Investigation of Production Progress Monitoring to Respond to Change Orders in Steel Fabrication Projects

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Abstract
The development of an effective decision-making system for change orders is necessary when considering a steel production management system, including efficient production progress monitoring and automatic data collection. This paper introduces the detailed decision-making processes and verification of the information required to make appropriate decisions to deal with change orders in steel fabrication projects. The study was performed based on a Japanese steel fabrication project, with components produced by a large-scale steel fabrication plant in Thailand. Firstly, the authors analyzed the detailed response process for order changes, and the information referenced in order to make those decisions. Secondly, we studied the monitoring methods of production progress in the factory. Finally, we introduce an implementation case, as a production management system for steel fabrication to support decision-making, this includes assignments remaining, such as the limitation of identification technology in harsh environments, delayed input information dependent on monitoring timing and input method.

Keywords: Steel fabrication project; change order; production progress; monitoring; decision-making

1. Introduction
1.1 Research Background and Purpose
During steel fabrication projects, general contractors (GC) often make changes to orders sent to steel fabricators (FAB). The process of response to such changes involves many participants, however in practical terms the FAB plays a fundamental role. This includes reviewing alternatives and deciding an appropriate response method, whilst monitoring production progress information from the production line. Changes in orders present great potential risks to projects, such as increasing production cost and schedule delay. Thus, an efficient response is essential in order to avoid escalating costs and delays. A major factor in this problem is the difficulty in monitoring production progress, in order to make changes and control the dynamics of the factory. Therefore it is necessary to develop an integrated monitoring system for steel fabrication projects, as a way to accurately monitor production progress and make informed decisions to minimize the impact of order changes. During the analysis of order change impacts and their causes, the authors noted many smaller changes requested from the GC during steel fabrication in the factory. In theory, detailed fabrication specifications for steel components are decided at the production design stage, however this investigation shows that over 40% of the changes occurred during the steel fabrication stage. The usual process of design change response, as described previously (Kim, 2011), involves the GC and the project participants (SC; subcontractor, SV; supervisor etc.) examining the scale of order change, and compiling a detailed request order to send to the steel fabricator. This is a major factor in responding to the requested changes. The FAB’s disposal process is a very complicated and lengthy process requiring detailed and precise information for the steel components (Kim, 2012a). Production progress information within the factory is vital for making such response decisions. This research is motivated by two factors, one is the request for an accelerated response in change order from the GC, the other is to develop a production management system to integrate all steel fabrication production stages, in order to implement a supply change management system for structural steel. As part of the research in this paper, the authors introduce an investigation of the details and time constraints most appropriate for the development of a monitoring system.

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1.2 Research Method

This research is performed based on a Japanese steel fabrication project, produced by a steel fabricator (M fabricator) in Thailand. M fabricator is a large-scale steel fabricator, with annual production of over 60~70 thousand tons and factories located in Thailand, China and Japan. They have actively developed an integrated information system based on barcodes to complete supply chain management, including steel production, and have a comparatively high level of automation.

(1) Investigation

Previously, the authors analyzed ISO 9001 documents and attended the necessary meetings in order to understand the organization system, work processes and document control systems for M fabricator. This investigation focuses on outlining the decision-making processes used to respond to change orders from the GC. This was carried out by observing meeting systems, as well as document control and document contents, in order to clarify the decision process and what kinds of information were being used to make the decisions.

(2) Test and Observations

The authors also examined the automated data collection methods currently implemented within the factory, in regards to the referencing information of the decision-making process. Observations of paper test specimens for a selected production lot were performed (of around one hundred items), in order to test the possibility of attaching barcodes on the welded component.

(3) Development and considerations

Lastly, the authors introduce an integrated system model to monitor production progress during steel fabrication. Assignments to improve this system are then discussed.

2. Literature Review

In the past decade, many researchers have dealt with automated data collection in the construction industry. Such studies were performed based on information technologies, such as barcodes and RFID tags (Chen, 2002; Chae, 2005; Song, 2006; Ikeda, 2006; Wang, 2007; Ergen, 2007; Yoshida, 2008; Kim, 2012b; Costin, 2012). Other visualization technologies studied include BIM (Building Information Modeling) and VR (Virtual Reality) (Zhang, 2008; Rebolj, 2008; Son, 2010; El-Omari, 2008; 2011; Azimi, 2011; Gong, 2011, Cheng, 2012), in order to measure project performance accurately. Navon (2002) has defined the concept of project performance monitoring as the "identification of deviations between the desired and the actual performance of a project". He also emphasized the importance of indicator values, such as cost, schedule, productivity, input consumption etc. (Navon, 2007). Research results vary in terms of data quality, the detail and accuracy of monitored data and the timing of monitoring, all of which are key elements to determine the value of an indicator. However, little work has been done concerning the issue of progress monitoring and change control. Therefore in this paper we deal with the constraint conditions of monitoring approaches in the factory, as well as change control issues on steel fabrication projects.

3. Change Orders in Steel Fabrication Projects

Change occurrence timing remains unpredictable, however patterns can be recognized following the analysis of 5 steel fabrication projects, including approximately 500 change orders. As a result, it was found that changes to the specifications of steel components initially decided by the architect/engineer, occupied about 3-5% of overall change orders. However during steel fabrication, most changes were related to temporary work, mechanical work, and finishing work, such as altering, moving, cutting smaller parts (such as odd steel plates), adding pieces, moving holes and so forth, highlighting the importance of monitoring and controlling smaller parts. The change orders are usually requested from the GC to the FAB using drawings which highlight the areas and parts to be changed, as in the example shown in Fig.1. Often these include hand drawn annotations to explain details.

4. Analyzing the Decision-Making Process to Change Order and Referenced Information

In the case of M fabricator, they have themselves continuously reformed their decision-making processes for change orders, adapting meeting systems to carefully review appropriate alternatives. Fig.2. shows the analytical result of the overall process of decision-making for M fabricator. They have used a document (defined by ISO 9001) named the DCL (Design Change List) to understand change orders and record decisions. Most changes are mainly controlled by sub-managers, and include production management (PM), fabrication drawing (FD), cutting planning (CP), production planning (PP), quality assurance (QA) and cost-estimation (CE). They hold a daily meeting (sub-manager meeting) to review and make decisions for change orders.

Table 1. shows the summarized results of the analysis for DCL with additional documents. In order
Fig. 2. Decision-Making Process for Change Orders in a Steel Fabrication Project (M Fabricator Case)
to provide comprehensive results, production progress information is monitored by the PM before the sub-manager meeting, followed by the more detailed investigation by the sub-manager and his/her team members from each department.

During the study, some important points became clear. Firstly the PM usually monitors production progress information in the factory using an application system, but occasionally he/she relies on monitoring via personnel (Fig.2.). That is, he/she uses delayed information to make decisions. Secondly, each working group checks their working information and inputs it into the database after each job stage is finished. In other words, this is also not real-time information, and their decisions are again performed relying on delayed input data. Their referenced documents and information from each decision-making stage are arranged in Table 1. Here, the data sheet is a list of changing parts and steel components.

| No. | Information/attached documents                                      | Data type          | Monitoring information |
|-----|---------------------------------------------------------------------|--------------------|------------------------|
| a, b| Change orders and modified drawing (marked change area)             | Text or e-mail,CAD data and PDF | No                     |
| c   | DCL (Design change list) to control change order and modified drawing | Document, Document | No                     |
| d, e| DCL + Changed drawing Add data sheet                                | Document, Document | No                     |
| f, g| DCL + modified drawing + Data sheet                                 | Document           | Monitored production progress for changing components from each group leader in factory added to database system |
| h, i, f| DCL + modified drawing + Data sheet                  | Document           | None                   |
| k, l| DCL + modified drawing + Data sheet                                | Document           | Monitored production progress for changing components from each group leader in factory added to database system |
| m, n| DCL + modified drawing + Data sheet                                | Document           | No                     |
| o   | Add total cost estimation sheet                                     | Document           | No                     |
| p   | DCL + modified drawing + Data sheet + total cost estimation sheet   | Document           | No                     |
| q, r| Add summary cover letter                                            | PDF                | No                     |

Table 1. Information Referenced during Decision-Making for Change Order (M Fabricator Case)

5. Production Information Monitoring

The decision-making process and referenced information are explained by case study analysis in the previous section. In this section, we will discuss the possible implementation of an automated data collection approach, to monitor production progress during steel fabrication. In spite of recent technical development however, it remains difficult to implement a monitoring system to cover all steel fabrication stages in terms of assignments. Thus it is necessary to define the relationship among the objective units. In the case of structural steel, the hierarchy of objective units can be classified as shown in Fig.3. In addition work is also considered as a monitoring objective level (level 5). Most related studies have dealt with steel components (level 3) to be managed in their proposed system. However, the study requires the inclusion of more detailed objects and subjects, such as parts, workers, machines and tasks. Thus, more detailed contents (on levels 3, 4 and 5) must be monitored in order to measure project performance accurately, in order to make decisions for changes and to control the production line.

5.1 Steel Components Monitoring (Level 3)

In terms of accuracy, directly monitoring steel components (level 3) and parts (level 4) is a useful method to evaluate production performance. However, it is difficult to monitor and control all small parts because of the increase in input time and the amount of data involved.
Thus identification technologies (barcodes and RFID) provide a good alternative method to automatically collect data from production lines. Nakazima (2009) studied a RFID implementation model to support quality data collection of steel work, highlighting the necessity of extending the application area into the steel fabrication plant, in order to integrate steel work and steel production. However, in reality it proves difficult to extend the RFID application area into the factory, because of for instance, welding heat damage to the test specimen papers, as shown in Fig.4.(d). The authors observed approximately one hundred specimens and, as a result of welding, over half of the test specimen papers were significantly damaged. The test specimen papers, which were least damaged, remained so due to their attachment position; this was found to be at the end center of the web. Therefore, identification approaches, such as barcodes, RFID, etc. are viable ways to collect data during welding, but are dependent upon the attachment position.

Welding has many advantages in fixing metal parts. Temperature is an important factor affecting the quality of weld joints, and thus tags could be attached after fabrication welding (in the case of box-columns), and after ends shot blaster (in the case of beams). When considering alternative monitoring methods for the welding stage, a PDA (Personal Digital Assistant) or Tablet PC application can be used to monitor production progress and status. Each working group leader can input the finishing information to be checked into the data table as in BOM (Kimoto, 2005; Yoshida, 2008). However, Ikeda (2006) pointed out a problem concerning the details of input data. If some input data is excessively detailed, the automation effect of the input system is diminished. As a result, we decided to extend the barcodes application area into the factory following consideration of the data input methods, while a data input function was also developed as an alternative to input information.

### 5.2 Production Progress and Parts Monitoring (Level 4 and 5)

Steel components and parts as materials, are an obvious objective unit to be monitored by attaching identification tags. On the other hand, production progress monitoring is also a useful method to measure overall project performance during steel fabrication. In order to measure production progress, the objective unit must be defined by using work duration or work unit in terms of data collection or input accordingly. One specific method of measurement is to monitor the job status of each working group within the factory. Normally, structural steel components are fabricated and welded by plural workers or working groups as specialized organizations. In the case of M fabricator, production organization in the factory is mainly composed of three working groups: cutting, fabrication and welding (Fig.3., level 5). Thus the authors propose a timing set for a production progress monitoring system, as shown in Fig.5., defined by the results of steel fabrication analysis (Fig.2.). In Fig.5., the right hand side depicts box-columns and the left hand side beams. Additionally, a monitoring system based on barcodes is made available as standard, requiring login and check by the work group leader, in order to reduce input time. The monitored information of production progress is available to review or correct the production plan. Many researchers have proposed simulation-based systems to make plans for steel production projects (Karumanasseri, 2002; Song, 2006). However, this method has a considerable problem, in that it cannot trace directly the changing parts and control the production plan in terms of implementation, in addition to monitoring. Therefore, it is necessary for us to develop an ideal model for the integration of a decision-making system and a production progress monitoring system as part of our improvement assignment (Fig.6.).
6. Development Case: A Steel Production Management System Based on Barcodes

Firstly, improvement assignments are clarified in order to develop a production progress monitoring system during steel fabrication. This involves a case study of a decision-making process. Then, the case for the development of a production management system based on barcodes is introduced, including a partially developed monitoring system to be used during steel fabrication, as shown in Fig. 8. (Kim, 2012).

M fabricators have already developed a small scale system based on barcodes to manage structural steel production, such as material and steel components control in the stockyard, and transport and shipment control (excluding the in-factory production stage) (Figs. 7. and 8.). Thus we tried to develop a new way to monitor overall production progress within the factory and to integrate these exclusive systems.

6.1 Development of a Monitoring System: Extended to Barcode in the Factory

In the past, when a change order was requested, it took a certain time to identify the production progress and state for the production manager. M fabricator also monitored production information via its workers.

Previously, the authors investigated various identification methods, such as barcode, RFID and other sensor technologies. In comparison to the other methods, barcode technology is commonly used in daily life, and is comparatively cheaper than other identification technologies. We have already developed and operated smaller systems for M-fabricator based on barcodes, thus making system integration more convenient for an overall monitoring method. The monitoring information of steel components from barcodes is mainly concerned with a steel component's position within the factory, and working group's information for login and data input workers. All input information is stored in a database and then compared with the monitoring timings set, in order to analyze the production status in the factory. On the other hand, work status monitoring has also been developed as a data input system by two alternative data input methods.

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Fig. 6. Diagram of Decision-Making Support System for Change Orders (M Fabricator Case)

Fig. 7. Web-Based Application System to Support Overall Production Stages (M Fabricator)
methods, one is a manual input method and another is a mobile input method. However after it was applied, most workers input data manually, because they dislike monitoring their work state in real time.

6.2 Web-Based System Integration

The authors had initially developed a partially integrated system, composed of smaller systems A, B and C (except for the areas subject to the technical limitations mentioned in the previous section). The smaller systems are integrated as a web based system to support production information as shown in Fig. 7.

These smaller systems have been fully integrated via smaller system D, with smaller system C working as a stand-alone system based in Japan. The dotted box areas are covered by a barcode based monitoring system, and we extended the

![Image](image_url)

**Fig. 8. Integration of Structural Steel Production Management via Smaller System D, Based on Barcodes Developed from Partial Systems A, B and C (Kim, 2012b)**
implementation area into all production stages. Fig.7 shows the web-based application system used to support overall production stages for M fabricator. The right side of Fig.7. presents production progress information, which can be checked by using a barcode or component number. All progress information is illustrated as percentage completion. The whole system architecture and function is illustrated in Fig.8.

7. Conclusion

Decision-making is an integral part of production for steel fabrication projects, and must be coordinated strictly by using accurate production progress information based on monitoring systems. In this paper, the decision-making process and the information referenced for response to change orders, were clarified based on a case study of a steel fabricator. By observing welding conditions and component tags during each stage of the fabrication process, the limitations of information monitoring methods were investigated, in order to deal with the feasibility of various data collection techniques in the working factory environment.

The authors introduced a production management system for steel fabrication projects, including a partially developed monitoring system to be used during steel fabrication within the factory. The proposed system is a useful method to diagnose production problems on the production line directly, as a way of monitoring overall production progress.

However, this does not entirely solve the problem of applying identification technology in harsh conditions, or the discrepancy between monitoring time and referencing time, in terms of data accuracy. Instead, we used a set of planned monitoring timings to identify the production progress, with barcodes being attached at the ends of components. Thus it is necessary to further develop a technology to endure harsh in-factory conditions, such as welding.

This system can support and accelerate the decision-making process for change orders, as well as the resulting response times. This potentially reduces the significant and accumulating costs which result from change orders from the GC. In terms of application in industry, the smaller integrated systems can be individually appropriated according to the scale of a fabricator and their requirements.

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