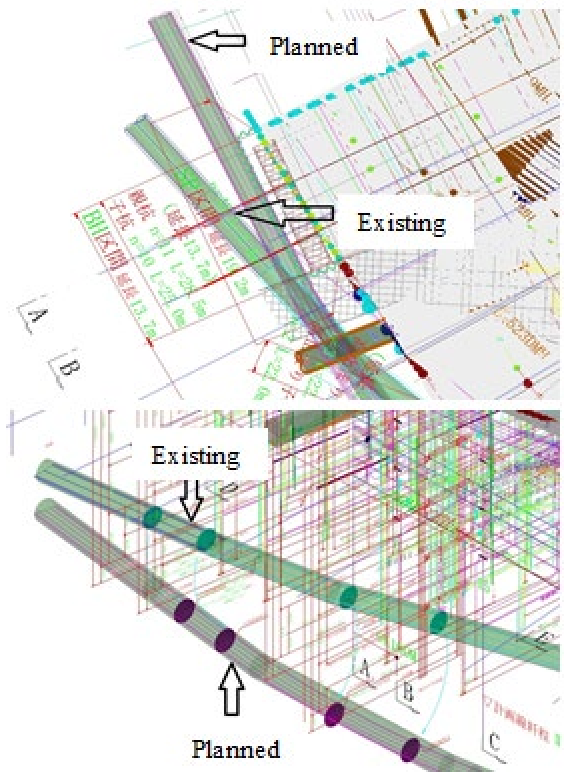


Fig.4 Inconsistency of 2D-drawings on the position of the sewage trunk line.

TABLE I
IDENTIFIED DELAY-CAUSING TASKS

| Task | Task name | Period | Duration |
|---|---|---|---|
| 1 | Emergency construction by electric power company | 2005/2/7-2/11 | 5 |
| 2 | Additional trial boring No.1 | 2005/3/12-3/16 | 4 |
| 3 | Additional trial boring No.2 | 2005/3/17-3/23 | 6 |
| 4 | Additional trial boring No.3 | 2005/3/29-4/8 | 10 |
| 5 | Unknown water pipe | 2005/8/26-8/27 | 2 |
| 6 | Processing of water pipe | 2005/9/17-9/20 | 3 |
| 7 | Pipeline relocation and trench excavation(sewage) | 2005/9/26-10/1 | 6 |
| 8 | Investigation and removal of unknown concrete | 2006/5/26-6/1 | 6 |

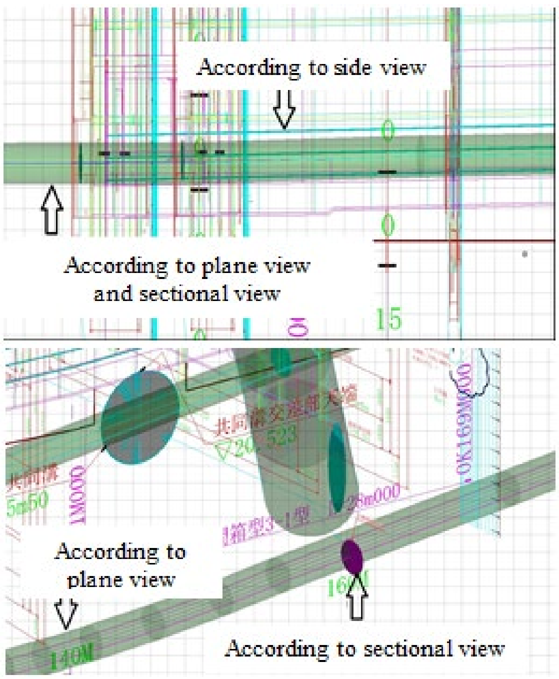


Fig.5 Inconsistency of 2D-drawings on the position of the joint groove.

*Identification of tasks causing delay*

Based on the monthly schedule up to road surface lumbering, tasks with risks affecting the project completion period are specified and these are called delay-causing tasks. Approximately ten years have elapsed since the target construction work was carried out and data on the actual process corresponding to the accident occurred could not be obtained. Therefore, from the schedule shown in the monthly process tables, the tasks that would had caused the delay were identified. Next, the initial plan was defined as the case where the assumed delay cause did not occur. Then, the influence on the schedule of the delay cause task was inversely calculated. Table I shows the identified delay-causing tasks.

If the accurate position information of the existing buried pipe is acquired at the time of designing and the positional relationship with the structure to be constructed is accurately grasped by BIM, an additional trial digging work should have been unnecessary. In addition, the risk of discovery of unexpected pipes and concrete members during construction is extremely small, and the accompanying relocation / treatment etc. should have been unnecessary. Therefore, we decided to use the construction plan without these construction delay-causing tasks as the virtual construction plan when applying BIM.

## III. Construction Delay Analysis

*Windows Analysis*

Delay analysis is a method for quantitatively determining whether the responsibility of the delay is in the ordering party or the contractor when the construction term is delayed due to unexpected events. This analysis provides information to make appropriate judgments regarding compensation for additional costs and extension of construction period. There are two types of delay as follows [5]:

- A delay for which the contractor is not entitled to both extension of construction period and additional cost payment
  (NN: Nonexcusable-Noncompensable delay)
- The contractor has the right to receive both time extension and additional cost payment
  (EC: Excusable Compensable delay)

Window Analysis is the most accurate method among various delay analysis methods. In this method, the schedule is updated every several intervals of the construction term called a window, and the intermediate evaluation of the construction delay is done for each window. Normally, the duration of the window is set based on major changes due to particularly important events in the plan or project. If a critical event occurs in one window and the plan is changed against the original plan, the critical path is changed. Even if no critical event has occurred within a certain window period, it may be affected by the change of the critical path. In the analysis, starting from the first window, how the period of the window changes by changing the period of the task in the window or adding a new task, and how the entire construction term is delayed due to the change is determined. And this particular event is regarded as a delay of EC or NN depending on whether it is the responsibility of the ordering party or the responsibility of the contractor. Such procedures are sequentially executed for all windows to calculate the sum total of EC and NN.

Every one of 8 delay-causing tasks was considered. The window period was set according to the period when each delay-causing task occurs. Window period from January to December 2005 is four every three months, and Window period from January to June 2006 is one of six months. Eventually, the set window period is a total of five periods.

*Results of window analysis*

Table II shows the results of delay analysis. Due to the

TABLE II
RESULTS OF WINDOW ANALYSIS

| Window | Task | Task name | Period | Duration | Delay in window | Total delay |
|---|---|---|---|---|---|---|
| 1 | 1 | Emergency construction by electric power company | Jan.-March '05 | 5 | 5 | 6 |
| 1 | 2 | Additional trial boring No.1 | | 4 | 5 | 1 |
| 1 | 3 | Additional trial boring No.2 | | 6 | 7 | 1 |
| 2 | 4 | Additional trial boring No.3 | April-June '05 | 10 | 21 | 1 |
| 3 | 5 | Unknown water pipe | July-Sep. '05 | 2 | 3 | 1 |
| 4 | 6 | Processing of water pipe | | 3 | 8 | 1 |
| 5 | 7 | Pipeline relocation trench excavation(sewage) | Oct.-Dec. '05 | 6 | 7 | 1 |
| 6 | 8 | Investigation and removal of unknown concrete | Jan.-June '06 | 6 | 7 | 1 |

TABLE III
SUMMARY OF WINDOW ANALYSIS

| Window | Process update | Duration for Completion | Total delay EC[*1] | Total delay NN[*2] |
|---|---|---|---|---|
| 1(Start) | Jan.-March '05 | 543 days | 8 | 0 |
| 2 | April-June '05 | 544 days | 1 | 0 |
| 3 | July-Sep. '05 | 546 days | 0 | 2 |
| 4 | Oct.-Dec. '05 | 547 days | 0 | 1 |
| 5 | Jan.-June '06 | 548 days | 0 | 1 |
| 5(Completion) | Jan. '05-June '06 | 548 days | 9 | 4 |

*1 EC:Excusable Compensable delay (Owner side is responsible)
*2 NN:Nonexcusable–Noncompensable delay (Contractor side is responsible)

existence of the delay-causing tasks, a large delay occurred

*Results of window analysis*

Table II shows the results of delay analysis. Due to the existence of the delay-causing task, a large delay occurred within the window. For example, in the case of an additional trial boring task of task # 4, an in-window delay of 21 days occurred for the task period of 10 days. On the other hand, the impact on the construction period was only one day.

When all assumed delay-causing tasks occur, the critical path continuously changes due to the influence of each delayed task. Therefore, in such a complicated construction, there is a significance of performing virtual construction using BIM models and Gantt charts from design stage.

Window analysis was performed using the shortest delay days envisioned. The delay-causing tasks of windows # 2, # 4 and # 5 were found to be tasks affecting the construction term even if delay occurs even for one day. Also, as the influence of the delay becomes larger, the change of the critical path becomes more intense. It is clear that the delay of only one day immediately affects the entire construction period and there is a risk that the construction cost will increase as the delay occurs.

Table III shows a summary of delay analysis. Among the delay-causing tasks, tasks # 1 to # 4 are considered to have not occurred if precise information on the existing buried pipe were previously provided by the owner. Therefore, the delay due to these tasks are classified as the responsibility of the owner (EC). If BIM technology were used at the design stage, it would have been possible to reduce these tasks. Task# 5, task#6, task#7 and task #8 are corresponding to events with low possibility of being found at the design stage. Therefore, there can be judgment of either the owner's responsibility (EC) or the contractor's responsibility (NN). If the project is a construction work based on judgment of the contractor, it can be judged to be the contractor's responsibility (NN).

*Impact analysis of delay-causing tasks*

It is assumed that the degree of influence of the task causing the delay of construction is virtually more serious. And we analyzed delay of construction against the situation. We used a construction plan that considered all delay-causing tasks. The duration of each delay cause task was multiplied. The number multiplied to durations is 2.0, 4.0, 6.0, 8.0 or10.0. And the delay of construction in those cases was evaluated.

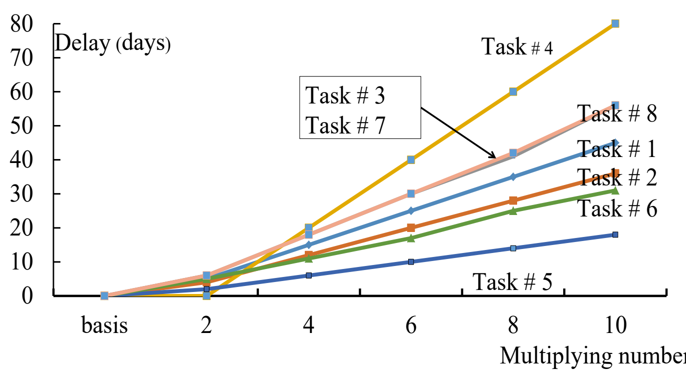


Fig.6 Impact analysis of delay-causing tasks

Fig.6 shows the relationships between the number multiplied to the delay date and corresponding delay for each one of delay-causing task. Tasks # 1, # 2, # 3, # 5, # 7, and # 8 were critical tasks in the construction plan. Therefore, in these cases, when the multiplying number is 2.0, the delay as many as each planned dates were produced. And the gradient for larger numbers becomes almost constant. This is because these delay-causing tasks were critical the extended period directly affected the completion of the construction.

For task # 4, when the multiplying number is 2.0, the delay did not affect the construction period. For the multiplying number larger than 4.0, the slope becomes a straight line, which affects the delay of the construction period. Therefore, when the multiplying number becomes 4.0, the task#4 became critical, after that, the construction period was affected.

The task # 6 changes to critical until the multiplying number becomes 2.0, and after that the delay affects the construction completion date.

By using Gantt charts in cooperation with BIM, it becomes possible to quantitatively grasp the influence of the delay of each task on the construction period.

## IV. Conclusions

The conclusions obtained in this study are as follows.

1) By constructing 3-dimensional BIM model by using 2-dimensional drawing used for the actual project, inconsistencies between some drawings were confirmed with respect to existing or planned buried pipe positions from the created simple three-dimensional model.
2) Delay-causing tasks were identified and the influence was quantitatively indicated by wind analysis.
3) Impact analysis was conducted by multiplying the construction period of the delay-causing tasks.
4) In complicated constructions, BIM technology should be used with CPM analysis, because critical path changes from moment to moment depending on delay-causing tasks.
5) The authors indirectly evaluated the effect of improving the workability of underground station construction by accurately grasping the information on the positions of buried pipes with BIM at the time of design.

## References

[1] C. Eastman, P. Teicholz, R. Sacks, K. Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. Hoboken NJ: John Wiley & Sons Inc., 2010, pp.1-30.

[2] Japan Construction Information Center Foundation, Standardization for Infrastructure Information, http://www.jacic.or.jp/english/standardization_for_infrastructure_information.pdf, 2017.

[3] M. Minagawa and S. Kusayanagi, “Study on BIM utilization for design improvement of infrastructure project,” Procedia Engineering, Elsevier Ltd., vol.125, no.1, 2015, pp. 431-437.

[4] A Construction Company, “Two-dimensional Drawings and Gantt Charts of an Underground Station Construction Project, “unpublished.

[5] N. Braimah, “Construction delay analysis techniques—A review of application issues and improvement needs,” Buildings, vol.3, 2013, pp. 506-531.