# Creation of New Manufacturing Diagnostic Process by Co-creation with Customer

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**A key issue at manufacturing sites is how to ensure that manufactured products are consistent with the design. Manual labor still remains a part of industrial manufacturing processes in many industries. Human intervention unavoidably involves human error and it is important to find ways to promptly detect them so as to prevent rework. In the steel structure industry, for example, shortening of construction period, cost reduction, and securing of quality are urgently needed to survive the fierce competition for orders, and manufacturers are taking active approaches to eradicate rework due to human error. Fujitsu has analyzed the causes of rework in existing manufacturing processes and tested hypotheses from a technical perspective and from the viewpoint of users. The purpose is to build a system that allows anybody to easily diagnose manufacturing defects by applying ICT. This has led to the establishment of a "new manufacturing diagnostic process" making use of augmented reality (AR) technology. This new manufacturing diagnostic process has been verified jointly with a customer to achieve a tenfold improvement in productivity from the conventional process and eradicate rework arising from human error. The new manufacturing diagnostic process has also contributed to the development of FUJITSU Manufacturing Industry Solution 3D-CHOJYO. CHOJYO in Japanese means "superimpose." This paper describes the course of activities relating to the new manufacturing diagnostic process, including hypothesis testing, demonstration, and product creation.**

## 1. Introduction

In the field of industrial manufacturing processes, full automation of manufacturing by machine work has become possible due to the spread of machine tools. However, industries in which work is completed entirely by machine work are limited, and many industries still require manual work to a greater or smaller extent. Human intervention in manufacturing processes unavoidably involves human error. As human error make rework necessary, delayed detection becomes a risk directly leading to cost increases and delivery delays, as well as a decline in confidence in the company. Therefore, finding ways to promptly detect human error so as to prevent rework is a common challenge faced by many industries.

Fujitsu has devised a new "manufacturing diagnostic process" to solve the common challenges faced by the steel structure industry (steel structure construction industry), whatever the specific form of the business or work process. In order to apply this process to business, we repeatedly conducted effect assessment with customers over a six-month period. The outcome was the creation of a new solution based on the manufacturing diagnostic process established by this demonstration.

This paper outlines the new manufacturing diagnostic process established based on the improvement of work processes in the steel structure industry, the demonstration experiment, and the solution created from these activities.

## 2. Trends in the steel structure industry

The steel structure industry, which is one of the 28 construction industries currently defined in Japan, deals with large, one-off 3D structures such as Tokyo Sky Tree and the National Stadium. As shapes and structures are growing increasingly complex, the level of manufacturing difficulty is dramatically rising. The


**Figure 1**
**Manufacturing processes in steel structure industry.**

construction of such structures is made possible by state-of-the-art design technology such as 3D CAD and structure analysis software.

The decision to hold the Tokyo Olympics and Paralympic Games in 2020 is generating new demand for large structures estimated to be worth about half a trillion yen.[1] In this booming situation, competition for orders among companies in the steel structure industry is intensifying, and construction period shortening and cost reduction are the most important themes for winning orders. At the same time, companies are trying to differentiate themselves from cheaper overseas competitors by offering high quality and high added value products for competitive advantage.

Against this backdrop, companies are increasingly inclined to improve the efficiency of their manufacturing processes through the introduction of ICT in order to shorten construction period, reduce costs, and achieve high quality and high added value. In design work, efficiency is improved by utilizing 3D CAD and analysis software, carrying out cost reduction and quality creation through front loading.[note1)]

## 3. Challenges faced by large structure manufacturing processes

The manufacture of large structures in the steel structure industry involves unique manufacturing processes. These manufacturing processes have a major influence on manufacturing sites.

### 3.1 Unique manufacturing processes

The manufacturing processes in the steel structure industry (**Figure 1**) include unique processes that are specific to this industry, namely "visual verification" and "temporary assembly." Visual verification consists in checking whether the manufactured members have been manufactured according to the design blueprints during the pre-welding stage, in which members can still be modified, and detecting any incorrect assembly by measuring the dimensions of the members and checking them against the blueprints. This process is a task that is highly dependent on workers with experience and skill, and since inspection of all members is difficult owing to labor and cost constraints, sampling inspections are usually carried out.

Temporary assembly is the process of temporarily assembling large-sized structures on the premise that they will be disassembled prior to final assembly, in order to find manufacturing defects. When, such as in the case of large products, it is not possible to ship the product in its assembled state, temporary assembly is carried out at the manufacturing premises, defects are identified and corrected, and the structure is then disassembled and shipped.

In the upstream design process, front loading is used to build in quality into downstream processes. Specifically, the structure is designed by 3D CAD and structural and strength calculations are made using analysis software. If the structure has been designed and manufactured according to the blueprints, it should be possible to assemble it without problems, even without temporary assembly. However, there are cases when manual processing is required at the manufacturing site. For this reason, temporary assembly verification and temporary assembly are performed for early detection of defects in manufactured members.

### 3.2 Challenges and risks of manufacturing processes

Manufacturing sites depend in part on manual work done by skilled workers, and the predicted shortage of skilled workers is an issue that needs to be addressed. Further, any work involving human beings unavoidably involves human error such as production mistakes and production oversights, which in turn

note1) A method that aims to achieve quality improvement through optimization studies and to shorten lead time through early problem discovery by allocating resources to upstream product development processes and moving subsequent processes forward.

cause rework. Rework due to manufacturing defects at the manufacturing site directly leads to delays in delivery and, further, to a decline in confidence in the company. As large structures become more and more challenging in terms of manufacturing complexity and difficulty, securing manufacturing quality and eradicating rework are key for continued industry growth.

Moreover, the processes specific to the steel structure industry directly involve risks. The first risk is time increases caused by visual verification. No matter how skilled and experienced workers who perform visual verification may be, the higher the manufacturing difficulty and the more complex a structure becomes, the longer the time required for visual verification. The second risk is that of delayed delivery due to rework in the assembly process (temporary assembly and final assembly). When a defective member that could not be detected as such by visual verification is found in the assembly process, this leads to a delivery delay due to work stoppage and the like as the defective member needs to be manufactured again.

## 4. Hypothesis testing of new manufacturing process

To solve the problem described in the previous section, we hypothesized that it is necessary for a new manufacturing process to realize a system that allows anyone to easily diagnose manufacturing defects through the application of ICT. For example, if it became possible for an ordinary technician to perform visual verification work that until now required a skilled technician, this would result in a leveling of labor. Further, if there were a system for easily identifying manufacturing defects, the risk of rework in the manufacturing process could also be eliminated.

This section examines this hypothesis from a technical point of view and user point of view and describes the testing of the hypothesis.

### 4.1 Consideration of the hypothesis from a technical point of view

With regard to technical aspects, we carried out an investigation of trends and issues concerning the type of ICT that could be applied to visual verification.

The development of 3D measuring technology has led to the use of methods for comparing manufactured products with design blueprints. Such methods involve the generation of 3D data through measurement of the actual object, and quantifying errors through comparison of the measurement data with the design CAD data.

Further, the Japan Bridge Technical Report published in 2000 included a research paper[2] from the viewpoint of quality assurance regarding elimination of the need for temporary assembly inspection work. The gist of that paper is that, following measurement of products with measuring instruments and data conversion of the obtained information, temporarily assembly simulation is carried out on a computer, eliminating the need for the temporary assembly process and contributing to quality assurance at the same time.

While these are achievable technically, we found out the following problems with regard to actual business application:

- Large initial introduction cost
- Complexity of preparations for use[3]
- Long measurement time of products

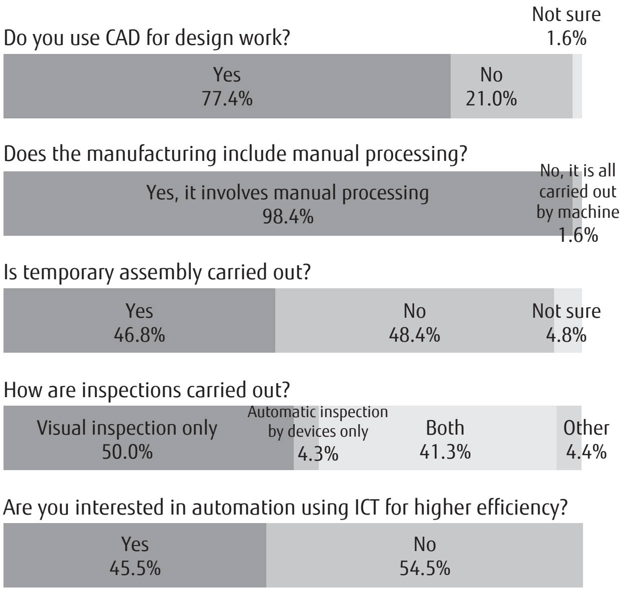
### 4.2 Consideration of the hypothesis from the viewpoint of users

Next, we studied the hypothesis from the viewpoint of users in the steel structure industry. An online survey was carried out and a number of customers were interviewed.

1) Online survey

The results of the survey are shown in **Figure 2**. About half of the respondents indicated a need for efficiency improvement of inspection work through automation using ICT. Moreover, the responses indicated that the rate of penetration of CAD in design work in the steel structure industry is a little less than 80%, and that use of ICT in design work is increasing. However, use of ICT for the manufacturing processes in the industry remains low for the following reasons:

- At least 98% of the companies have manual processing in their manufacturing.
- Approximately 50% of the companies carry out temporary assembly.
- Over 90% of the companies carry out visual verification even when inspection devices are used, and such work is highly dependent on workers with skill and experience.
- The reason why some customers show little interest in improving inspection work efficiency with ICT is that they consider this to be impossible.




| Reason for not being interested in automation using ICT for higher efficiency |
|---|
| No significant efficiency gain is likely |
| Ultimately no improvement in efficiency can be gained |
| Automation is difficult |
| There are parts that need to be checked with one's own eyes |
| The final appearance is important |
| Because many of our products are not mass produced |
| Because specifications vary for each product |
| Because our products are each designed independently as one-off items and thus do not lend themselves to automated production |
| Visual verification is the most accurate |
| I think it is impossible |
| It cannot be done |

**Figure 2**
**Results of survey on needs of steel structure industry.**

2) Results of customer interviews regarding needs

To confirm the validity of the survey, we interviewed six companies in the steel construction industry. All the interviewed companies gave responses similar to the survey results, indicating a strong need for efficiency improvement through the introduction of ICT. There were companies that were already experimenting with the use of 3D measuring equipment and/or proprietary systems developed in house, but most companies were still at the stage of looking for an approach to solving their problems and had not yet reached the stage of application to actual operations.

## 4.3 Results of hypothesis testing

The hypothesis testing confirmed the usefulness of the hypothesis based on the results of the above-mentioned investigation from a technological point of view and a user's point of view. From a technical point of view, we determined that by performing measurements with 3D measuring equipment, products can be converted into data with a level of accuracy approximating the design quality achieved through careful calculations with 3D CAD. Through the application of 3D measuring equipment and the integration of design quality and manufacturing quality, we think that it is possible to solve common problems in the industry such as how to prevent rework due to human error. At present, however, the introduction of 3D measuring equipment is problematic due to high initial introduction cost and complicated procedures, and visual verification and temporary assembly highly dependent on skilled workers are still being carried out.

We considered why measurement technology capable of solving the problem at hand is not being applied to business though it exists. What users are seeking with visual verification is a system that is easy to set up and operate and enables instant detection of manufacturing defects. This finding made it clear that for visual verification, there is demand for a method that anyone can easily use without special equipment.

## 5. System of new manufacturing diagnostic process

Based on the results of the hypothesis testing, Fujitsu devised a new manufacturing diagnostic process for the diagnosis of manufacturing defects that works by superimposing the 3D CAD blueprint created during the design work with photographs of the product (2D data) through the use of augmented reality (AR)[note2] technology (**Figure 3**). By integrating design quality and manufacturing quality, we believe that this new process will enable reduction of construction period and costs, as well as the attainment of high quality and high added value. Going forward, by quantifying errors in products from the diagnostic results of the new manufacturing diagnostic process, a new approach to manufacturing in the steel structure industry that

note2) Augmented reality (AR) refers to technology that expands and strengthens human senses by superimposing digital information obtained through the use of ICT to information (reality) obtained by the five human senses.


**Figure 3**
**Fujitsu's new manufacturing diagnostic process.**

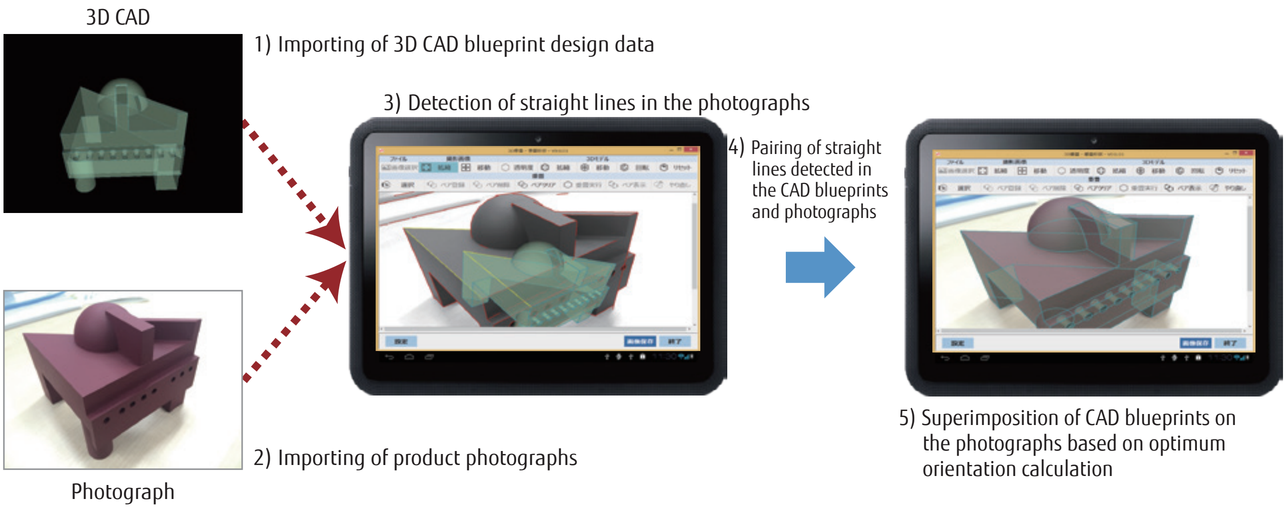



**Figure 4**
**Outline of operation of manufacturing diagnostic process.**

renders temporary assembly unnecessary may well come into being.

To verify the effect of "3D superimposed diagnosis" shown in Figure 3, we developed a prototype that allows anyone to easily diagnose manufacturing defects with one general-purpose device in just five steps. The five steps are shown below (**Figure 4**):

1) The user imports the 3D CAD blueprint design data.
2) The user imports product photographs taken with a smartphone or tablet.
3) The program automatically detects straight lines in the photographs.
4) It correlates (pairs) the straight lines in the photographs with the lines in the CAD blueprint.
5) The program then calculates the optimum orientation of the 3D CAD blueprints and superimposes it on the photographs.

As a result, as shown in **Figure 5**, manufacturing defects can be easily found.

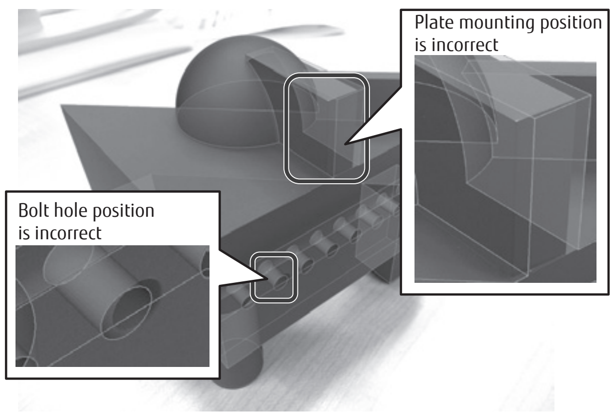



**Figure 5**
**Detection of manufacturing defects.**

## 6. Demonstration and effect

To verify the effect of the new manufacturing diagnostic process, demonstrations and improvements in actual operations were repeatedly carried out over a period of six months in collaboration with TOMOE Corporation. The demonstration conditions were as follows:

- A prototype system for manufacturing diagnosis was created and demonstrated.
- Diagnosis was carried out by a person in charge of manufacturing operations at TOMOE Corporation.

### 6.1 Effect verification

Verification of the productivity improvement effect found that visual verification work was shortened from the usual 30 minutes to about 3 to 4 minutes, up to a ten-fold efficiency improvement.

Manufacturing defects in actual operations were successfully found during verification of the effect in terms of quality. Further, the efficiency improvement meant that all the manufactured members could be inspected, whereas previously visual verification could be applied only by sampling.

### 6.2 Assessment

In collaboration with TOMOE Corporation, we performed demonstrations and made usability and other improvements over a period of six months. The following are comments received from TOMOE Corporation:

- We were able to achieve eradication of rework for the targeted construction during the demonstration period (manufacturing site supervisor).
- The system has already reached a practical application level and we would like to start using it for operations immediately (corporate executive)
- It is overwhelmingly easy to handle compared with what we've had in the past, and it is easy to explain to the workers at the construction site (information systems department manager).

## 7. Solution creation

To improve work efficiency at construction sites, we added a diagnostic preparation function and diagnostic results management and utilization functions to the new manufacturing diagnostic process established by demonstration experiment with TOMOE Corporation, and began offering it in December 2016 as the FUJITSU Manufacturing Industry Solution 3D-CHOJYO, a PLM[note3)] solution for manufacturers.[4)] CHOJYO in Japanese means "superimpose." CHOJYO in Japanese means "superimpose."

3D-CHOJYO is a solution that allows anyone to easily and quickly discover manufacturing defects by superimposing a 3D model created in the design process on product photographs with AR technology to eradicate rework in later process. The results of the diagnosis by 3D-CHOJYO are stored in a database as diagnostic information and can be used for know-how sharing, quality control, and progress management of diagnostic work.

### 7.1 Features of the solution

The following are some of the features of 3D-CHOJYO:

1) CAD software-independent

The 3D models handled by 3D-CHOJYO use Standard Triangulated Languages (STL), which is supported by many CAD software, thereby allowing easy adoption.

2) Easy set up

Products can be diagnosed simply by preparing a 3D model (STL) and product photographs. Tablets, smartphones, digital cameras, etc., can be used for taking the photographs, and photo resolutions up to 4K are supported.

3) Easy operation

3D-CHOJYO supports intuitive touch operation. Therefore, it can start being used after only 30 minutes of training, regardless of the level of skill and know-how of the technician.

4) Use anywhere

Diagnosis is possible anywhere with a tablet or personal computer, regardless of the availability of a wired network or Wi-Fi environment, whether at the manufacturing site or in the office.

5) Improve operations with diagnostic records

Diagnostic results are saved to a server and can be used for operations improvement including training of technicians through sharing of diagnostic know-how, daily work progress management, and manufacturing diagnostic record-keeping.

### 7.2 Manufacturing operations transformation through solution application

Through 3D-CHOJYO, manufacturing defects whose detection until recently required the expense of considerable time and effort by skilled technicians

note3) Acronym of Product Lifecycle Management. Generally, product-related information such as design, development, maintenance, disposal, and recycling, is centrally managed by ICT throughout the product lifecycle, in order to maximize revenue. Fujitsu provides various PLM-related solutions as part of integrated support for manufacturing.

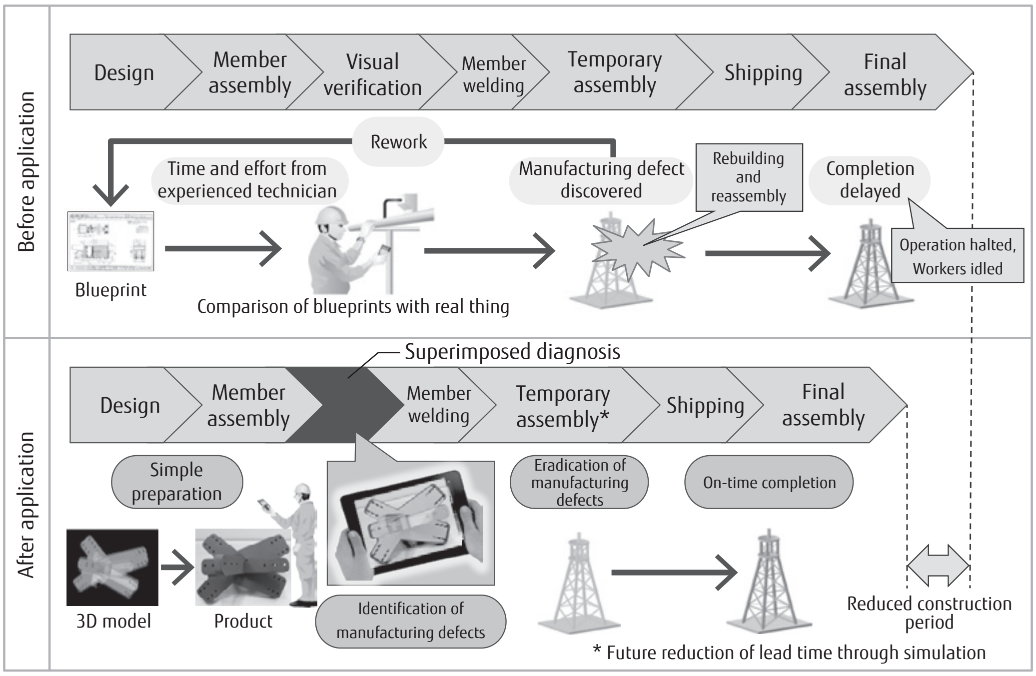



**Figure 6**
**Image of manufacturing operations transformation through 3D-CHOJYO.**

can now be detected in the early stage of the manufacturing process, with a resulting lower of risks in the subsequent processes (**Figure 6**). As a result, it is possible to drastically reduce manufacturing cost while securing both high manufacturing quality and shorter construction period.

## 8. Conclusion

The FUJITSU Manufacturing Industry Solution 3D-CHOJYO developed this time is expected to be broadly adopted not only in the steel structure industry but also by the construction industry at large for on-site inspections, as well as at sites where large-scale equipment is assembled.

Further expansion of this solution will require coordination with inspection standards and basic information of respective industries, and efficient management of 3D design information and inspection/diagnostic information will be necessary. We are committed to further growth and innovation of the new manufacturing diagnostic process introduced in this paper to allow it to reach its full potential as a manufacturing solution that can powerfully contribute to the growth of companies in various industries.

In closing, we would like to express our deepest gratitude to everyone concerned at TOMOE Corporation for their invaluable cooperation in the demonstration and realization of the new manufacturing diagnostic process, including the provision of an actual construction site for demonstration purposes and advice regarding the application and management of the process for actual manufacturing operations.

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