AN APPLICATION OF LEAN CONCEPT TO STRUCTURAL STEEL FABRICATION PROCESS: A CASE STUDY OF STEEL BOX GIRDER FABRICATION FOR A BRIDGE PROJECT

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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วรวัฒน์ ศรีอุดม : การประยุกต์แนวคิดลีนกับกระบวนการประกอบเหล็กรูปพรรณ : กรณีศึกษาการประกอบคานเหล็กกล่องสำหรับโครงการก่อสร้างสะพาน. (AN APPLICATION OF LEAN CONCEPT TO STRUCTURAL STEEL FABRICATION PROCESS: A CASE STUDY OF STEEL BOX GIRDER FABRICATION FOR A BRIDGE PROJECT) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ.ดร.วีระศักดิ์ ลิขิตเรืองศิลป์, 189 หน้า.

งานวิจัยนี้เสนอการประยุกต์แนวคิดลีนกับกระบวนการประกอบเหล็กรูปพรรณโดยวิธีกรณีศึกษาของคานรูปกล่องโครงการก่อสร้างสะพาน ข้อมูลสำคัญได้เก็บจากโรงงานประกอบในประเทศไทยบนพื้นฐานที่จำเป็นของเครื่องมือ Value Stream Mapping แบบจำลองของกระบวนการที่มีอยู่ได้วิเคราะห์โดยการเน้นที่เวลาทำงานทั้งหมด ซึ่งประกอบด้วยเวลาทำงานที่เกิดผลลัพธ์ (Process Time) และเวลารอคอยการทำงาน (Waiting Time) แนวคิดลีนได้ประยุกต์ใช้หลังจากนั้นเพื่อปรับปรุงกระกวนการ การปรับปรุงกระบวนการได้รวมการรักษาสมรรถภาพในการทำงาน การลดเวลารอคอยการทำงาน และการกำจัดกิจกรรมคอขวด (Bottleneck) เข้าไว้ด้วยกัน

เนื่องจากข้อจำกัดที่ว่า การปรับปรุงกระบวนการไม่สามารถทำให้เกิดในโรงงานจริง แบบจำลองเลียนแบบ (Simulation Model) จึงถูกเลือกใช้เพื่อตรวจสอบแนวทางปฏิบัติที่วางแผนไว้ ในแบบจำลองเลียนแบบ แนวทางปฏิบัติการปรับปรุงกระบวนการที่แตกต่างถูกทำหน้าที่แทนโดยกรณีการทดลองที่ต่างกัน พบว่า การรักษาสมรรถภาพในการทำงานช่วยลดเวลาทำงานที่เกิดผลลัพธ์ การรวมกิจกรรมการทำงานเข้าด้วยกันสามารถลดเวลารอคอยการทำงาน และการเพิ่มสถานีทำงานสามารถกำจัดคอขวดได้ ท้ายที่สุด งานวิจัยนี้จัดหาแนวทางปฏิบัติของการปรับปรุงกระบวนการเหล็กรูปพรรณเพื่อลดการทำงานที่เปล่าประโยชน์ (Waste) โดยการใช้สมรรถภาพคนงานและเครื่องจักรสูงสุด และการลดเวลาการทำงาน

ภาควิชา วิศวกรรมโยธา.................................. ลายมือชื่อนิสิต...

สาขาวิชา โครงสร้างพื้นฐานทางวิศวกรรมโยธา ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

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WORAWAT SRIUDOM : AN APPLICATION OF LEAN CONCEPT TO STRUCTURAL STEEL FABRICATION PROCESS: A CASE STUDY OF STEEL BOX GIRDER FABRICATION FOR A BRIDGE PROJECT. ADVISOR : ASSOC. PROF. VEERASAK LIKHITRUANGSILP, Ph.D., 189 pp.

This thesis presents an application of lean concept to a structural steel fabrication process through a case study of a box girder bridge project. Relevant data were collected from a fabrication factory in Thailand based on the requirements of a value stream mapping tool. The model of the existing process was analyzed by focusing on the total working time, which consists of process time and waiting time. Lean concept was then applied to improve the process. The process improvement encompassed conserving working performance, reducing waiting time, and eliminating bottleneck activity.

Owing to the limitation that the process improvement cannot be implemented in the actual factory, a simulation model was adopted to verify the proposed guidelines. In the simulation model, various process improvement guidelines were represented by different trial cases. It was found that conserving working performance helps reduce process time, merging working activity can reduce waiting time, and increasing working station can eliminate bottleneck. Finally, this thesis provides a guideline of structural steel process improvement to reduce waste by maximizing workers performance and machine usage and reducing working time.

Department : Civil Engineering
Field of Study : Infrastructure in Civil Engineering
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Student's Signature ....
Advisor's Signature ....

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LIST OF ABBREVIATIONS

Abbreviations	**Full Name**
AB	Assembly Block Activity
AS	Assembly Stiffener Activity
AT	Assembly T-Shape Activity
ATB	Assembly T-Shape for Box Girder Activity
ATD	Assembly T-Shape for Diaphragm Activity
BJ	Butt Joint Activity
BL	Blast Activity
BP	Blast and Paint Activities
BR	Bracing Part
BT	Bottom Part
BJA	Butt Joint Station A
BJB	Butt Joint Station B
BJC	Butt Joint Station C
CT	Cut Activity
CV	Coefficient of Variation
CCT	Cycle Time
CNC	Computer Numerical Control
CPM	Critical Path Method
CTP	Cut for Steel Plate Activity
CTS	Cut for Steel Shape Activity
DI	Diaphragm Part
DM	Dimension Activity
DR	Drill Activity
FN	Finish Activity
FIFO	First-In-First-Out
I	Inventory
JIT	Just in Time
LF	Lift out Activity

Abbreviations	**Full Name**
LOB	Line of Balance
MRP	Material Requirements Planning
PA	Paint Activity
PC	Pack Activity
PCT	Process Time
PERT	Program Evaluation and Review Technique
RM	Raw Material
RMP	Raw Material Plate
RMS	Raw Material Shape
SD	Standard Deviation
SL	Left-Stiffener Part
SR	Right-Stiffener Part
SIM	Simulation
SBGF	Steel Box Girder Fabrication
SMED	Single-Minute Exchange of Dies
TA	Trial Assembly Activity
TL	Left-Top Flange Part
TP	Taper Activity
TR	Right-Top Flange Part
TS	Transport Activity
TPS	Toyota Production System
VSM	Value Stream Mapping
WB	Weld Block Activity
WH	Whole Box Girder
WL	Left-Web Flange Part
WR	Right-Web Flange Part
WS	Weld Stiffener Activity
WT	Weld T-Shape Activity
WIP	Work in Progress
WTB	Weld T-Shape for Box Girder Activity

Abbreviations	Full Name
WTD	Weld T-Shape for Diaphragm Activity
WTT	Waiting Time

CHAPTER I

INTRODUCTION

1.1 Background

Construction work consists of numerous complicated tasks involving various components and work processes. Structural steel bridge construction exemplifies this complexity and can refer to a variety of different types such as beam girder and box girder bridges. Structural steel and concrete box girder bridges have been widely used because of their advantages, including long span and design flexibility (Bishop, 2008). Most of these bridges are fabricated in the factory and then transported to construction sites for assembly, which is known as semi-conventional construction.

The fabrication work is a continual process that includes feeding raw materials through the fabrication line and passing these elements along the work stations to produce sections of the bridge, called box girders, which are then transported to the construction site. This can be considered a materials management process, which is part of the whole construction operation. Throughout this thesis, the term “structural steel fabrication process of a box girder bridge project” is referred to as “steel box girder fabrication” or “SBGF.”

As found in previous studies, many concepts and theories have been applied to construction project management, including “lean” concept. This concept was created for process improvement in the Toyota Motor Corporation, where it is referred to as Toyota Production System (TPS) lean production (Liker and Meier, 2006). Since its creation this concept has been applied to many disciplines such as manufacturing, construction, and hospitals (Melles, 1997).

One of the managerial project goals is project performance improvement, especially appropriate resource usage. According to lean concept, value stream mapping can be used to display the sequence of fabrication processes and calculate the project overall performance percentage. This concept can also be applied to the fabrication process to eliminate time wastage (Rother and Shook, 1999). Most of structural steel fabrication project was subject to time wastage for working process therefore, lean concept can utilize to solve this problem.

1.2 Research Objectives

The objective of this research is to propose the improvement of SBGF by applying lean concept. The current process was analyzed and redesigned by using value stream mapping and discrete-event simulation through the case study of an actual steel bridge project.

1.3 Scope of Research

This research focuses on a case study of SBGF, which encompasses the assemblage of 20 girders, each of which embraces nine assemblies. The process is associated with 18 activities, namely, cut, taper, drill, butt joint, assemble t-shape, weld t-shape, assemble stiffener, weld stiffener, assemble block, weld block, dimension, finish, lift, trial assembly, blast, paint, pack, and transport.

1.4 Research Steps

This research consists of 11 steps.

1) Conduct a literature review of textbooks, journals, and research reports regarding

- Steel fabrication process
- Waste of time

- Lean concept and lean production
- Value stream mapping
- Process improvement
- Simulation model

2) Survey preliminary SBGF data by:

- Recording actual working time and taking photos of every important process involving raw materials, manpower, and machine management
- Interviewing personnel in charge of the production planning, machinery performance, manpower, and assembly dimensions regarding process problems

3) Analyze actual SBGF working time by grouping the working time of each station versus the assemblage of box girders in terms of average with uniform or PERT formulas distribution.

4) Build a value stream mapping model of the current or existing process by using value stream mapping and analyzing the model by applying lean concept.

5) Calculate percentage of utilization and coefficient of variation of the current process.

6) Identify problems associated with the SBGF and wastes by applying lean concept for each SBGF activity.

7) Map an improved process and recalculate the working time.

8) Verify results by using a simulation model of the STROBOSCOPE computer program to compare the results from the improved process.

9) Create different scenarios or trial cases for the improvement process directions.

10) Propose process improvements, which include adjustments to the scenario cases and the recommendations for the personnel in charge.

11) Conclude the thesis.

1.5 Research Outcomes

The main outcome of this thesis is a comprehensive of methodology for data collection and analysis by using lean concept and value stream mapping. In addition, percentage of utilization for working activity and improvement process guideline are other outcomes.

1.6 Contributions

This research presents a methodology to analyze and improve the SBGF process by using lean concept and value stream mapping. The steps consist of data collections along with data analysis using value stream mapping, including lean concept application. This methodology can also be applied to similar fabrication processes in construction such as precast concrete production.

CHAPTER II

LITERATURE REVIEW

2.1 Steel Bridge

There are various types of bridges such as the steel box girder, concrete box girder, concrete arch and cable-stayed bridges (Bishop, 2008). The steel box girder bridge consists of many components and working activities which are fabricated in the factory, referred to as a semi-conventional construction.

Most steel box girder construction is separated into two main phases, including the fabrication process at the factory and the installation at the construction site. Since steel box girder fabrication (SBGF) comprises many activities, they are usually performed with a variety of workers and machines, making them both complex and risky. To improve SBGF, it is necessary to reduce wasted working time and appropriately manage the fabrication process.

2.2 Lean Construction

Howell (1999) described the origin of lean construction as being created from lean production concept of the Toyota Motor Corporation by Taiichi Ohno who was dedicated to eliminating waste at the company. He also realized that machine operation with maximum production led to extensive inventories or “waste of over production.” The features of lean production concept can be summarized as follows.

- Eliminate steps that do not add value for customers
- Arrange the production process as a continual flow
- Create proper and stable flow by instituting the non-stop line, reducing inventory with the pull system, and disseminating information

- Meet product requirements of customers with no inventory

Cudney (2009) explained the benefits of lean concept such as focusing on waste elimination and prevention, and flow improvement. Also, he described implementation of the concept to improve quality, productivity, profitability, and market competitiveness.

Lean construction can be defined as a continual process to eliminate waste by emphasizing value stream, and instructions or procedures of construction project (Salem and Zimmer, 2005). Howell (1999) suggested that different construction management and lean concept application consist of four elements, including clear intent of the delivery process, maximum performance at the project level, concurrent product and process, and production management.

Forbes et al. (2002) presented lean construction implementation as being able to control processes and improve productivity performance in terms of cost control. Moreover, the advantage of lean construction is waste and non-value added activity reduction. It was explained that lean construction, can improve project performance in every project phase. Even though it might more time for designing and planning, lean construction can minimize time and budget required. Moreover, Lehman and Reiser (2002) supported this advantage stating that lean construction is an efficient tool for creating and providing the continuous flow of the process; also it emphasizes main schedules and reliable tasks.

2.3 Lean Tools

Cudney (2009) summarized lean tools such as Value Stream Mapping (VSM), Six Sigma (6σ), 5S, Single-Minute Exchange of Dies (SMED), Standard Work, and Mistake-Proofing (Poka-Yoke), which are explained below.

1) Six Sigma (6σ)

Six Sigma can reduce variation and improve quality and is a methodology based on standard deviation (SD). The benefits of Six Sigma include reduction of defects, increasing customer satisfaction and improving communication amongst a team. This tool consists of five strategic phases as follows: define, measure, analyze, improve, and control.

2) 5S

5S is a tool which creates a work environment that focuses on quality and leads to a clean and manageable workplace. The benefits of 5S are reducing waste by eliminating unnecessary steps to search for tools or equipment, and also workplace cleanliness and organization. 5S is short for five Japanese words including:

- Seiri (Simplify the workplace) means separating the necessary tools or equipment from unneeded materials. All items in the work area are sorted
- Seiton (Straighten up the workplace) means arranging and identifying parts, materials, and tools to facilitate usage and return. Items should be placed in the best location for use and visually organized
- Seiso (Scrub the workplace) means performing a cleanup in which all parts of the work areas are cleaned such as floors, furniture, and equipment
- Seiketsu (Stabilize the workplace standards) means performing Seiri, Seiton, and Seiso by implementing necessary changes. A daily checklist of cleaning and organizing activities can be created
- Shisuke (Sustain) is the habit of following the first four 5S

3) Single-Minute Exchange of Dies (SMED)

Single-Minute Exchange of Dies (SMED) was created to develop and improve machine tool setups and is a methodology to reduce setup time, the goal being zero setup time. Setup time is calculated from the time the last good product A item is completed until the first good product B item is completed. The main benefits are reducing inventory, improving flexibility, and increasing capacity. SMED increases capacity by reducing the amount of changeover and variation between setups including defects from setup errors.

4) Standard Work

Standard Work is tool to determine maximum performance with minimum waste through a combination of operator and machine. It helps eliminate variability from the process, and also identifies waste and drives the process to use kaizen.

5) Mistake-Proofing (Poka-Yoke)

Poka-Yoke is a methodology that focuses on preventing defects from human error and improving quality by using inspection techniques. Poka-Yoke identifies an item by its characteristics such as weight, shape, or dimension, and determines defect deviation from the process.

Figure 2.1 displays all lean tools mentioned.

2.4 Definition of Terms

2.4.1 Waste

Toyota has identified seven major types of waste (Muda in Japanese) or non-value-added activities in businesses and manufacturing processes (Liker and Meier, 2006) including:

1) Overproduction: Production of significant quantity over that which the customers require due to excessive work and stocking, which are also reasons for excess inventory.

2) Waiting: Workers wait for work at the next process and automatically work when materials arrive.

3) Unnecessary transportation or conveyance: Materials, parts, and finished products are moved unnecessarily during work processes.

4) Overprocessing or incorrect processing: Poor processing design causes over processing as does inefficient use of tools and machines.

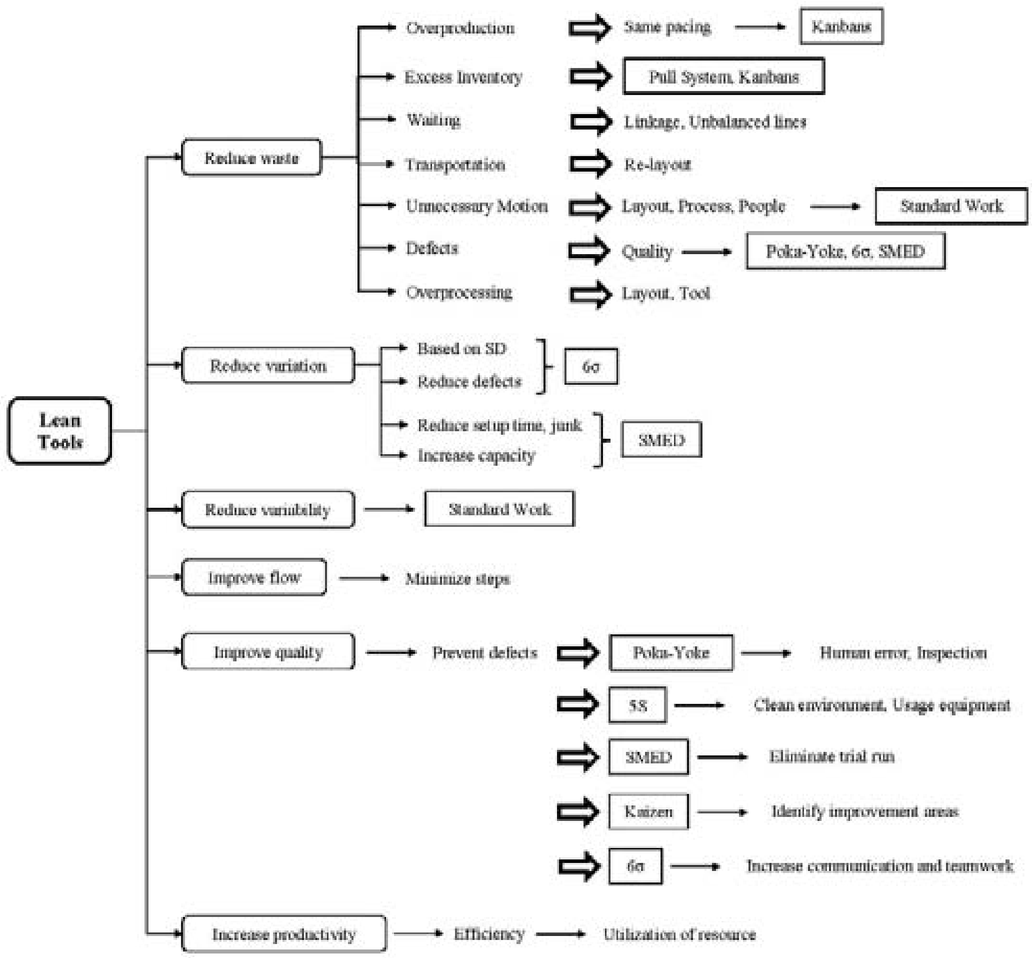


Figure 2.1 Lean tools chart

5) Excess inventory: Excess quantity of raw material inventory effects lead time, as does the lateness of material supply, improper production or equipment break down.

6) Unnecessary movement: Employee activities during their work that do not contribute to productivity of the assembly, for example, walking and looking around.

7) Defects: Inspection, changing production or redoing work which results in wasted of time.

Furthermore, a value-added activity is defined as an activity that adapts materials and information to meet customer requirements.

2.4.2 Lean concept

Lean concept is well-known and used to improve the working process by reducing time wastage and improving process performance (Locher, 2008). Koskela (1997) put forth a new production philosophy that combines three existing concepts (Koskela, 1992) in terms of 1) tools like “Kanban”, 2) manufacturing like “JIT” (Just-In-Time) and 3) general management like lean production. These include:

1) Reducing non-value-adding activities.
2) Increasing the system output value by adding customer requirements.
3) Reducing variability.
4) Reducing cycle time.
5) Simplifying by minimizing the number of work stations, parts or assemblies, and links.
6) Increasing output flexibility.
7) Increasing processing.
8) Focusing on complete process control.
9) Creating continuous improvement of processes.
10) Balancing flow improvement with conversion improvement.
11) Benchmarking.

Lean production is a philosophy for reducing the amount of waste in a company’s production and can also be applied in the construction field. This philosophy focuses on implementing a method like just-in-time delivery at the construction site and without simultaneous or multifunctional task groups (Melles, 1997). Moreover, the application of lean production theory in a construction project incorporating the design and construction process can be beneficial because increasingly complex projects are the cause of great uncertainty. Importantly, a construction project is similar to the product development phase in manufacturing, although the flow management in construction is more difficult because there are more uncertainties to be overcome and parts required (Howell and Ballard, 1997).

Abdelhamid (2004) explained that lean production is a production philosophy which reduces the working time of an existing process and can eliminate waste while increasing customer demand. In addition, Maclnnes (2002) supported using this system which he described as saving time lost from over working and improper worker or material usage by including techniques and methods to reduce production costs and lead time.

2.4.3 Value stream mapping

Value Stream Mapping (VSM) encompasses three main meanings namely 1) Value, which is demonstrated in budgetary terms (Pryke, 2009), 2) Value Stream, which is the aim of lean construction in that it supports systematic waste elimination and the development of value creation (Arbulu and Tommelein, 2002); moreover, it implies overall global improvement as explained in the book “Learning to See”, and outlines a process that considers the flow from a requisition point to all processes after the product or service is done and provided (Rother and Shook, 1999), and 3) Value Stream Mapping, which is widely used, but in manufacturing, has been changed to focus on the lean practitioners, as well as improvement for better techniques concerning the system and output. Therefore, VSM is described as a process mapping tool which monitors both process flow and communication within that process or value stream (Nash and Poling, 2008). Furthermore, VSM includes improvements for both material flow of production and information flow from the customer through to the production process (Arbulu and Tommelein, 2002). Finally, VSM is a tool that can be used to illustrate the process flow by separating the process into steps and calculating their working times.

Furthermore, Cudney (2009) explained the benefits of VSM which are:

1) It increases understanding of an entire process more rather than a single process.

2) It utilizes a common display of a manufacturing process which can combine lean concepts and VSM techniques as well as being a tool to provide linkage between information flow and material flow.

In addition, VSM provides a platform which is applied with various lean principles and tools and creates a plan to follow for implementation.

Locher (2008) created the value stream mapping process below, and suggested steps to assess both current and improved processes.

- Preparation - identify product or project to study, and how it will be mapped
- Current process - agree on a well understood map of the current process
- Improved process - agree on a shared vision for the lean improvement process
- Implementation - develop a plan to achieve an improved process

Steps of the current process:

1) Identify current factors such as lead time, current production rate of process, and variability.

2) Identify the main processes such as the level of detail and process the data boxes.

3) Select process metrics for the data attributes of process time, number of worker, lead time, waiting time, and inventory.

4) Perform the value stream and fill in the data boxes.

5) Calculate the value stream using the lead time, waiting time, and cycle time of the current process.

Steps to an improved process:

1) Calculate the Takt time to determine the requirements.

2) Check performance.

3) Identify processes which create values or wastes.

4) Find interruptions in the work flow and control them by using the pull production system.

5) Define the necessary improvement processes.

Rother and Shook (1999) and Hopp (2003) provided several definitions of process capacity rate and other parameters as follows:

1) Takt time is calculated by dividing working time available and customer demand.

2) Capacity: A maximum rate of work which flows through the process.

3) Utilization: A rational input rate for a process with capacity.

4) Bottleneck: The highest utilization of the process.

5) Process flow: Sequence of processes and inventory stock that pass through processing.

Process time is categorized into various types and consists of components which Locher (2008) defined as the following

1) Lead time: Time starts from entry until completed and out of the process.

2) Process time: Actual working time from the beginning until the end of production, which gets measured by process monitoring or staff estimation.

3) Process inventory: Excess lead time.

Cycle time is the starting time from when raw materials are inputted into the process until the final product is shipped to the customer, including defect time or time wasted in production (Hopp, 2003).

Cycle Time = Process Time + Waiting Time (Koskela, 1992)

Maclnnes (2002) explained that under the push system, materials are automatically moved from one station to the next, but materials for the pull system are only shifted when the next station requests them. The pull system is a controlling method of post activities which depend on previous activities; however, this system has the capacity to eliminate overproduction (Locher, 2008). Maclnnes (2002) explained the difference between push and pull systems stating that the push system produces and hands the product downstream which will be stored there and causes excess inventory; on the other hand, the products in the pull system will only be produced when the processes downstream request them. The advantages of a pull system are as follows:

- It reduces the working time in non-value-added activities such as waiting time and transporting time
- It reduces downtime from equipment adjustments
- It eliminates inspection requirements or material rework

Nash and Poling (2008) described the pull system as using many tools and provided other definitions as well, such as:

1) Kanban: A signal of work-in-progress (WIP) and the inventory requirements are provided to the employees who use them in value stream mapping. Moreover, Maclnnes (2002) said the Kanban system can prevent overproduction which is the largest source of waste in manufacturing and also outlined a general guidelines for using the Kanban system as:

- Upstream processing never sends flawed parts to the downstream processing
- Downstream processing takes only what it needs from the upstream processing
- Upstream processing produces the exact amount of products that will be taken by the downstream processing

- Synchronization of production is achieved by maintaining machines

- The Kanban system is a way of fine-tuning the amount of production

- Work is designed for stability and the improvement of the production processes

2) Supermarkets: An inventory controller which incorporates a maximum level of Kanban usage. Maclnnes (2002) defined steps of the supermarket system as follows:

- The process of manufacturing parts which are stored at a marketplace and for which production will stop when the marketplace is full

- Downstream processing requests materials from the upstream processing when it needs them

- Material transportation responds to one process which flows downstream

3) First-In-First-Out (FIFO): A lane ensures that products are completed before moving them to the next step, thus there is no need to wait.

4) Waiting time: Amount of processing time that has no flow.

5) Process: A series of activities that create results, products, and services.

Moreover, Cudney (2009) explained that material requirements planning (MRP) is a system of material supply to determine quantities and times such as production schedules, bills of materials, or inventories.

Production is material and information flow which starts at the raw material stage and continues to the end product. It involves feeding into the processing line by moving or waiting at the first station. When material comes to be processed, it is subject to several activities including inspection, movement, and waiting for the next process (Koskela, 1992).

Furthermore, Taghizadegan (2006) provided more definitions including:

- Variation - the high level of reason to affect rejected of reworked activity. Wilson (2010) defined this as the differential output of the process
- Velocity **-** the speed of product order to input into the process

Finally, Alarcon (1997) defined performance elements such as effectiveness, efficiency, productivity, and variability as follows:

- Effectiveness is a measurement of the correct quality, quantity, objective, and activity in terms of time
- Efficiency is a measurement of utilization of resources by calculating the difference between expected consumed resources and actually consumed resources
- Productivity is the ratio between output and input, mainly in terms of cost
- Variability is deviation from the target such as schedule and performance

2.5 Supply Chain Model

Beamon (1998) defined a supply chain as a process of the manufacturing field composing of raw material transformed into the finished product. The supply chain model was created and categorized by O'Brien, et al. (2009) and is detailed as follows:

1) Reduce product lead time (Eliminating or combining activities):
    - Identify the number of processes

- Identify the time usage of each process (Conversion and flow)
- Classify each process performance (Value-added or non-value-added)
- Simplify processes (Eliminating non-value-added activities, relocating inventories, consolidating points for distribution)

2) Evaluate the effect of capacity:

- Inventory behavior
- Lead time
- Throughput (Amount of work done in a particular period of time)

3) Model goal and metrics:

- Lead time reduction

Metrics: Processing time, engineering time, assembly time, delivery time

- Reducing inventory buffers in a production factory

Metrics: Number of items in stock, average waiting time, average inventory turnover, installation demand rate

2.6 Application of Lean Concept

According to previous studies, there are many applications of lean production principle that can be used to reduce waste in the construction field. For instance, studying the construction process flows is composed of examination, determination, and identification of waste in construction using lean principle (Leng, 2004).

For the manufacturing field, lean concept is used to identify an opportunity in the cycle time, and decreased order processing or planning before the work begins. Also, supply chain metrics can be used as a case study, including analyses of order data in the pre-engineered metal market. Not only can it be used with supply chain of management practices but it also applies to lean production. As a result, a manufacturer realizes additional improvements in areas such as batching, transparency, synchronization, production balancing, alliance, horizontal integration, process maps, and the array of products produced (Akel et al., 2004).

2.7 Application of Value Stream Mapping

There have been numerous research studies conducted to solve or evaluate problems of wastage in construction by value stream mapping. For instance, identifying the amount of waste in the supply chain of pipe support starts from total lead time reduction along with design, procurement, fabrication, and engineering. Then, it would follow the supply chain configuration analysis. It is also used for performance improvement which is based on the flow attitude rather than the activity attitude. Therefore, the results of the pipe support study provide two conclusions. The first is that there is non-value-added work or time wastage of more than 96% in the supply chain of the pipe support, and the second is that there is a need for supply chain improvement. It is implied that early supplier identification is needed to provide raw materials for the engineering design, clear communication is needed to standardize processes, and merged supply chains to the site are needed for performance improvement (Arbulu and Tommelein, 2002).

Abdelhamid (2004) identified VSM as consisting of value-added and non-value-added processing time and working duration which is recorded, as well as time delays with all stations requiring transformation of inputs to outputs. The steps of VSM are as follows:

1) Create value mapping.
2) Identify improvement opportunities.

3) Adjust process location.

4) Develop a working process to implement.

5) Define performance metrics.

Areas of value stream mapping creation should focus on production activities, material flow, customer value, push system, pull system, takt time, and lead time (Maclnnes, 2002).

2.8 Process Improvement

Process improvement involves some parameters, concepts and methods explained by Maclnnes (2002) including:

1) Improving quality starts with understanding customer requirements, then designing a process which conforms to the requirements. Steps of quality improvement are as follows:

- Understand customer requirements
- Review characteristics of product design
- Review process metrics
- Identify error areas that cause defects in products
- Conduct activity problem-solving
- Apply techniques to prevent defects re-occurring
- Establish performance metrics to evaluate solutions

2) Eliminating waste includes the following steps:

- Identify the product or process that is inefficient
- Identify existing processes which have poor performance or require improvement

- Create a process map from the value stream mapping for review

- Review the value stream mapping and establish lean metrics to identify the working station and frequency of the waste of each station. “Lean metrics” are measurements of progressive monitoring which relate to data collection

- Solve problems by using lean principle to reduce or eliminate waste and review the waste association of each station

- Repeat this process with other inefficient working activities

3) Reducing lead time is the most effective way for waste and cost reduction. Lead time is divided into three basic components such as the cycle time, batch delay (the time a service operation or product unit must wait while other activities are completed), and process delay (waiting time for one station to finish before the next station can begin). The steps of lead time reduction are similar to waste elimination which has been explained in a previous study.

In a prior study of process improvement measurement, Yu, et al. (2009) developed the lean model for house construction by using value stream mapping and presented methods of data collection, current process mapping, existing analysis and lean metrics development, as well as formulation of a lean production model. Measurement results were calculated resulting in a total working construction day reduction of 27 days, percentage of waiting time decreasing from 76% to 65%, and value-added ratio increasing from 17% to 26%. As a result, it can be seen that VSM can offer process improvement and restructuring of the production system as well as support a practical approach to construction.

2.9 Simulation Model

Alves and Tommelein (2004) examined the interface detailing-fabrication-installation of HVAC ductwork and ran a simulation model using the STROBOSCOPE program to improve understanding, as well as to investigate different scenarios including behavior and output of working processes, and the lead time of the pull system. Results of this simulation showed improvement in lead time and an increase in the working process, but a decrease in throughput, thus implementation failed regarding the pull system.

CHAPTER III

RESEARCH METHODOLOGY

This chapter presents the details of research methodology and modeling process. This research consists of five steps: conduct a literature review, collect data to create models, analyze the model to improve the process, verify the process improvement by simulation, and conclude the research. Last four steps of research methodology are formed into modeling process which consist of five sections: explore process waste, create data collection format, establish method of data collection, collect and transform data, and create model mapping and improvement.

3.1 Research Steps

1) Conduct a literature review

    - Review definitions, concepts, theories, and previous research results related to waste, lean concept, value stream mapping, and process improvement which support each work activity
    - Investigate model creation and data collection methods
    - Study general information of steel box girder fabrication (SBGF) such as resources, assemblies, activities, and working time

2) Collect data to create models

    - Interview personnel in charge of data collection and waste in working activity
    - Create product metrics of box girder assembly for working activity

- List all data to be collected and create data collection format in the terms of table
- Explore and record working data from an actual process
- Classify all data for each assembly and working activity

3) Analyze the model to improve the process

- Summarize working time data by averaging terms of deterministic data with uniform distribution or PERT (Program Evaluation and Review Technique) formulas for subjective data
- Input all data into current process maps by value stream mapping and calculate process times, waiting time for each activity and cycle time of the whole process
- Calculate percentage of utilization and other variables such as coefficient of variation (CV) and capacity rate, and identify bottleneck activity
- Select critical path of the process
- Identify the time waste in working activities and then group it into seven types according to waste definitions
- Apply lean concept to transform existing processes into an improved process by identification of process changes with kaizen burst. Calculate new process time and waiting time, and eliminate bottleneck
- Map an improved process by value stream mapping and recalculate new overall cycle time
- Calculate different percentages of process time, waiting time, and cycle time between the current process and the improved process and analyze results

4) Verify the process improvement by simulation

- Define current and improved process case scenarios of various adjusted processes
- Create a simulation model using STROBOSCOPE, discrete event program and trial different case scenarios
- Summarize results of each case scenario and analyze
- Select a suitable case from trial case scenarios
- Create improvement process guidelines from selected simulation cases

5) Conclude the research

- Suggest an improved process to personnel in charge of the factory and offer some opinions and responses
- Conclude all analysis results from calculations and simulations

For last four steps of research methodology, they are established into process model for analysis which will be explained in the next section.

3.2 Modeling Process

3.2.1 Explore process waste

Regarding general SBGF considerations, the origin of problems and modified points are considered parameters for adjustments and improvements to increase efficiency. Hence, process details should be explored to comprehend mistakes. This should include the following variables.

1) Work processes consist of various steps which these steps are called activities, and work areas are called stations, depending on the process designation. For example, to start, raw materials are fed into the fabrication line for

preparation and after that are shifted or moved to the next station. For this reason, every activity should be examined by inquiry or interview with the personnel in charge to gain more experience in the same field as it involves judgment about optimal or adjusted activity. Implied working activities are similar to waste identification and include unnecessary movement or incorrect processing according to the initial process design. The waste concept was theorized about by Liker and Meier (2006), the results of which are related to capacity of resource usage.

2) Material flow is raw materials input into the system and transformed by the working activities to create part of the finished product assembly. Many kinds of raw materials are supplied to various stations. Therefore, over-feeding of raw material or excess inventory (Liker and Meier, 2006) of raw material and the assembly are factors to improve.

The two major factors outlined above are effective influences which are recorded in terms of primary data, which will be explained in the next section.

3.2.2 Create the format of data collection

Data formulation consists four major information groups and the data collection format is summarized as follows:

1) Product data relate to the type and quantity of commodities produced, including the number of parts and assemblies involved in SBGF.

2) Working activity comprises many patterns and various product components of each activity, hence all data should be separated for convenient gathering.

Furthermore, the relationship between product data and working activity displayed in terms of product metrics.

3) Working duration is working time per activity, which is divided into two categories, namely actual working time and waiting time.

- Actual working time comprises fabrication time of SBGF, called process time (Locher, 2008) or value-added time

- Waiting time is nonproductive time, for example, workers and machines available wait for raw materials or assemblies to be fed to stations, which is described in terms of time waste or being non-value-added (Nash and Poling, 2008)

4) Workers and machinery performing to production rate depends on the quantity of workers and machines as earlier stated. Data collection involves recording process times and is separated into activity for part of the assembly to determine production rate of workers and machines.

3.2.3 Establish method of data collection

1) All documents should be prepared for actual data collection as earlier mentioned.

2) Interviews with personnel in charge can be used to summarize preliminary production rate since they have more experience with the working process and are able to estimate working time in terms of maximum, minimum, and mode value. All data will then be accommodated in the next analysis and all outputs will be simplified as a deterministic function.

3.2.4 Collect and transform data

Data collection of working processes is used to analyze and improve the process, which begins with feeding raw materials into the production line and ending the finished output. The significant characteristics of this procedure are explained below.

1) Collect data

- Data collection components consist of working steps involving product assemblies which pass through all activities. Initial time counting starts with raw materials being fed into the first station until they pass though the final station. Records are made in terms of dates and times

- Volume and detail of the data collected do not correlate with productive quantity, but provide representative information of the group. As a result, it is only necessary to obtain data with sufficient detail to be considered appropriate for analysis and relied upon for analysis of procedures. Furthermore, the level of detail depends upon the duration of various activities, which can be either long or short, and also using the appropriate scale. Data recording of ordinary SBGF comprises working time per activity, amount of product, manpower, and machinery. However, this research selected the fabrication process which fits steel plates together for SBGF production in a factory and collected a working time of box girder assemblies for the case study

Actual data collected of the process, called primary data, is not possible for this study, therefore, secondary data is used for the analysis in the next section.

2) Transform data

Data collection of various identical outputs is necessary for precision analysis, therefore, primary data should be converted into averaged values and mean and standard deviation determined by calculation. Some data can be summarized or grouped as a single dataset for easy analysis.

3.2.5 Create model mapping and improvement

This section concludes with data summation of model analysis and improvement which consist of four subsections.

1) Create model mapping

After data transformation, the entire process is mapped and data is inputted into the model for monitoring or compiling, as mapping tools would provide reliable information. However, these tools, for example, Value Stream Mapping (VSM), Critical Path Method (CPM), Line of Balance (LOB), etc. have both advantages and disadvantages along with different constraints. Therefore, tool selection should suit the data collection and improvement methods. In addition, clear display and convenient calculations are considered. This research selects value stream mapping to illustrate the fabrication process and quantify process time and waiting time.

2) Analyze data

Using model mapping, the counted cycle time of each activity is displayed as working performance. Afterwards, important parameters such as capacity and bottle neck are initially calculated. This research determines data into two processes - the first is the current process (existing process) and the second is the improved process.

3) Improve system

The process improvement method consists of determining percentage of utilization for working activities and adjusting process with lean concept by lean tools, for example Six Sigma, Standard Work, or Poka-Yoke. Concern parameters comprise of process time and waiting time which they will be reduced and also applied to create guidelines for process improvement.

4) Verify results

After improvement, the results such as process time and waiting time reduction are implemented in an actual process which followed process improvement guidelines for implementation in the factory. Nevertheless, this method requires more investment cost and time to verify the results, therefore, another method should be used instead. This research selects a simulated model using the STOBOSCOPE program to represent improvement in the factory.

In this case study, for model mapping creation and process improvement, the above methods are applied to ordinary processes.

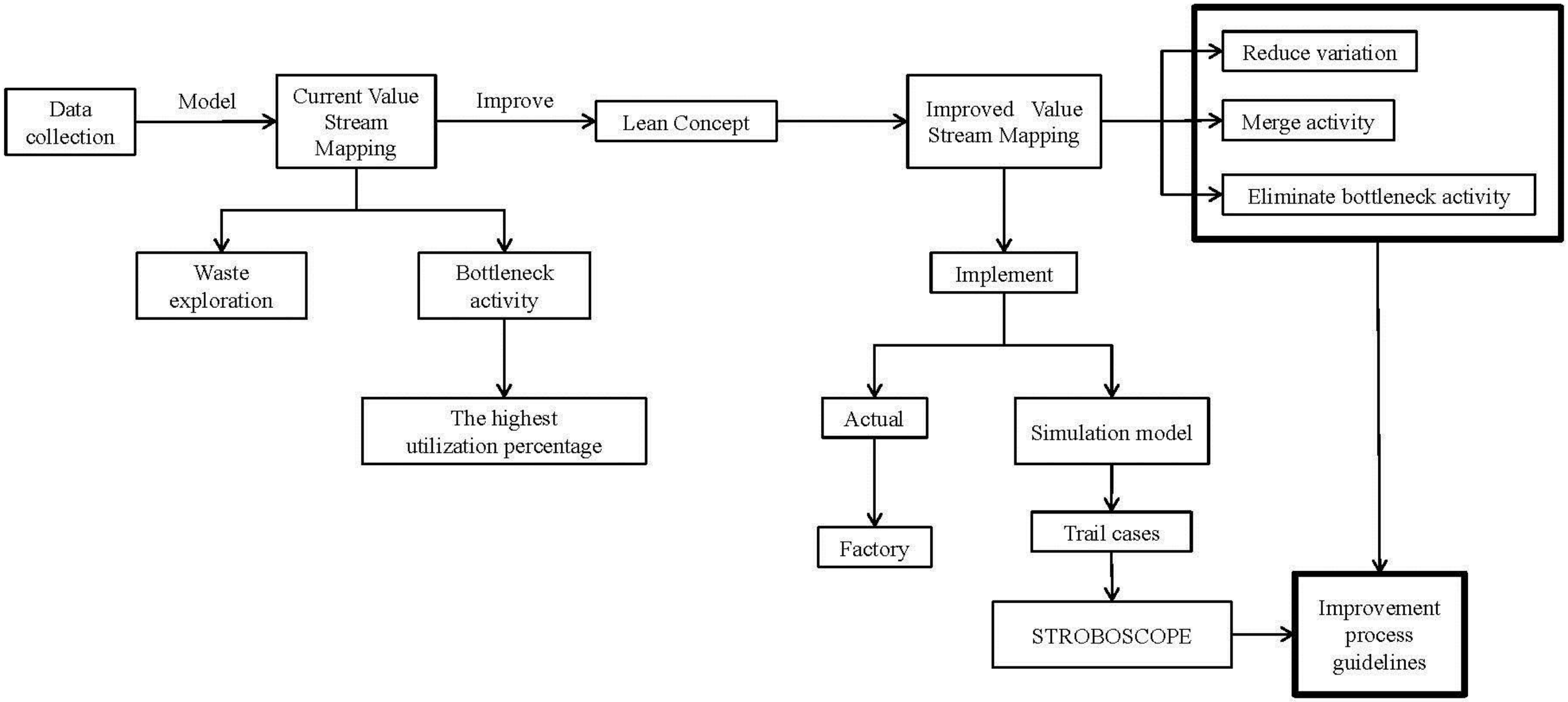


Figure 3.1 Research steps

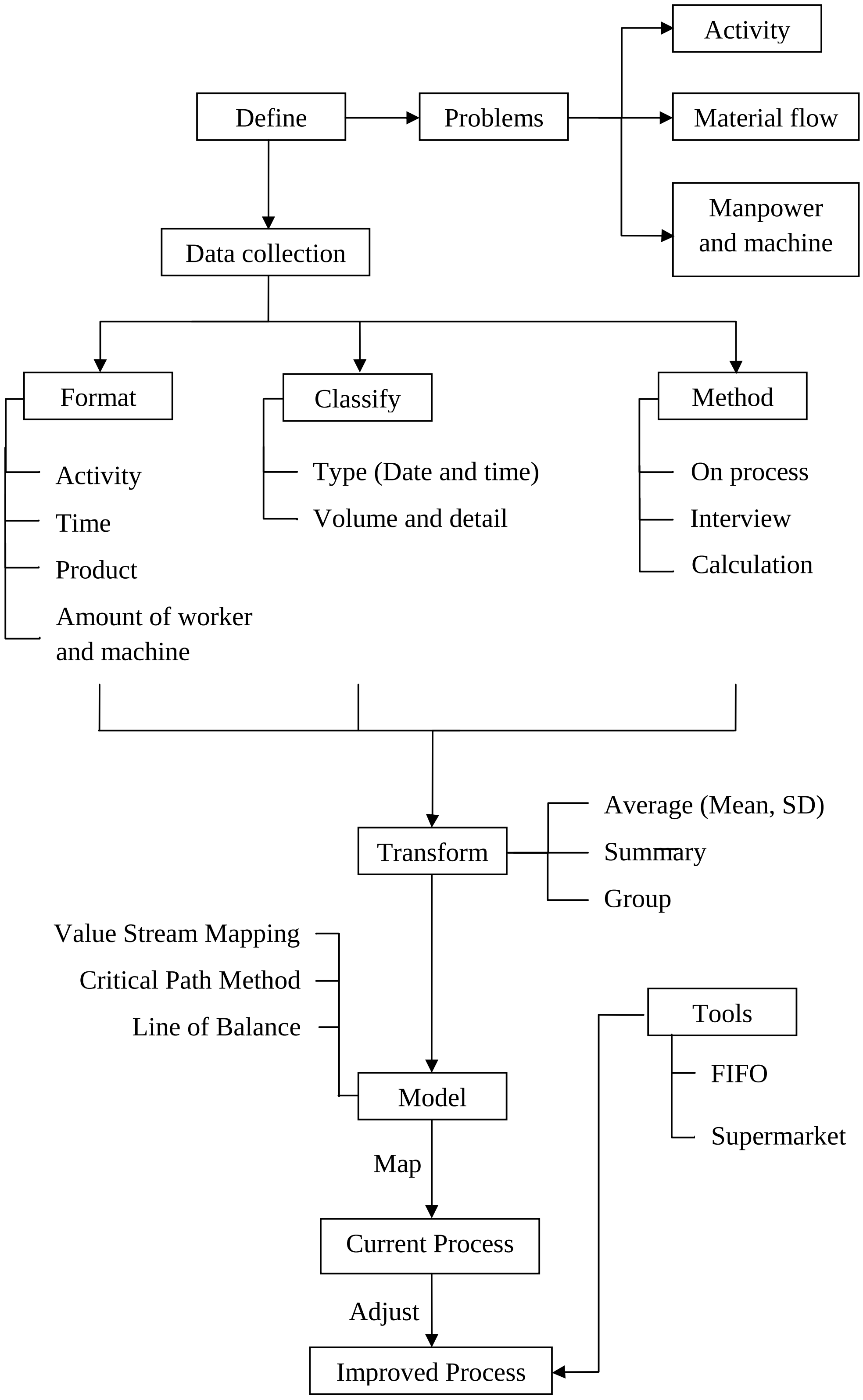


Figure 3.2 Methods and modeling of process improvement

3.3 **Summary**

This chapter describes research steps regarding how to collect, summarize, analyze, and verify data and draw conclusions as seen in the flow chart in Figure 3.1. Most steel box girder fabrication (SBGF) or general processes have compounded problems including raw material usage, manpower and machines, production performance and also time waste. Moreover, the conclusions include many process improvement steps such as problem indications, data collection for analysis, adjustment methods and developments as shown in Figure 3.2. The research procedures applied in the case study will be explained in the next chapter.

CHAPTER IV

ANALYSIS OF STRUCTURAL STEEL FABRICATION PROCESS FOR BRIDGE PROJECT

This chapter explains the details of steel box girder fabrication (SBGF) including raw materials and components, activities, manpower and machines, work stations, as well as working time duration. Working activities and areas are divided into three zones: internal factory, external factory with roof covering, and outdoor space. It then examines a project in Thailand as the case study. The project comprises 18 total work stations: 13 stations located inside the factory, two stations outside the factory with a roof covering, and the remaining in an open-air area. Figure 4.1 depicts these working locations.

4.1 Dimension and Components of Steel Box Girder

Steel box girders have various characteristics depending on the design function which conforms to stated methods of erection. This project was designed for 10 box girders per side and jointed together for a total of 20 box girders. Each box girder is trapezoid-shaped and approximately similar in size with an average width of 3.30 meters, maximum of length 30.00 meters, and height of 2.16 meters (see Figures 4.2 and 4.3). Table 4.1 provides the name and all physical characteristics of all 20 box girders.

Each steel box girder comprises nine parts (i.e., bottom, left-top flange, right-top flange, left-web flange, right-web flange, diaphragm, left stiffener, right stiffener, and bracing part). They are constructed from raw materials and with various thicknesses of steel plate. Only the bracing part is steel shape. The details of all components are as follows:

1) The bottom is steel plate with thicknesses of 32, 40, and 50 millimeters consisting of 3-7 pieces welded together, and the part under the box girder

is connected with web flanges at both side edges and a diaphragm at the middle or end of the bottom plate.

2) The left and right top flanges are steel plate with thicknesses of 25 and 32 millimeters consisting of 3-5 pieces welded together and connected to the web flange to form a t-shape at each side edge of the box girder.

3) The left and right web flanges are steel plate with a thickness of 16 millimeters consisting of 3-4 pieces welded together at both the left and right edge of a box girder and connected to the bottom and top flange at the bottom and top of the box girder positions, respectively. These are also perpendicularly jointed with a stiffener through the length.

4) The diaphragm is a single trapezoid-shaped steel plate with thicknesses of 20 and 32 millimeters at center or end of the box girder, and is connected to the bottom and the web flange at the bottom and both sides of the box girder positions, respectively.

5) The left and right stiffeners are small steel plates with a thickness of 16 millimeters consisting of 7-17 pieces perpendicularly welded to each web flange.

6) The bracing is a square steel tube consisting of 16-26 pieces, located in a diagonal direction between the top and web flanges, and tightened by welding with the gusset plate.

The assemblage of the box girder is depicted in Figure 4.3, and each component is defined by the following terms.

- "Part" is a small component which is built from raw materials by the cutting and consists of nine types as earlier mentioned. The number of parts is shown in Table 4.2

- "Assembly" is a combination of a few parts joined together by butt joint welding up to a total of five parts such as bottom, left-top, right-top, left-web, and right-web

- "Box girder" is combination of all assemblies together by butt joint welding.

4.2 Structural Steel Fabrication Area

The work area of SBGF can be divided into two main zones.

1) The interior factory consists of particular and fixed location machines distributed throughout the factory which raw materials being fed to the processing line instead of machines moving. The interior spaces can further be split into two sub-factories:

- The part-preparation factory organizes raw materials like steel plate into parts including bottom, top-flange, web-flange, diaphragm, and stiffener. In addition, steel shape is the bracing part. All raw materials are transferred into the manufacturing process such as cut, taper, and drill activities, which are illustrated in Figure 4.4. Furthermore, piece marks are both integer and alphabet sign indicating the direction of installation and part number which shows that it is a unique part of a small assembly SBGF, labeled at this location for transit to a nearby fabrication factory.

- The fabrication factory fits all parts together at a preparation zone and separates each by their dimensions before feeding them into the process. Because the previous activities are not produced parts for individual box girders, although they are only made of optimum raw material usage for steel plate cutting. The fabrication factory's activities include fixed work stations such as butt joint, assembly and weld t-shape, assembly and weld stiffener, assembly and weld block along with the finishing activity, as shown in Figure 4.5. All assemblies are input chronologically into fabrication lines, which conform to fabrication plans and allowing the box girder to be set up. After completion of the box girder block, it is taken to an outside factory for other activities.

2) The exterior factory is an outside area which comprises both a roof covered area and an outdoor space. They are explained below.

- The roof covered area is an open space with a roof covering for blast and paint activities because these activities require rain protection and good air flow

- The outdoor area is for two activities: trial assembly after finishing and packing of the finished product. Because of the considerable span length of the three box girders for the full scale trial assembly, a large space is required without height limitation (see Figure 4.6).

4.3 Structural Steel Fabrication Process

SBGF is executed both inside and outside fabrication factory and associated with product metrics, as shown in Table 4.3. Fabrication process comprises a number of activities such as cut, taper, drill, butt joint, assembly, weld, finish, trial assembly, blast, paint, pack, and transport as shown in Figure 4.7.

1) The cut activity is an initial step of feeding in steel plates which will be shaped through a CNC (Computer Numerical Control) machine. It is specifically used for steel plate and conforms to early arrangement of material cutting orders. In addition, the cutting plan is set according to the steel plate thickness and joined with subordinate assemblies of raw materials sized 4x8 square feet. They are set to produce the least scrap and not grouped production as the same box girders, but also lined up with many identical parts of steel plate (see Figure 4.8a). In addition, the raw material of bracing assembly is cut using a band saw because the shape includes angles and square tubes. The cutting steps consist of:

- Lifting the steel plate from the stock area to the CNC machine by internal gantry crane

- Inputting the cutting plan data into the machine and operating it. After, the finished parts are taken to a storage space

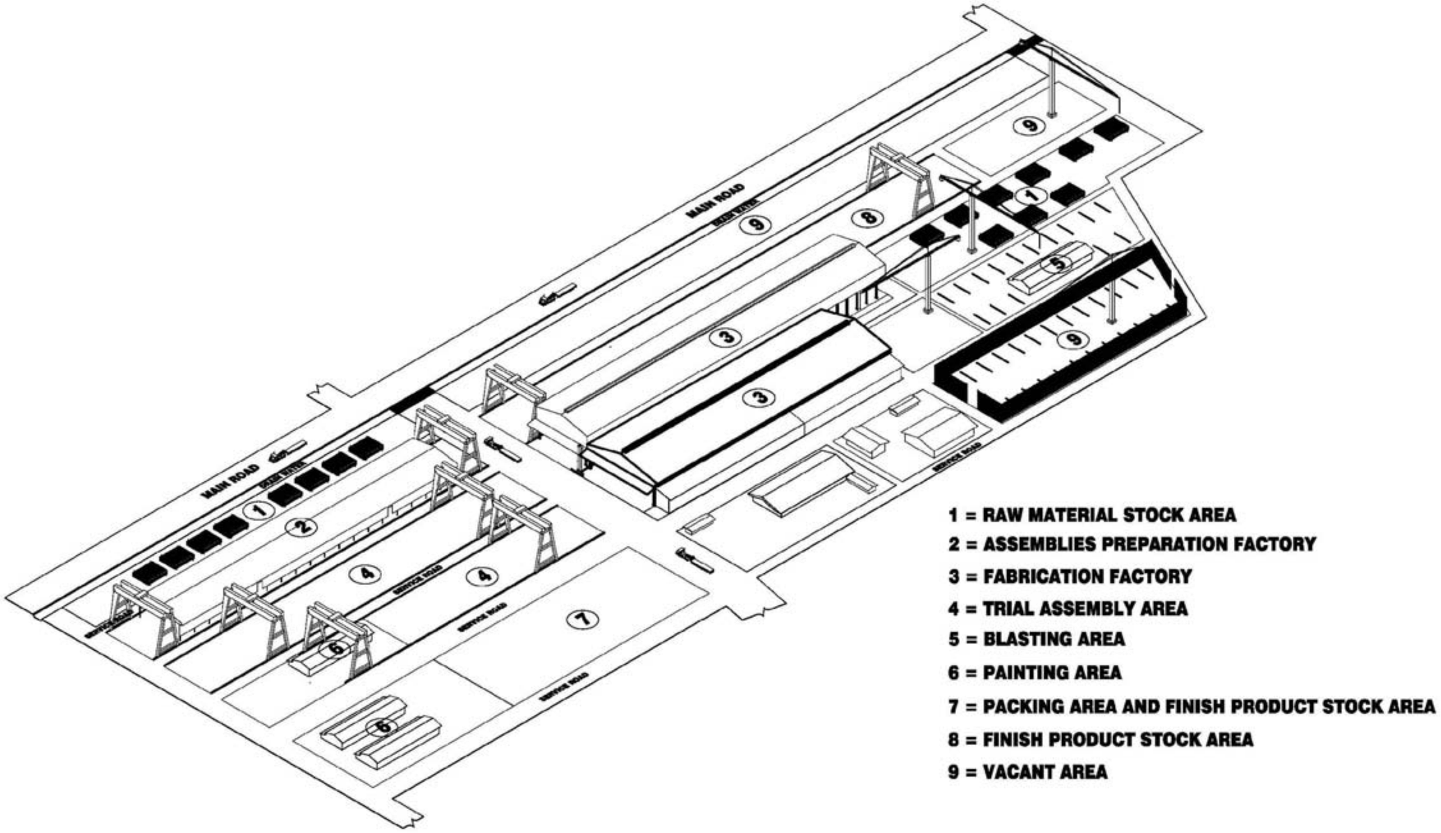


Figure 4.1 Fabrication area layout

2) The tapering activity is the secondary step, which trims the steel plate edge to increase the welding area. Then the butt joint is welded. The tapering steps consist of:

- Setting the taper alignment throughout the trimming plate width (see Figure 4.8b)

- Smooth rubbing the steel plate edge by hand buffering (see Figure 4.9)

3) The drill activity encompasses a variety of parameters based on the hole diameter and plate thickness, and includes time spent on other activities as well. The station comprises both large and hand machines. The working steps include:

- Using a drawing template with hole patterns to cover the assembly and mark the drilling positions (see Figure 4.10a)

- Laying parts on the drilling machine or pallet to prepare for work and drilling with lubrication at all times (see Figure 4.10b)

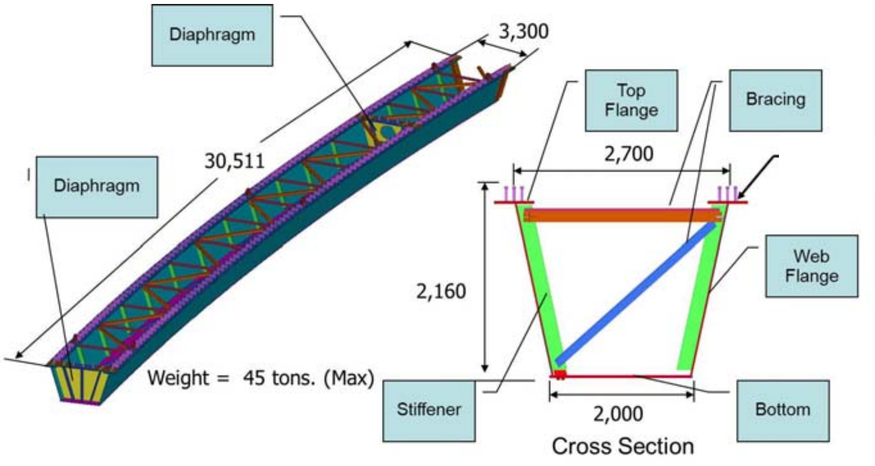


Figure 4.2 Box girder cross section and longitudinal dimension

Figure 4.3 Steel box girder

Table 4.1 Dimension, weight, volume, and name of all box girders

No.	Box Girder Name	Width (m)	Length (m)	Height (m)	Volume (m^3)	Weight (Ton)
1	S5A1	3.100	26.022	2.160	204	32.589
2	S5A2	3.100	26.111	2.160	205	32.654
3	P4A1	3.100	21.278	2.160	172	27.055
4	P4A2	3.100	21.180	2.160	172	26.963
5	S4A1	3.100	27.789	2.160	225	35.334
6	S4A2	3.100	27.603	2.160	223	35.139
7	P3A1	3.100	24.160	2.160	195	31.579
8	P3A2	3.100	24.022	2.160	194	31.419
9	S3A1	3.100	30.511	2.160	254	39.881
10	S3A2	3.100	30.371	2.160	253	39.723
11	S3B1	3.500	28.540	2.160	265	44.403
12	S3B2	3.500	27.464	2.160	255	42.907
13	P3B1	3.500	27.616	2.160	256	42.966
14	P3B2	3.500	26.649	2.160	247	41.634
15	S4B1	3.500	24.027	2.160	212	37.066
16	S4B2	3.500	22.800	2.160	201	35.394
17	P4B1	3.500	27.677	2.160	257	42.697
18	P4B2	3.500	26.496	2.160	246	41.131
19	S5B1	3.500	28.381	2.160	263	40.721
20	S5B2	3.500	27.156	2.160	252	39.105

Table 4.2 Number of parts

No.	Box Girder Name	Number of Parts									Total
		BT	TL	TR	WL	WR	DI	SL	SR	BR	
1	S5A1	3	3	3	3	3	6	11	11	21	64
2	S5A2	3	3	3	3	3	6	11	11	21	64
3	P4A1	4	3	3	3	3	5	12	12	16	61
4	P4A2	4	3	3	3	3	5	12	12	16	61
5	S4A1	4	3	3	3	3	-	10	10	26	62
6	S4A2	4	3	3	3	3	-	10	10	26	62
7	P3A1	4	3	3	3	3	5	13	13	21	68
8	P3A2	4	3	3	3	3	5	13	13	21	68
9	S3A1	4	3	3	3	3	8	12	12	24	72
10	S3A2	4	3	3	3	3	8	12	12	23	71
11	S3B1	5	3	3	3	3	7	8	8	22	62
12	S3B2	5	3	3	3	3	7	8	8	22	62
13	P3B1	7	5	5	4	4	5	17	17	25	89
14	P3B2	7	5	5	4	4	5	17	17	26	90
15	S4B1	4	3	3	3	3	-	7	7	20	50
16	S4B2	4	3	3	3	3	-	7	7	20	50
17	P4B1	7	5	5	4	4	5	16	16	23	85
18	P4B2	6	5	5	4	4	5	16	16	23	84
19	S5B1	5	4	4	3	3	7	9	9	23	67
20	S5B2	5	4	4	3	3	7	9	9	22	66
Total		93	70	70	64	64	96	230	230	441	1358
Max		7	5	5	4	4	8	17	17	26	
Min		3	3	3	3	3	5	7	7	16	
Mean		4.65	3.50	3.50	3.20	3.20	6.00	11.50	11.50	22.05	
SD		0.67	0.33	0.33	0.17	0.17	0.50	1.67	1.67	1.67	

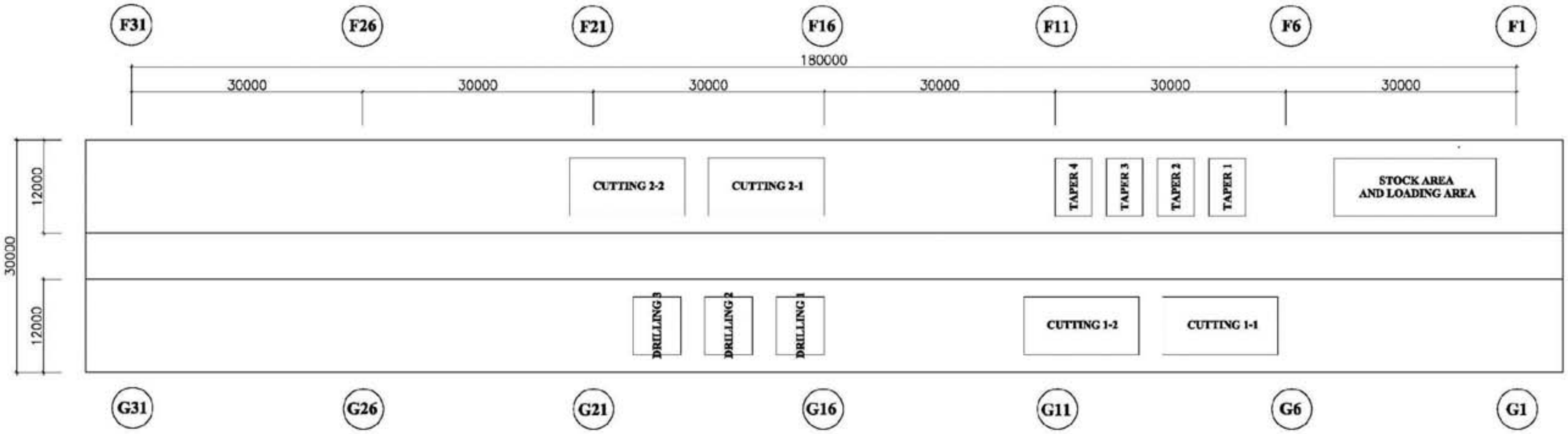


Figure 4.4 Assembly preparation factory plan

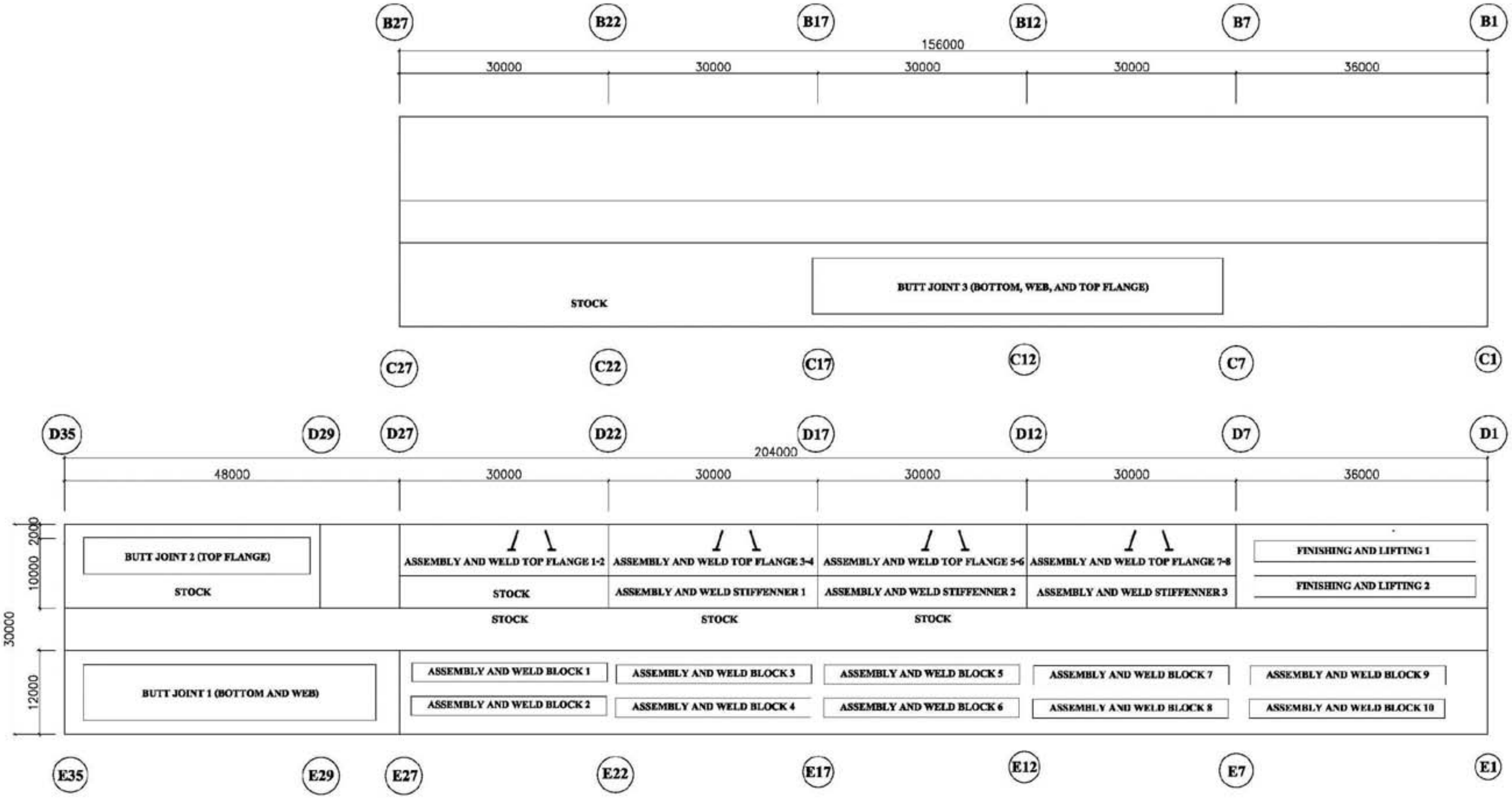


Figure 4.5 Fabrication factory plan

Figure 4.6 Trial assembly of three span length box girders

Table 4.3 Production metrics

Item	Part	Activity																		Total Activities
		CT	TP	DR	BJ	AT	WT	AS	WS	AB	WB	DM	FN	LF	TA	BL	PA	PC	TS	
1	BT	x	x	x	x	-	-	-	-	x	x	-	-	-	-	-	-	-	-	6
2	TL	x	x	x	X	x	-	-	-	-	-	-	-	-	-	-	-	-	-	5
3	TR	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	5
4	WL	x	x	x	x	x	x	-	-	x	x	-	-	-	-	-	-	-	-	8
5	WR	x	x	x	x	x	x	-	-	x	x	-	-	-	-	-	-	-	-	8
6	DI	x	-	-	-	x	x	-	-	x	x	-	-	-	-	-	-	-	-	5
7	SL	x	x	-	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-	6
8	SR	x	x	-	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-	6
9	BR	x	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-	3
10	WH	-	-	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	8
Total Parts		9	7	5	5	5	3	2	2	7	7	1	1	1	1	1	1	1	1	

Remark x Have activity - Not have activity

4) The butt joint activity is merging small parts such as the bottom, top and web flange into a larger assembly. Because the maximum length of steel plate is approximately 10 meters and the average box girder length is 30 meters, it is essential to weld the raw materials into a longer steel plate. The welding time depends on the steel plate thickness and width. The steps of butt joint welding are:

- Carrying parts from the same assembly line to the welding platform and welding following the manual as shown in Figure 4.11

- Polishing the welding line

5) The assembly activity is the combination of parts for box girder manufacture which consists of four shapes for fitting. Each shape consists of:

- T-shape (i.e., top and web flange) assembly (see Figure 4.12a)
- Stiffener with web flange assembly (see Figure 4.12b)
- Diaphragm assembly (see Figure 4.12c)
- Trapezoid-shaped assembly (see Figure 4.12d)

The steps of assembly are as follows:

- Lay down assemblies on temporary support by an interior gantry crane. Then the alignment and levels of dimensions are set with a level-measuring instrument. After that, the parts are locked with a steel splice.
- Weld a temporary pattern of assemblies.

6) The weld activity will be performed after the entire assembly of the box girder has already been set up and all the connection joints are united. Regarding the welding procedure, the web and top flanges (see Figure 4.13a), stiffener and web flange (see Figure 4.13b) are combined to make a box girder (see Figure 4.13c) using an electrode device, then ground to be a smooth steel surface.

7) The dimension and finish activities consider width, length, and height of the box girder including alignment and level of the completed box girder using a measuring camera. However, this activity can be completed by a representative owner checking before it is transferred to the next activity. Both activities are illustrated in Figures 4.14a and 4.14b.

8) The lift out activity is the last activity in the factory. The box girder will be moved to this area by an overhead crane, and then transported to the outdoor area by a trailer truck (see Figure 4.15a).

9) The trial assembly activity is a full scale mock-up of an actual erection in the outdoor space, and is also checked against the level and direction of the

bridge following the sequence and specifications. The trial assembly area is separated into two zones, including the stock area zone for finished box girders and the erection area zone. Because of the area limitation, the working steps cannot be trialed at the same time with all 20 box girders. Therefore, some box girders have to be lifted out to the erection area and released afterwards. The area is then available to set up the other box girders (see Figure 4.15b). All box girders will be erected at a maximum span length of three pairs (see Figure 4.15c). The erection method includes:

- Setting temporary support complying with the mock-up direction
- Lifting the box girder above the temporary support by an exterior overhead crane

10) The blast activity is the steel surface of the box girder being burnished by fine aggregate such as sand as shown in Figure 4.16a. Because the space of the area is limited, this activity consists of one work point and can support one box girder per trailer truck transit trip.

11) The paint activity consists of three layers of spray covering on the box girder surface. The painting area comprises the same four stations which can offer a maximum space of four box girders after blasting has finished. Because this activity requires a lot of drying time, it covers a large stock area. Figure 4.16b is an illustration of the activity.

12) The pack activity is carried out after the last coat of paint on the box girder surface has dried, thus allowing all the box girders to be shifted to the packing zone, which is situated not far away from the painting area. Normally the pack activity consists of packing components into boxes, but for this product, this cannot be done. Therefore, all box girders are stored using a particular method which involves putting the box girders in a vertical direction and tying them with wood and steel rods for safe transportation (see Figure 4.16c).

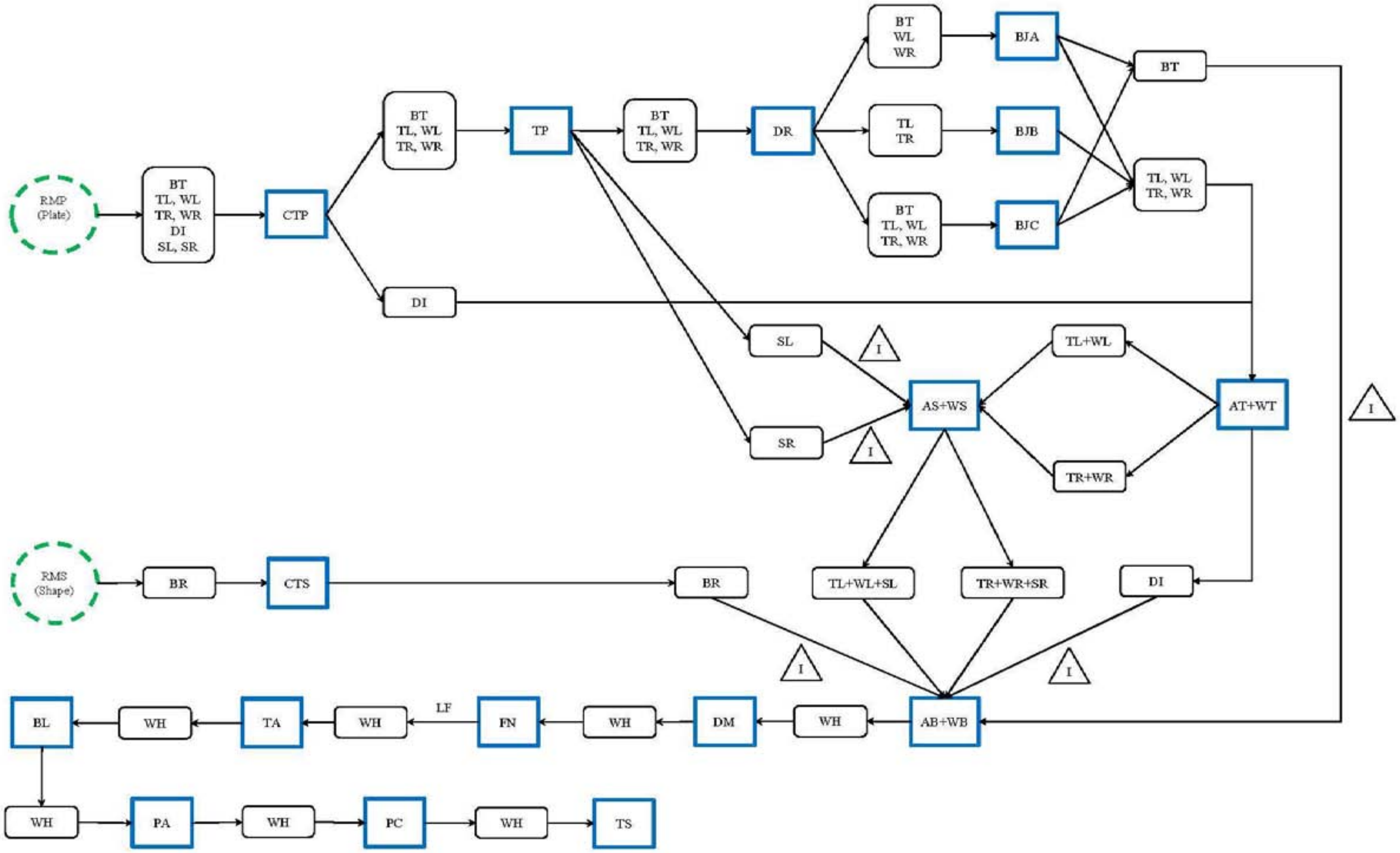


Figure 4.7 Fabrication process flow

Figure 4.8a Cut activity

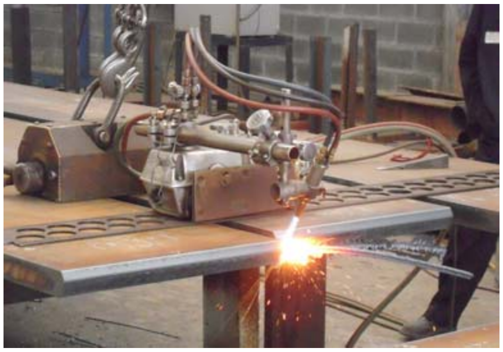


Figure 4.8b Taper activity

Figure 4.9 Smooth grinding

Figure 4.10a Drilling template preparations

Figure 4.10b Drilling with grease

Figure 4.11 Butt joint activity

Figure 4.12a T-shape assembling

Figure 4.12b Stiffener assembling

Figure 4.12c Diaphragm assembling

Figure 4.12d Box girder assembling

Figure 4.13a Web and top flange welding

Figure 4.13b Stiffener and web flange welding   Figure 4.13c Box girder welding

13) The transport activity comprises of all 20 box girders being separated for two trips (10 box girders per trip) and each trip having only one transit which is done at night. Figure 4.16d is an illustration of transportation.

4.4 Working Documents

This fabrication process consists of additional work documents including cut plans, shop drawings, weld procedures, check lists, erection sequences, blast procedures, paint procedures, pack lists, and delivery orders which are defined below.

1) Cut plan is the schedule of cutting both plate and shape materials and depicts the shape of the plate steel on the cutting machine.

2) Shop drawing is the details of the box girder components and installation method.

3) Weld procedure is the work steps of welding.

4) Check list is the table form for checking each part of the box girder for assembling activity or quality control.

5) Erection sequence is the steps of full trial assembly of the box girder.

6) Blast procedure is the working steps of blast activity.

7) Paint procedure is the working steps of paint activity including surface preparation, and material or tool usage.

8) Pack list is a set of packages to prepare before transportation.

9) Delivery order is a request for transportation to the installation site.

4.5 Working Stations

Each work station involves a number of steps. The process starts with raw materials being input into the production line. Every station comprises additional and different activities and working times as shown in Table 4.4. In the case of SBGF, raw materials and assemblies are important variables, and manpower and machines are essential factors of concern. Worker quantity is related to machinery because every machine needs to be operated by a worker. As a result, the number of workers must be in proportion to the machinery. Furthermore, both workers and machines are located at the same work station at which raw material is fed into the production line. The number of workers and machines are summarized in Tables 4.5 and 4.6 respectively.

Figure 4.14a Dimension activity

Figure 4.14b Finish activity

4.6 Working Duration

Regarding the working time of SBGF, there is both regular time and overtime for every activity of the day shift except for the transportation activity, which is conducted only at night. The total time period for this project is around four months, with working times classified into two types as follows:

1) Ordinary working time: Monday-Saturday from 8AM-5PM with a lunch break from 12AM-1PM for 1 hour.

2) Overtime: Monday-Saturday from 6-11PM and Sunday from 8AM-5PM including a break of 1 hour and also a break at 5-6PM. Overtime for each activity consists of different periods as shown in Table 4.7.

Figure 4.15a Lift out activity

Figure 4.15b Trial assembly activity

Figure 4.15c Three pairs of box girders

Figure 4.16a Blast activity

Figure 4.16b Paint activity

Figure 4.16c Pack activity

Figure 4.16d Transport activity

Table 4.4 Station workload

Item	Part	Total	Quantity of parts per station															
			CT (4)		TP (4)	DR (3)	BJ (3)			AT+WT (8)	AS+WS (3)	AB+WB (10)	FN (2)	TA (6)	BL (1)	PA (4)	PC (5)	TS (1)
			CTP (2)	CTS (2)			BJA (1)	BJB (1)	BJC (1)									
1	BT	93	47	-	23	31	47	-	47	-	-	-	-	-	-	-	-	-
2	TL	70	35	-	18	23	-	35	35	5	-	-	-	-	-	-	-	-
3	TR	70	35	-	18	23	-	35	35	5	-	-	-	-	-	-	-	-
4	WL	64	32	-	16	21	32	-	32	5	-	-	-	-	-	-	-	-
5	WR	64	32	-	16	21	32	-	32	5	-	-	-	-	-	-	-	-
6	DI	96	48	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-
7	SL	230	115	-	58	-	-	-	-	-	77	-	-	-	-	-	-	-
8	SR	230	115	-	58	-	-	-	-	-	77	-	-	-	-	-	-	-
9	BR	441	-	221	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	WH	20	-	-	-	-	-	-	-	-	-	2	10	3	20	5	4	20
Total			459	221	207	119	111	70	181	26	154	2	10	3	20	5	4	20

<u>Remark</u> (-) Number of station

Table 4.5 Number of workers

Activity	Quantity	Period				Average Per Month	Average per Activity
		Oct' 10	Nov' 10	Dec' 10	Jan' 11		
Cut	4	18	23	65	89	49	12
Drill	3	-	7	18	14	13	4
Finish (Part)	4	-	8	17	21	15	4
Butt Joint	3	-	-	28	-	28	9
Assembly	8	-	63	171	-	117	15
Welding	8	-	36	74	-	55	7
Finish (Assembly)	2	-	-	1	-	1	1
Lift out	1	-	-	-	-	N/A	N/A
Trial Assembly	6	-	-	-	-	N/A	N/A
Blast	1	-	-	-	-	N/A	N/A
Paint	4	-	-	-	13	13	3
Pack	5	-	-	-	-	N/A	N/A
Transport	1	2	30	-	-	16	16
Summary		20	167	374	137	307	56

Remark	Lift out, Trial Assembly, Blast, and Pack activities data are not available.

Table 4.6 Number of machines

No.	Activity	Machine	
		Type	Quantity
1	Cut Plate	Pro Arc (CNC)	2
2	Cut Shape	Band Saw	2
3	Taper	Press Trimming	2
4	Drill	Electric Drilling	5
5	Butt Joint	Welding Set	6
6	Assembly Block	Welding Set	16
		Theodolite Camera	2
		Overhead Crane	9
		Gantry Crane	11
7	Weld Block	Welding Set	28
8	Dimension	Theodolite Camera	2
9	Lift out	Overhead Crane	2
		Trailer Truck	1
10	Trial Assembly	Overhead Crane	4
11	Blast	Blast Hose	1
12	Paint	Painting Set	5
13	Transport	Trailer Truck	10

Table 4.7 Total working time

Activity	Overtime hour	Total working time per day (minutes)
Cut	6 - 11 PM	780
Taper	6 - 9 PM	660
Drill	6 - 9 PM	660
Butt Joint	6 - 10 PM	720
Assembly	6 - 10 PM	720
Weld	6 - 10 PM	720
Dimension	6 - 8 PM	600
Finish	6 - 8 PM	600
Trial Assembly	6 - 8 PM	600
Blast	6 - 8 PM	600
Paint	6 - 8 PM	600
Pack	-	480
Transport	6 - 12 PM	840

4.7 Summary

This chapter explains the elements of steel box girder fabrication (SBGF) which comprises assemblies, working activities, manpower, and machines. It can be summarized as:

1) Box girder components being composed of steel plate and divided into eight parts including bottom, left-right top flanges, left-right web flanges, diaphragm, and left-right stiffeners. Furthermore, there is an additional part, bracing, which is a steel box shape. All assemblies consist of various characteristics.

2) Work stations for box girders mainly consisting of thirteen steps. Work areas differ in each step, and the inside and outside factory have their own workers and machines. Moreover, the duration of the ordinary working time of all stations is the same; however, overtime differs for some activities.

CHAPTER V

DATA COLLECTION AND TRANSFORMATION

This chapter explains data collection and transformation regarding steel box girder fabrication (SBGF), limitations of data recording and data transformation. It also discusses the process of data collection and the parameters involved.

5.1 Data Collection

1) Data volume

The application of lean concept to SBGF is illustrated through an actual box girder fabrication. Relevant data were collected from the fabrication process of 20 similar steel box girders performed in Thailand, as discussed in Section 4.1. The data included process time and waiting time. Raw materials were input into fabrication processes and were passed through all working stations in being transformed into parts and assemblies (see Figure 5.1). The assemblage of each box girder comprised nine parts of steel plate and steel shape, including bottom, left and right top-flanges, left and right web-flanges, left and right stiffeners, diaphragm, and bracing parts. The total process time was quite long, so it was recorded in a five-minute period.

2) Data recording

Table 5.1 shows the data collection of box girder No.S5B2. It shows the fabrication date and time of each part for every activity from the beginning until the end. Next, process time was calculated from actual starting and ending work times, and waiting time which is non-working time covering the period of time among work being finished at one station and before the next station starts working. Moreover, this table presents work times of the dimension activity (DM) from part preparation process until all parts and assemblies were transformed into a box girder. The fabrication time recorded for box girder construction is at the top of the table or bottom part (BT) row. The hyphen symbol (-) means no assembly carried out for an activity, and a blank box means data were not available. All the key data are presented in Table 5.2 (The complete box girder information is illustrated in Appendix A). Table 5.3 displays the complete data collection of this project. A percentage of data available for both date and time was simplified as being equal to 5% per data box but if there only the date or time is 2.5% per data box and zero representing no data.

Some data regarding production rate and calculated process time of taper (TP), drill (DR), and cut for steel shape (CTS) activities were not available. The work time information is presented in Appendix A. Additionally, the process times of pack (PC) and transport (TS) activities were obtained from interviews with personnel in charge on the form of maximum, minimum, and most likely (mode) value.

3) Working duration

Recording the total duration of this project was estimated to take 3 months or 90 days (see schedule plan in Table 5.4). Actually, it took 127 days for 20 box girders to be finished as shown in Table 5.5 (The highlighted cells are initial working dates of each box girder). The actual time which was the base data used to calculate percentage of utilization is presented in section 6.2.

It is essential to state that all the information collected as the primary data was not practical to be used for analysis. Consequently, the primary data were transferred, and became the secondary data, as will be explained in the next section.

5.2 Data Transformation

Since some data were incomplete, primary data regarding the fabrication process of 20 similar steel box girders were collected and averaged for increasing accuracy. Many patterns of transformation are available. In this research, data was transformed using the following steps:

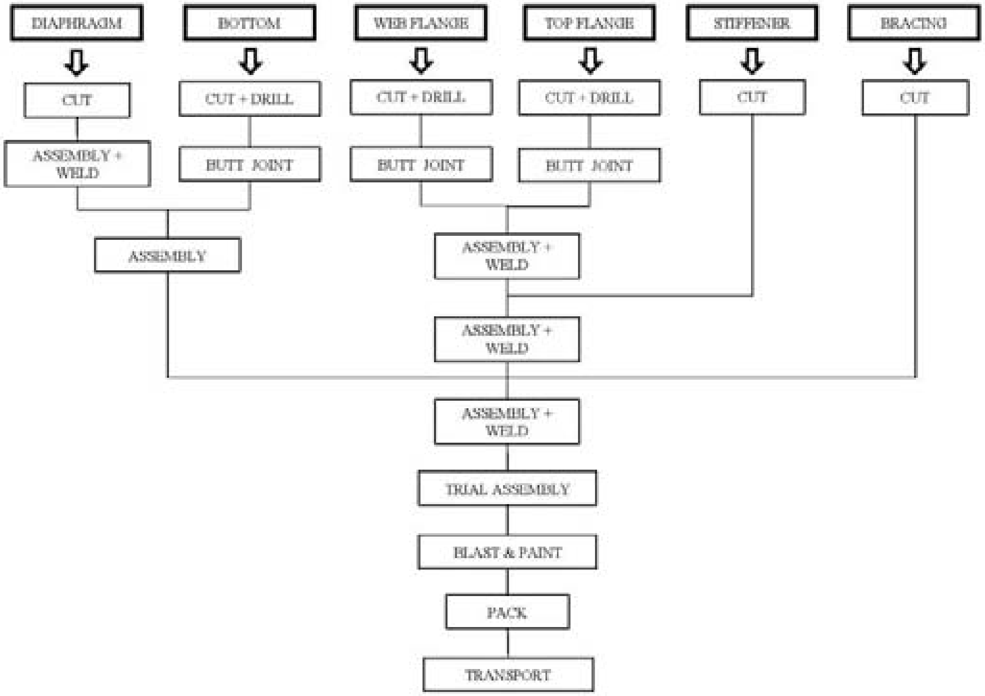


Figure 5.1 Fabrication and assembly flowchart

1) Arrange the independent assembly of 20 box girders for each activity as shown in Table 5.6 for the bottom part.

2) Calculate the average data by using simplified uniform distribution. Some subjective data from interviews was averaged in terms of PERT (Program Evaluation and Review Technique) formulas.

3) Table 5.7 illustrates the total average data of every part.

In Table 5.7, the mean and standard deviation of cut (CT), assembly t-shape (AT), and weld t-shape (WT) activities were divided into two groups depending on the work station. The cut activity consisted of two material types such as plate and shape, assembly and weld t-shape activities response for t-shape (top and web flanges), and diaphragm of box girder. The last one was the butt joint activity which was separated into three values - the first point for the bottom, left-right web flanges, the second point for left-right top flanges, and the final point supports all parts which include mean and standard deviation of implied activities located at the top and the bottom of the table.

All the data are input into a mapping procedure by using the value stream mapping tool which will be explained later. In addition, the complete of data transformation is presented in Appendix B.

5.3 Constraints of Data Collection

Because SBGF comprises many activities and components, it also located on a large area. Therefore, there are many data collection constraints and classified and explained separately, for example:

1) Working area

For a maximum steel box girder size of 45 meters in length, Table 4.1 indicates the box girder dimensions and the activities performed in large areas both inside and outside the factory for the fabrication process. The working area was approximately 7,500 square meters, and it consisted of several workstations (see Figure 4.1). Unfortunately, data collection was not complete since there was only one researcher and some stations started and finished their operations at the same time.

2) Patterns of data collection

Most data were gathered from the actual fabrication process. Because of incomplete data recording, the researcher assigned operators, which were posted at their stations, to record work times instead. For this reason, some information contains errors. Moreover, some data such as working capacity, and pack and transport activities were subjectively assessed by the personnel in charge for maximum, minimum, and mode value. Thus, all values were calculated to determine the work times of these activities. In addition, some collective data such as taper and drill activities were counted using production rate to determine work times.

Table 5.1 Data collection of girder No.S5B2

Girder	Part	Part Preparation Time												Fabrication Time											
		CT		PCT	WTT	TP		PCT	WTT	DR		PCT	WTT	BJ		PCT	WTT	AT		PCT	WTT	WT		PCT	WTT
		Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)
S5B2	BT	20.35	19.25	220										8.00	14.30	2490	4910	-	-	-	-	-	-	-	-
		21/1/11	22/1/11											1/2/11	4/2/11			-	-			-	-		
	TL	9.05	11.40	155										8.00	16.20	3080						-	-	-	-
		21/1/11	21/1/11											29/1/11	2/2/11							-	-		
	TR	17.50	20.25	155										10.30	16.15	1005						-	-	-	-
		21/1/11	21/1/11											29/1/11	30/1/11							-	-		
	WL	13.00	19.30	160										14.45	18.30	885	1650					14.05	16.00	835	2475
		18/1/11	18/1/11											31/1/11	1/2/11			4/2/11				8/2/11	9/2/11		
	WR	18.05	11.30	465										15.00	9.00	1140	1380					13.00	14.05	785	
		17/1/11	18/1/11											31/1/11	2/2/11			4/2/11				7/2/11	8/2/11		
	DI	16.35	8.45	1260		-	-	-	-	-	-	-	-	-	-	-	-								2550
		18/1/11	21/1/11			-	-			-	-			-	-								9/2/11		
	SL	15.35	14.35	745						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		24/1/11	25/1/11							-	-			-	-			-	-			-	-		
	SR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-			-	-			-	-			-	-		
	BR					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-			-	-			-	-			-	-		

Table 5.1 (Cont.) Data collection of girder No.S5B2

Girder	Part	Fabrication Time																							
		AS		PCT	WTT	WS		PCT	WTT	AB		PCT	WTT	WB		PCT	WTT	DM		PCT	WTT	FN		PCT	WTT
		Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)
S5B2	BT	-	-	-	-	-	-	-	-	16.20	16.30	10	5310		11.10	670	2990	14.00	15.50	110	2000	10.10	14.20	190	1230
		-	-			-	-			11/2/11	11/2/11			20/2/11	21/2/11			25/2/11	25/2/11			1/3/11	1/3/11		
	TL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-			-	-			-	-			-	-		
	TR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-			-	-			-	-			-	-		
	WL	-	-	-	-	-	-	-	-	16.00	9.00	360	2820			1440	2460	-	-	-	-	-	-	-	-
		-	-			-	-			15/2/11	16/2/11			20/2/11	21/2/11			-	-			-	-		
	WR	-	-	-	-	-	-	-	-	8.10	14.10	300					2460	-	-	-	-	-	-	-	-
		-	-			-	-			13/2/11	13/2/11				21/2/11			-	-			-	-		
	DI	-	-	-	-	-	-	-	-	15.30	9.15	165	4725			1440	1740	-	-	-	-	-	-	-	-
		-	-			-	-			13/2/11	14/2/11			21/2/11	22/2/11			-	-			-	-		
	SL	8.15	14.20	785						-	-	-						-	-	-	-	-	-	-	-
		13/2/11	14/2/11							-	-							-	-			-	-		
	SR									-	-	-						-	-	-	-	-	-	-	-
			11/2/11							-	-							-	-			-	-		
	BR	-	-	-	-	-	-	-	-				1440			1440	3180	-	-	-	-	-	-	-	-
		-	-			-	-				16/2/11			19/2/11	20/2/11			-	-			-	-		

Table 5.1 (Cont.) Data collection of girder No.S5B2

Girder	Part	Fabrication Time														Transportation Time					
		LF	PCT	TA		PCT	WTT	BL		PCT	WTT	PA		PCT	WTT	PC		PCT	WTT	TS	
		Start	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish	(mins)	(mins)	Start	Finish
S5B2	BT	13.50	3550			2880	7560	8.00	14.50	350	130	17.55	16.55	1800							
		3/3/11		10/3/11	14/3/11			28/3/11	28/3/11			28/3/11	31/3/11							11/4/11	11/4/11
	TL		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	TR		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	WL		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	WR		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	DI		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	SL		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	SR		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-
	BR		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-			-	-			-	-			-	-			-	-

3) Work time recording

Work times were divided into two periods: ordinary time and overtime. Because of technical constraints, however, only the data of regular time were collected, whereas other times were recorded by workers.

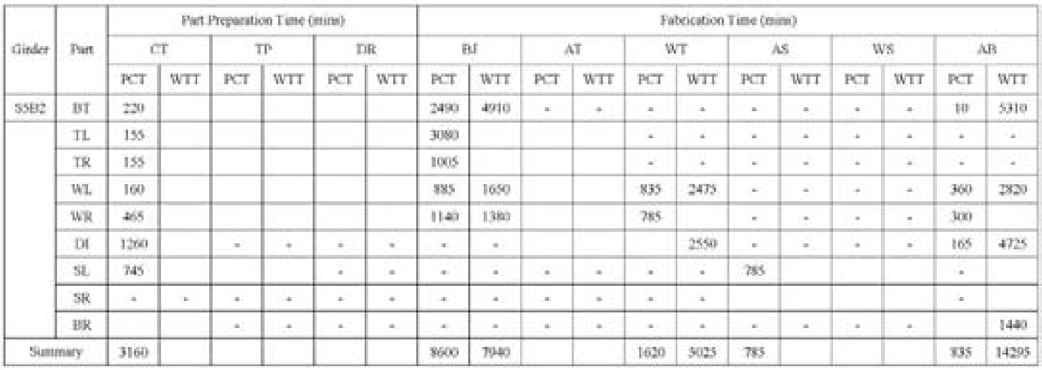
4) Manpower and machine

Workers and machines of SBGF were located at fixed individual stations whereas raw material or assemblies are fed along the fabrication line. In case of excess workload, extra manpower requested at a station could not be recorded. Thus, the number of workers and machines was limited and simplified on ordinary work times as shown in Tables 4.5 and 4.6, respectively. It was also assumed that all work stations, workers, and machines were allocated to one working process only.

5) Raw material supply

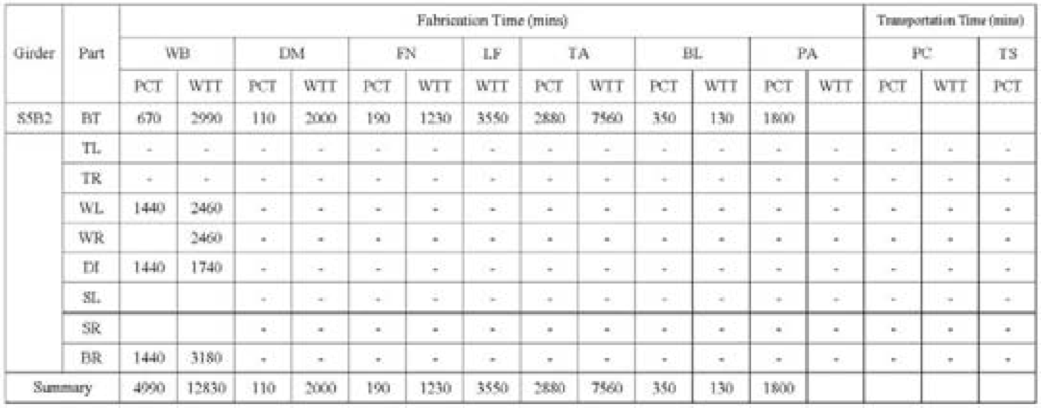
Raw material supply was not concerned and analyzed for the time of material supply because work times start with material being fed into the production line. Moreover, the researcher assumed that there were always sufficient raw materials available for the process.

Table 5.2 Summary data collection of girder No.S5B2



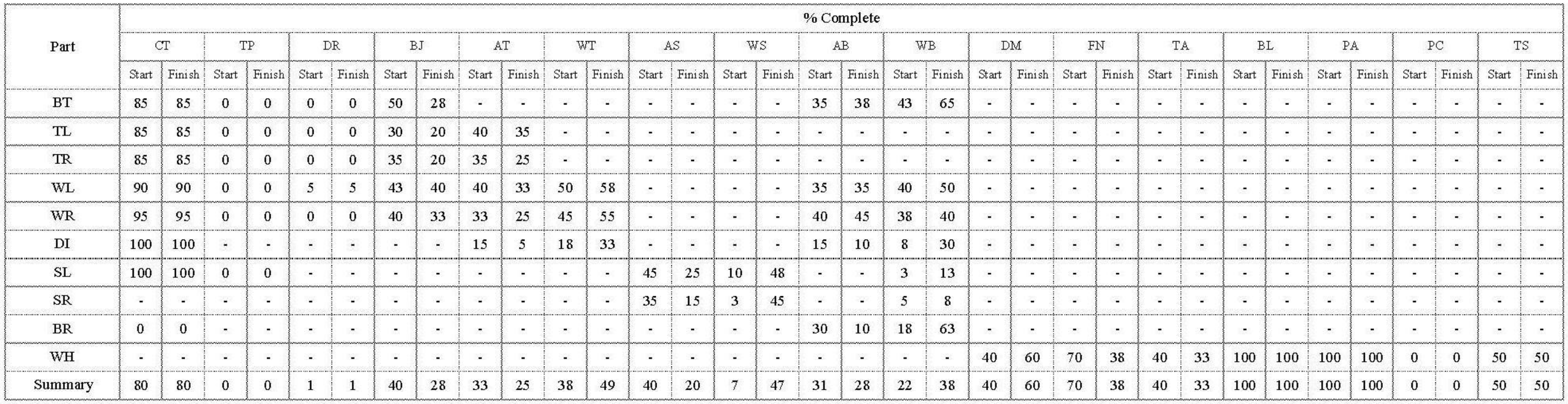
Girder	Part	Part Preparation Time (mins)						Fabrication Time (mins)											
		CT		TP		DR		BJ		AT		WT		AS		WS		AB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5B2	BT	220						2490	4910	-	-	-	-	-	-	-	-	10	5310
	TL	155						3080				-	-	-	-	-	-	-	-
	TR	155						1005				-	-	-	-	-	-	-	-
	WL	160						885	1650			835	2475	-	-	-	-	360	2820
	WR	465						1140	1380			785		-	-	-	-	300	
	DI	1260		-	-	-	-	-	-				2550	-	-	-	-	165	4725
	SL	745				-	-	-	-	-	-	-	-	785				-	
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-	
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-		1440
Summary		3160						8600	7940			1620	5025	785				835	14295

Table 5.2 (Cont.) Summary data collection of girder No.S5B2



Girder	Part	Fabrication Time (mins)													Transportation Time (mins)		
		WB		DM		FN		LF	TA		BL		PA		PC		TS
		PCT	WTT	PCT	WTT	PCT	WTT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT
S5B2	BT	670	2990	110	2000	190	1230	3550	2880	7560	350	130	1800				
	TL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	1440	2460	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR		2460	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1440	1740	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL			-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR			-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR	1440	3180	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		4990	12830	110	2000	190	1230	3550	2880	7560	350	130	1800				

Table 5.3 Data repletion



Part	% Complete																																	
	CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		TA		BL		PA		PC		TS	
	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish
BT	85	85	0	0	0	0	50	28	-	-	-	-	-	-	-	-	35	38	43	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TL	85	85	0	0	0	0	30	20	40	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TR	85	85	0	0	0	0	35	20	35	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WL	90	90	0	0	5	5	43	40	40	33	50	58	-	-	-	-	35	35	40	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WR	95	95	0	0	0	0	40	33	33	25	45	55	-	-	-	-	40	45	38	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DI	100	100	-	-	-	-	-	-	15	5	18	33	-	-	-	-	15	10	8	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SL	100	100	0	0	-	-	-	-	-	-	-	-	45	25	10	48	-	-	3	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-	-	-	-	-	-	-	-	-	-	-	-	35	15	3	45	-	-	5	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	10	18	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40	60	70	38	40	33	100	100	100	100	0	0	50	50
Summary	80	80	0	0	1	1	40	28	33	25	38	49	40	20	7	47	31	28	22	38	40	60	70	38	40	33	100	100	100	100	0	0	50	50

Table 5.4 Working schedule plan

Girder	Nov. 2010									December 2010																															January 2011															
	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU
	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S5A1																	CT	CT	CT	BJ		BJ	BJ	AT	WT	AT	WT		AS	WS	AB	AB	AB	AB		AB	AB	Holiday					Holiday	AB	WB	WB	WB	WB		WB	FN	FN	DM	TA	TA	
S5A2																	CT	CT	CT	BJ		BJ	BJ	AT	WT	AT	WT		AS	WS	AB	AB	AB	AB		AB	AB							AB	WB	WB	WB	WB		WB	FN	FN	DM	TA	TA	
P4A1																										CT	CT		BJ	BJ	BJ	AT	WT	AT		WT	AS							WS	AB	AB	AB	AB		AB	WB	WB	WB	WB	WB	
P4A2																										CT	CT		BJ	BJ	BJ	AT	WT	AT		WT	AS							WS	AB	AB	AB	AB		AB	WB	WB	WB	WB	WB	
S4A1																									CT	CT	CT		BJ	BJ	BJ	AT	WT	AT		WT	AS							WS	AB	AB	AB	AB		AB	WB	WB	WB	WB	WB	
S4A2																															CT	CT	CT	BJ		BJ	BJ							AT	WT	AT	WT	AS		WS	AB	AB	AB	AB	AB	
P3A1																																CT	CT	BJ		BJ	BJ							AT	WT	AT	WT	AS		WS	AB	AB	AB	AB	AB	
P3A2																																	CT	CT		BJ	BJ							BJ			AT	WT		AT	WT	AT	WT	AS	WS	
S3A1																																CT	CT	CT		BJ	BJ							BJ				AT		WT	AT	WT	AS	AS	WS	
S3A2																																		CT		CT	CT							BJ	BJ	BJ				AT	WT	AT	WT	AS	WS	
S3B1																																												CT	CT	BJ	BJ	BJ		AT	WT	AT	WT	AS	WS	
S3B2																																												CT	CT	CT	CT	BJ		BJ	BJ	AT	WT	AT	WT	
P3B1																																														CT	CT	CT		BJ	BJ	BJ	AT	WT	AT	
P3B2																																															CT	CT		CT	BJ	BJ	BJ	AT	WT	
S4B1																																																CT		CT	CT	BJ	BJ	BJ	AT	
S4B2																																																		CT	CT	CT	BJ	BJ	BJ	
P4B1																																																				CT	CT	CT	BJ	
P4B2																																																					CT	CT	CT	
S5B1																																																					CT	CT	CT	
S5B2																																																							CT	

Table 5.4 (Cont.) Working schedule plan

Girder	January 2011															February 2011																												March 2011																		
	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S	SU	M	T	W	TH	F	S
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
S5A1	TA	TA	TA	TA	TA	BP		BP																																																		TS				
S5A2	TA	TA	TA	TA	TA				BP	BP																																																				
P4A1	FN	FN	DM	TA	TA	TA		TA	TA	TA	TA	BP	BP																																																	
P4A2	FN	FN	DM	TA	TA	TA		TA	TA	TA	TA				BP	BP																																														
S4A1	FN	FN	DM	TA	TA	TA		TA	TA	TA	TA	TA	TA		TA	TA	TA	BP	BP																																											
S4A2	WB	WB	WB	WB	WB	FN		FN	DM	TA	TA	TA	TA		TA	TA	TA	TA		BP		BP																																								
P3A1	WB	WB	WB	WB	WB	FN		FN	DM	TA	TA	TA	TA		TA	TA	TA	TA					BP	BP																																						
P3A2	AB	AB	AB	AB	AB	WB		WB	WB	WB	WB	FN	FN		DM	TA	TA	TA							BP	BP																																				
S3A1	AB	AB	AB	AB	AB	WB		WB	WB	WB	WB	FN	FN		DM	TA	TA	TA	TA	TA		TA	TA				BP		BP																																	
S3A2	AB	AB	AB	AB	AB	WB		WB	WB	WB	WB	FN	FN		DM	TA	TA	TA	TA	TA		TA	TA				BP		BP																																	
S3B1	AB	AB	AB	AB	AB	WB		WB	WB	WB	WB	FN	FN		DM	TA	TA	TA	TA	TA		TA	TA	TA	TA	TA	TA				BP	BP																														
S3B2	AS	AS	AS	AS	WS	AB		AB	AB	AB	AB	WB	WB		WB	WB	WB	FN	FN	DM		TA	TA	TA	TA	TA	TA				BP	BP																														
P3B1	WT	AS	AS	AS	WS	AB		AB	AB	AB	AB	WB	WB		WB	WB	WB	FN	FN	DM		TA	TA	TA	TA	TA	TA		TA				BP	BP																												
P3B2	AT	WT	AS	AS	WS	AB		AB	AB	AB	AB	WB	WB		WB	WB	WB	FN	FN	DM		TA	TA	TA	TA	TA	TA		TA				BP	BP																												
S4B1	WT	AT	WT	AS	WS	AB		AB	AB	AB	AB	WB	WB		WB	WB	WB	FN	FN	DM		TA	TA	TA	TA	TA	TA		TA	TA	TA					BP	BP																									
S4B2	AT	WT	AT	WT	AS	AS		AS	AS	AS	WS	AB	AB		AB	AB	AB	WB	WB	WB		WB	WB	FN	FN	DM	TA		TA	TA	TA					BP	BP																									
P4B1	BJ	BJ	AT	WT	AT	WT		AS	AS	AS	WS	AB	AB		AB	AB	AB	WB	WB	WB		WB	WB	FN	FN	DM	TA		TA	TA	TA	TA	TA	TA				BP	BP																							
P4B2	BJ	BJ	BJ	AT	WT	AT		WT	AS	AS	WS	AB	AB		AB	AB	AB	WB	WB	WB		WB	WB	FN	FN	DM	TA		TA	TA	TA	TA	TA	TA				BP	BP																							
S5B1	CT	BJ	BJ	BJ	AT	WT		AT	WT	AS	WS	AB	AB		AB	AB	AB	WB	WB	WB		WB	WB	FN	FN	DM	TA		TA	TA	TA	TA	TA	TA						BP	BP																					
S5B2	CT	CT	BJ	BJ	BJ	AT		WT	AT	WT	AS	AS	AS		AS	AS	WS	AB	AB	AB		AB	AB	WB	WB	WB	WB		WB	FN	FN	DM	TA	TA						BP	BP																					

Table 5.5 Actual working day summary

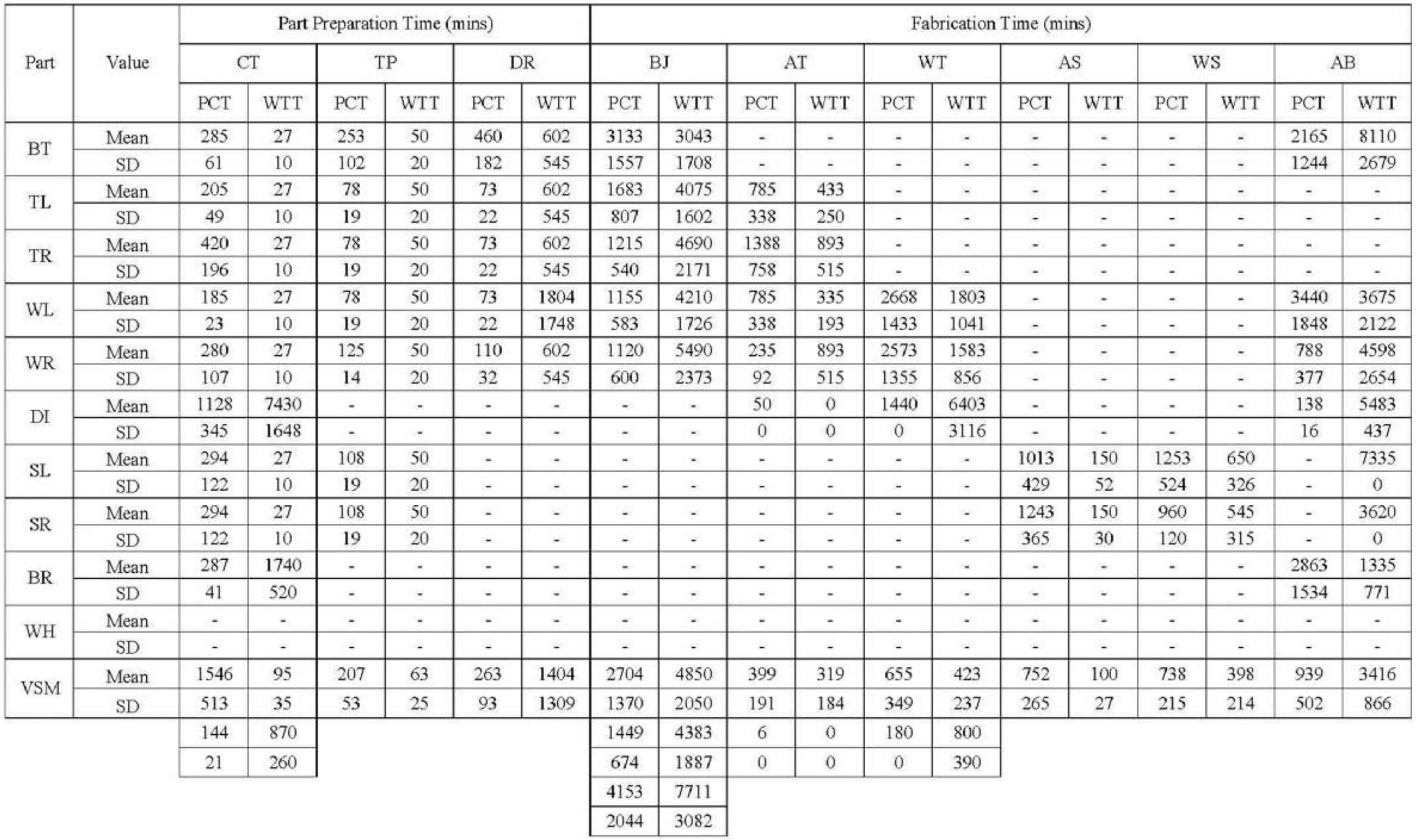
Girder	Date									Working Days (Days)						Working Days Summary (Days)
	Start CTP								End PC	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Apr'11	
	BT	TL	TR	WL	WR	DI	SL and SR	BR								
S5A1					27 Nov 10	26 Nov 10	25 Nov 10		8 Mar 11	6	28	29	28	8	-	99
S5A2						26 Nov 10	25 Nov 10		8 Mar 11	6	28	29	28	8	-	99
P4A1				11 Dec 10	12 Dec 10	26 Nov 10	21 Jan 11		8 Mar 11	5	28	29	28	8	-	98
P4A2	1 Dec 10	2 Dec 10	2 Dec 10	12 Dec 10	13 Dec 10	26 Nov 10	21 Jan 11		9 Mar 11	5	28	29	28	9	-	99
S4A1	7 Dec 10	6 Dec 10	6 Dec 10	15 Dec 10	15 Dec 10	19 Dec 10	9 Dec 10		11 Mar 11	-	22	29	28	11	-	90
S4A2	7 Dec 10	6 Dec 10	6 Dec 10	15 Dec 10	15 Dec 10	19 Dec 10	9 Dec 10		11 Mar 11	-	22	29	28	11	-	90
P3A1	16 Dec 10	16 Dec 10	16 Dec 10	17 Dec 10	17 Dec 10	27 Nov 10	20 Dec 10		17 Mar 11	4	28	29	28	17	-	106
P3A2	16 Dec 10	16 Dec 10	17 Dec 10	18 Dec 10	18 Dec 10	27 Nov 10	20 Dec 10		16 Mar 11	4	28	29	28	16	-	105
S3A1	21 Dec 10	23 Dec 10	23 Dec 10	19 Dec 10	20 Dec 10	26 Nov 10	22 Dec 10		19 Mar 11	5	28	29	28	19	-	109
S3A2	21 Dec 10	23 Dec 10	24 Dec 10	19 Dec 10	21 Dec 10	26 Nov 10	22 Dec 10		19 Mar 11	5	28	29	28	19	-	109
S3B1	27 Dec 10	27 Dec 10	27 Dec 10	23 Dec 10	25 Dec 10	18 Jan 11	18 Jan 11		23 Mar 11	-	5	29	28	23	-	85
S3B2	27 Dec 10	25 Dec 10	28 Dec 10	24 Dec 10	24 Dec 10	18 Jan 11	18 Jan 11		22 Mar 11	-	4	29	28	22	-	83
P3B1	7 Jan 11	7 Jan 11	7 Jan 11	8 Jan 11	7 Jan 11	18 Jan 11	20 Jan 11		30 Mar 11	-	-	25	28	30	-	83
P3B2	7 Jan 11	7 Jan 11	7 Jan 11	8 Jan 11	7 Jan 11	18 Jan 11	20 Jan 11		29 Mar 11	-	-	25	28	29	-	82
S4B1	10 Jan 11	9 Jan 11	9 Jan 11	11 Jan 11	10 Jan 11	19 Jan 11	21 Jan 11		30 Mar 11	-	-	23	28	30	-	81
S4B2	10 Jan 11	9 Jan 11	9 Jan 11	11 Jan 11	10 Jan 11	19 Jan 11	21 Jan 11		31 Mar 11	-	-	23	28	31	-	82
P4B1	14 Jan 11	11 Jan 11	11 Jan 11	11 Jan 11	12 Jan 11	18 Jan 11	22 Jan 11		2 Apr 11	-	-	21	28	31	2	82
P4B2	11 Jan 11	11 Jan 11	11 Jan 11	11 Jan 11	12 Jan 11	18 Jan 11	22 Jan 11		4 Apr 11	-	-	21	28	31	4	84
S5B1	22 Jan 11	20 Jan 11	21 Jan 11	18 Jan 11	17 Jan 11	18 Jan 11	24 Jan 11		5 Apr 11	-	-	15	28	31	5	79
S5B2	21 Jan 11	21 Jan 11	21 Jan 11	18 Jan 11	17 Jan 11	18 Jan 11	24 Jan 11		5 Apr 11	-	-	15	28	31	5	79

Table 5.6 Data of bottom part

Girder	Part	Part Preparation Time (mins)						Fabrication Time (mins)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	BT			75	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-				
S5A2	BT			75	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-				
P4A1	BT			125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-				675
P4A2	BT	195	0-60, 25	125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-			2160	
S4A1	BT	210	0-60, 25	115	0-120, 45	285	30-3300, 70			-	-	-	-	-	-	-	-		5895	1010	600
S4A2	BT	195	0-60, 25	115	0-120, 45	285	30-3300, 70			-	-	-	-	-	-	-	-		4455	2160	
P3A1	BT	180	0-60, 25	125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-			1920	1515
P3A2	BT	200	0-60, 25	125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-			3120	430
S3A1	BT	190	0-60, 25	115	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-		3470	2570	250
S3A2	BT	180	0-60, 25	115	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-		4080	1760	90
S3B1	BT	270	0-60, 25	275	0-120, 45	390	30-3300, 70	1645		-	-	-	-	-	-	-	-		12750	990	1530
S3B2	BT	235	0-60, 25	275	0-120, 45	390	30-3300, 70	435		-	-	-	-	-	-	-	-			1905	1125
P3B1	BT	390	0-60, 25	430	0-120, 45	775	30-3300, 70	2800	2470	-	-	-	-	-	-	-	-	4320			990
P3B2	BT	390	0-60, 25	430	0-120, 45	775	30-3300, 70	1320	6000	-	-	-	-	-	-	-	-	2970	7440	2160	
S4B1	BT	185	0-60, 25	210	0-120, 45	775	30-3300, 70	1950	1350	-	-	-	-	-	-	-	-			1440	2880
S4B2	BT	290	0-60, 25	210	0-120, 45	775	30-3300, 70	2400	4140	-	-	-	-	-	-	-	-			1200	
P4B1	BT	360	0-60, 25	430	0-120, 45	775	30-3300, 70	5830	85	-	-	-	-	-	-	-	-			7440	
P4B2	BT	350	0-60, 25	430	0-120, 45	775	30-3300, 70	1590	2250	-	-	-	-	-	-	-	-	2880	10320	1890	3150
S5B1	BT	250	0-60, 25	280	0-120, 45	390	30-3300, 70	1430	4320	-	-	-	-	-	-	-	-			1810	
S5B2	BT	220	0-60, 25	280	0-120, 45	390	30-3300, 70	2490	4910	-	-	-	-	-	-	-	-	10	5310	670	2990
Mean		285	27	253	50	460	602	3133	3043	-	-	-	-	-	-	-	-	2165	8110	4055	1620
SD		61	10	102	20	182	545	1557	1708	-	-	-	-	-	-	-	-	1244	2679	1954	883

Remark Waiting time (WTT) of Cut (CT), Taper (TP), and Drill (DR) activities are displayed in terms of maximum, minimum, and mode values.

Table 5.7 Data of all girders



Part	Value	Part Preparation Time (mins)						Fabrication Time (mins)											
		CT		TP		DR		BJ		AT		WT		AS		WS		AB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
BT	Mean	285	27	253	50	460	602	3133	3043	-	-	-	-	-	-	-	-	2165	8110
	SD	61	10	102	20	182	545	1557	1708	-	-	-	-	-	-	-	-	1244	2679
TL	Mean	205	27	78	50	73	602	1683	4075	785	433	-	-	-	-	-	-	-	-
	SD	49	10	19	20	22	545	807	1602	338	250	-	-	-	-	-	-	-	-
TR	Mean	420	27	78	50	73	602	1215	4690	1388	893	-	-	-	-	-	-	-	-
	SD	196	10	19	20	22	545	540	2171	758	515	-	-	-	-	-	-	-	-
WL	Mean	185	27	78	50	73	1804	1155	4210	785	335	2668	1803	-	-	-	-	3440	3675
	SD	23	10	19	20	22	1748	583	1726	338	193	1433	1041	-	-	-	-	1848	2122
WR	Mean	280	27	125	50	110	602	1120	5490	235	893	2573	1583	-	-	-	-	788	4598
	SD	107	10	14	20	32	545	600	2373	92	515	1355	856	-	-	-	-	377	2654
DI	Mean	1128	7430	-	-	-	-	-	-	50	0	1440	6403	-	-	-	-	138	5483
	SD	345	1648	-	-	-	-	-	-	0	0	0	3116	-	-	-	-	16	437
SL	Mean	294	27	108	50	-	-	-	-	-	-	-	-	1013	150	1253	650	-	7335
	SD	122	10	19	20	-	-	-	-	-	-	-	-	429	52	524	326	-	0
SR	Mean	294	27	108	50	-	-	-	-	-	-	-	-	1243	150	960	545	-	3620
	SD	122	10	19	20	-	-	-	-	-	-	-	-	365	30	120	315	-	0
BR	Mean	287	1740	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2863	1335
	SD	41	520	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1534	771
WH	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VSM	Mean	1546	95	207	63	263	1404	2704	4850	399	319	655	423	752	100	738	398	939	3416
	SD	513	35	53	25	93	1309	1370	2050	191	184	349	237	265	27	215	214	502	866
		144	870					1449	4383	6	0	180	800						
		21	260					674	1887	0	0	0	390						
								4153	7711										
								2044	3082										

Table 5.7 (Cont.) Data of all girders

Part	Value	Fabrication Time (mins)													Transportation Time (mins)		
		WB		DM		FN		LF	TA		BL		PA		PC		TS
		PCT	WTT	PCT	WTT	PCT	WTT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT
BT	Mean	4055	1620	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	1954	883	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TL	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TR	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WL	Mean	3960	2190	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	2009	1259	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WR	Mean	2565	2430	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	1065	1120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DI	Mean	3120	2785	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	970	1608	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SL	Mean	1200	1530	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	0	878	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	Mean	1560	1770	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	208	1016	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR	Mean	3120	3460	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	970	1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WH	Mean	-	-	600	1000	1608	3370	5153	10208	4665	690	108	2020	2878	25	830	397
	SD	-	-	283	577	818	1946	2975	4577	2018	225	42	713	550	2	290	10
VSM	Mean	1958	1579	60	100	804	1685	5153	1701	778	690	108	505	720	5	166	397
	SD	718	876	28	58	409	973	2975	763	336	225	42	178	138	0	58	10

5.4 Summary

This chapter explained steel box girder fabrication (SBGF) components including work processes, box girder assemblies, and number of workers and machines. Moreover, it summarized data collection steps which consisted of creating a data collection format, recording work times of the actual process, and transforming all data by averaging with uniform distribution or PERT formulas. Also, it defined limitations of the data collection. Lastly, all collected and transformed data will be put through process mapping with value stream mapping and be presented in the next chapter.

CHAPTER VI

VALUE STREAM MAPPING MODELING AND ANALYSIS

This research illustrates overall process by using a value stream mapping tool. The analysis phase considers two processes: current and improved processes. The existing process was improved by incorporating lean concept, to reduce time wastage.

6.1 Mapping Current Process

The original steel box girder fabrication (SBGF) components consist of numerous combinations of assemblies and involve basic activities carried out along a single line. For this reason, value stream mapping was selected to map the entire process. Typical of value stream mapping components comprises of data box, number of operator, arrow, and summary of work times for both process time and waiting time at bottom lines. Table 6.1 displays an illustration of value stream mapping components of current and improved processes. Every data box contains the activity name, process time and waiting time which they are recorded from actual work. Work times of individual data box are calculated and inserted into bottom lines and will be summarized as total process time and waiting time.

The mapping of current process consists of three steps.

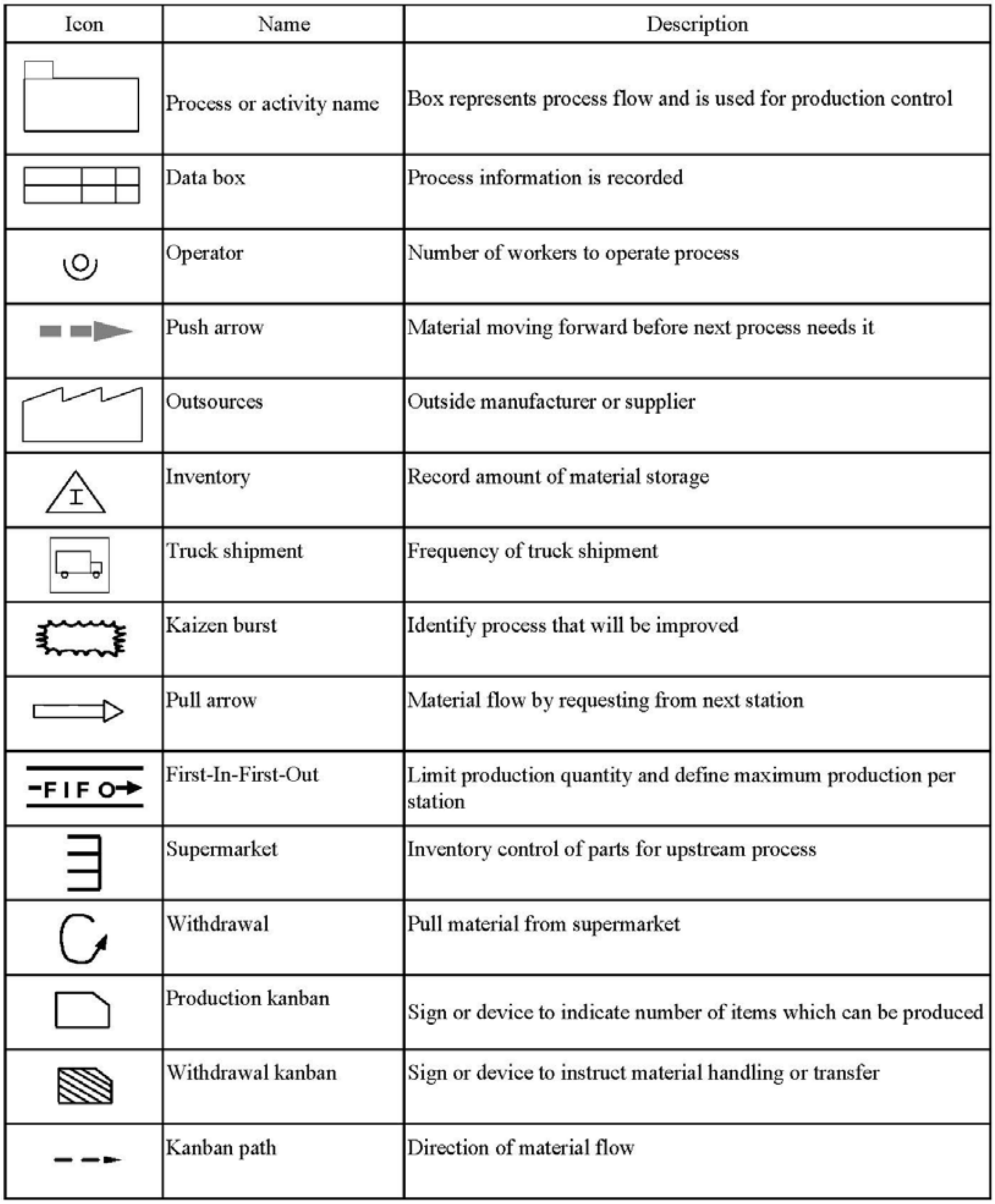
1) Conduct value stream mapping of the current process in accordance with the fabrication flow including process time, waiting time, and the number of workers needed and input into the data box

2) Input transformed data into each data box

3) Summarize process time and waiting time for each activity, the total of process time and waiting time combination is the cycle time

Afterwards, process time, waiting time, and cycle time (the total of process time and waiting time) were summarized. Figure 6.1 shows the entire work process included total process time of 15,772 minutes, total waiting time of 34,792 minutes, and total cycle time of 50,564 minutes. These results were used as reference points for process improvement by consideration for percentage of utilization which will be explained in the next section.

Table 6.1 Value stream mapping icons (Rother and Shook, 1999 and Nash and Poling, 2008)



Icon	Name	Description
	Process or activity name	Box represents process flow and is used for production control
	Data box	Process information is recorded
	Operator	Number of workers to operate process
	Push arrow	Material moving forward before next process needs it
	Outsources	Outside manufacturer or supplier
I	Inventory	Record amount of material storage
	Truck shipment	Frequency of truck shipment
	Kaizen burst	Identify process that will be improved
	Pull arrow	Material flow by requesting from next station
FIFO	First-In-First-Out	Limit production quantity and define maximum production per station
	Supermarket	Inventory control of parts for upstream process
	Withdrawal	Pull material from supermarket
	Production kanban	Sign or device to indicate number of items which can be produced
	Withdrawal kanban	Sign or device to instruct material handling or transfer
	Kanban path	Direction of material flow

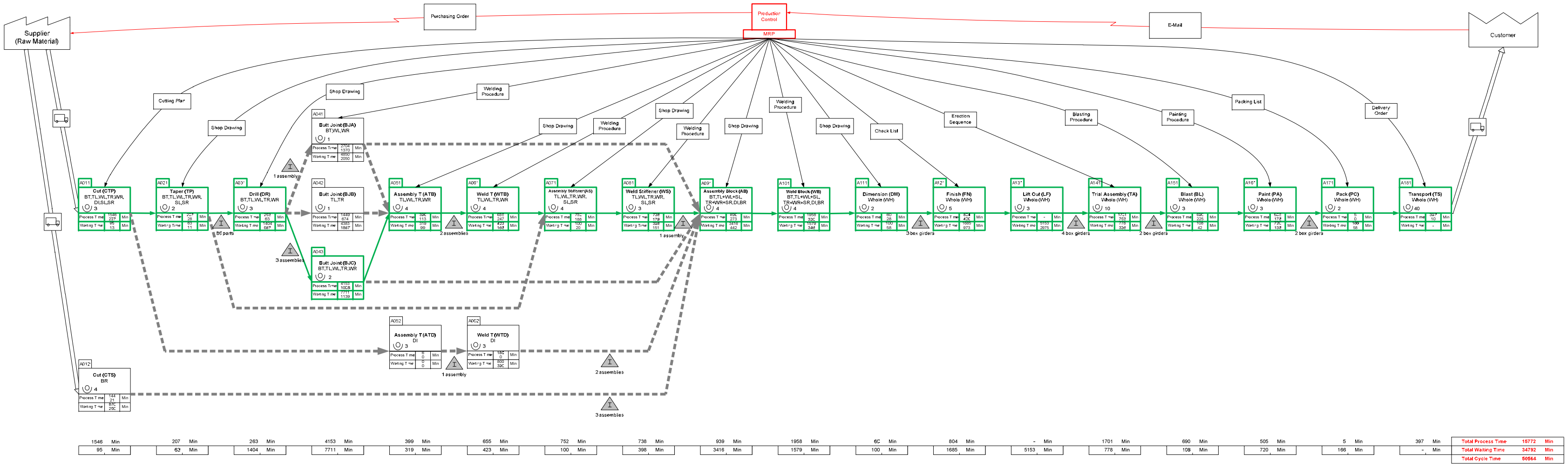


Figure 6.1 Current process mapping

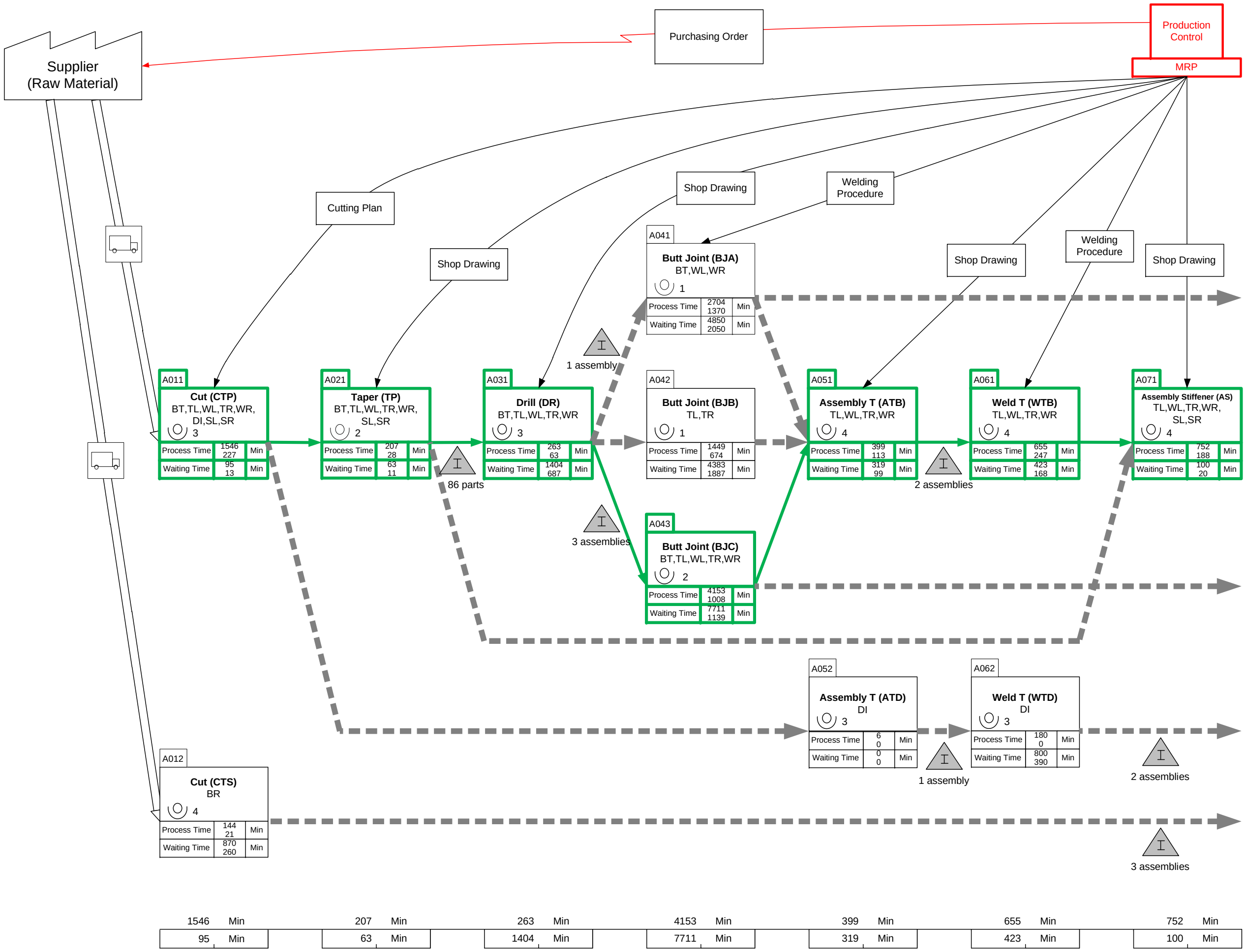


Figure 6.1 (Cont.) Current process mapping

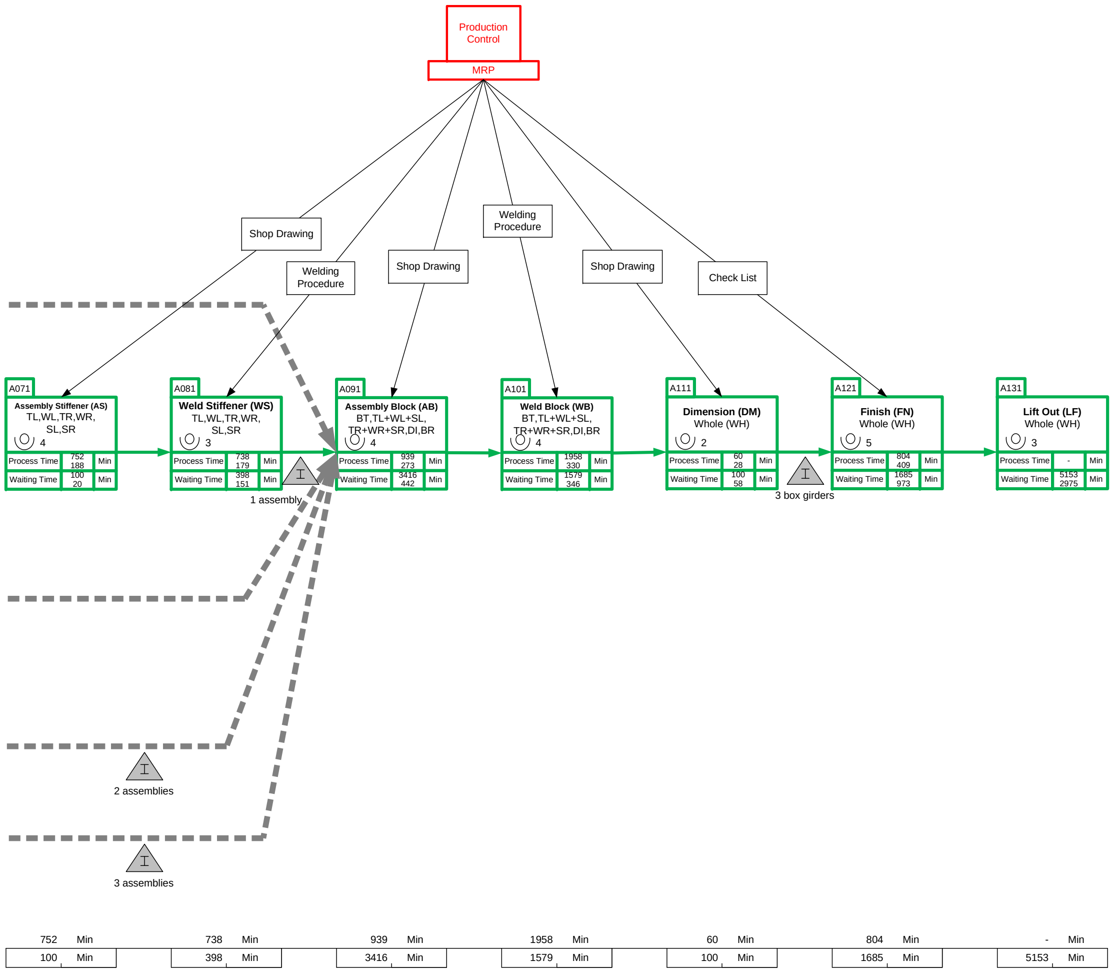


Figure 6.1 (Cont.) Current process mapping

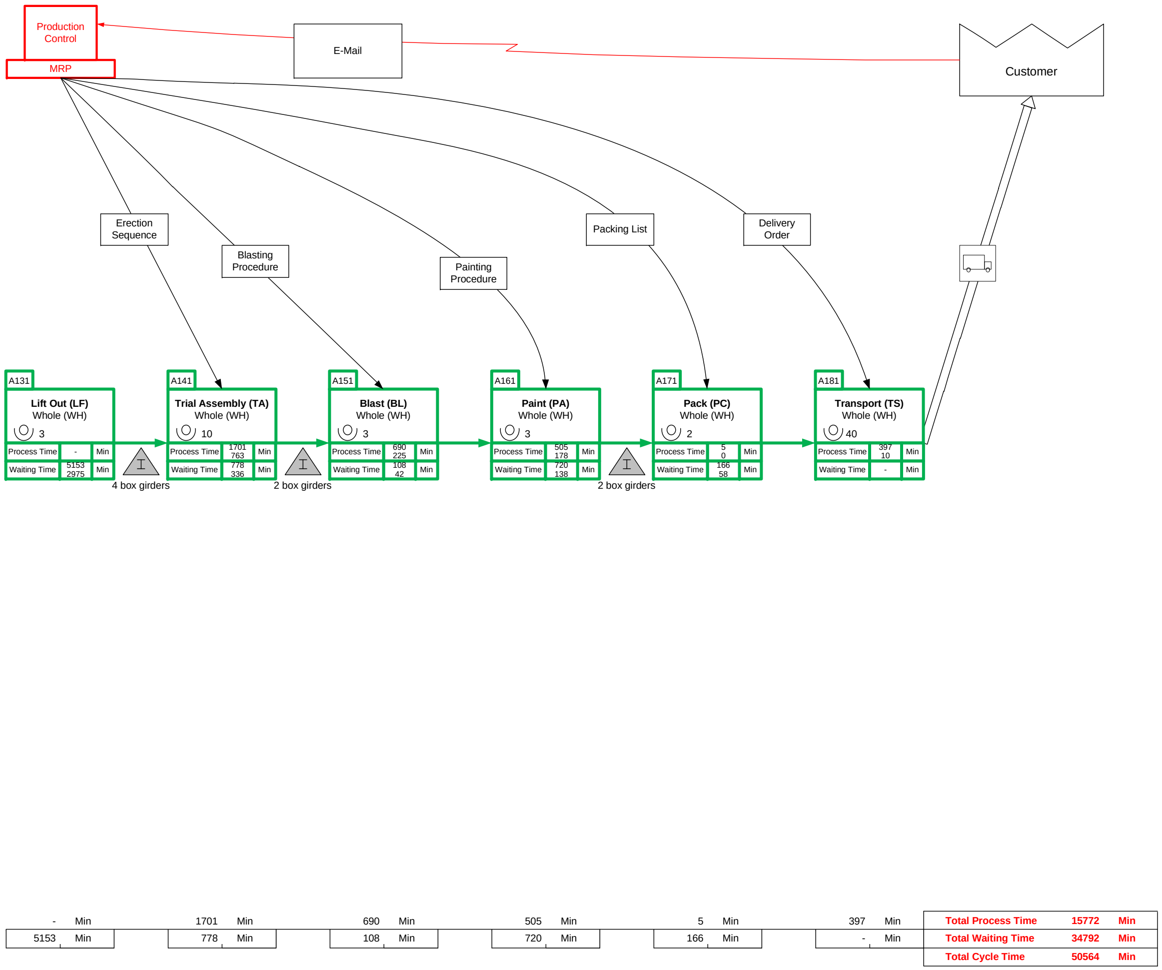


Figure 6.1 (Cont.) Current process mapping

6.2 Calculate Percentage of Utilization

SBGF can be improved using lean concept by focusing on production performance and resource usage, which can be measured through utilization ratio, rational number of input rate of process, and capacity (Hopp, 2003). Table 6.2 displays the results, the details of which are as follows.

1) Coefficient of variation calculation

The coefficient of variation is the ratio of the standard deviation to mean value of each activity (in Table 6.2, column 6 divided by column 5 or column 9 divided by column 8). It represents production time deviation. If its value is low, the work time of each box girder production is steady.

2) Input and capacity rate calculation

The input rate of the current process is equal to the output rate of the previous activity except for the cut for steel plate and cut for steel shape activities because these activities are initial activities of the process. The capacity rate of every activity is the working capability regarding the workload which is equal to the maximum production rate of each activity.

3) Percentage of utilization calculation and bottleneck exploration

Utilization ratio is calculated by dividing the input and capacity rate of the same activity (in Table 6.2, column 13 divided by column 14) and it was converted to percentage. Obviously, utilization ratio cannot be more than 100% because work load is always less than the capacity.

After percentages of utilization were calculated, it was found that the trial assembly activity (TA) (highlighted cells in Table 6.2) had the highest percentage of utilization or “bottleneck.” Furthermore, there were errors results from data collection of the assembly t-shape for diaphragm (ATD) and pack (PC) activities. The ATD activity had insufficient process time and waiting time, and the PC activity had insufficient process time. Both activities affected percentage of utilization.

Table 6.2 Summary of utilization percentage

Station	Q'ty of	Q'ty of Assembly/Girder (pieces)		Max. Production	Working time per day	Process Time (mins)			Waiting Time (mins)			Cycle Time		Input Rate	Capacity Rate	Utilization	
	Station	Total	Per girder	Rate (pieces/ day)	(mins)	Mean	SD	Coefficient of Variation	Mean	SD	Coefficient of Variation	(mins)	(days)	(pieces/ day)	(pieces/ day)	Ratio	%
CTP	2	917	46	60.0	780	1546	227	0.1466	95	13	0.1400	1640	2.10	44.0	60.0	0.7333	73
CTS	2	441	22	100.0	780	144	21	0.1429	870	260	0.2989	1014	1.30	36.0	100.0	0.3600	36
TP	4	821	41	140.0	660	207	28	0.1345	63	11	0.1789	270	0.41	33.0	140.0	0.2357	24
DR	3	361	18	60.0	660	263	63	0.2391	1404	687	0.4891	1667	2.53	51.2	60.0	0.8533	85
BJA	1	30	2	2.5	720	2704	1370	0.5067	4850	2050	0.4226	7554	10.49	1.8	2.5	0.7000	70
BJB	1	20	1	2.0	720	1449	674	0.4648	4383	1887	0.4305	5832	8.10	1.8	2.0	0.8750	88
BJC	1	50	3	4.5	720	4153	1008	0.2428	7711	1139	0.1477	11864	16.48	3.5	4.5	0.7778	78
ATB	8	40	2	8.0	720	399	113	0.2821	319	99	0.3108	718	1.00	0.9	8.0	0.1125	11
WTB	8	40	2	6.0	720	655	247	0.3763	423	168	0.3980	1078	1.50	4.8	6.0	0.8000	80
ATD	3	16	1	2.0	720	6	0	0.0000	0	0	-	6	0.01	0.2	2.0	0.1196	12
WTD	3	16	1	4.5	720	180	0	0.0000	800	390	0.4866	980	1.36	1.5	4.5	0.3333	33
AS	3	40	2	2.5	720	752	188	0.2497	100	20	0.2001	852	1.18	0.3	2.5	0.1249	12
WS	3	40	2	3.0	720	738	179	0.2429	398	151	0.3793	1136	1.58	1.8	3.0	0.6000	60
AB	10	20	1	7.0	720	939	273	0.2907	3416	442	0.1293	4355	6.05	5.0	7.0	0.7071	71
WB	10	20	1	4.5	720	1958	330	0.1687	1579	346	0.2192	3537	4.91	4.0	4.5	0.8889	89
DM	10	20	1	15.0	600	60	28	0.4717	100	58	0.5770	160	0.27	3.0	15.0	0.2000	20
FN	2	20	1	3.0	600	804	409	0.5087	1685	973	0.5774	2489	4.15	1.5	3.0	0.5000	50
LF	1	20	1	-	600	-	-	-	5153	2975	0.5773	5153	8.59	-	-	-	-
TA	6	20	1	2.0	600	1701	763	0.4484	778	336	0.4326	2479	4.13	2.0	2.0	1.0000	100
BL	1	20	1	1.5	600	690	225	0.3261	108	42	0.3889	798	1.33	1.0	1.5	0.6667	67
PA	4	20	1	2.0	600	505	178	0.3530	720	138	0.1911	1225	2.04	1.0	2.0	0.5000	50
PC	5	20	1	4.0	480	5	0	0.0800	166	58	0.3494	171	0.36	0.8	4.0	0.2000	20
TS	1	20	1	20.0	840	397	10	0.0252	-	-	-	397	0.47	3.0	20.0	0.1500	15
Column No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

4) Critical path of current process exploration

The value stream mapping of the current process depicts several paths of process flow which go in parallel directions such as cut activity and butt joint activity along with assembly and weld t-shape activity. The highest working time is selected as the critical path, which is the path of the cut for steel plate activity (CTP) through butt joint station C (BJC) connecting to assembly t-shape for box girder activity (ATB) until the end at transport activity (TS). This is shown by the value stream mapping in bold data boxes and arrows in Figure 6.1. This critical path identifies the important activities, which have the top priority for eliminating or reducing time waste.

6.3 Explore Waste of Current Process

Value stream mapping of the current process was concluded to explore wastes or problems at each activity. These wastes conform to the seven types of waste, which is summarized in Table 6.3. Waste categorization is described below:

1) Waiting

The drill activity had significant waiting time. That is, material flow was inefficient. Or workers and machines had to wait for parts to arrive. Waiting time at the drill activity occurred from the next activity, namely the butt joint activity. As a result, the butt joint activity should be improved to reduce the waiting time of the drill activity. The first three activities were operated as part of the fabrication process such as cut plate, taper, and drill and were a continual process; therefore, improvements should be made at all these activities.

The cut steel shape and weld t-shape for diaphragm activities were parallel production lines of the main line and result in too much waiting time at the assembly block activity. This explained why these activities had to wait for the main box girder production to put bracing and diaphragm assemblies together. Furthermore, the finishing activity had greater waiting time because it had to wait for the overhead crane to be available to lift the box girder out of the factory. Also, the paint activity experienced excessive waiting time because the next activity (the pack activity) did not have enough workers.

2) Overproduction

There were many activities that must be process inventory in terms of number of parts, assemblies, or box girders before that activity began, including drill, butt joint station C, weld t-shape, assembly block, finish, trial assembly, blast, and pack. All inventories were shown in Figure 6.1. These activities produced more output than next activity's capacity, therefore some outputs needed to be stored before being fed into that activity.

3) Unnecessary transportation

The first three activities located in part of the preparation area and the continual workplace located in a different area from the fabrication zone that was the butt joint activity, therefore it toke more time to move parts from the drill activity to the butt joint activity which affected waiting time. In addition, transportation for the trial assembly activity, because trailer trucks were not always available, box girders had to wait at the trial assembly activity before being moved to the blast activity.

4) Overprocessing

The finish activity is separated from the previous activity (the dimension activity); therefore, it resulted in more waiting time. Moreover, due to trial assembly and pack areas being adjacent areas although the blast activity being farther away, transportation time was required to transfer the box girder from the trial assembly area to the blast activity and return to the existing place. For these reasons, these work areas should be improved to eliminate inappropriate steps.

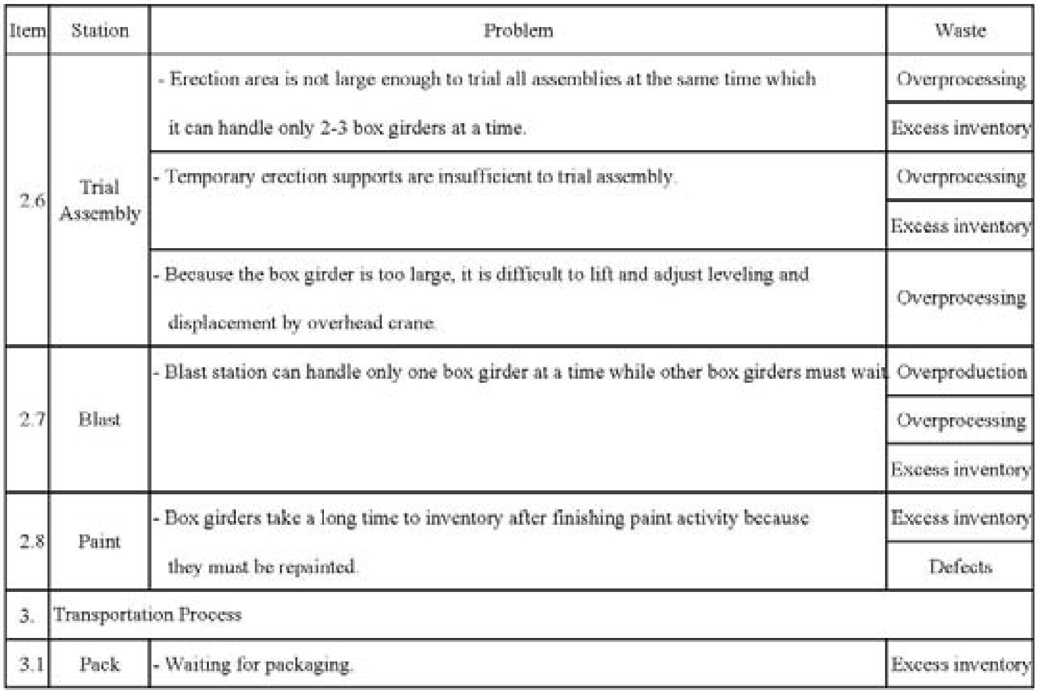
5) Unnecessary movement

These movements may also involve workers walking, taking a rest during work periods, or going to the toilet, which may be unnecessary. Unfortunately, data collection of this project did not cover these actions.

Table 6.3 Exploration for waste of current process

Item	Station	Problem	Waste
1.	Part Preparation		
1.1	Cut	- Machinery cut errors in parts.	Defects
1.2	Taper	- Workers wait for assemblies from the cut station for tapering at the taper station.	Overproduction Waiting
1.3	Drill	- Workers wait for assemblies from the taper station for drilling at the drill station.	Overproduction Waiting
1.4	Transit	- Assembly transportation from part preparation area to fabrication area takes excess time because of the distance and improper transit direction.	Transportation Overprocessing
2.	Fabrication Process		
2.1	Butt Joint	- Workers wait for assemblies from the part preparation area for welding at the butt joint station.	Overproduction Overprocessing Waiting
		- Sub-assemblies have excess waiting for fit-up at storage area.	Overproduction Excess inventory
2.2	Assembly	- Waiting for temporary support such as jig at assembly block station.	Overprocessing
		- Waiting for overhead crane to be available to lift the sub-assembly at assembly block station.	
		- Assembly fit-up mistakes.	Overprocessing Defects
		- Drawing and actual assembly of fabrication process do not conform due to complexity.	Defects
		- If engineering department revises drawings, fabrication process will have to wait for the revised drawing.	Overprocessing Defects
2.3	Weld	- After the welding block process, some components have distortions which need to be straightened.	Defects
2.4	Dimension	- Inaccurate box girder dimensions need to be corrected by bending at the welding station.	Defects
2.5	Finish	- Waiting for quality checking by owner representative.	Defects
		- No storage area for completed box girders, therefore they must be stored at welding station and also have to wait for the overhead crane to be available for lift out.	Overprocessing Transportation

Table 6.3 (Cont.) Exploration for waste of current process



Item	Station	Problem	Waste
2.6	Trial Assembly	- Erection area is not large enough to trial all assemblies at the same time which it can handle only 2-3 box girders at a time.	Overprocessing
			Excess inventory
		- Temporary erection supports are insufficient to trial assembly.	Overprocessing
			Excess inventory
		- Because the box girder is too large, it is difficult to lift and adjust leveling and displacement by overhead crane.	Overprocessing
2.7	Blast	- Blast station can handle only one box girder at a time while other box girders must wait	Overproduction
			Overprocessing
			Excess inventory
2.8	Paint	- Box girders take a long time to inventory after finishing paint activity because they must be repainted.	Excess inventory
			Defects
3.	Transportation Process		
3.1	Pack	- Waiting for packaging.	Excess inventory

6) Defects

Defects regarding the output quality of each work activity such as size, straightness, or smoothness are factors affecting product quality. As this research, it focused on analyzing quantity of work time, these defects were not a parameter of concern.

7) Excess inventory

This type of waste related to excess raw material and process inventory. This research did not monitor raw material storage and process inventory, which was similar to overproduction, because it depended on the work performance of each activity.

6.4 Improve The Process

Before improving the current process, it was necessary to identify the specific parameters to improve of each activity through kaizen burst. This outlined the improvements to the current process and explained the details of the changes (Nash and Poling, 2008). Table 6.1 illustrates as changes through value stream mapping in Figure 6.2. Furthermore, the improvement points of the current process using lean concept can be described as follows:

1) Reduce variation

The data collection involved production of 20 box girders in terms of work time for each activity. The data were the averaged. For this reason, for the same activity, some data had a high or low value which meant this activity had a work performance deviation which was calculated as a coefficient of variation (CV) as shown in Table 6.2. The coefficients are rational numbers between standard deviation (SD) and the mean of both process time and waiting time which were less than 1. To demonstrate improvement, researcher defined CV as not being over 0.3 to represent steady work performance for each activity. Based on this, the activities to be improved were butt joint station A and B, weld t-shape for box girder, dimension, finish, trial assembly, blast, and pack (see changes in process time in the highlighted cells in Table 6.4).

Regarding implementation, reduced CV can conform to actual work performance by training workers to maintain stable performance. Nevertheless, in terms of analysis, CV can be adjusted but not be over 0.3 by recalculating only the mean and SD of process time. Afterward, all adjusted process times were input into the improved process of value stream mapping and recalculated to determine total process time and cycle time.

2) Reduce waiting time

For value stream analysis, one method of waste reduction would be activity combination by the merging of some activities together to become a single activity. These activities would be located in the same areas and consist of:

- Assembly t-shape for diaphragm (ATD) combined with weld t-shape for diaphragm (WTD)

- Assembly t-shape for box girder (ATB) combined with weld t-shape for box girder (WTB)
- Assembly stiffener (AS) combined with weld stiffener (WS)
- Assembly block (AB), weld block (WB), dimension (DM), finish (FN) and lift out (LF) combined
- Paint (PA) combined with pack (PC)

For mean and SD combination, SD was calculated in terms of variance (SD^2) but mean was normally included. Next, all data was input into value stream mapping and recalculated.

3) Eliminate bottleneck

The bottleneck forms at the busiest activity in the process. As previously mentioned, a bottleneck formed at the trial assembly activity, affecting the prior activities (the finishing and lift out activities) which resulted in more waiting time. For this reason, the trial assembly activity should double capacity to eliminate the bottleneck, and should be made to conform to the erection or trial assembly sequence to reduce the inventory of box girders.

4) Reduce variability

In SBGF production, parts or assemblies had unique characteristics and can be separated into nine types (as explained in Section 4.1). For this reason, all outputs were not replaceable, which implied that parts or assemblies of box girders had less variability regardless of parameters.

5) Increase productivity

Productivity is the ratio between output and input of activity, which can be considered resource utilization. The utilization of each activity can be calculated as explained earlier (see Table 6.2). As a result, some activities had a high or low percentage of utilization; therefore, process improvement could be adjusted by increasing capacity. However, increasing productivity in this regard was not part of the research objective.

6) Improve quality

Production quality can be represented by qualitative function by including such factors as defects or production errors which were caused by workers, machines, or other factors. This research emphasized quantitative function in regards to work times, therefore this parameter was not in the scope of study.

6.5 Analyze Improved Process

The parameters of process improvement were calculated and remapped through value stream mapping which were process time and waiting time, and combine to be cycle time. Process time can be reduced through coefficients of variation by adjusting process time and waiting time, combining some work activities, and applying the pull technique. Furthermore, the process bottleneck can be eliminated although this must be illustrated in terms of simulation because there was not enough improvement data to input into value stream mapping. This improvement will be explained in the next chapter. Afterwards, the current process mapping will be adapted to incorporate lean concept and the entirety of improvements categorized into three types which can be summarized as follows:

1) Process time reduction

After recalculating process times using the reduced coefficient of variation, data were input into value stream mapping of the current process to determine total process time, total waiting time, and total cycle time.

2) Waiting time reduction

Value stream mapping of the current process was modified for process improvement using lean concept and pull technique adjustment, including merging activities, FIFO (First-In-First-Out), and supermarkets. The detailed changes for each activity are as follows.

Merge activity

The process times of the activities to be merged were added together, for example, process time of assembly t-shape for box girder and weld t-shape for box girder are 399 and 655 minutes, respectively. The summation is 1,054 minutes. As a result, waiting time between the combined activities would be reduced. Furthermore, merging activities can eliminate the inventory of parts, assemblies, or box girders which were stored at the activities including the drill activity which had 86 parts, the butt joint station C which had three assemblies, or the trial assembly activity had four box girders.

Use FIFO and supermarket

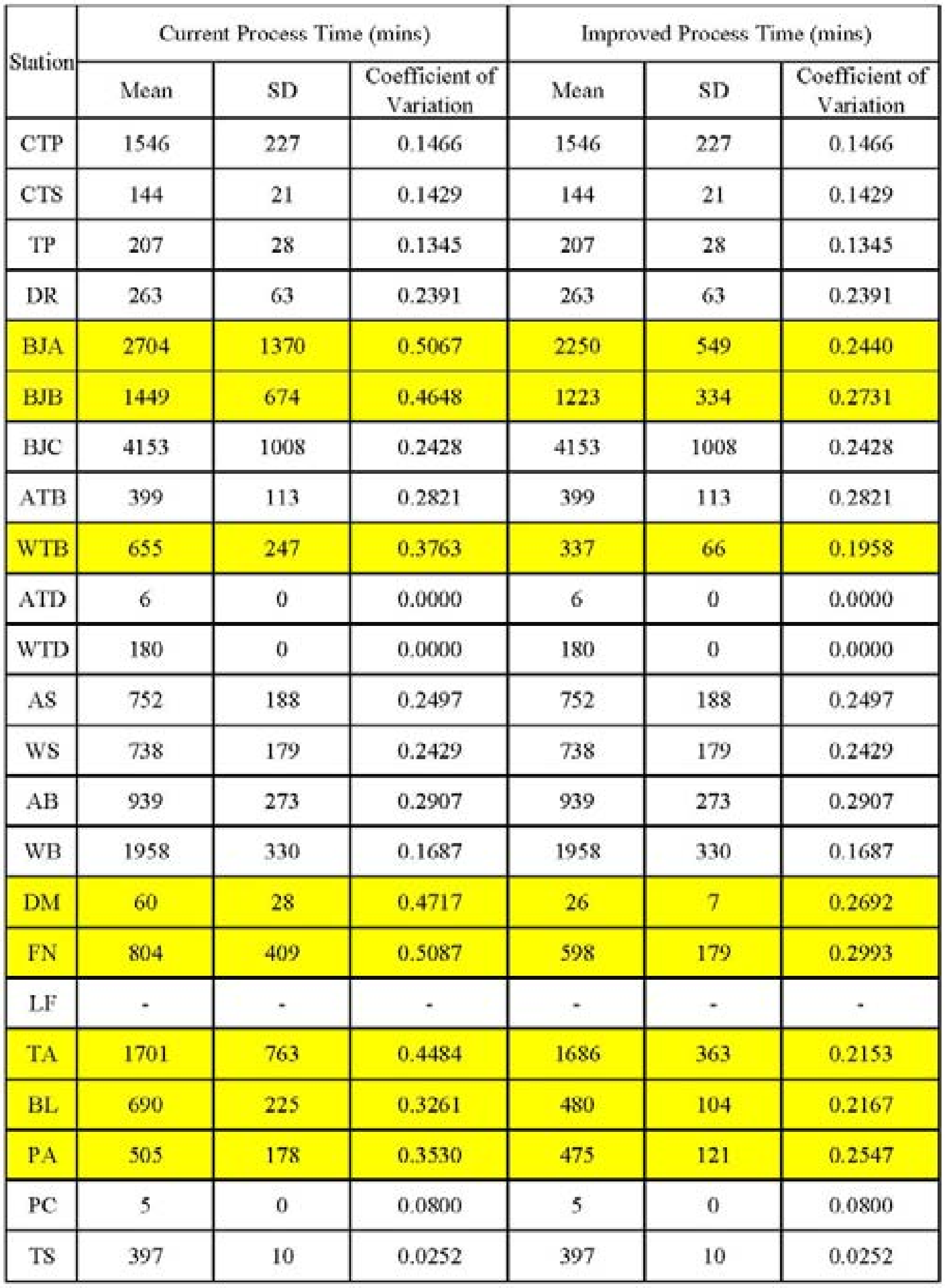
FIFO is an immediate work step. As a result, the waiting time between two connected activities was zero. For example, raw material was fed into the cut activity and quickly sent to the taper activity piece by piece. Supermarkets similarly allow for a small inventory but the work process must still flow. Considering the cut for steel shape activity, this activity produced a bracing part which will be combined with a box girder at the assembly block activity, thus this activity would incur waiting time. The supermarket time of the cut steel shape activity was calculated by totality the process time of all post activities from the cut steel shape to assembly block activities, which equals to 7,167 minutes. Moreover, the trial assembly activity was located in a limited work area which can handle three box girders per an erection set, therefore the supermarket time of this activity is approximately two times the process time. It means that a box girder must wait for other two box girders to trial.

3) Process time and waiting time reduction

This improvement is a combination of process time and waiting time reduction. It indicated that the process will reduce process time by reducing variation and waiting time due to the merging of some activities and applying the FIFO and supermarket concepts.

Worker quantity calculations displayed in the data box of value stream mapping for the improved processes are not adjusted. They will be fixed as the current process, but will be modified to eliminate the bottleneck in the simulation model in the next chapter as they have already been demonstrated through value stream mapping.

Table 6.4 Coefficient of variation adjustment



Station	Current Process Time (mins)			Improved Process Time (mins)		
	Mean	SD	Coefficient of Variation	Mean	SD	Coefficient of Variation
CTP	1546	227	0.1466	1546	227	0.1466
CTS	144	21	0.1429	144	21	0.1429
TP	207	28	0.1345	207	28	0.1345
DR	263	63	0.2391	263	63	0.2391
BJA	2704	1370	0.5067	2250	549	0.2440
BJB	1449	674	0.4648	1223	334	0.2731
BJC	4153	1008	0.2428	4153	1008	0.2428
ATB	399	113	0.2821	399	113	0.2821
WTB	655	247	0.3763	337	66	0.1958
ATD	6	0	0.0000	6	0	0.0000
WTD	180	0	0.0000	180	0	0.0000
AS	752	188	0.2497	752	188	0.2497
WS	738	179	0.2429	738	179	0.2429
AB	939	273	0.2907	939	273	0.2907
WB	1958	330	0.1687	1958	330	0.1687
DM	60	28	0.4717	26	7	0.2692
FN	804	409	0.5087	598	179	0.2993
LF	-	-	-	-	-	-
TA	1701	763	0.4484	1686	363	0.2153
BL	690	225	0.3261	480	104	0.2167
PA	505	178	0.3530	475	121	0.2547
PC	5	0	0.0800	5	0	0.0800
TS	397	10	0.0252	397	10	0.0252

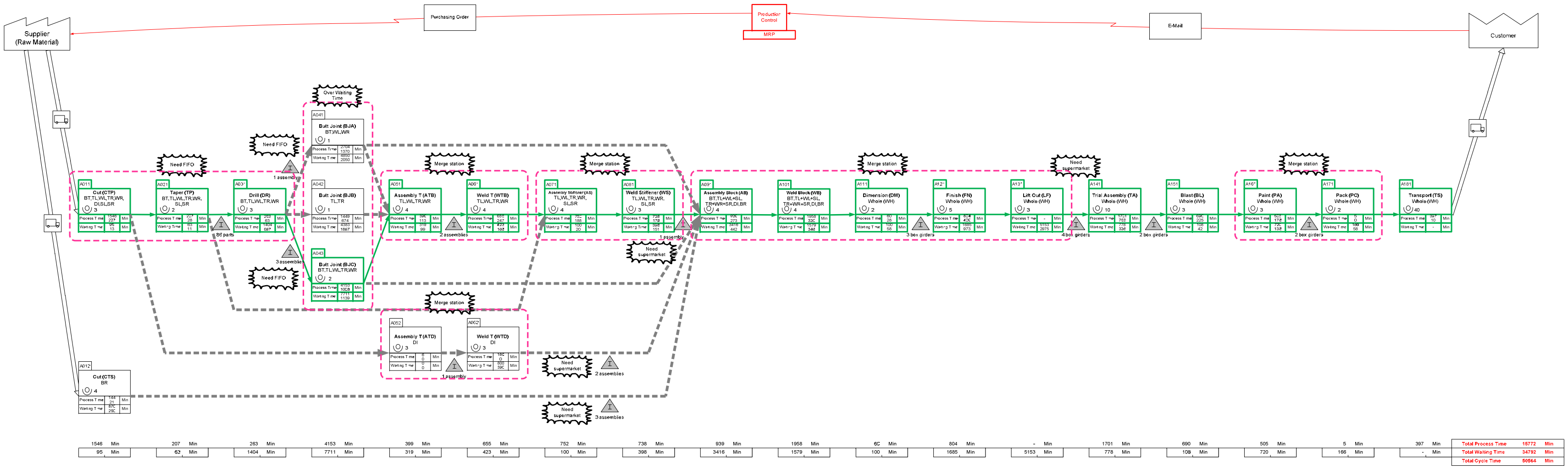


Figure 6.2 Kaizen identification of current process

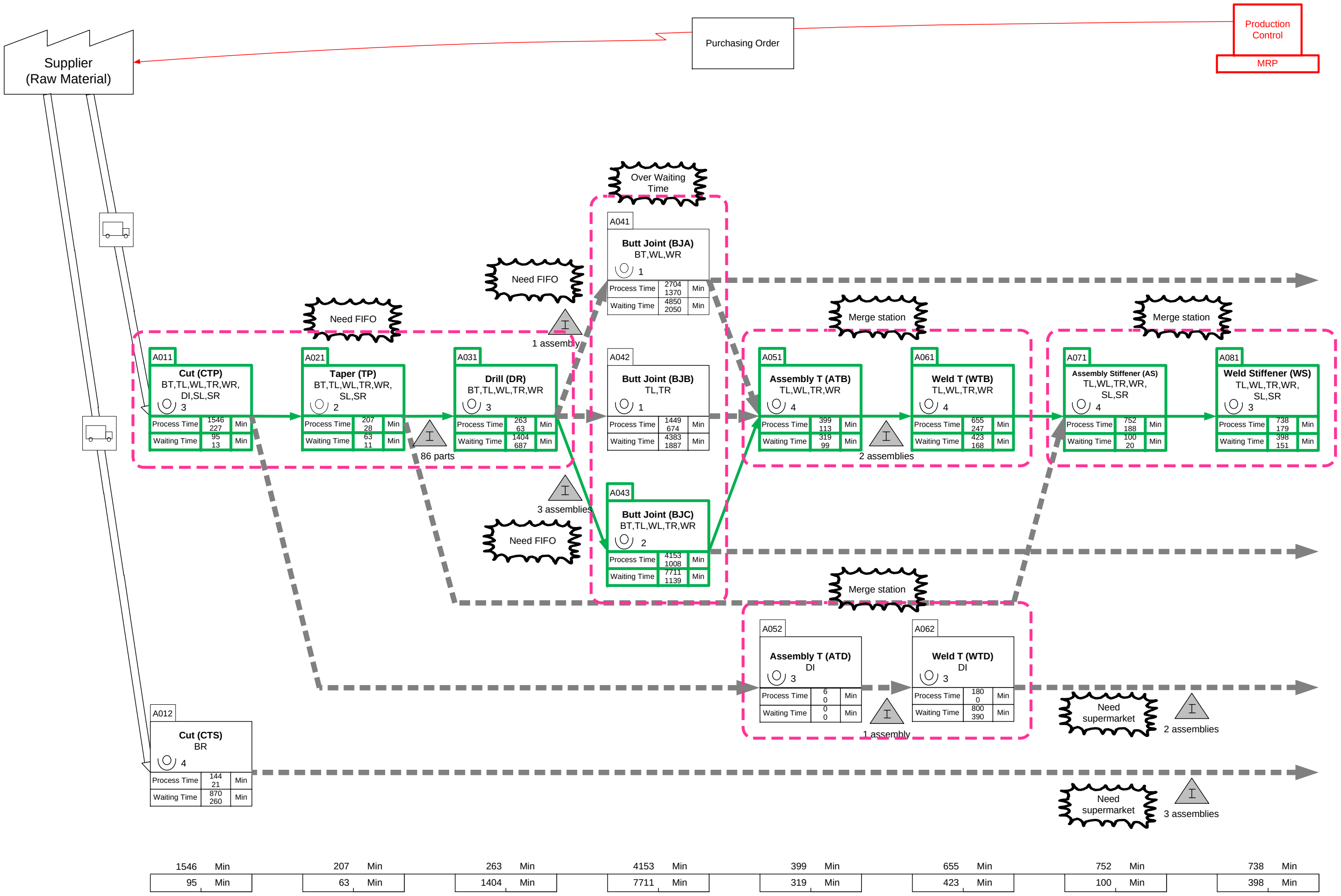


Figure 6.2 (Cont.) Kaizen identification of current process

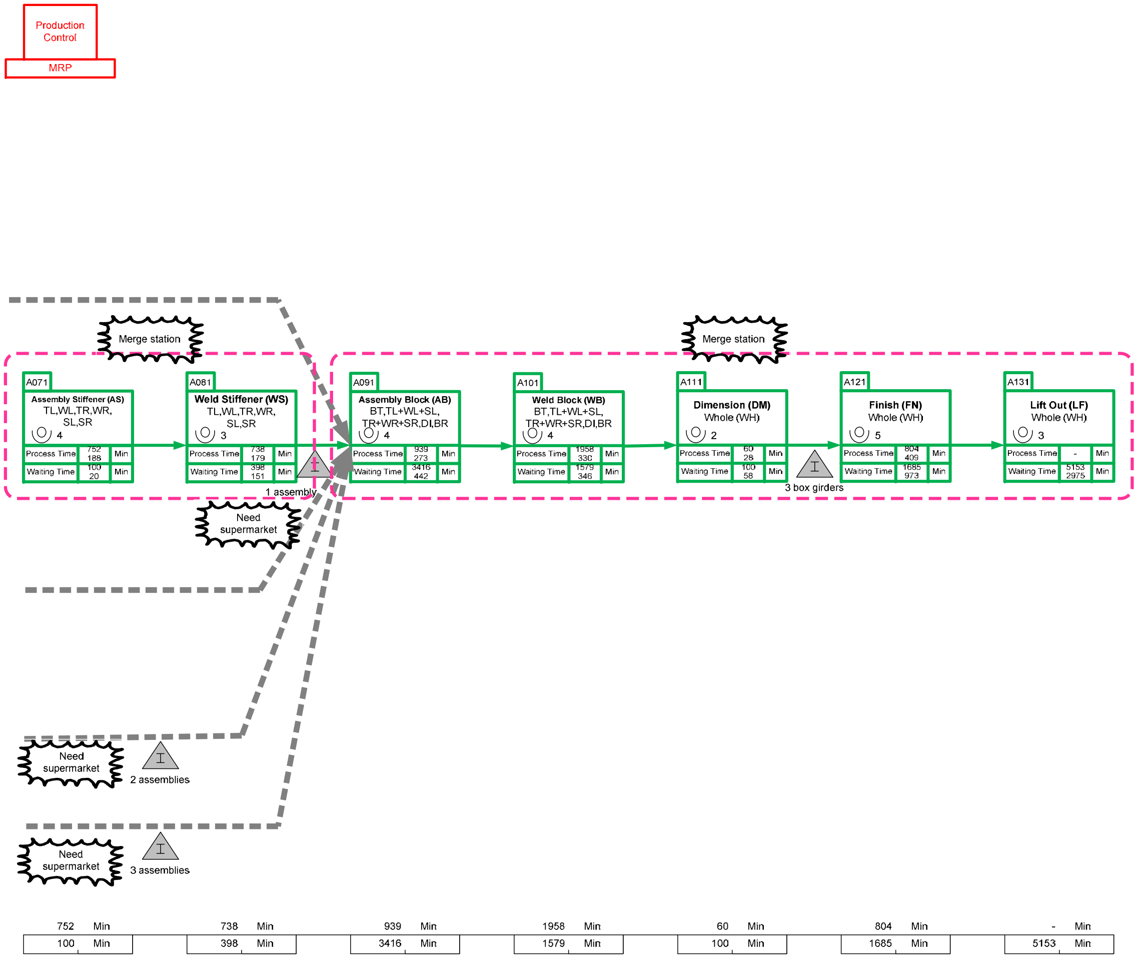


Figure 6.2 (Cont.) Kaizen identification of current process

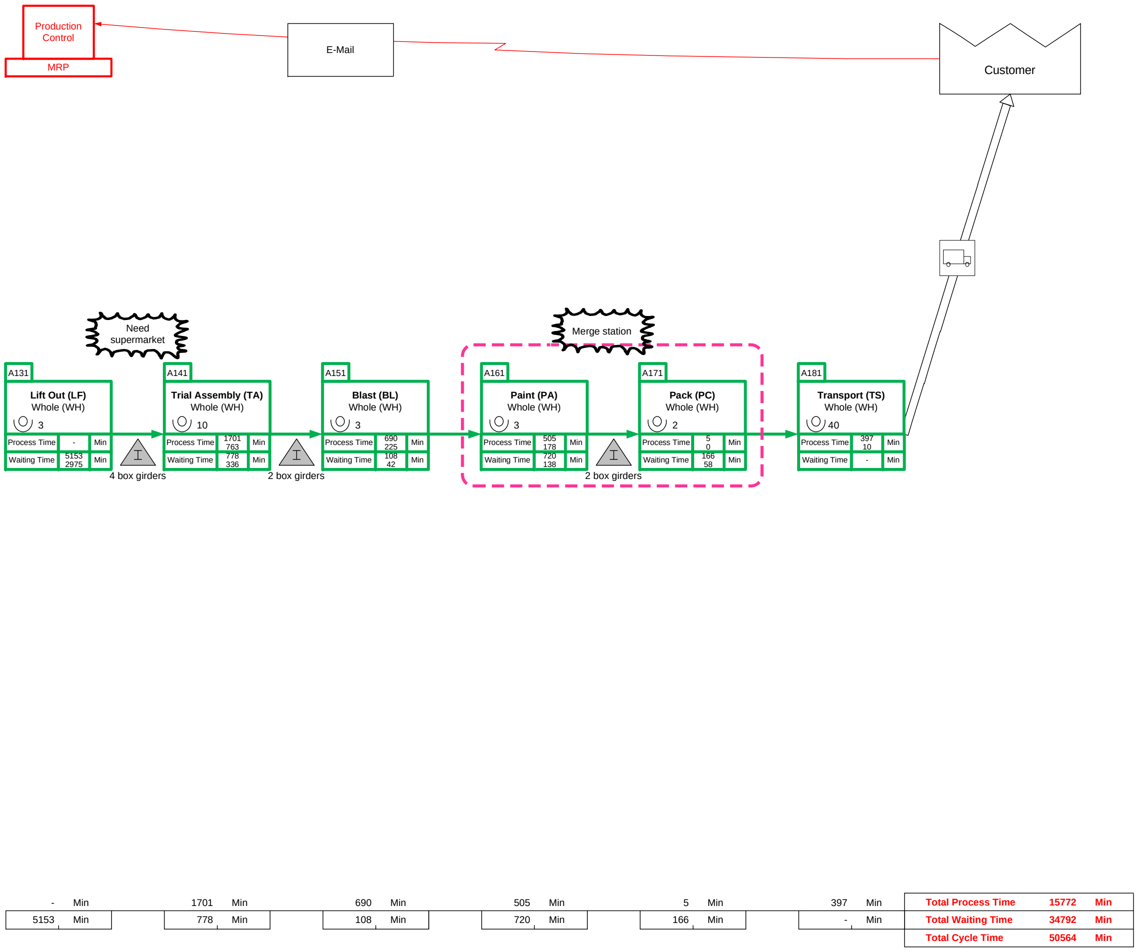


Figure 6.2 (Cont.) Kaizen identification of current process

6.6 Results from Process Improvement

After process improvement, total process time, waiting time, and cycle time can be computed as shown in value stream mapping (see Figure 6.1 and 6.3) and it separated into three improvement directions including variation reduction, waiting time reduction, and a combination of both.

Firstly, reduced variation by revising total process time, waiting time, and cycle time, which were reduced to 14,959 minutes, 34,792 minutes, and 49,157 minutes, respectively (i.e. 5.15%, 0.00%, and 1.61% reduction). Secondly, waiting time reduction could reduce total waiting time and cycle time to 20,073 minutes and 35,845 minutes, respectively (i.e. 42.31%, and 29.11% reduction). Lastly, a combination of reduced variation and waiting time reduction reduced total process time, waiting time, and cycle times, which were reduced to 14,959 minutes, 19,089 minutes, and 34,048 minutes, respectively (i.e. 5.15%, 45.13%, and 32.66% reduction). A comparison of all results is shown in Table 6.5. For actual production rates, production of one box girder toke 91.20 days (see work day summary in Table 5.5), although value stream mapping revealed a work day total equal to 80.34 days (see column 12 in Table 6.2). These two values differ around 19%, which implied that this value stream model was correct.

Improvement of variation showed a slight decrease in process time due to an adjusted coefficient of variation which represents steady worker performance. Otherwise, waiting time reduction was only due to merging activities as the same value of the current process. Finally, work processes were reduced from 18 steps to 11 steps under the improved process as shown in Figure 6.3.

The value stream mapping model had a limitation regarding work time which was that it was simplified and did not calculate idle time of workers such as taking a rest or going to the toilet because data was not available. Unfortunately, due to limitations regarding work areas and investment costs, it was hard to implement this in an actual process. As a result, a computer-programmed simulated model was used as explained in the next chapter.

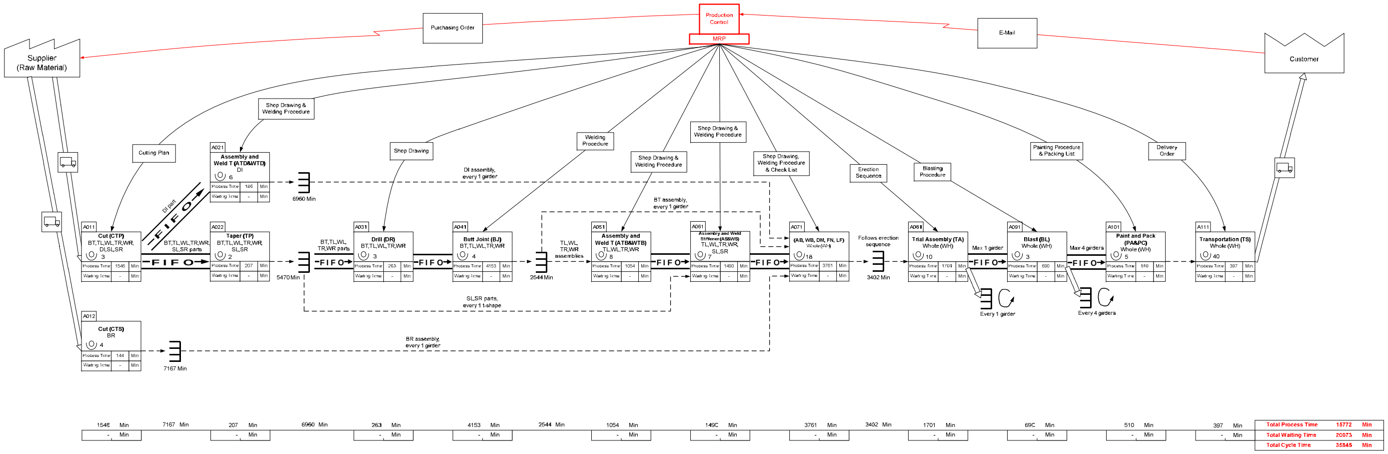


Figure 6.3 Improved process mapping

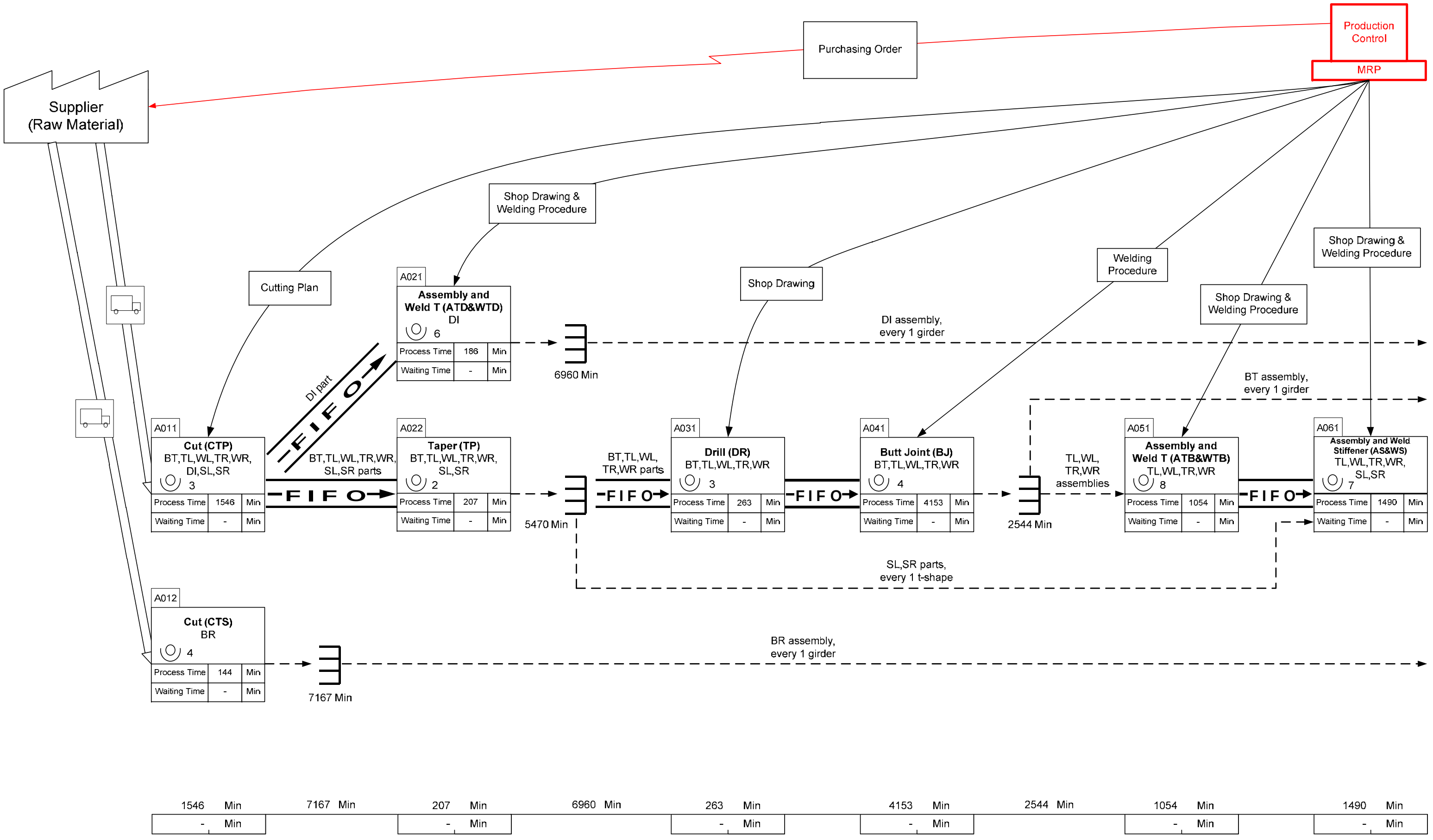


Figure 6.3 (Cont.) Improved process mapping

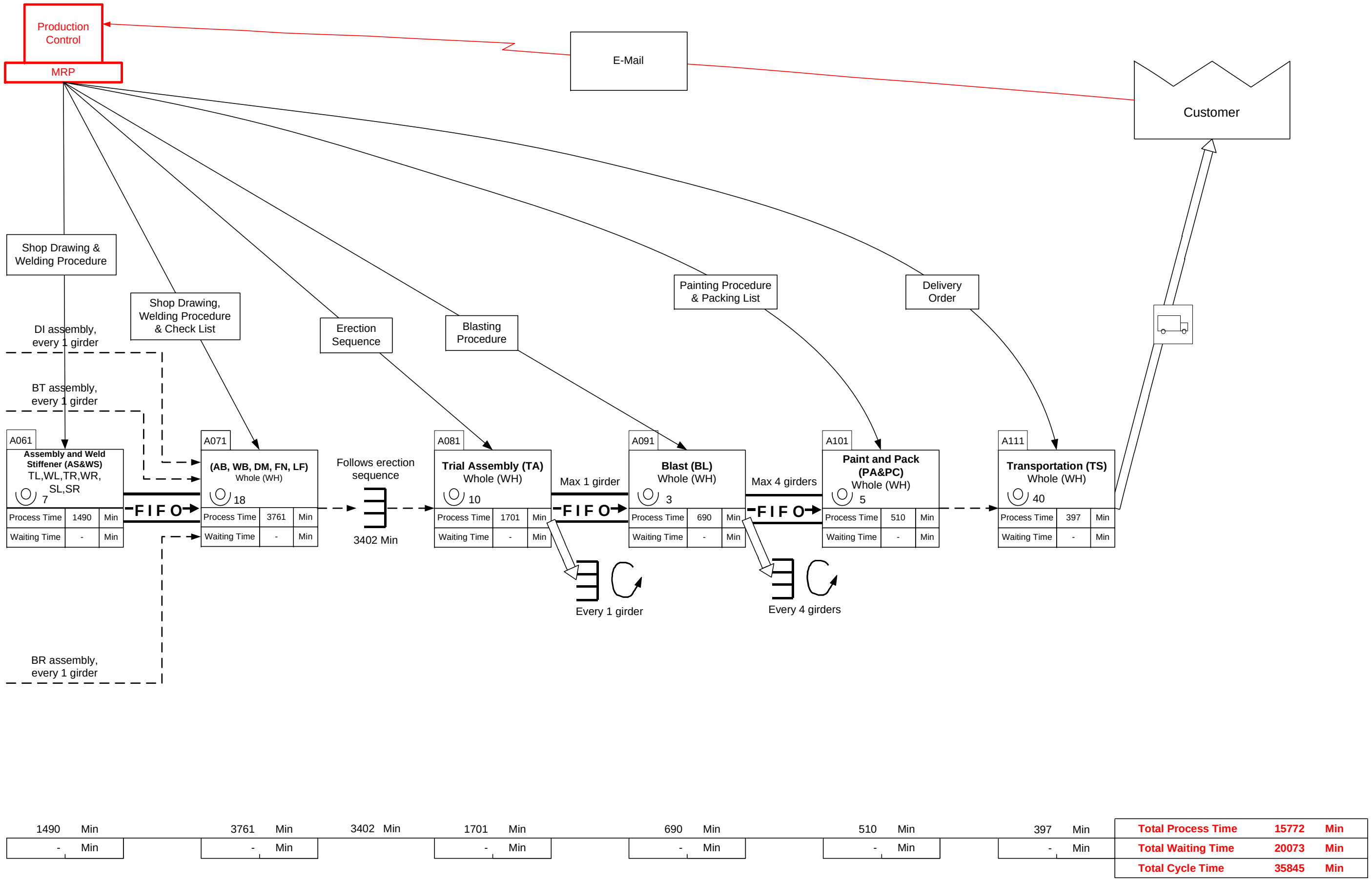
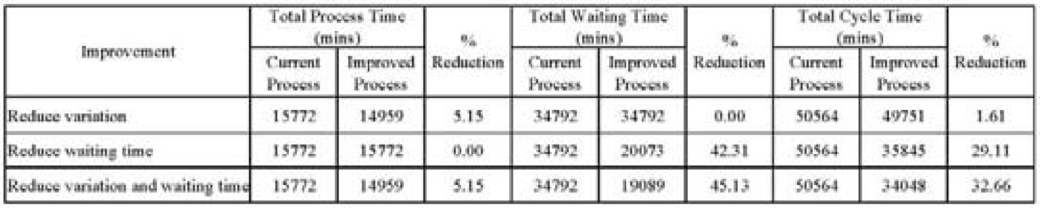


Figure 6.3 (Cont.) Improved process mapping

Table 6.5 Comparing results of value stream mapping improvement



Improvement	Total Process Time (mins)		% Reduction	Total Waiting Time (mins)		% Reduction	Total Cycle Time (mins)		% Reduction
	Current Process	Improved Process		Current Process	Improved Process		Current Process	Improved Process	
Reduce variation	15772	14959	5.15	34792	34792	0.00	50564	49751	1.61
Reduce waiting time	15772	15772	0.00	34792	20073	42.31	50564	35845	29.11
Reduce variation and waiting time	15772	14959	5.15	34792	19089	45.13	50564	34048	32.66

6.7 Summary

This chapter described the method of creating an analytical model and calculating the work performances of current and improved processes by value stream mapping applied with lean concept. The process improvement was divided into three areas including variation reduction, waiting time reduction, and bottleneck elimination, and the results consisted of improvement in percentage of process time, waiting time, and cycle time reduction (5%, 45%, and 33%, respectively). Due to the work area and cost limitations, this verification cannot be done in the factory and had been done using a simulated model.

CHAPTER VII

SIMULATION MODELING AND ANALYSIS

The previous chapter discussed the process improvement of steel box girder fabrication (SBGF) to determine work times reduction by applying lean concept. The improvements consisted of reducing variation of process time, merging activities, and eliminating the bottleneck activity which all results were calculated in term of maps by value stream mapping. For implementation, this research selected complete fabrication project as case study, including investment cost and work area constraints, therefore, process improvement was not carried out with actual work. For this reason, simulation model was utilized to represent the actual implementation on factory.

This chapter describes about the simulation model such as model creation, model components, and scenario execution as well as trial case results and suitable case selection. Also, the suitable case was established process improvement guideline which was in term of work policy and conformed to research objective.

7.1 Simulation Model

After analyzing the process by value stream mapping, which it issued the results as total process time and waiting time reduction. Thus, actual work should be implemented by adjusting followed the improvements such as reducing variation, merging activities, and eliminating bottleneck activity. Unfortunately, due to investment cost and work area constraints, fabrication processes cannot be impossible to adjust overall processes, therefore, simulation model was selected as the representation method to adjust instead of actual work process.

Because the improvements consist of several directions, simulation model was utilized in many trial cases of improvement directions. It can trial and error number of worker and machine along with working stations. This SBGF was single-line processes that combine various assemblies and the data was collected in term of uniform and PERT distributions which they were a deterministic format. The STROBOSCOPE program, discrete event program was selected to imitate this system (Martinez, 1996).

7.1.1 Model creation

The creation of the model consisted of the following steps:

1) Model components consist of the Queue, Combi, Normal, and Link which are described in Table 7.1.

2) The parameters of SBGF inputting into the model consist of process time of current process, number of workers, machines, and work stations, and raw material throughout the work time per day of each activity which all parameters are shown in Table 7.2. Obviously, process time of simulation model was in term of maximum, minimum, and most likely values which differed to value stream mapping as average values because simulation program can calculate values of distribution functions.

3) Assign program command and run.

7.1.2 Scenarios execution

After specifying the simulation model components, next trial runs of the model scenarios covering various situations of the SBGF were conducted. The model created of existing conditions or the current process by using value stream mapping was explained in Chapter 6 which they were single model. Simulation model was separated into three parts including 1) the preparation process (from CTP to WT activity), 2) part combination to be assembled (from CTS to WB activity), and 3) combination of all assemblies to form a box girder (from DM to TS activity). All models are depicted in Figure 7.1. The simulated model calculated overall work time for producing 20 box girders which differs under the value stream mapping model which calculated work time per box girder. The input and output of simulation source codes of the current process are shown in Appendix C.

Some trial and error was needed to help improve the process and create better efficiency. The main trial case categorizations conformed to the three improvement directions including variation reduction, waiting time reduction, and bottleneck elimination. The trial cases was described as follows:

1) Base case of current or existing process (case no.1 in Table 7.3).

2) Trial case of improved process to reduce variation. The process times of stations with a coefficient of variation over 0.3 were adjusted and the description is shown in Table 7.3 (case no.2).

3) For waiting time reduction, trial cases specifically adjusted by merging activities and maximum and minimum of process times were recalculated (see case no.3 in Table 7.3).

4) The bottleneck can be eliminated by doubling the work station or number of workers and was separated into two cases: case no.4A (for increasing working station) and case no.4B (for increasing number of workers). See Table 7.3.

5) The last trial case group was a combination of cases no.2 and 3, cases no.2 and 4A/4B, cases no.3 and 4A/4B, and cases no.2, 3 and 4A/4B together (see case no.5-8B in Table 7.3).

Finally, all simulated cases were run three times and their results were averaged.

Table 7.1 Simulation symbols (Martinez, 1996)

Symbol	Name	Description
	Queue	Resource storage to input into simulation flow or collect resources for other activities
	Combi	Simulation activity has work time duration
	Normal	Continual activity that starts immediately
→	Link	Connection between resource node and activity in simulation flow which consists of direction and type of resource

Table 7.2 Input data for simulation model

Item	Station	Type	Total Quantity		Raw Material Quantity		Parts Quantity per Assembly		Station Capacity			Working Time	Current Process Time for Uniform or PERT Distribution (Mins/Girder)			Current Process Time for Uniform or PERT Distribution (Mins/Part/Machine)		
			Part	Assembly	Raw Material	Parts per Raw Material	Mean	SD	Station Quantity	Machine per Station	Worker per Machine	(Mins/Day)	Max	Mode	Min	Max	Mode	Min
1	CTP	BT	93	-	91	3	-	-	2	1	3	780	390	-	180	42.86	-	19.78
		TL	70	-	27	6	-	-					290	-	120	107.41	-	44.44
		TR	70	-	24	6	-	-					760	-	80	316.67	-	33.33
		WL	64	-	65	3	-	-					225	-	145	34.62	-	22.31
		WR	64	-	65	3	-	-					465	-	95	71.54	-	14.62
		DI	96	-	30	4	-	-					1725	-	530	575.00	-	176.67
		SL	230	-	30	15	-	-					505	-	83	168.33	-	27.67
		SR	230	-	30	15	-	-					505	-	83	168.33	-	27.67
2	CTS	BR	441	-	140	2	-	-	2	2	2	780	357	-	216	12.75	-	7.71
3	TP	BT	93	-	-	-	-	-	4	2	1	660	430	-	75	11.56	-	2.02
		TL	70	-	-	-	-	-					110	-	45	3.93	-	1.61
		TR	70	-	-	-	-	-					110	-	45	3.93	-	1.61
		WL	64	-	-	-	-	-					110	-	45	4.30	-	1.76
		WR	64	-	-	-	-	-					150	-	100	5.86	-	3.91
		SL	230	-	-	-	-	-					140	-	75	1.52	-	0.82
		SR	230	-	-	-	-	-					140	-	75	1.52	-	0.82
4	DR	BT	93	-	-	-	-	-	3	1	3	660	775	-	145	55.56	-	10.39
		TL	70	-	-	-	-	-					110	-	35	10.48	-	3.33
		TR	70	-	-	-	-	-					110	-	35	10.48	-	3.33
		WL	64	-	-	-	-	-					110	-	35	11.46	-	3.65
		WR	64	-	-	-	-	-					165	-	55	17.19	-	5.73

Table 7.2 (Cont.) Input data for simulation model

Item	Station	Type	Total Quantity		Raw Material Quantity		Parts Quantity per Assembly		Station Capacity			Working Time	Current Process Time for Uniform or PERT Distribution (Mins/Girder)			Current Process Time for Uniform or PERT Distribution (Mins/Part/Machine)		
			Part	Assembly	Raw Material	Parts per Raw Material	Mean	SD	Station Quantity	Machine per Station	Worker per Machine	(Mins/Day)	Max	Mode	Min	Max	Mode	Min
5	BJ	BT	-	20	-	-	4.65	0.67	3	2	2	720	5830	-	435	971.67	-	72.50
		TL	-	20	-	-	3.50	0.33					3080	-	285	513.33	-	47.50
		TR	-	20	-	-	3.50	0.33					2150	-	280	358.33	-	46.67
		WL	-	20	-	-	3.20	0.17					2165	-	145	360.83	-	24.17
		WR	-	20	-	-	3.20	0.17					2160	-	80	360.00	-	13.33
6	ATB	TL	-	20	-	-	-	-	8	1	4	720	1370	-	200	171.25	-	25.00
		TR	-	20	-	-	-	-					2700	-	75	337.50	-	9.38
		WL	-	20	-	-	-	-					1370	-	200	171.25	-	25.00
		WR	-	20	-	-	-	-					395	-	75	49.38	-	9.38
7	WTB	TL-WL	-	20	-	-	-	-	8	4	1	720	5150	-	185	160.94	-	5.78
		TR-WR	-	20	-	-	-	-					4920	-	225	153.75	-	7.03
8	ATD	DI	-	16	-	-	6.00	0.50	3	1	3	720	50	-	50	16.67	-	16.67
9	WTD	DI	-	16	-	-	-	-	3	1	3	720	1440	-	1440	480.00	-	480.00
10	AS	SL	-	20	-	-	11.50	1.67	3	1	4	720	1755	-	270	585.00	-	90.00
		SR	-	20	-	-	11.50	1.67					1875	-	610	625.00	-	208.33
11	WS	TL-WL-SL	-	20	-	-	-	-	3	3	1	720	2160	-	345	240.00	-	38.33
		TR-WR-SR	-	20	-	-	-	-					1440	900	720	160.00	100.00	80.00
12	AB	BT	-	20	-	-	-	-	10	1	4	720	4320	-	10	432.00	-	1.00
		TL-WL-SL	-	20	-	-	-	-					6640	-	240	664.00	-	24.00
		TR-WR-SR	-	20	-	-	-	-					1440	-	135	144.00	-	13.50
		DI	-	16	-	-	-	-					165	-	110	16.50	-	11.00
		BR	-	20	-	-	22.05	1.67					5520	-	205	552.00	-	20.50

Table 7.2 (Cont.) Input data for simulation model

Item	Station	Type	Total Quantity		Raw Material Quantity		Parts Quantity per Assembly		Station Capacity			Working Time	Current Process Time for Uniform or PERT Distribution (Mins/Girder)			Current Process Time for Uniform or PERT Distribution (Mins/Part/Machine)		
			Part	Assembly	Raw Material	Parts per Raw Material	Mean	SD	Station Quantity	Machine per Station	Worker per Machine	(Mins/Day)	Max	Mode	Min	Max	Mode	Min
13	WB	BT	-	20	-	-	-	-	10	4	1	720	7440	-	670	186.00	-	16.75
		TL-WL	-	20	-	-	-	-					7440	-	480	186.00	-	12.00
		TR-WR	-	20	-	-	-	-					4410	-	720	110.25	-	18.00
		DI	-	16	-	-	-	-					4800	-	1440	120.00	-	36.00
		TL-WL-SL	-	20	-	-	-	-					1200	-	1200	30.00	-	30.00
		TR-WR-SR	-	20	-	-	-	-					1920	-	1200	48.00	-	30.00
		BR	-	20	-	-	-	-					4800	-	1440	120.00	-	36.00
14	DM	WH	-	20	-	-	-	-	10	2	1	600	1090	-	110	54.50	-	5.50
15	FN	WH	-	20	-	-	-	-	2	1	5	600	3025	-	190	1512.50	-	95.00
16	TA	WH	-	20	-	-	-	-	6	2	5	600	18135	-	2280	1511.25	-	190.00
17	BL	WH	-	20	-	-	-	-	1	3	1	600	1080	-	300	360.00	-	100.00
18	PA	WH	-	20	-	-	-	-	4	3	1	600	3255	-	785	271.25	-	65.42
19	PC	WH	-	20	-	-	-	-	5	1	2	480	30	25	20	6.00	5.00	4.00
20	TS	WH	-	20	-	-	-	-	1	10	4	840	1920	720	180	192.00	72.00	18.00

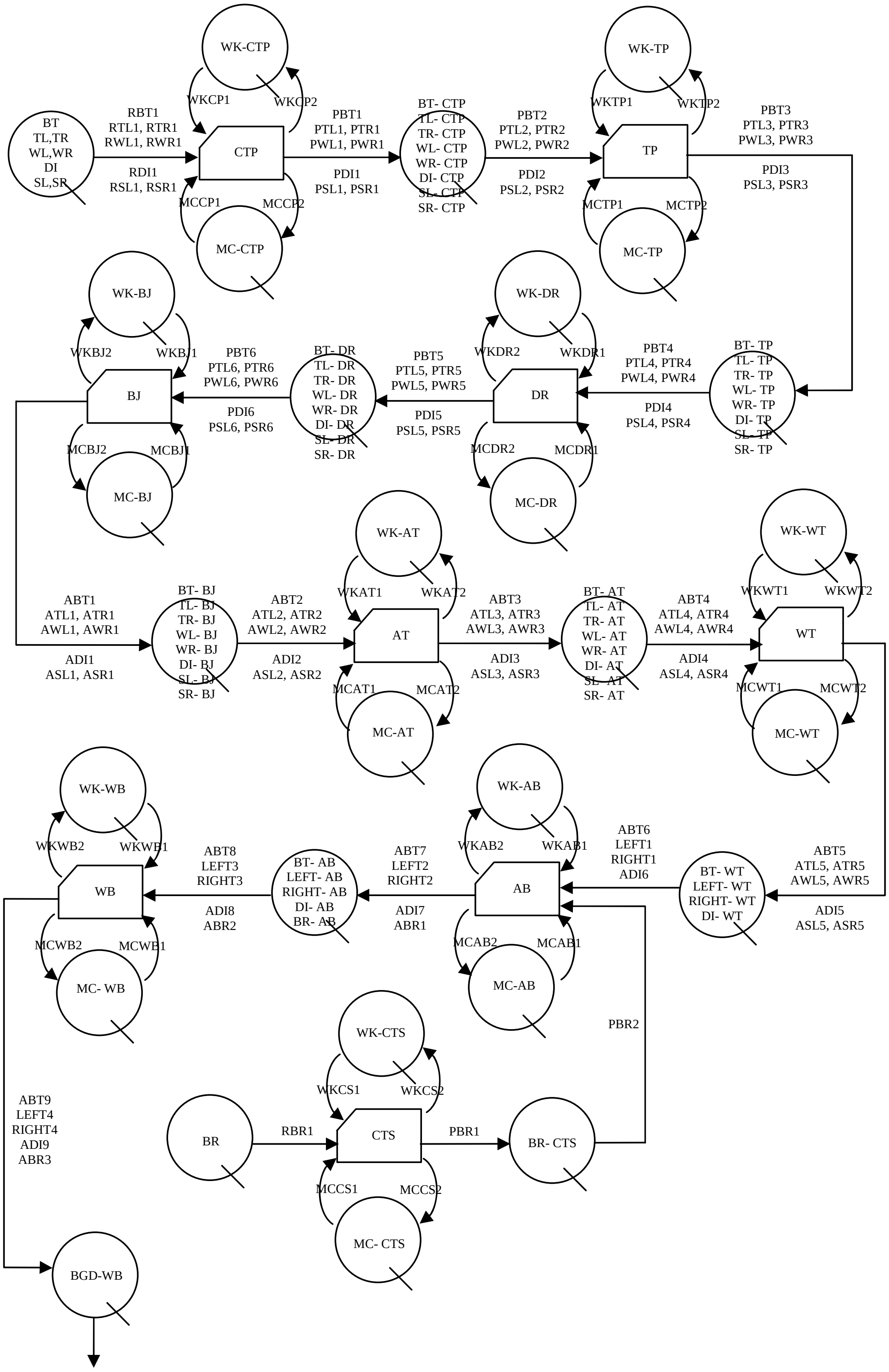
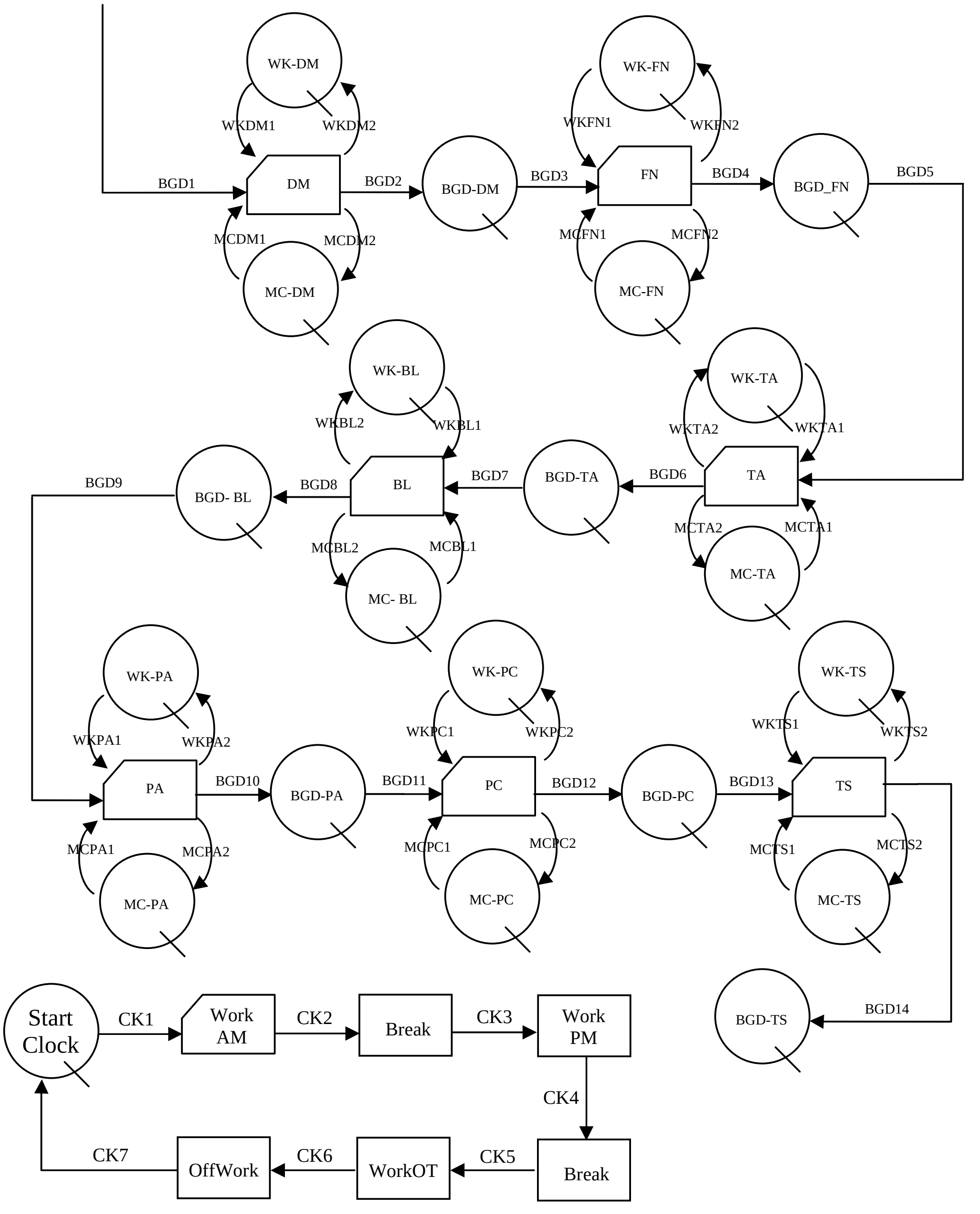


Figure 7.1 Simulation model flow



RBT = Raw Material Bottom
RTL = Raw Material Left Top-Flange
RTR = Raw Material Right Top-Flange
RWL = Raw Material Left Web-Flange
RWR = Raw Material Right Web-Flange
RDI = Raw Material Diaphragm
RSL = Raw Material Left Stiffener
RSR = Raw Material Right Stiffener
RBR = Raw Material Bracing
PBT = Part Bottom
PTL = Part Left Top-Flange
PTR = Part Right Top-Flange
PWL = Part Left Web-Flange
PWR = Part Right Web-Flange
PDI = Part Diaphragm
PSL = Part Left Stiffener
PSR = Part Right Stiffener
PBR = Part Bracing
ABT = Assembly Bottom
ATL = Assembly Left Top-Flange
ATL = Assembly Right Top-Flange
AWL = Assembly Left Web-Flange
AWR = Assembly Right Web-Flange
ADI = Assembly Diaphragm
ASL = Assembly Left Stiffener
ASR = Assembly Right Stiffener
BGD = Box Girder
LEFT = Left Side Flange
RIGHT = Right Side Flange
WK = Worker
MC = Machine
CK = Clock

Figure 7.1 (Cont.) Simulation model flow

7.2 Simulation Results, Verification, and Comparison

The simulated model was designed to verify process improvements that comprised process time and waiting time variables (especially waiting time divided in terms of materials, machines, and workers). The simulation (SIM) results, verifications, and comparison with value stream mapping (VSM) can be categorized as follows:

1) Current process base case (case no.1)

This case calculates work time of the current process for complete box girder production by inputting the same data of VSM into the model. The results of SIM cannot directly compare with VSM because SIM computed entire work time and VSM computed work time for production of one box girder. For this reason, SIM work time should be compared with actual work time equal to 127 days and SIM work time equal 132 days with a different percentage of work time comparison around 4%, which is insufficient. Therefore, this SIM model was considered reliable and can be the base model for comparison with other trial cases for improvement.

2) Improved process of variation reduction (case no.2)

The results of this case consisted of increasing process time around 2% and reducing waiting time around 5%. The increased process time was because the maximum or minimum input data was changed which effected the process time calculation. Nevertheless, this increase in process time was insufficient and can be simplified as being “no change”. Compared to VSM (process time reduction of 5%), it is not different in value. VSM cannot reduce waiting time but SIM reduces it around 5%. Actual process time of variation reduction could not be reduced, therefore this SIM result is acceptable.

3) Improved process of waiting time reduction (case no.3)

Waiting time of the simulated model was divided into three parts including materials, machines, and workers which were reduced by 26%, 69%, and 64%, respectively. VSM results decreased around 42%, which is not very different from the SIM results which averaged equal to 52%. Obviously, the greater reduction of process time of SIM was influenced by merging stations and the changing process time which affected the simulation program. On the other hand, VSM process time was calculated by ordinary summation which did not affect the total process time.

4) Improved process of bottleneck elimination (case no.4A/4B)

The bottleneck of the VSM model is the busiest activity or highest utilization percentage (see Table 6.2). The SIM model used an activity under which the bottleneck of the previous activity has the most waiting time – the weld t-shape for box girder activity. The SIM model combined the weld stiffener and weld t-shape for diaphragm activities. As a result, the next activity is assembly block which formed a bottleneck. On the other side, the bottleneck of VSM was at the trial assembly because this activity had the highest utilization percentage which it rather different from SIM. Therefore, SIM analysis follows the bottleneck of the VSM model because the SIM model was created to verify the VSM results.

Due to the elimination of the bottleneck under the VSM model, process time and waiting time reduction cannot be determined. Thus SIM was used instead for this action. Obviously, both total process time and waiting time of SIM results increased because the trial assembly activity was adjusted by increasing the work area or number of workers. Doubling the work area reduced process time by half. Therefore, it increased total process time output around 48% because this process required more work time to complete the entire project. Moreover, increasing the number of workers decreases total process time by around 25%, which is less than increasing the work area.

Total waiting time increased by around 20% meaning that doubling the size of the work station or number of workers was not an advantage for eliminating the bottleneck. It did however increase waiting time as both machines and workers have to wait for approaching materials.

5) Combination of improved process (case no.5-8B)

In case no.5, the process time and waiting time were reduced more than in case no.3. This implies that variation reduction is an effective improvement when combined with waiting time reduction. Also, VSM waiting time was greatly reduced when improvements combine both variation and waiting time reduction. Furthermore, combination of bottleneck elimination and waiting time reduction (case no.7A or 7B) is more effective than variation reduction (case no.6A or 6B) because materials have more flow ability which can reduce machine and worker waiting time. Comparison between doubling the station size and number of workers at the trial assembly activity reveals little difference as shown in cases 7A and 7B. This indicated that increasing the work area or number of workers of the trial assembly activity was equally effective depending on suitable application and concerned parameters of operation cost, work area, and number of workers.

Cases no.8A and 8B are an all improvement combination. If compared to cases no. 7A and 7B, the difference is insignificant. Obviously, material waiting time of case no.8A or 8B is reduced two times more than 7A and 7B because material has a good flow as a result of the merging activity.

6) Suitable case selection

Based on the simulation results comparison above, the most suitable case for improvement is case no.8A because it can reduce process time by around 80% and waiting time of materials, machines, and workers by around 70% (on average). This case involves adjustment of variation, waiting time, and also work area of the trial assembly activity. As this activity had a limited work area, increasing the work area can increase workflow and reduce waiting time which is easily implemented.

All results were estimated working times to develop improvement guidelines in each case scenario which will be explained in the next section.

7.3 Improvement Process Guideline

The results of both the value stream mapping model and simulation model presented guidelines for implementation in terms of actual work application which should be summarized as proper working policy of improvement. The policy was described as having both quantitative and qualitative functions which result in work time reduction, material, machine and worker management, and quality control as follows:

7.3.1 Working time reduction

The SBGF project consists of three types of work time including process time, waiting time, and cycle time (a combination of process time and waiting time) which will be reduced by applying lean concept. Actual work time can be adjusted by following these methods:

1) Process time

Reducing the variation of each activity by maintaining was steady work time. The control is implemented in the actual work process by training workers to improve performance and always fulfill their potential.

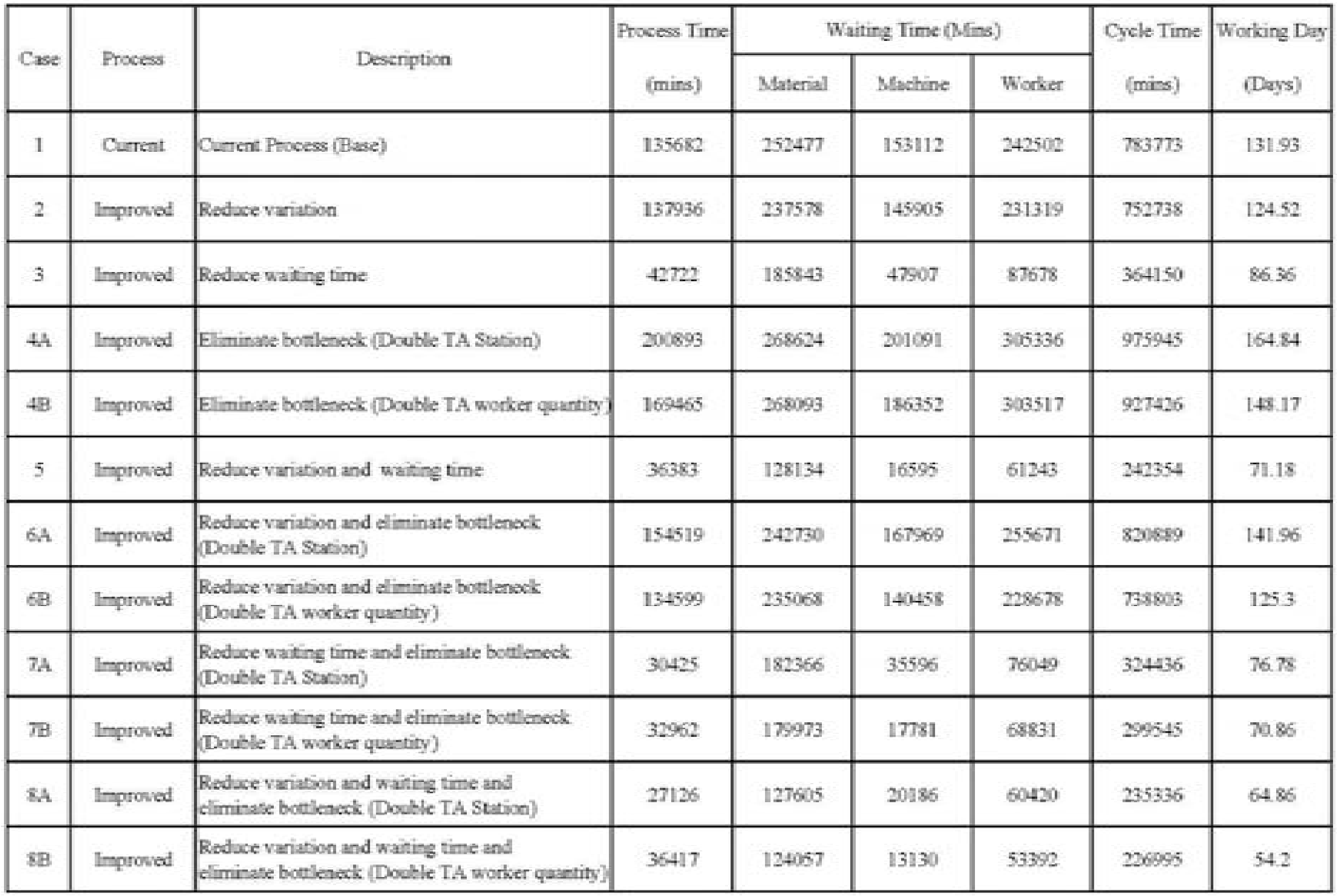
2) Waiting time

- Merging activities which were located in the same area such as assembly and weld t-shape for diaphragm (ATD-WTD), assembly and weld t-shape for box girder (ATB-WTB), assembly and weld stiffener (AS-WS), assembly and weld block, dimension, finish, and lift out (AB-WB-DM-FN-LF), and paint and pack (PA-PC). This merging can reduce material transportation time during the process.

- Using a FIFO (First-In-First-Out) lane of fabrication process to reduce waiting time of flowing material. This application arranges some activities to continually start after the previous activity has finished. These activities are taper, drill, butt joint, assembly and weld stiffener, assembly and weld t-shape for diaphragm, assembly block, blast, and pack (see Figure 6.3).

- Allowing process inventory of some activities such as cut shape, taper, assembly and weld t-shape for diaphragm, and butt joint by using the supermarket tool because these activities must wait for other box girder assemblies although the main process is still going on (see Figure 6.3).

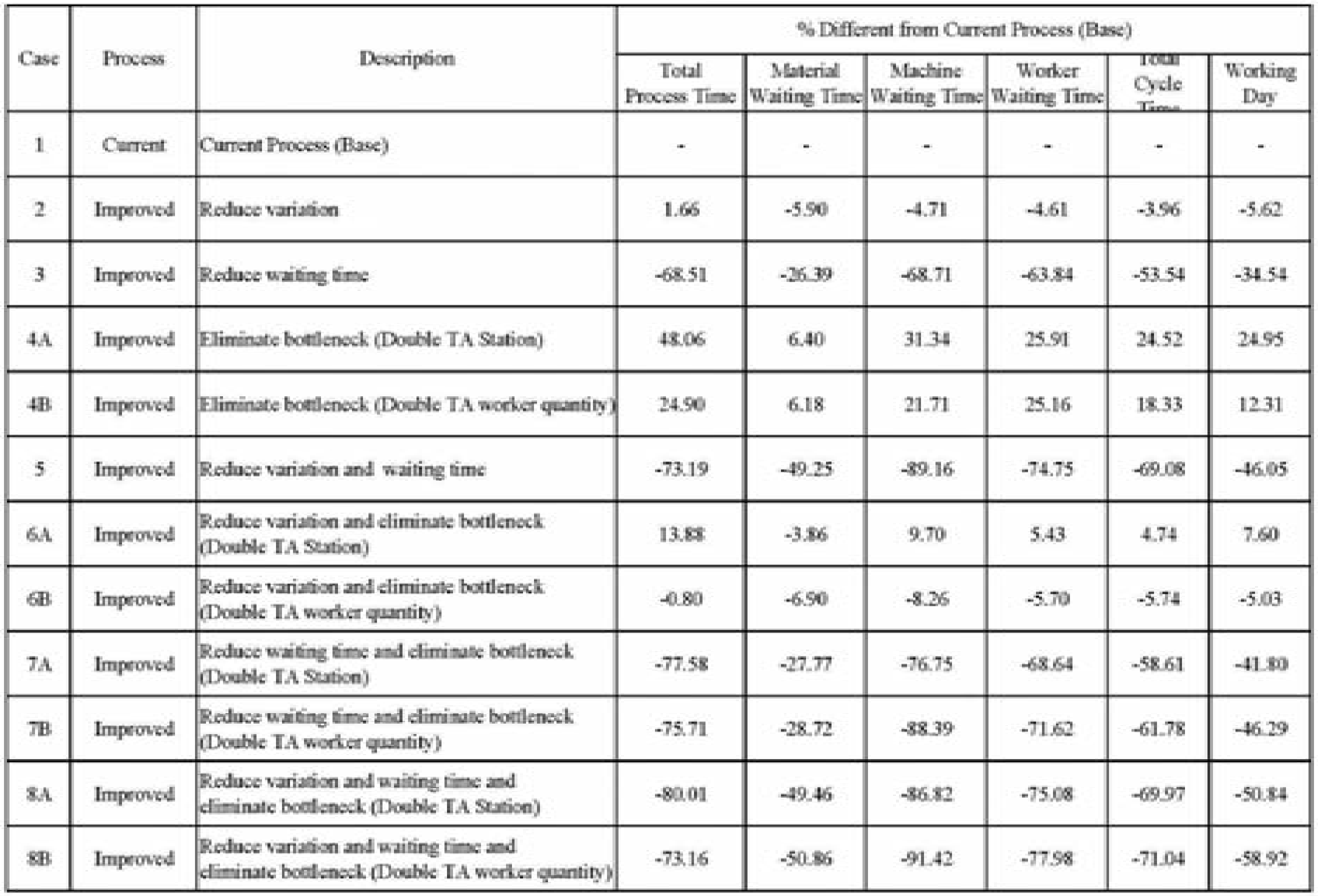
Table 7.3 Simulation results and comparisons



Case	Process	Description	Process Time (mins)	Waiting Time (Mins)			Cycle Time (mins)	Working Day (Days)
				Material	Machine	Worker		
1	Current	Current Process (Base)	135682	252477	153112	242502	783773	131.93
2	Improved	Reduce variation	137936	237578	145905	231319	752738	124.52
3	Improved	Reduce waiting time	42722	185843	47907	87678	364150	86.36
4A	Improved	Eliminate bottleneck (Double TA Station)	200893	268624	201091	305336	975945	164.84
4B	Improved	Eliminate bottleneck (Double TA worker quantity)	169465	268093	186352	303517	927426	148.17
5	Improved	Reduce variation and waiting time	36383	128134	16595	61243	242354	71.18
6A	Improved	Reduce variation and eliminate bottleneck (Double TA Station)	154519	242730	167969	255671	820889	141.96
6B	Improved	Reduce variation and eliminate bottleneck (Double TA worker quantity)	134599	235068	140458	228678	738803	125.3
7A	Improved	Reduce waiting time and eliminate bottleneck (Double TA Station)	30425	182366	35596	76049	324436	76.78
7B	Improved	Reduce waiting time and eliminate bottleneck (Double TA worker quantity)	32962	179973	17781	68831	299545	70.86
8A	Improved	Reduce variation and waiting time and eliminate bottleneck (Double TA Station)	27126	127605	20186	60420	235336	64.86
8B	Improved	Reduce variation and waiting time and eliminate bottleneck (Double TA worker quantity)	36417	124057	13130	53392	226995	54.2

Remark (-) is % reduced value, (+) is % increased value

Table 7.3 (Cont.) Simulation results and comparisons



Case	Process	Description	% Different from Current Process (Base)					
			Total Process Time	Material Waiting Time	Machine Waiting Time	Worker Waiting Time	Total Cycle Time	Working Day
1	Current	Current Process (Base)	-	-	-	-	-	-
2	Improved	Reduce variation	1.66	-5.90	-4.71	-4.61	-3.96	-5.62
3	Improved	Reduce waiting time	-68.51	-26.39	-68.71	-63.84	-53.54	-34.54
4A	Improved	Eliminate bottleneck (Double TA Station)	48.06	6.40	31.34	25.91	24.52	24.95
4B	Improved	Eliminate bottleneck (Double TA worker quantity)	24.90	6.18	21.71	25.16	18.33	12.31
5	Improved	Reduce variation and waiting time	-73.19	-49.25	-89.16	-74.75	-69.08	-46.05
6A	Improved	Reduce variation and eliminate bottleneck (Double TA Station)	13.88	-3.86	9.70	5.43	4.74	7.60
6B	Improved	Reduce variation and eliminate bottleneck (Double TA worker quantity)	-0.80	-6.90	-8.26	-5.70	-5.74	-5.03
7A	Improved	Reduce waiting time and eliminate bottleneck (Double TA Station)	-77.58	-27.77	-76.75	-68.64	-58.61	-41.80
7B	Improved	Reduce waiting time and eliminate bottleneck (Double TA worker quantity)	-75.71	-28.72	-88.39	-71.62	-61.78	-46.29
8A	Improved	Reduce variation and waiting time and eliminate bottleneck (Double TA Station)	-80.01	-49.46	-86.82	-75.08	-69.97	-50.84
8B	Improved	Reduce variation and waiting time and eliminate bottleneck (Double TA worker quantity)	-73.16	-50.86	-91.42	-77.98	-71.04	-58.92

Remark (-) is % reduced value, (+) is % increased value

3) Working process

- Eliminating the bottleneck in the trial assembly activity by dividing the erection area into two areas. Importantly, this bottleneck elimination cannot independently adjust to the process because it results in excessive machine and worker waiting time. Therefore, process adjustment should be combined with the merging activity.

- Re-laying out the blast activity which was located too far away from trial assembly (previous activity) and paint activity (post activity) to reduce transportation time and prevent excessive transportation.

7.3.2 Material, machine and worker management

This section explains material, machine, and worker usage which should increase efficiency by monitoring utilization percentage and includes the following components:

1) Material control

- Production control should comply with the erection sequence of the trial assembly activity because this activity had a bottleneck. For this reason, the first activity begins with the first box girder of the erection sequence because whole process can flow without waiting for the box girder to arrive.

- The blast and pack activities were limited due to the work area. The means that the blast activity can produce one box girder and pack activity can produce four box girders per work period. For this reason, if the previous activity feeds more box girders than its capacity, these box girders would have to wait which is overproduction waste.

2) Machine performance

Machine efficiency should be measured by percentage of utilization calculation to meet optimum performance and prevent overprocessing waste. However, if percentage of utilization was increased, station capacity would increase; therefore, it would increase machine quantity and not conform to lean concept.

3) Worker performance

Human error is simple problem of production which can be eliminated by inspection of output characteristics such as dimension, shape, and thickness.

7.3.3 Quality control

The last section provides a qualitative description which cannot be verified in terms of calculation. However, it does provide an explanation of quality improvement of output which consists of the following parameters:

1) Prevent defects

As mentioned earlier, training workers can reduce work variation and prevent defects or errors which occur during work resulting in wasted time and money.

2) Workplace environment

- Cleaning or organizing the workplace will make it easier to work in and provide a better environment in which workers can produce a quality product.
- Reducing or eliminating unnecessary tools or equipment in the process.

3) Documentation

Each work step should be detailed in a document to instruct or support work methods to reduce work errors.

Suitable implementation of process improvement combines training workers to reduce variation, merging activities to reduce waiting time, and increasing trial assembly areas to eliminate bottleneck.

7.4 Recommendations for Process Improvement

This section contains the results of interviews with personnel in charge of this project which were conducted proposing improvements and requesting opinions regarding implementation in the factory. Four summarized interviewee opinions are as follows:

1) In terms of increasing performance, increasing the number of workers was more important than the number of machines because the adding of machines was a direct cost, therefore increasing the number of workers was more suitable. Also excess manpower can be allocated to other work stations, which was one advantage of this arrangement (Somsak Nualyai, interview, April 10, 2012). See Figure 7.2.

2) Witit Sinthong (interview, March 28, 2012) and Sansuk Phengphaeng (interview, March 29, 2012) mentioned that the quality control of parts during the preparation process, including the cut and taper activities, should be fine to control the output quality before the parts were transferred to the next activity. They added that the checkers should put more emphasis on the quality assurance of parts. Moreover, they suggested that the process should have more flow ability and a well-prepared machine to support material serving. Also, when the factory requested more productivity, the work load should be shared with a sub-contractor. In addition, Witit Sinthong advised that training workers can improve their work performance. See Figure 7.2.

3) Montri Sarai (interview, April 17, 2012) suggested adding workers to parts preparation such as the cut activity would be more effective as this activity was a bottleneck in the process because it consisted of multiple work steps. Due to cutting plan orders and for economic reasons, some parts that were already cut cannot be used for fabrication since they were not comprised of other assemblies like box girders. Furthermore, manpower relocation affects some work processes because of a lack of workers, leaving machines unused and the station temporary halted. The controlling of materials being inputted can be adjusted, but should be well coordinated between the departments.

4) Jarin Phinyoying (interview, April 17, 2012) stated that shop drawing performance did not have problems. Moreover, he advised that welding improvements should comply with procedures to protect distortion of materials by setting the welding points from the middle to the end of the assembly. In addition, the calibration of machines should be standard to reduce material output errors. See Figure 7.2.

Figure 7.2 Interview with personnel in charge (a)

Figure 7.2 Interview with personnel in charge (b)

Figure 7.2 Interview with personnel in charge (c)

7.5 Simulation Model Limitation

1) The butt joint activity under value stream mapping consists of three activities, but for simulation these were grouped into a single and simplified average process time for the three activities to be equal.

2) The welding time of two or three jointed assemblies are equal and share the process time for each assembly. For example, welding time of the left-top flange and left-web flange was calculated by dividing the two to have equal time for each assembly.

3) Work time per day was calculated by averaging all work times for each activity as shown in Table 4.7.

4) The equipment of each activity was grouped and counted as a set unit.

5) Raw material was independent of each part and cannot be combined with other parts as they are just one raw material.

7.6 Summary

This chapter explained the creation of a simulation model including model components and input data along with scenarios or trial cases which cover many improvement directions. Also, it included a proper selected case which illustrated a process improved by reducing both process time and waiting time, and eliminating the bottleneck activity. For this, the selected case was explained in regards to improved process guidelines as well as simulation limitations and recommendations of personnel in charge.

CHAPTER VIII

CONCLUSIONS

The last chapter provides overall research conclusions, research limitations, and suggestions for future research. In addition, it explains the research details which consist of improvement results for both value stream mapping and simulation model and improvement process guidelines along with interviews with personnel in charge to regarding recommendations for process improvement.

8.1 Conclusions

This research examines the steel fabrication process in the factory. As it involves numerous parts and activities, the work times of each activity are the parameters of concern. The research began by studying steel box girder fabrication (SBGF) including setting the data collection format, and recording the data of the actual processes at the factory. Afterwards, all data was transformed in terms of uniform and PERT distribution into “current process data”.

Next, the current process data was input into value stream mapping to explore process waste and determine work times such as process time, waiting time, and cycle time, including percentage of utilization calculation and bottleneck activity identification. Subsequently, lean concept was used to reduce work times and improve work processes. All work times and processes were adjusted in various analysis directions such as reducing variation, merging activities, and eliminating bottleneck activity. As the results, all values were remapped through value stream mapping of the improved process and process time, waiting time, and cycle time were recalculated.

After analysis the improved process by value stream mapping, it summarized that process time can be reduced by reducing variation, waiting time was reduced by merging work activities, and bottleneck activity can be eliminated by increasing work area. The improvement results of value stream mapping displayed total process time, total waiting time, and total cycle time reduction as equal 5%, 45%, and 33%, respectively.

It was determined that the improved process can be implemented with actual processes at the factory by creating improvement process guidelines and applying them for process improvement. Unfortunately, this implementation could not be done on an actual process because it involves the limitation of investment cost constraints. Therefore, a simulated model was created to solve this problem by STROBOSCOPE, a discrete event program. Also, trial cases of simulation models were executed and conformed to improvement directions such as variation and waiting time reduction, bottleneck elimination, including trial case combinations. Simulation results were used to verify and compare the differential improvement results of the value stream mapping model and served as the basis for improvement guidelines for actual process application.

Improvement process guidelines were separated into working time reduction, materials, machines, worker management, and quality control. Process time reduction involved reducing variation within each activity by training workers to conserve work performance as steady. Furthermore, waiting time reduction is achieved by merging work activities together and using lean tools such as the FIFO (First-In-First-Out) lane and supermarket. In addition, bottleneck activity can be eliminated by doubling the stations where the bottleneck occurs or doubling the number of workers.

Another improvement guideline relates to quality; for example, defect prevention or workplace environment adjustment which can be improved by using lean tools. However, this research focused exclusively on quantitative analysis of work time, thus only a brief explanation of qualitative function is provided. The study used interviewing to obtain recommendations of experts regarding the suggestions for process improvement

8.2 Research Limitations

SBGF located in large area and divided into several work zones which all areas are operated at the same time. Also, there was only one researcher collecting data, therefore, data collection was not complete and contained errors. Moreover, some data were subjectively assessed by the personnel in charge for maximum, minimum, and mode value, and were counted using production rate to determine work times which were affected some information errors. In addition, number of workers and machines were simplified only for ordinary work times. Regarding work times was simplified and did not calculate idle time of workers such as taking a rest or going to the toilet because data was not available. For process analysis, some input data of both value stream mapping model and simulation model were simplified to accommodate calculation.

8.3 Suggestions for Future Research

This research applied lean concept to SBGF to improve the fabrication process by reducing time wastage. SBGF comprises numerous work steps and components which are similar to construction projects, consisting of work activities and raw materials. For this reason, lean concept can be applied to SBGF projects utilizing the same methodology such as data collection, analysis and implementation. For example, precast concrete work is complex because it consists of both production in the factory and installation at the construction site. The precast concrete production process similarly involves raw materials, assembly, machines, workers and activities. For this reason, lean concept can be applied to explore ways to reduce waste in the process.

Furthermore, a construction project can be categorized as work activity that involves using raw materials like the fabrication process. In terms of operation cost, research can monitor the increase or decrease of work time under each case scenario because various cases require different work times which affect daily machine and worker costs.

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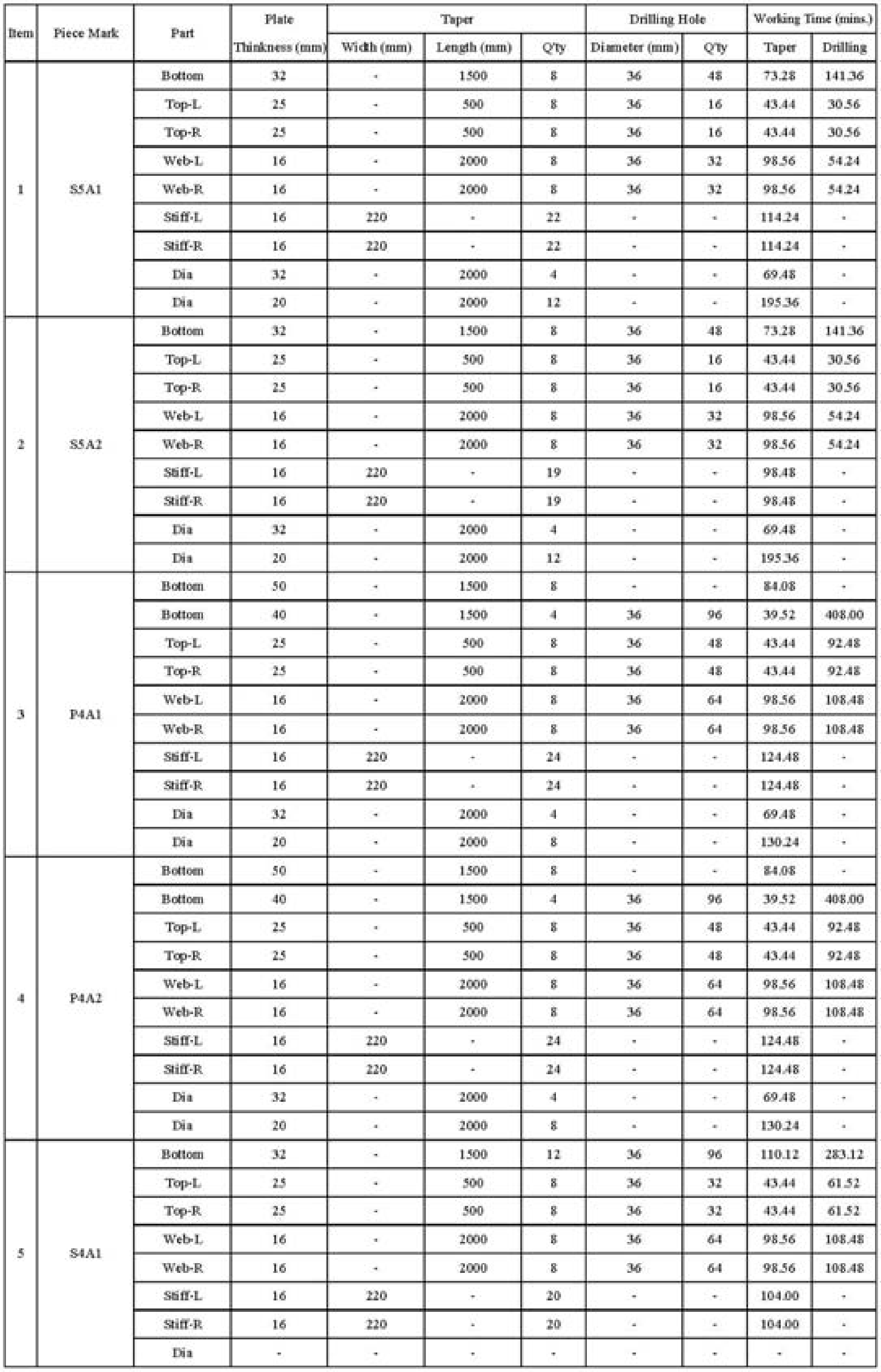
APPENDICES

APPENDIX A

Data collection

Table A.1 Taper and drill working time



Item	Piece Mark	Part	Plate	Taper			Drilling Hole		Working Time (mins.)	
			Thinkness (mm)	Width (mm)	Length (mm)	Q'ty	Diameter (mm)	Q'ty	Taper	Drilling
1	S5A1	Bottom	32	-	1500	8	36	48	73.28	141.36
		Top-L	25	-	500	8	36	16	43.44	30.56
		Top-R	25	-	500	8	36	16	43.44	30.56
		Web-L	16	-	2000	8	36	32	98.56	54.24
		Web-R	16	-	2000	8	36	32	98.56	54.24
		Stiff-L	16	220	-	22	-	-	114.24	-
		Stiff-R	16	220	-	22	-	-	114.24	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-
2	S5A2	Bottom	32	-	1500	8	36	48	73.28	141.36
		Top-L	25	-	500	8	36	16	43.44	30.56
		Top-R	25	-	500	8	36	16	43.44	30.56
		Web-L	16	-	2000	8	36	32	98.56	54.24
		Web-R	16	-	2000	8	36	32	98.56	54.24
		Stiff-L	16	220	-	19	-	-	98.48	-
		Stiff-R	16	220	-	19	-	-	98.48	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-
3	P4A1	Bottom	50	-	1500	8	-	-	84.08	-
		Bottom	40	-	1500	4	36	96	39.52	408.00
		Top-L	25	-	500	8	36	48	43.44	92.48
		Top-R	25	-	500	8	36	48	43.44	92.48
		Web-L	16	-	2000	8	36	64	98.56	108.48
		Web-R	16	-	2000	8	36	64	98.56	108.48
		Stiff-L	16	220	-	24	-	-	124.48	-
		Stiff-R	16	220	-	24	-	-	124.48	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
4	P4A2	Bottom	50	-	1500	8	-	-	84.08	-
		Bottom	40	-	1500	4	36	96	39.52	408.00
		Top-L	25	-	500	8	36	48	43.44	92.48
		Top-R	25	-	500	8	36	48	43.44	92.48
		Web-L	16	-	2000	8	36	64	98.56	108.48
		Web-R	16	-	2000	8	36	64	98.56	108.48
		Stiff-L	16	220	-	24	-	-	124.48	-
		Stiff-R	16	220	-	24	-	-	124.48	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
5	S4A1	Bottom	32	-	1500	12	36	96	110.12	283.12
		Top-L	25	-	500	8	36	32	43.44	61.52
		Top-R	25	-	500	8	36	32	43.44	61.52
		Web-L	16	-	2000	8	36	64	98.56	108.48
		Web-R	16	-	2000	8	36	64	98.56	108.48
		Stiff-L	16	220	-	20	-	-	104.00	-
		Stiff-R	16	220	-	20	-	-	104.00	-
		Dia	-	-	-	-	-	-	-	-

Table A.1 (Cont.) Taper and drill working time

Item	Piece Mark	Part	Plate	Taper			Drilling Hole		Working Time (mins.)	
			Thinkness (mm)	Width (mm)	Length (mm)	Q'ty	Diameter (mm)	Q'ty	Taper	Drilling
6	S4A2	Bottom	32	-	1500	12	36	96	110.12	283.12
		Top-L	25	-	500	8	36	32	43.44	61.52
		Top-R	25	-	500	8	36	32	43.44	61.52
		Web-L	16	-	2000	8	36	64	98.56	108.48
		Web-R	16	-	2000	8	36	64	98.56	108.48
		Stiff-L	16	220	-	20	-	-	104.00	-
		Stiff-R	16	220	-	20	-	-	104.00	-
		Dia	-	-	-	-	-	-	-	-
7	P3A1	Bottom	50	-	1500	8	-	-	84.08	-
		Bottom	40	-	1500	4	36	96	39.52	408.00
		Top-L	25	-	500	8	36	48	43.44	92.48
		Top-R	25	-	500	8	36	48	43.44	92.48
		Web-L	16	-	2000	8	36	64	98.56	108.48
		Web-R	16	-	2000	8	36	64	98.56	108.48
		Stiff-L	16	220	-	26	-	-	135.12	-
		Stiff-R	16	220	-	26	-	-	135.12	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
8	P3A2	Bottom	50	-	1500	8	-	-	84.08	-
		Bottom	40	-	1500	4	36	96	39.52	408.00
		Top-L	25	-	500	8	36	48	43.44	92.48
		Top-R	25	-	500	8	36	48	43.44	92.48
		Web-L	16	-	2000	8	36	64	98.56	108.48
		Web-R	16	-	2000	8	36	64	98.56	108.48
		Stiff-L	16	220	-	26	-	-	135.12	-
		Stiff-R	16	220	-	26	-	-	135.12	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
9	S3A1	Bottom	32	-	1500	12	36	48	110.12	141.36
		Top-L	25	-	500	8	36	16	43.44	30.56
		Top-R	25	-	500	8	36	16	43.44	30.56
		Web-L	16	-	2000	8	36	32	98.56	52.24
		Web-R	16	-	2000	8	36	32	98.56	52.24
		Stiff-L	16	220	-	24	-	-	124.48	-
		Stiff-R	16	220	-	24	-	-	124.48	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-
10	S3A2	Bottom	32	-	1500	12	36	48	110.12	141.36
		Top-L	25	-	500	8	36	16	43.44	30.56
		Top-R	25	-	500	8	36	16	43.44	30.56
		Web-L	16	-	2000	8	36	32	98.56	52.24
		Web-R	16	-	2000	8	36	32	98.56	52.24
		Stiff-L	16	220	-	24	-	-	124.48	-
		Stiff-R	16	220	-	24	-	-	124.48	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-

Table A.1 (Cont.) Taper and drill working time

Item	Piece Mark	Part	Plate	Taper			Drilling Hole		Working Time (mins.)	
			Thinkness (mm	Width (mm)	Length (mm)	Q'ty	Diameter (mm)	Q'ty	Taper	Drilling
11	S3B1	Bottom	40	-	2000	10	42	80	173.10	385.20
		Bottom	32	-	2000	6	-	-	104.42	-
		Top-L	25	-	500	8	36	16	43.44	30.56
		Top-R	25	-	500	8	36	16	43.44	30.56
		Web-L	16	-	2000	8	36	48	98.56	81.36
		Web-R	16	-	2000	8	36	48	98.56	81.36
		Stiff-L	16	220	-	16	-	-	83.12	-
		Stiff-R	16	220	-	16	-	-	83.12	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-
12	S3B2	Bottom	40	-	2000	10	42	80	173.10	385.20
		Bottom	32	-	2000	6	-	-	104.42	-
		Top-L	25	-	500	8	36	16	43.44	30.56
		Top-R	25	-	500	8	36	16	43.44	30.56
		Web-L	16	-	2000	8	36	48	98.56	81.36
		Web-R	16	-	2000	8	36	48	98.56	81.36
		Stiff-L	16	220	-	18	-	-	93.36	-
		Stiff-R	16	220	-	18	-	-	93.36	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-
13	P3B1	Bottom	50	-	2000	16	-	-	288.48	-
		Bottom	40	-	2000	8	42	160	138.32	770.40
		Top-L	32	-	700	12	36	16	87.48	47.12
		Top-L	25	-	500	4	36	32	21.52	61.52
		Top-R	32	-	700	12	36	16	87.48	47.12
		Top-R	25	-	500	4	36	32	21.52	61.52
		Web-L	16	-	2000	12	36	96	148.24	163.12
		Web-R	16	-	2000	12	36	96	148.24	163.12
		Stiff-L	16	220	-	14	-	-	72.48	-
		Stiff-R	16	220	-	14	-	-	72.48	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
14	P3B2	Bottom	50	-	2000	16	-	-	288.48	-
		Bottom	40	-	2000	8	42	160	138.32	770.40
		Top-L	32	-	700	12	36	16	87.48	47.12
		Top-L	25	-	500	4	36	32	21.52	61.52
		Top-R	32	-	700	12	36	16	87.48	47.12
		Top-R	25	-	500	4	36	32	21.52	61.52
		Web-L	16	-	2000	12	36	96	148.24	163.12
		Web-R	16	-	2000	12	36	96	148.24	163.12
		Stiff-L	16	220	-	17	-	-	88.24	-
		Stiff-R	16	220	-	17	-	-	88.24	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
15	S4B1	Bottom	40	-	2000	12	42	160	207.48	770.40
		Top-L	25	-	500	8	36	32	43.44	61.52
		Top-R	25	-	500	8	36	32	43.44	61.52
		Web-L	16	-	2000	8	36	96	98.56	163.12
		Web-R	16	-	2000	8	36	96	98.56	163.12
		Stiff-L	16	220	-	14	-	-	72.48	-
		Stiff-R	16	220	-	14	-	-	72.48	-
		Dia	-	-	-	-	-	-	-	-

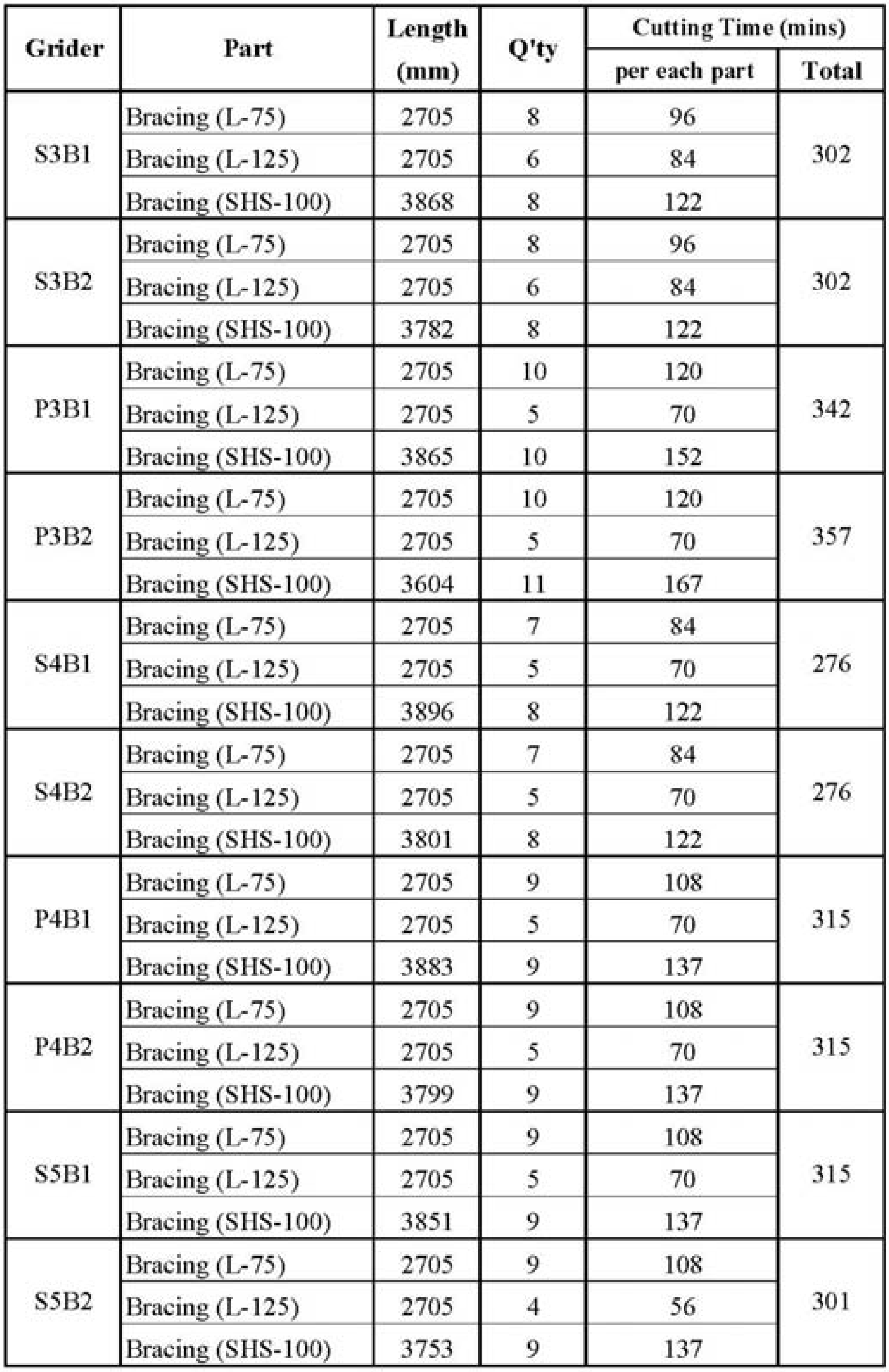
Table A.1 (Cont.) Taper and drill working time

Item	Piece Mark	Part	Plate	Taper			Drilling Hole		Working Time (mins.)	
			Thinkness (mm	Width (mm)	Length (mm)	Q'ty	Diameter (mm)	Q'ty	Taper	Drilling
16	S4B2	Bottom	40	-	2000	12	42	160	207.48	770.40
		Top-L	25	-	500	8	36	32	43.44	61.52
		Top-R	25	-	500	8	36	32	43.44	61.52
		Web-L	16	-	2000	8	36	96	98.56	163.12
		Web-R	16	-	2000	8	36	96	98.56	163.12
		Stiff-L	16	220	-	14	-	-	72.48	-
		Stiff-R	16	220	-	14	-	-	72.48	-
		Dia	-	-	-	-	-	-	-	-
17	P4B1	Bottom	50	-	2000	16	-	-	288.48	-
		Bottom	40	-	2000	8	42	160	138.32	770.40
		Top-L	32	-	700	12	36	16	87.48	47.12
		Top-L	25	-	500	4	36	32	21.52	61.52
		Top-R	32	-	700	12	36	16	87.48	47.12
		Top-R	25	-	500	4	36	32	21.52	61.52
		Web-L	16	-	2000	12	36	96	148.24	163.12
		Web-R	16	-	2000	12	36	96	148.24	163.12
		Stiff-L	16	220	-	16	-	-	83.12	-
		Stiff-R	16	220	-	16	-	-	83.12	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
18	P4B2	Bottom	50	-	2000	16	-	-	288.48	-
		Bottom	40	-	2000	4	42	160	138.32	770.40
		Top-L	32	-	700	12	36	16	87.48	47.12
		Top-L	25	-	500	4	36	32	21.52	61.52
		Top-R	32	-	700	12	36	16	87.48	47.12
		Top-R	25	-	500	4	36	32	21.52	61.52
		Web-L	16	-	2000	12	36	96	148.24	163.12
		Web-R	16	-	2000	12	36	96	148.24	163.12
		Stiff-L	16	220	-	16	-	-	83.12	-
		Stiff-R	16	220	-	16	-	-	83.12	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	8	-	-	130.24	-
19	S5B1	Bottom	40	-	2000	10	42	80	173.10	385.20
		Bottom	32	-	2000	6	-	-	104.42	-
		Top-L	25	-	500	12	36	16	65.36	30.56
		Top-R	25	-	500	12	36	16	65.36	30.56
		Web-L	16	-	2000	8	36	48	98.56	81.36
		Web-R	16	-	2000	8	36	48	98.56	81.36
		Stiff-L	16	220	-	18	-	-	93.36	-
		Stiff-R	16	220	-	18	-	-	93.36	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-
20	S5B2	Bottom	40	-	2000	10	42	80	173.10	385.20
		Bottom	32	-	2000	6	-	-	104.42	-
		Top-L	25	-	500	12	36	16	65.36	30.56
		Top-R	25	-	500	12	36	16	65.36	30.56
		Web-L	16	-	2000	8	36	48	98.56	81.36
		Web-R	16	-	2000	8	36	48	98.56	81.36
		Stiff-L	16	220	-	18	-	-	93.36	-
		Stiff-R	16	220	-	18	-	-	93.36	-
		Dia	32	-	2000	4	-	-	69.48	-
		Dia	20	-	2000	12	-	-	195.36	-

Table A.2 Cut working time for bracing part

Grider	Part	Length (mm)	Q'ty	Cutting Time (mins)	
				per each part	Total
S5A1	Bracing (L-75)	2299	8	96	285
	Bracing (L-90)	2299	5	67	
	Bracing (SHS-100)	3532	8	122	
S5A2	Bracing (L-75)	2299	8	96	285
	Bracing (L-90)	2299	5	67	
	Bracing (SHS-100)	3524	8	122	
P4A1	Bracing (L-75)	2299	6	72	216
	Bracing (L-90)	2299	4	53	
	Bracing (SHS-100)	3533	6	91	
P4A2	Bracing (L-75)	2299	6	72	216
	Bracing (L-90)	2299	4	53	
	Bracing (SHS-100)	3444	6	91	
S4A1	Bracing (L-75)	2299	10	120	350
	Bracing (L-90)	2299	7	93	
	Bracing (SHS-100)	3531	9	137	
S4A2	Bracing (L-75)	2299	10	120	350
	Bracing (L-90)	2299	7	93	
	Bracing (SHS-100)	3530	9	137	
P3A1	Bracing (L-75)	2299	8	96	285
	Bracing (L-90)	2299	5	67	
	Bracing (SHS-100)	3613	8	122	
P3A2	Bracing (L-75)	2299	8	96	285
	Bracing (L-90)	2299	5	67	
	Bracing (SHS-100)	3597	8	122	
S3A1	Bracing (L-75)	2299	9	108	325
	Bracing (L-90)	2299	6	80	
	Bracing (SHS-100)	3598	9	137	
S3A2	Bracing (L-75)	2299	9	108	312
	Bracing (L-90)	2299	5	67	
	Bracing (SHS-100)	3587	9	137	

Table A.2 (Cont.) Cut working time for bracing part



Grider	Part	Length (mm)	Q'ty	Cutting Time (mins)	
				per each part	Total
S3B1	Bracing (L-75)	2705	8	96	302
	Bracing (L-125)	2705	6	84	
	Bracing (SHS-100)	3868	8	122	
S3B2	Bracing (L-75)	2705	8	96	302
	Bracing (L-125)	2705	6	84	
	Bracing (SHS-100)	3782	8	122	
P3B1	Bracing (L-75)	2705	10	120	342
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3865	10	152	
P3B2	Bracing (L-75)	2705	10	120	357
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3604	11	167	
S4B1	Bracing (L-75)	2705	7	84	276
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3896	8	122	
S4B2	Bracing (L-75)	2705	7	84	276
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3801	8	122	
P4B1	Bracing (L-75)	2705	9	108	315
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3883	9	137	
P4B2	Bracing (L-75)	2705	9	108	315
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3799	9	137	
S5B1	Bracing (L-75)	2705	9	108	315
	Bracing (L-125)	2705	5	70	
	Bracing (SHS-100)	3851	9	137	
S5B2	Bracing (L-75)	2705	9	108	301
	Bracing (L-125)	2705	4	56	
	Bracing (SHS-100)	3753	9	137	

Table A.3 Data collection of box girder no.S5A1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S5A1	BT																	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	18/1/11			
	TL																					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR																					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL													8/1/11	10/1/11	1920										- -	- -	-	-	- -	- -	-	-				
	WR	13:55 27/10/10	15:30 27/10/10	95										19:00 8/1/11	14:00 9/1/11	540						11/1/11				- -	- -	-	-	- -	- -	-	-				
	DI	17:55 26/10/10	12:00 15/12/10	330		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	-	- -	- -	-	-				
	SL	9:40 22/10/10	20:20 9/12/10	465						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-				

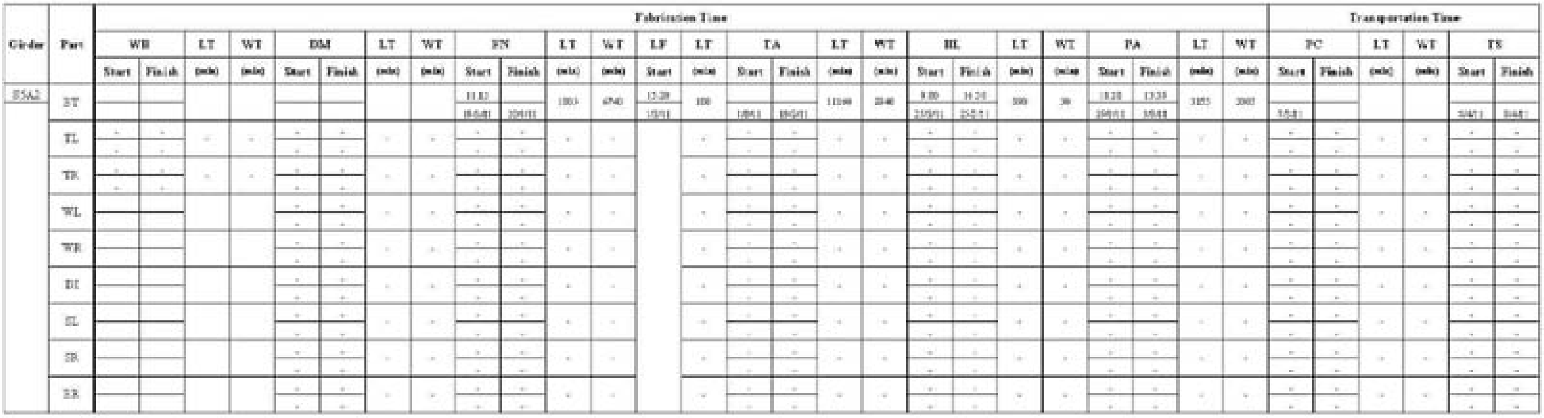
Table A.3 (Cont.) Data collection of box girder no.S5A1

Girder	Part	Fabrication Time																										Transportation Time					
		WD		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	EL		LT	WT	PA		LT	WT	FC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S5A1	BT	10/1/11								8:10 10/1/11				14:30 1/2/11	0	1/2/11	19/2/11	11110	2802	14:20 23/2/11	13:40 24/2/11	560	80	17:20 24/2/11	13:00 25/2/11	2002	3830	7/3/11				8/3/11	8/3/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.4 Data collection of box girder no.S5A2

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S5A2	ST																	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-				
	TL																					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR																					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL													7/1/11	9/1/11	2160										- -	- -	-	-	- -	- -	-	-				
	WR													7/1/11	8/1/11	1440										- -	- -	-	-	- -	- -	-	-				
	DI	17.35 26/11/10	12.00 15/12/10	330		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	-	- -	- -	-	-				
	SL	9.45 23/11/10	20.20 9/12/10	421						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-				

Table A.4 (Cont.) Data collection of box girder no.S5A2



Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S5A2	ST									11.12 18/4/11	 20/4/11	1803	6740	12.20 1/5/11	100	 1/5/11	 19/5/11	11160	2040	9.00 23/5/11	14.20 25/5/11	500	30	13.20 29/5/11	13.30 3/6/11	3185	2000	 7/5/11				 3/6/11	 3/6/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.5 Data collection of box girder no.P4A1

Table A.5 (Cont.) Data collection of box girder no.P4A1

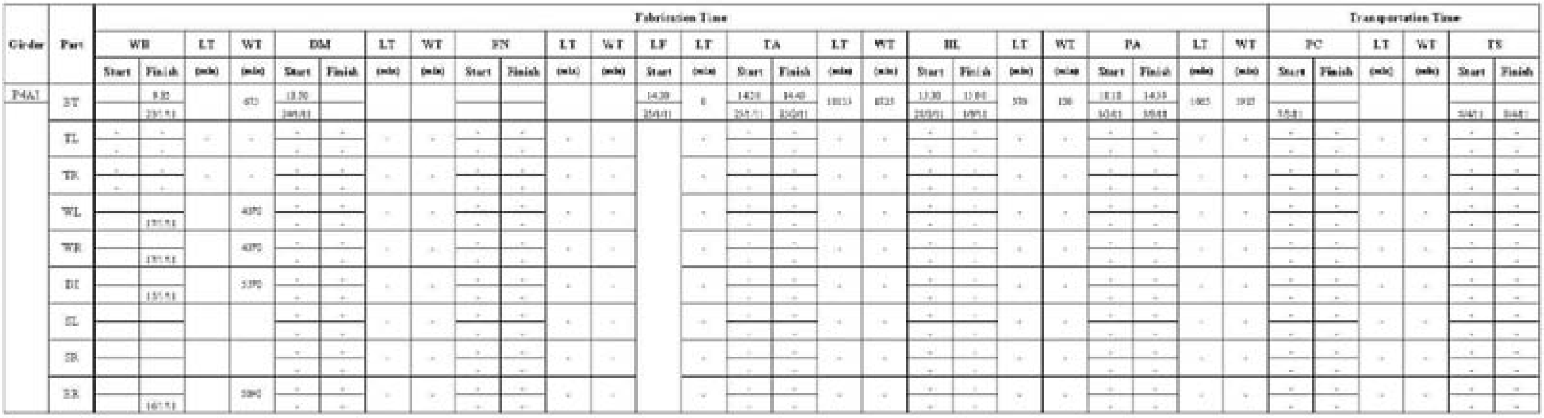


Table A.6 Data collection of box girder no.P4A2

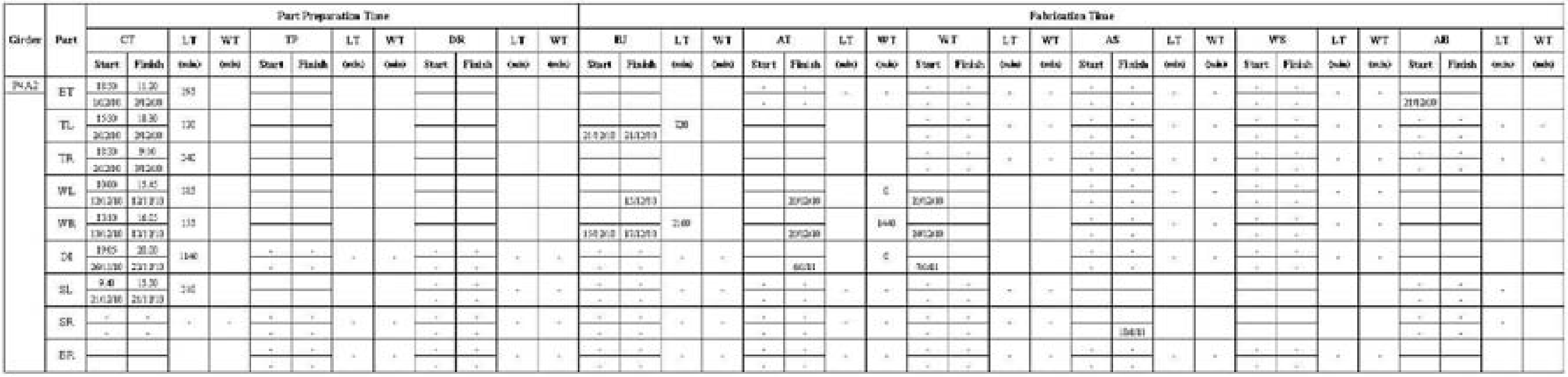


Table A.6 (Cont.) Data collection of box girder no.P4A2

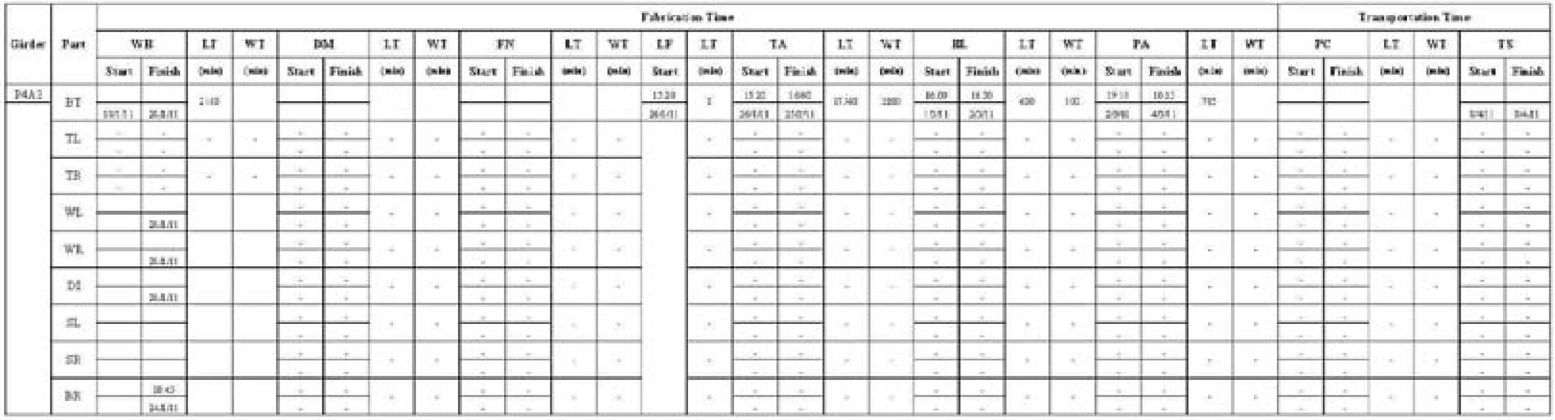
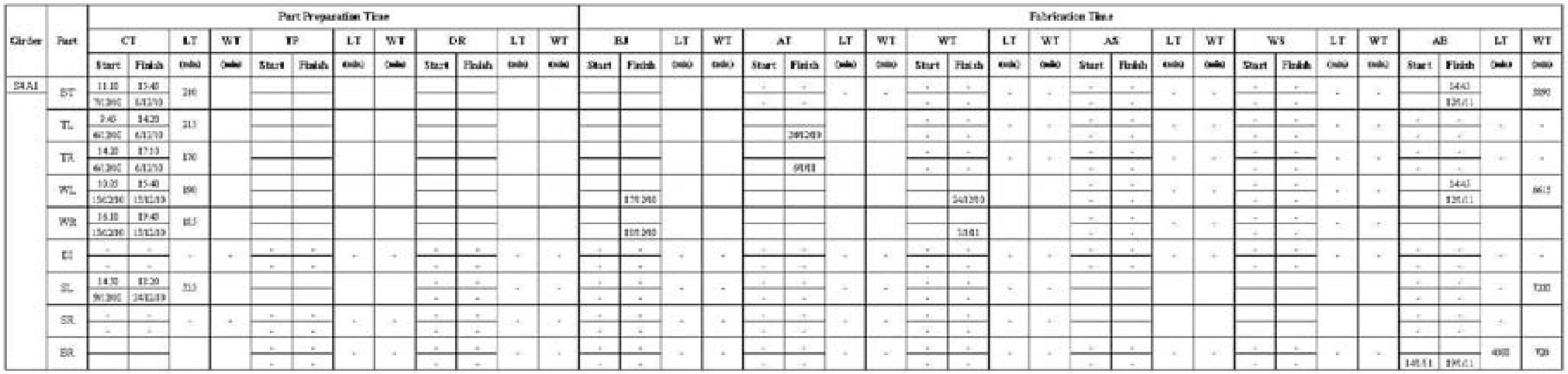
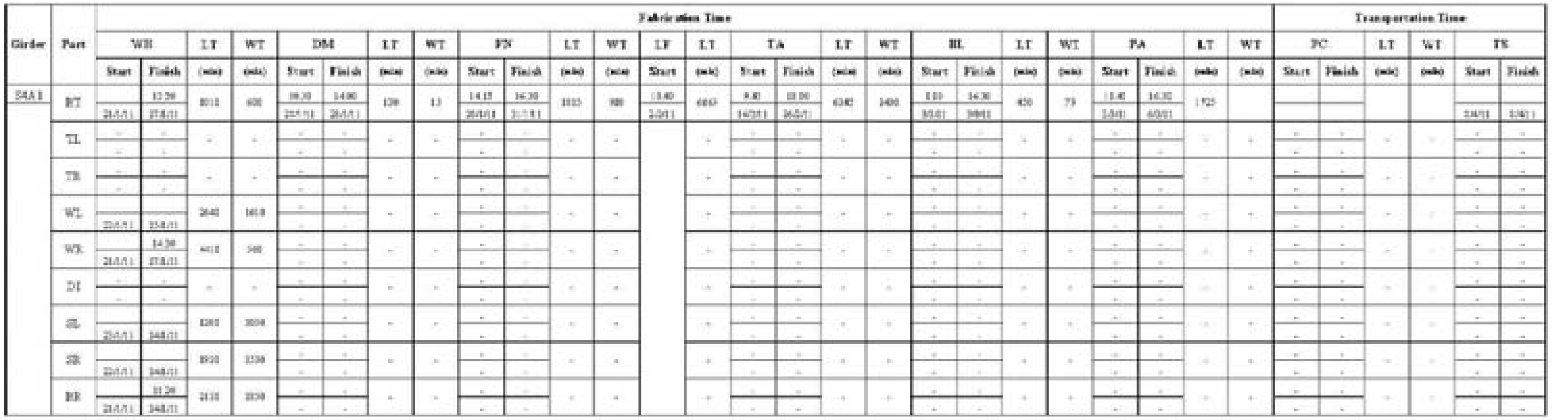


Table A.7 Data collection of box girder no.S4A1



Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S4A1	BT	11.10 7/12/10	15.40 6/12/10	210														- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		14.40 13/5/11		3090
	TL	9.40 6/12/10	14.20 6/12/10	213															20/12/10			- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	14.20 6/12/10	17.10 6/12/10	170															9/1/11			- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	10.20 15/12/10	15.40 15/12/10	190											17/12/10								24/12/10			- -	- -	-	-	- -	- -	-	-		14.40 13/5/11		6615
	WR	16.10 15/12/10	19.40 15/12/10	163											18/12/10								3/1/11			- -	- -	-	-	- -	- -	-	-				
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	SL	14.30 9/12/10	18.20 24/12/10	213						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	7200
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	 14/5/11	 19/5/11	4080	720

Table A.7 (Cont.) Data collection of box girder no.S4A1



Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S4A1	BT	 21/4/11	12.30 27/4/11	8010	600	10.30 25/5/11	14.00 26/5/11	120	13	14.15 28/4/11	16.30 31/5/11	1035	900	13.40 1/3/11	6063	9.40 14/3/11	11.00 16/5/11	6302	2400	1.10 3/5/11	14.30 3/6/11	450	79	11.40 3/6/11	14.32 6/6/11	1725						 2/6/11	 3/6/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	 22/4/11	 23/4/11	2640	1410	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	 21/4/11	14.30 27/4/11	6410	540	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL	 23/4/11	 24/8/11	1260	3030	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR	 22/4/11	 24/8/11	1920	1230	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	 21/4/11	11.30 24/8/11	2130	2230	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.8 Data collection of box girder no.S4A2

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S4A2	ST	15:10 3/12/10	18:55 8/12/10	105														- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		14:45 12/01/11		4823
	TL	11:30 6/12/10	20:30 6/12/10	170															5/1/11			- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	20:30 6/12/10	10:00 8/12/10	250															5/1/11			- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	10:30 13/12/10	15:40 17/12/10	310																	8	3/1/11	6/1/11	1440		- -	- -	-	-	- -	- -	-	-		10/01/11		0
	WR	16:40 15/12/10	20:40 17/12/10	125											6/1/11								7/1/11			- -	- -	-	-	- -	- -	-	-		10/01/11		0
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	SL	14:30 16/12/10	18:20 24/12/10	310						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		13/1/11							- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	12/01/11			

Table A.8 (Cont.) Data collection of box girder no.S4A2

Girder	Part	Fabrication Time																										Transportation Time							
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S4A2	BT	19/1/11	21/1/11	2160										14:45 26/1/11	9345	9:30 13/2/11	18:30 24/2/11	4380	2900	2:10 4/3/11	16:00 4/3/11	410	70	11:10 4/3/11	16:20 5/3/11	1140						5/4/11	5/4/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	19/1/11	21/1/11	2160		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WB	19/1/11	21/1/11	2160		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	19/1/11	19/1/11	1440		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.9 Data collection of box girder no.P3A1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
P3A1	BT	1605 16/12/10	1200 17/12/10	180														- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-				
	TL	1400 16/12/10	1630 16/12/10	150										 7/1/11	 7/1/11	720						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	1700 16/12/10	1920 16/12/10	80										 8/1/11	 8/1/11	720						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	1915 15/12/10	1000 16/12/10	225										 21/12/10	 22/12/10	1440			 7/1/11		0	 3/1/11	 8/1/11	1440	2240	- -	- -	-	-	- -	- -	-	-	1430 12/1/11	 20/1/11	[illegible]	0
	WR	1530 15/12/10	2200 17/12/10	180										 21/12/10	 21/12/10	720			 8/1/11		0	 8/1/11	 10/1/11	2160		- -	- -	-	-	- -	- -	-	-		 20/1/11		0
	DI	1935 [illegible]	2000 22/12/10	900		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-					 11/1/11	 12/1/11	1440		- -	- -	-	-	- -	- -	-	-				
	SL	1440 20/12/10	1530 21/1/11	985						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	 11/1/11			

Table A.9 (Cont.) Data collection of box girder no.P3A1

Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
P3A1	BT	 22/1/11	 24/1/11	1920	1315	915 19/1/11	1430 27/1/11	225	45	1215 25/1/11				830 31/1/11	4375	1340 9/3/11	 4/3/11	13873	1200	1400 5/3/11	1400 5/3/11	600	90	1530 6/3/11	1130 12/3/11	2380						 3/4/11	 3/4/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	 22/1/11	 24/1/11	1920	1315	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	 22/1/11	 24/1/11	1920	1315	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR		1820 24/1/11		2090	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.10 Data collection of box girder no.P3A2

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
P3A2	BT	14:35 19/12/49	14:40 19/12/49	200														- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	15:15 14/1/51			
	TL	19:30 19/12/49	22:00 19/12/49	150											14/3/51				13:55 14/1/51		20	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	13:00 17/12/49	17:40 19/12/49	560																		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	10:15 10/12/49	14:20 10/12/49	145										21/12/50	22/12/50	1440			13:55 14/1/51		20	14:15 14/1/51	15/1/51	1125	1040	- -	- -	-	-	- -	- -	-	-	15:45 20/1/51			
	WR	9:10 10/12/49	14:00 10/12/49	180										24/12/50	25/12/50	1440			15/1/51		0	15/1/51	16/1/51	1200		- -	- -	-	-	- -	- -	-	-				
	DI	10:35 27/12/49	20:00 29/12/49	1185		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		15/1/51				19/1/51			- -	- -	-	-	- -	- -	-	-				
	SL	14:40 20/12/49	15:30 2/1/51	705						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-						14:20 20/6/51		11	- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		15/1/51		250

Table A.10 (Cont.) Data collection of box girder no.P3A2

Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	HL		LT	WT	PA		LT	WT	FC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
P3A2	BT	8:00 27/1/51	17:00 31/1/51	3120	450	11:10 1/2/51	16:30 1/2/51	230	20	10:15 2/2/51	8:15 8/2/51	523	100	13:00 4/2/48	2200	13:40 9/2/51	4/3/51	12030	2070	15:30 1/3/51	15:20 9/3/51	400	75	16:15 8/3/51	16:21 11/3/51	3170						5/4/51	5/4/51
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	8:00 27/1/51	11:20 31/1/51	3020	150	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	8:00 27/1/51	20/1/51	1440	2110	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	11:55 24/1/51	29/1/51	4025	1190	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL		29/1/51		1190	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR		29/1/51		1190	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	20/1/51	27/1/51	4000	4915	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.11 Data collection of box girder no.S3A1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S3A1	BT	13.10 21/12/10	13.35 22/12/10	190														- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		11.20 22/1/11		3400
	TL	16.03 22/12/10	15.05 23/12/10	240										23/12/10	28/12/10	2160			13/1/11		0	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	13.33 22/12/10	13.25 23/12/10	110										23/12/10	28/12/10	1440	7140	11.00 14/1/11	10/1/11	2700	7	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	16.00 19/12/10	16.20 19/12/10	190										25/12/10	24/12/10	1440			13/1/11		0	14/1/11	14/1/11	720	3600	- -	- -	-	-	- -	- -	-	-	20/1/11			
	WR	13.00 20/12/10	17.00 23/12/10	230										22/12/10	24/12/10	2160	9400	14/1/11				18/1/11	18/1/11	720	720	- -	- -	-	-	- -	- -	-	-				
	DI	15.21 20/12/10	20.00 23/12/10	1560		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-					19/1/11	23/1/11	1440		- -	- -	-	-	- -	- -	-	-				
	SL	13.00 22/12/10	13.30 21/1/11	1010						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	13.23 20/1/11					11.45 24/1/11		1215	- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	20/1/11					13.15 24/1/11			- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-				

Table A.11 (Cont.) Data collection of box girder no.S3A1

Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	FC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S3A1	BT	14.18 27/1/11	12.00 30/1/11	2270	230	8.10 31/1/11	11.30 3/2/11	310	1440	2.30 3/2/11	4/2/11	1870	1130	8.30 7/2/11	10322	13.15 28/4/11	15.00 7/5/11	4023	1642	8.40 13/5/11	17.30 16/5/11	210	23	13.35 16/5/11	13.00 14/5/11	1237						3/6/11	3/6/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL		30/1/11		10	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	14.18 27/1/11	29/1/11	8130	490	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL	29/1/11	30/1/11	8200	10	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR	28/1/11	30/1/11	8200	10	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	11.13 24/1/11	30/1/11	4605	10	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.12 Data collection of box girder no.S3A2

Girder	Part	Part Preparation Time											
		CT		LT	WT	TP		LT	WT	DR		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S3A2	ST	17:35 21/12/10	8:35 22/12/10	180									
	TL	19:35 20/12/10	22:20 23/12/10	175									
	TR	9:30 24/12/10	14:30 24/12/10	250									
	WL	16:10 19/12/10	17:10 19/12/10	180									
	WR	8:25 21/12/10	13:45 21/12/10	225									
	DI	15:55 20/11/10	20:00 23/12/10	1485		- -	- -	-	-	- -	- -	-	-
	SL	17:00 22/12/10	13:50 21/1/11	1060						- -	- -	-	-
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	BR					- -	- -	-	-	- -	- -	-	-

Girder	Part	Fabrication Time																							
		BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S3A2	ST					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	 	 24/1/11		4005
	TL					 	 13/1/11		240	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	 27/12/10	 25/12/10	720		 	 15/1/11		0	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL					 	 13/1/11		240	13:00 14/1/11	16:05 14/1/11	185	2995	- -	- -	-	-	- -	- -	-	-	 	5:45 25/1/11		3975
	WR	 27/12/10	 25/12/10	720		 	 15/1/11		0	 14/1/11	 18/1/11	1920		- -	- -	-	-	- -	- -	-	-	 	16:40 25/1/11		3140
	DI	- -	- -	-	-					 	 18/1/11			- -	- -	-	-	- -	- -	-	-				
	SL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	 19/1/11								- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-									- -	- -	-	3600
	BR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	8:30 23/1/11	14:13 27/1/11	225	

Table A.12 (Cont.) Data collection of box girder no.S3A2

Girder	Part	Fabrication Time													
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)
S3A2	ST	8:00 31/1/11	14:25 3/2/11	1760	90	13:30 3/2/11	14:00 4/2/11	1530	1300	 7/2/11	 8/2/11	1200	0	16:10 13/2/11	1440
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-
	WL	8:00 31/1/11	17:00 31/1/11	480	1370	- -	- -	-	-	- -	- -	-	-		-
	WR	 30/1/11	 31/1/11	720	1180	- -	- -	-	-	- -	- -	-	-		-
	DI	 30/1/11	 3/2/11	4020	480	- -	- -	-	-	- -	- -	-	-		-
	SL	 	 3/2/11		480	- -	- -	-	-	- -	- -	-	-		-
	SR	 31/1/11	 3/2/11	1440	480	- -	- -	-	-	- -	- -	-	-		-
	BR	 	16:45 28/1/11		3060	- -	- -	-	-	- -	- -	-	-		-

Girder	Part	Fabrication Time												Transportation Time					
		TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S3A2	ST	13:20 28/2/11	 7/3/11	4300	1890	9:30 11/3/11	11:20 11/3/11	420	45	18:22 11/3/11	19:00 14/3/11	1445						 30/4/11	 30/4/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

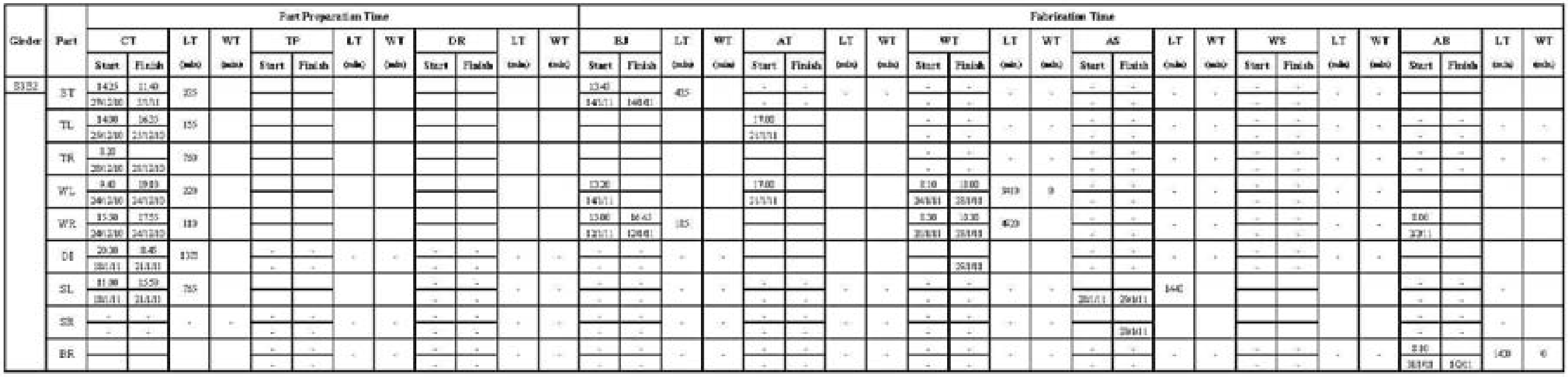
Table A.13 Data collection of box girder no.S3B1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S3B1	BT	9.15 27/12/10	9.20 3/1/11	276										13.32 14/1/11	16/1/11	3443		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		14.30 18/1/11		12758
	TL	8.45 27/12/10	18.45 27/12/10	180											21/1/11		1803	17.00 24/1/11				- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	13.20 27/12/10	16.00 27/12/10	135										10/1/11	11/1/11	1440	2880	29/1/11				- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	13.55 27/12/10	13.20 28/12/10	115										15.15 12/1/11	13/1/11	3030	7200	17.00 24/1/11				8.15 27/1/11	12.00 29/1/11	225		- -	- -	-	-	- -	- -	-	-	11.00 2/2/11			
	WR	8.15 27/12/10	18.45 27/12/10	115										15.00 12/1/11	16.20 12/1/11	80	4060	19/1/11				8.40 24/1/11	14.23 24/1/11	223	1063	- -	- -	-	-	- -	- -	-	-	17.30 2/2/11	15.30 3/2/11	1290	90
	DI	20.20 18/1/11	13.30 20/1/11	882		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-					27/1/11	26/1/11	1440	1200	- -	- -	-	-	- -	- -	-	-	13.40 2/2/11			
	SL	11.20 18/1/11	15.50 21/1/11	765						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-					9.10 24/1/11	15.55 26/1/11	345	485	- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	14.18 26/1/11					28/1/11		0	- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	3/2/11	3/2/11	1200	0

Table A.13 (Cont.) Data collection of box girder no.S3B1

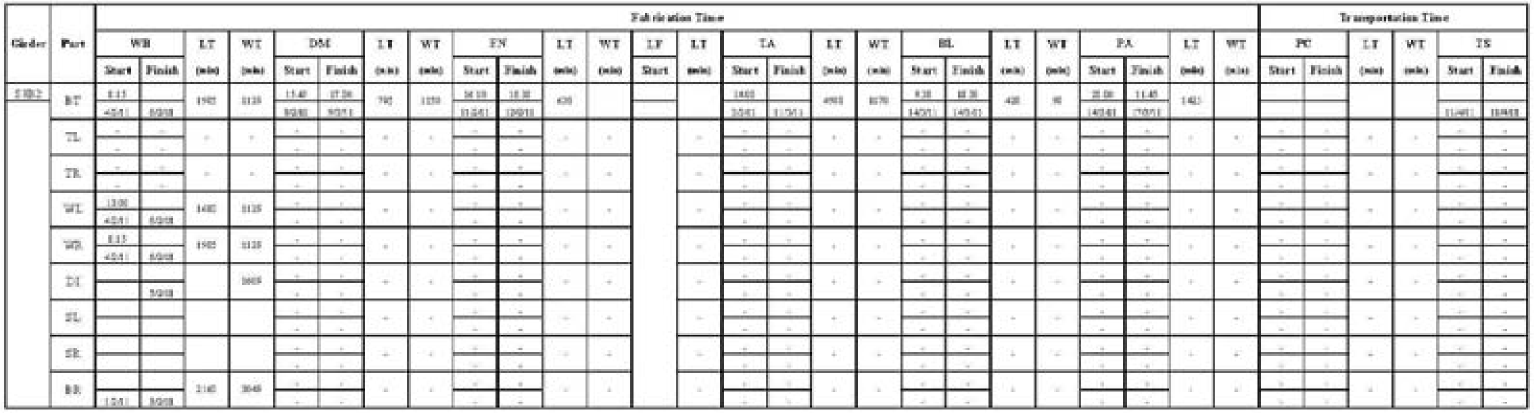
Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DSE		LT	WT	EN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S3B1	BT	10.00 4/2/11	13.30 5/2/11	800	1530	5/2/11	16.00 9/2/11	1830	0	9/2/11				9.30 11/2/11	1413	9.15 14/2/11	11/2/11	1560	1540	8.00 13/2/11	11.00 13/2/11	480	30	11.30 13/2/11	14.40 15/2/11	1402						11/4/11	13/4/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	10.00 4/2/11	13.30 5/2/11	800	1530	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	8.00 30/1/11	5/2/11	4320	1200	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI		5/2/11		1200	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL		5/2/11		1200	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	1/2/11	5/2/11	2160	2640	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.14 Data collection of box girder no.S3B2



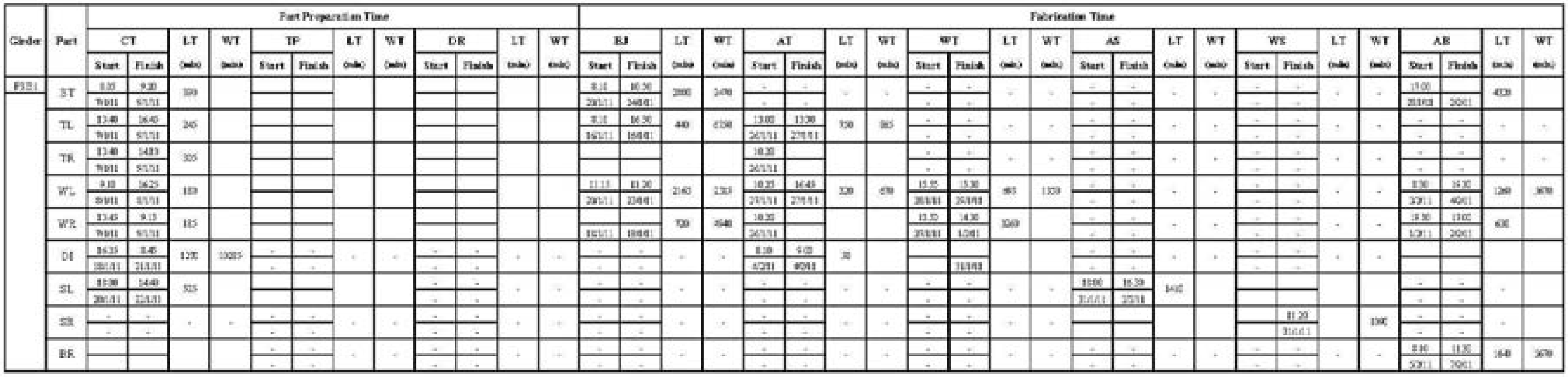
Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S3B2	ST	14:25 29/12/10	11:40 3/1/11	325										13:40 14/1/11	14/1/11	415		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-				
	TL	14:00 29/12/10	16:25 23/12/10	155														17:00 21/1/11				- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	8:20 20/12/10	20/12/10	750																		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	9:40 24/12/10	19:03 24/12/10	229										13:20 14/1/11				17:00 21/1/11				8:10 24/1/11	18:00 25/1/11	3419	9	- -	- -	-	-	- -	- -	-	-				
	WR	15:30 24/12/10	17:55 24/12/10	119										13:00 12/1/11	16:43 12/1/11	115						8:30 25/1/11	13:30 28/1/11	4620		- -	- -	-	-	- -	- -	-	-	8:00 2/2/11			
	DI	20:30 19/1/11	8:45 21/1/11	1335		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-						26/1/11			- -	- -	-	-	- -	- -	-	-				
	SL	11:00 19/1/11	15:59 21/1/11	765						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	28/1/11	29/1/11	1440						- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		29/1/11		-					- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	8:10 31/1/11	1/2/11	1430	0

Table A.14 (Cont.) Data collection of box girder no.S3B2



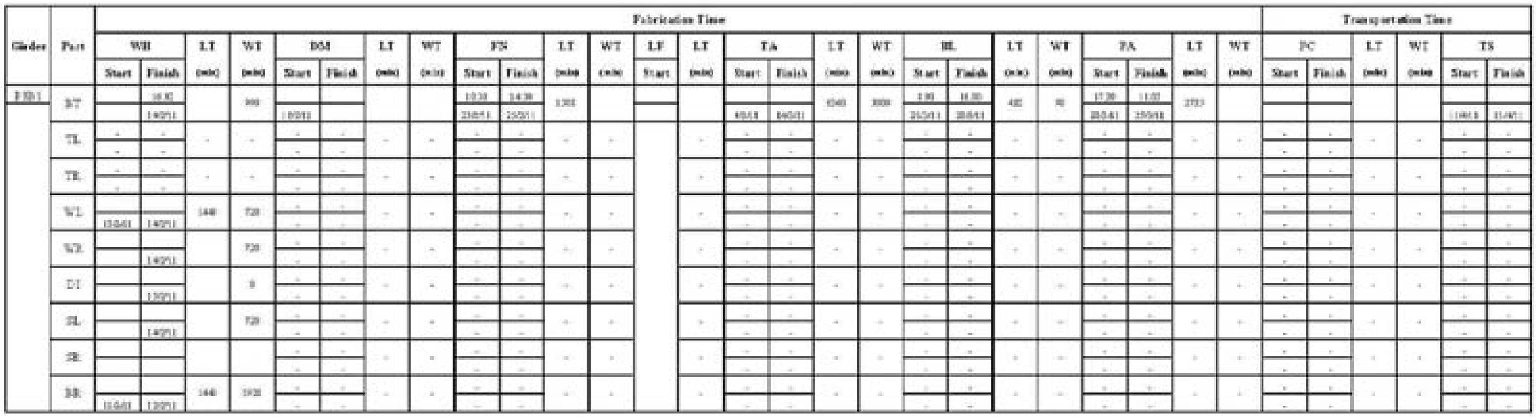
Girder	Part	Fabrication Time																										Transportation Time							
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S3B2	BT	8:15 4/2/11	5/2/11	1905	3135	13:40 8/2/11	17:20 9/2/11	795	1250	16:10 11/2/11	18:30 12/2/11	420				18:00 3/3/11	11/3/11	4905	8170	8:30 14/3/11	18:30 14/3/11	420	90	21:00 14/3/11	11:45 17/3/11	1425						11/4/11	18/4/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	13:00 4/2/11	5/2/11	1440	3135	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	8:15 4/2/11	5/2/11	1905	3135	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI		5/2/11		1605	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	1/2/11	5/2/11	2145	3645	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.15 Data collection of box girder no.P3B1



Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
P3B1	ST	[illegible] [illegible]	[illegible] [illegible]	[illegible]										[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	[illegible] [illegible]	 [illegible]	[illegible]	
	TL	[illegible] [illegible]	[illegible] [illegible]	[illegible]										[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	[illegible] [illegible]	[illegible] [illegible]	[illegible]														[illegible] [illegible]				- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	[illegible] [illegible]	[illegible] [illegible]	[illegible]										[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	- -	- -	-	-	- -	- -	-	-	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]
	WR	[illegible] [illegible]	[illegible] [illegible]	[illegible]										 [illegible]	 [illegible]	[illegible]	[illegible]	[illegible] [illegible]				[illegible] [illegible]	[illegible] [illegible]	[illegible]		- -	- -	-	-	- -	- -	-	-	[illegible] [illegible]	[illegible] [illegible]	[illegible]	
	DI	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	[illegible] [illegible]	[illegible] [illegible]	[illegible]			 [illegible]			- -	- -	-	-	- -	- -	-	-				
	SL	[illegible] [illegible]	[illegible] [illegible]	[illegible]						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	[illegible] [illegible]	[illegible] [illegible]	[illegible]						- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-						[illegible] [illegible]		[illegible]	- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]

Table A.15 (Cont.) Data collection of box girder no.P3B1



Girder	Part	Fabrication Time																												Transportation Time					
		WH		LT	WT	DM		LT	WT	FS		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	FA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
P3B1	ST		[illegible] [illegible]		[illegible]	 [illegible]				[illegible] [illegible]	[illegible] [illegible]	[illegible]				 [illegible]	 [illegible]	[illegible]	[illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible]	[illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible]						 [illegible]	 [illegible]
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	 [illegible]	 [illegible]	[illegible]	[illegible]	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR		 [illegible]		[illegible]	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI		 [illegible]		[illegible]	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL		 [illegible]		[illegible]	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	 [illegible]	 [illegible]	[illegible]	[illegible]	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.16 Data collection of box girder no.P3B2

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
P3B2	BT	17.30 7/1/11	13.20 8/1/11	390										11.30 20/1/11	 21/1/11	1320	6000	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	15.30 10/2/11	 5/2/11	2970	7440
	TL	8.30 7/1/11	14.00 10/1/11	285										 15/1/11	 20/1/11	1440	6130	13.10 20/1/11	16.30 25/1/11	320	270	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	8.30 7/1/11	10.30 10/1/11	200										9.00 15/1/11	16.30 19/1/11	390	8430	8.10 20/1/11	10.45 25/1/11	395	0	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	8.30 8/1/11	17.20 8/1/11	185														8.30 31/1/11	10.40 18/2/11	220	0	 18/2/11	15.20 20/2/11	1320	1200	- -	- -	-	-	- -	- -	-	-				
	WR	14.00 7/1/11	20.00 8/1/11	200										 15/1/11	 17/1/11	220	6570	8.10 20/1/11	10.45 25/1/11	395	0	 25/2/11				- -	- -	-	-	- -	- -	-	-	 20/2/11	 4/2/11	1440	5720
	DI	14.22 18/1/11	8.45 21/1/11	1270	8235	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	14.00 1/2/11								- -	- -	-	-	- -	- -	-	-		 6/2/11		5240
	SL	11.00 20/1/11	14.40 20/1/11	335						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	10.20 4/2/11	15.50 4/2/11	270			 12/2/11			- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	13.00 10/2/11					18.00 20/2/11		240	- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	13.00 8/2/11	 10/2/11	2640	

Table A.16 (Cont.) Data collection of box girder no.P3B2

Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
P3B2	BT	 13/5/11	 15/5/11	2160			16.20 20/5/11		1400	11.20 20/5/11	13.20 22/5/11	190				 4/5/11	 14/5/11	6360	5400	8.00 21/5/11	12.00 21/5/11	420	140	17.20 21/5/11	13.30 24/5/11	1790						 13/6/11	 14/6/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	 13/5/11	 15/5/11	2160		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	 13/5/11	 15/5/11	2160		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	 16/5/11	 15/5/11	1440		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR		 16/5/11			- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.17 Data collection of box girder no.S4B1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TF		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S4B1	BT	19:30 15/4/61	10:25 18/4/61	185										18:30 26/8/61	20:30 28/8/61	1950	1230	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	9:00 31/12/61			
	TL	17:30 09/5/61	13:35 15/4/61	290										 24/8/61					15:00 20/9/61		600	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	16:10 09/5/61	13:35 15/4/61	420										8:30 25/8/61				13:30 20/9/61	16:00 20/9/61	130		- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	17:15 18/4/61	16:35 18/4/61	155										8:10 26/8/61	10:35 26/8/61	140			15:00 20/9/61		600	11:00 31/9/61	16:30 31/6/61	210	1110	- -	- -	-	-	- -	- -	-	-		11:30 4/9/61		
	WR	14:30 15/4/61	17:35 15/4/61	180										8:30 25/8/61	10:50 26/8/61	860	1560	13:30 20/9/61	16:00 20/9/61	130			11:40 31/6/61		100	- -	- -	-	-	- -	- -	-	-	8:15 20/9/61	10:30 20/9/61	135	
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	SL	20:30 21/4/61	20:30 22/4/61	185						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	10:00 20/9/61	17:30 20/9/61	390						- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	14:20 30/8/61	11:30 1/9/61	610						- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	14:20 4/9/61	 7/9/61	2520	0

Table A.17 (Cont.) Data collection of box girder no.S4B1

Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S4B1	BT	 5/2/61	 10/2/61	1440	2130	 11/2/61				14:10 13/2/61						 16/2/61	 14/3/61	9340	3480	16:00 21/3/61	14:00 22/3/61	480	130	09:10 22/3/61	12:30 25/3/61	1700						 11/4/61	 11/4/61
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL		 9/2/61		2490	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR		 10/2/61		2130	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR	 5/2/61	13:50 9/2/61	2100	3190	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

Table A.18 Data collection of box girder no.S4B2

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	BR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S4B2	BT	14:40 13/1/11	19:30 13/1/11	290										16:00 21/1/11	21:00 21/1/11	2400	4140	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	 4/2/11			
	TL	9:45 19/1/11	13:30 19/1/11	230										8:15 24/1/11	14:00 24/1/11	213	4980	13:00 31/1/11	15:30 2/2/11	1530	540	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	TR	9:45 19/1/11	11:55 19/1/11	130										8:18 24/1/11	13:30 24/1/11	280	4730	13:00 31/1/11	15:15 31/1/11	135	1485	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	WL	8:30 18/1/11	12:30 18/1/11	130										9:45 24/1/11	10:05 25/1/11	140	4435	13:00 31/1/11	13:30 2/2/11	1530	540	13:10 3/2/11	11:30 4/2/11	700		- -	- -	-	-	- -	- -	-	-				
	WR	17:30 13/1/11	20:55 13/1/11	155														13:00 31/1/11	15:15 31/1/11	135	1485	16:00 2/2/11	 3/2/11	1020	200	- -	- -	-	-	- -	- -	-	-				
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-
	SL	20:30 21/1/11	23:00 22/1/11	165						- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-						 15/2/11			- -	- -	-	
	SR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	11:20 4/2/11					 15/2/11			- -	- -	-	
	BR					- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		 11/2/11		

Table A.18 (Cont.) Data collection of box girder no.S4B2

Girder	Part	Fabrication Time																										Transportation Time					
		WH		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S4B2	BT	 12/2/11	 13/2/11	1200						9:30 20/2/11	11:20 21/2/11	1200				 20/2/11	 14/5/11	5040	8440	11:00 22/5/11	12:00 24/3/11	1000	190	14:40 24/3/11	13:15 26/3/11	1100						 11/4/11	 18/4/11
	TL	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	TR	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WL	 12/2/11	 13/2/11	1200		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	WR	 12/2/11	 13/2/11	1200		- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	DI	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SL					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	SR					- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -
	BR		13:15 14/2/11			- -	- -	-	-	- -	- -	-	-		-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -	-	-	- -	- -

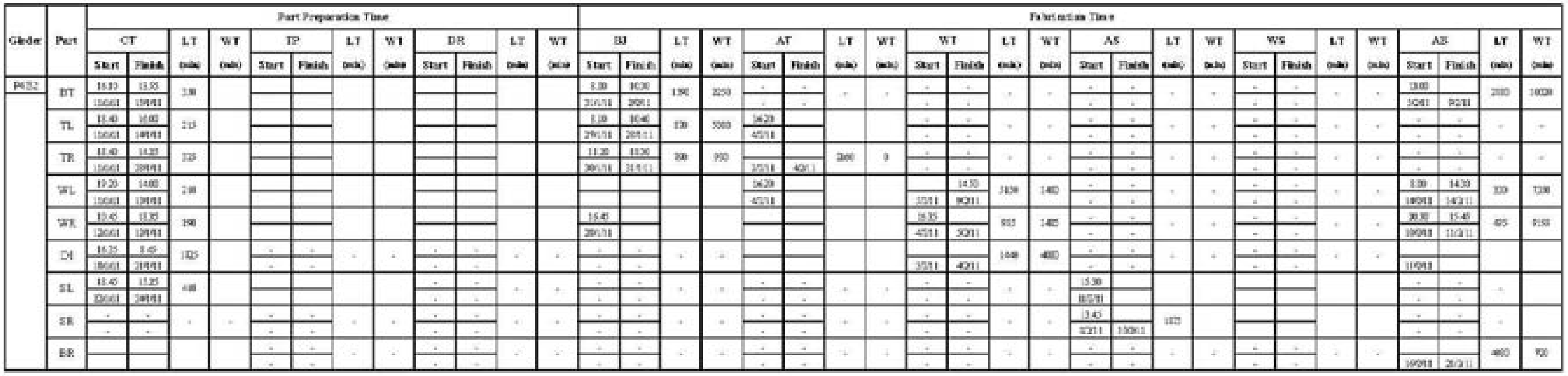
Table A.19 Data collection of box girder no.P4B1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
P4B1	ST	16:35	15:15	389										8:10	14:20	5030	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13:42			
		14/1/11	15/1/11											21/1/11	10/2/11			-	-			-	-			-	-			-	-			12/2/11			
	TL	20:15	17:20	165										11:13	15:00	1605	1300	11:40	16:00	200		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/11	13/1/11											21/1/11	2/2/11			4/2/11	9/2/11			-	-			-	-			-	-			-	-		
	TR	20:15	15:30	215										18:30	15:00	570	1230	17:30	19:15	75	1780	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/11	13/1/11											20/1/11	10/2/11			8/2/11	10/2/11			-	-			-	-			-	-			-	-		
	WL	17:00	13:25	209						14:10	16:20	130	10315	13:13	16:20	1625	1220	11:40	16:00	200						-	-	-	-	-	-	-	-				
		11/1/11	13/1/11							14/1/11	14/1/11			21/1/11	2/2/11			4/2/11	9/2/11							-	-			-	-						
	WR	8:33	17:25	325														17:30	19:15	75	1780	11:35				-	-	-	-	-	-	-	-	9:00	18:15	250	
		12/1/11	13/1/11															8/2/11	10/2/11			4/2/11				-	-			-	-			10/2/11	11/2/11		
	DI	16:35	8:45	1720	4575	-	-	-	-	-	-	-	-	-	-	-	-	13:00					15:30		6573	-	-	-	-	-	-	-	-				
		20/1/11	21/1/11			-	-			-	-			-	-			27/1/11					1/2/11			-	-			-	-			11/2/11			
	SL	18:45	15:25	403						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15:45		1735						-	-	-	
		22/1/11	24/1/11							-	-			-	-			-	-			-	-			9/2/11	11/2/11							-	-		
	SR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8:00	15:50	1830						-	-	-	
		-	-			-	-			-	-			-	-			-	-			-	-			9/2/11	9/2/11							-	-		
	BR					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8:00		3320	0
						-	-			-	-			-	-			-	-			-	-			-	-			-	-			14/2/11	21/2/11		

Table A.19 (Cont.) Data collection of box girder no.P4B1

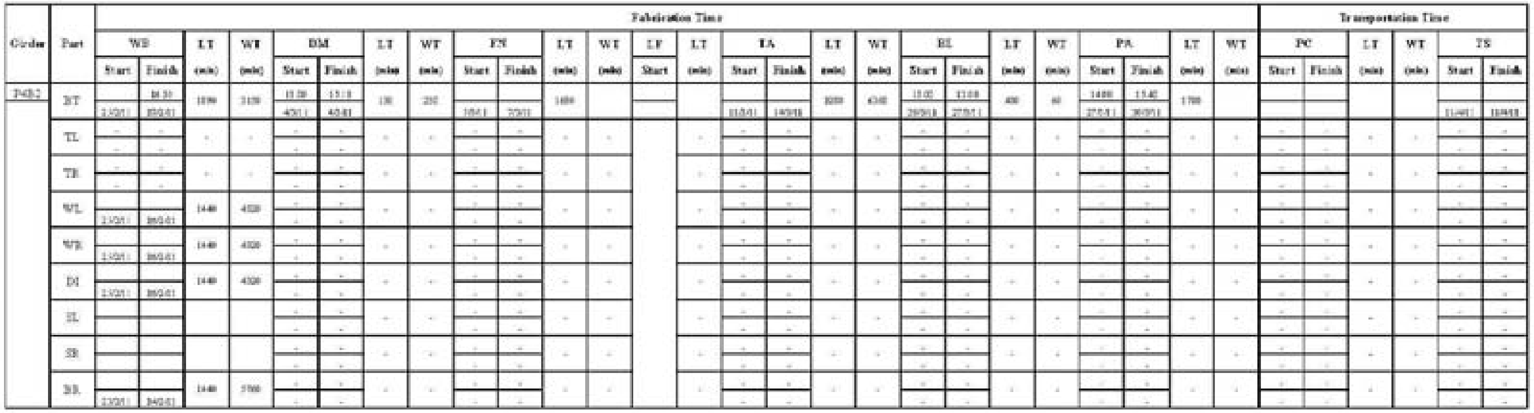
Girder	Part	Fabrication Time																										Transportation Time					
		WH		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	FA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
P4B1	ST			7440			11:20		1565	8:12	11:40	3022						2200	4800	8:00	14:30	392	110	13:20	16:45	1363							
		13/4/11	23/5/11				20/5/11			2/6/11	7/6/11					11/5/11	14/6/11			24/5/11	26/6/11			26/6/11	25/6/11							1/6/11	11/6/11
	TL	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	TR	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WL			7440		-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		13/4/11	23/5/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WR					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			23/5/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	DI					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SL					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SR					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	BR		16:00	2580		-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		22/4/11	23/5/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-

Table A.20 Data collection of box girder no.P4B2



Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AS		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
P4B2	BT	16:10	15:55	330										8:30	10:30	1590	2250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18:00		2010	10020
		[illegible]	[illegible]											[illegible]	[illegible]			-	-			-	-			-	-			-	-			[illegible]	[illegible]		
	TL	18:40	16:00	215										8:30	10:40	830	5300	16:20				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]											[illegible]	[illegible]			[illegible]				-	-			-	-			-	-			-	-		
	TR	18:40	18:25	325										11:20	10:30	800	930			2660	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]											[illegible]	[illegible]			[illegible]	[illegible]			-	-			-	-			-	-			-	-		
	WL	19:20	14:00	[illegible]														16:20					14:30	3150	1410	-	-	-	-	-	-	-	-	8:30	14:30	330	7230
		[illegible]	[illegible]															[illegible]				[illegible]	[illegible]			-	-			-	-			[illegible]	[illegible]		
	WR	10:45	18:35	190										15:45								18:35		935	1405	-	-	-	-	-	-	-	-	20:30	15:45	495	8150
		[illegible]	[illegible]											[illegible]								[illegible]	[illegible]			-	-			-	-			[illegible]	[illegible]		
	DI	16:25	8:45	1025		-	-	-	-	-	-	-	-	-	-	-	-							1440	4080	-	-	-	-	-	-	-	-				
		[illegible]	[illegible]			-	-			-	-			-	-							[illegible]	[illegible]			-	-			-	-			[illegible]			
	SL	18:45	15:25	[illegible]						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15:30								-	-	-	
		[illegible]	[illegible]							-	-			-	-			-	-			-	-			[illegible]								-	-		
	SR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13:45		1875						-	-	-	
		-	-			-	-			-	-			-	-			-	-			-	-			[illegible]	[illegible]							-	-		
	BR					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			[illegible]	920
						-	-			-	-			-	-			-	-			-	-			-	-			-	-			[illegible]	[illegible]		

Table A.20 (Cont.) Data collection of box girder no.P4B2



Girder	Part	Fabrication Time																										Transportation Time							
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
P4B2	BT		16:30	1590	3150	11:30	15:10	130	235			1680						1020	4340	11:02	13:08	400	60	14:00	15:40	1700							
		[illegible]	[illegible]			[illegible]	[illegible]			[illegible]	[illegible]					[illegible]	[illegible]			[illegible]	[illegible]			[illegible]	[illegible]							[illegible]	[illegible]
	TL	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	TR	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WL			1440	4320	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WR			1440	4320	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	DI			1440	4320	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SL					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SR					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	BR			1440	5760	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]			-	-			-	-					-	-			-	-			-	-			-	-			-	-

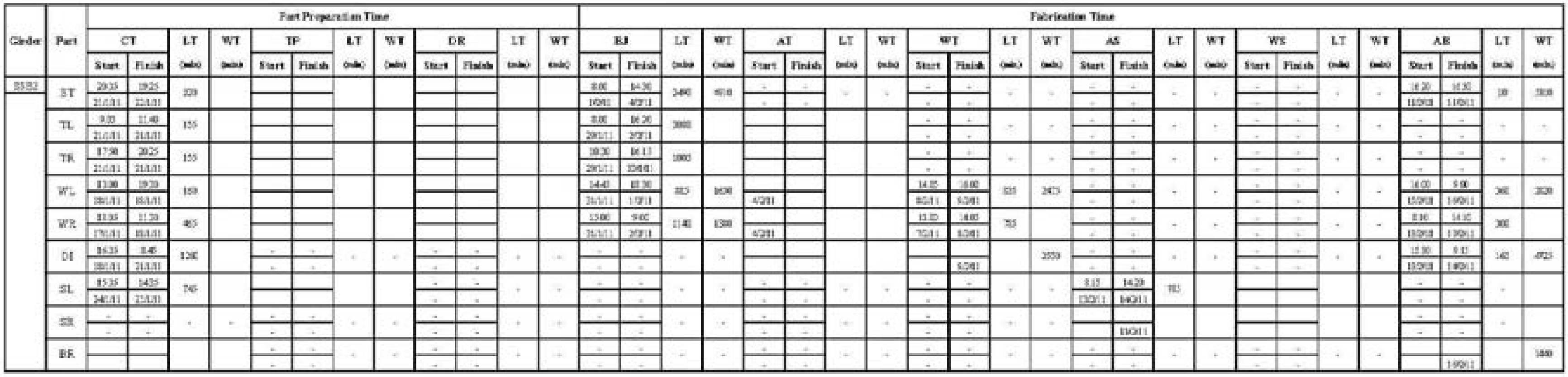
Table A.21 Data collection of box girder no.S5B1

Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AS		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S5B1	BT	8:30	8:25	230										8:30		1400	4320	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18:00			
		[illegible]	[illegible]											[illegible]	[illegible]			-	-			-	-			-	-			-	-			[illegible]			
	TL	13:30	16:10	160										13:35		1080	3870	14:10				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]											[illegible]	[illegible]			[illegible]				-	-			-	-			-	-			-	-		
	TR	13:20	16:10	160										8:30		2130	1215	8:15	13:30	255	280	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]											[illegible]	[illegible]			[illegible]	[illegible]			-	-			-	-			-	-			-	-		
	WL	15:20	18:30	165										8:15		1425	2230	14:10				14:30		1110	700	-	-	-	-	-	-	-	-	8:30	13:30	240	3230
		[illegible]	[illegible]											[illegible]	[illegible]			[illegible]				[illegible]	[illegible]			-	-			-	-			[illegible]	[illegible]		
	WR	14:30	13:45	175										8:30		1410	1935	8:15	13:30	255	280	14:10		1130		-	-	-	-	-	-	-	-	8:15	15:30	135	3030
		[illegible]	[illegible]											[illegible]	[illegible]			[illegible]	[illegible]			[illegible]	[illegible]			-	-			-	-			[illegible]	[illegible]		
	DI	16:25	8:45	1200		-	-	-	-	-	-	-	-	-	-	-	-						16:30		11800	-	-	-	-	-	-	-	-	16:30	19:20	183	
		[illegible]	[illegible]			-	-			-	-			-	-								[illegible]			-	-			-	-			[illegible]	[illegible]		
	SL	15:35	14:30	745						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14:00								-	-	-	
		[illegible]	[illegible]							-	-			-	-			-	-			-	-			[illegible]								-	-		
	SR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-									-	-	-	
		-	-			-	-			-	-			-	-			-	-			-	-				[illegible]							-	-		
	BR					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			2880	480
						-	-			-	-			-	-			-	-			-	-			-	-			-	-			[illegible]	[illegible]		

Table A.21 (Cont.) Data collection of box girder no.S5B1

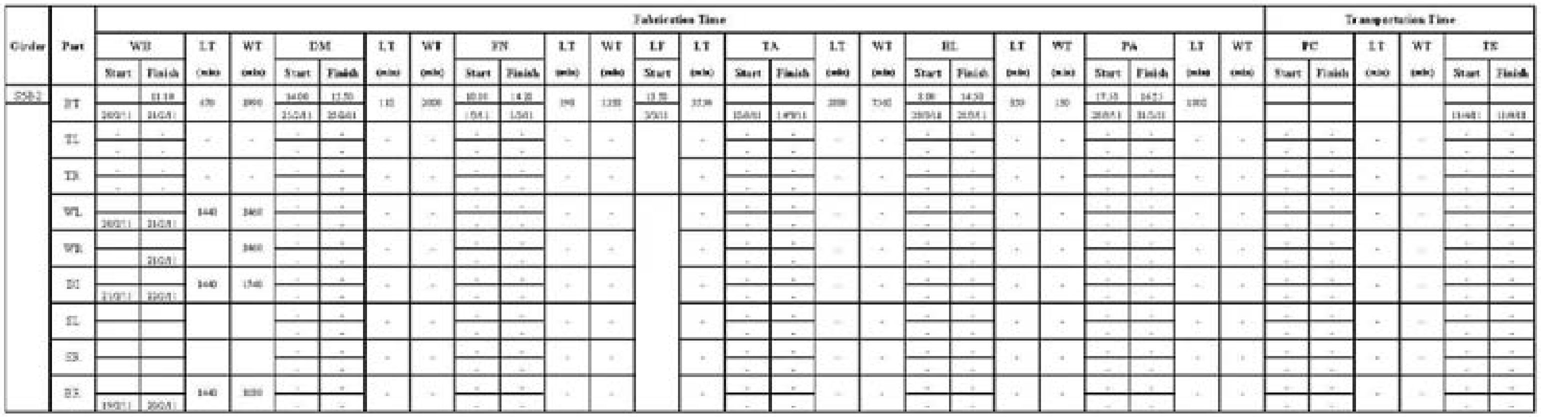
Girder	Part	Fabrication Time																										Transportation Time					
		WB		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	FA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S5B1	BT		17:10	8110			9:10		965	17:15				11:30	2190			2130	2260	8:00	17:00	240	820	17:20	17:30	1103							
		[illegible]	[illegible]				[illegible]			[illegible]				[illegible]		[illegible]	[illegible]			[illegible]	[illegible]			[illegible]	[illegible]							[illegible]	[illegible]
	TL	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	TR	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WL					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]				-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WR					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]				-	-			-	-					-	-			-	-			-	-			-	-			-	-
	DI					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			[illegible]			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SL					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SR					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	BR			2340		-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]			-	-			-	-					-	-			-	-			-	-			-	-			-	-

Table A.22 Data collection of box girder no.S5B2



Girder	Part	Part Preparation Time												Fabrication Time																							
		CT		LT	WT	TP		LT	WT	DR		LT	WT	BJ		LT	WT	AT		LT	WT	WT		LT	WT	AS		LT	WT	WS		LT	WT	AB		LT	WT
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)
S5B2	ST	20:35	19:25	320										8:00	14:30	2490	4510	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16:20	16:30	10	2800
		21/1/11	22/1/11											10/2/11	4/2/11			-	-			-	-			-	-			-	-			10/2/11	11/2/11		
	TL	9:00	11:40	155										8:00	16:20	3000						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		21/1/11	21/1/11											28/1/11	2/2/11							-	-			-	-			-	-			-	-		
	TR	17:50	20:25	155										10:30	16:13	1860						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		21/1/11	21/1/11											29/1/11	30/1/11							-	-			-	-			-	-			-	-		
	WL	13:00	19:20	159										14:40	13:30	315	1630					14:05	16:00	325	2475	-	-	-	-	-	-	-	-	16:00	9:00	360	2820
		18/1/11	18/1/11											31/1/11	1/2/11			4/2/11				8/2/11	9/2/11			-	-			-	-			15/2/11	16/2/11		
	WR	12:30	11:20	465										15:00	9:00	1140	1380					13:20	16:00	705		-	-	-	-	-	-	-	-	8:10	14:10	300	
		17/1/11	18/1/11											31/1/11	2/2/11			4/2/11				7/2/11	8/2/11			-	-			-	-			15/2/11	15/2/11		
	DI	16:35	8:45	1250		-	-	-	-	-	-	-	-	-	-	-	-								2550	-	-	-	-	-	-	-	-	15:30	9:15	160	4725
		20/1/11	21/1/11			-	-			-	-			-	-								9/2/11			-	-			-	-			15/2/11	16/2/11		
	SL	15:35	14:35	745						-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8:15	14:20	705						-	-	-	
		24/1/11	25/1/11							-	-			-	-			-	-			-	-			13/2/11	14/2/11							-	-		
	SR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-									-	-	-	
		-	-			-	-			-	-			-	-			-	-			-	-				11/2/11							-	-		
	BR					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				1440
						-	-			-	-			-	-			-	-			-	-			-	-			-	-				16/2/11		

Table A.22 (Cont.) Data collection of box girder no.S5B2

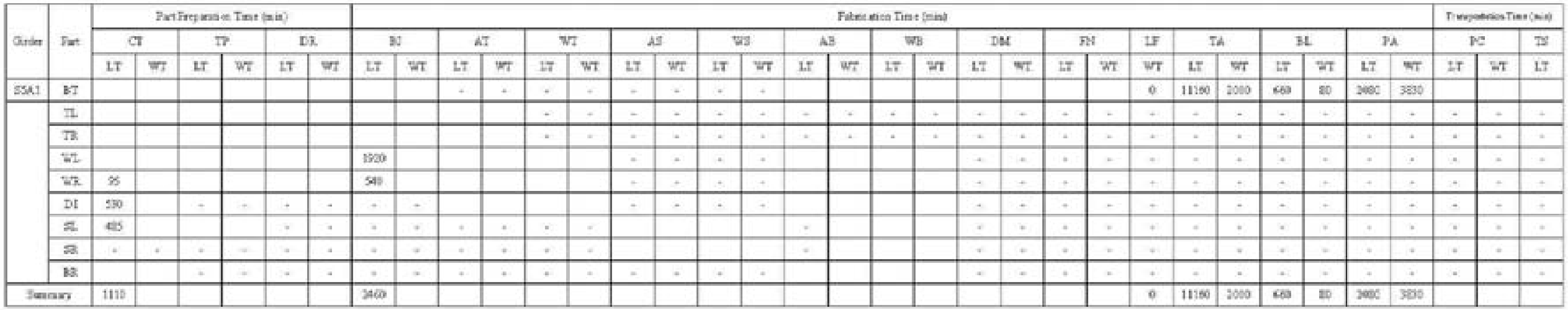


Girder	Part	Fabrication Time																										Transportation Time					
		WH		LT	WT	DM		LT	WT	FN		LT	WT	LF	LT	TA		LT	WT	BL		LT	WT	PA		LT	WT	PC		LT	WT	TS	
		Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish	(min)	(min)	Start	Finish
S5B2	ST		11:18	470	1990	14:00	12:50	110	2000	10:10	14:20	190	1230	13:30	3730			2880	7140	8:00	14:30	330	180	17:15	16:21	1802							
		20/2/11	21/2/11			23/2/11	25/2/11			1/3/11	1/3/11			3/3/11		15/3/11	14/3/11			20/3/11	21/3/11			28/3/11	31/3/11							11/4/11	11/4/11
	TL	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	TR	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WL			1440	2460	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		20/2/11	21/2/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	WR				2460	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			21/2/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	DI			1440	1540	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		21/2/11	22/2/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SL					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	SR					-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
						-	-			-	-					-	-			-	-			-	-			-	-			-	-
	BR			1440	1030	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		19/2/11	20/2/11			-	-			-	-					-	-			-	-			-	-			-	-			-	-

APPENDIX B

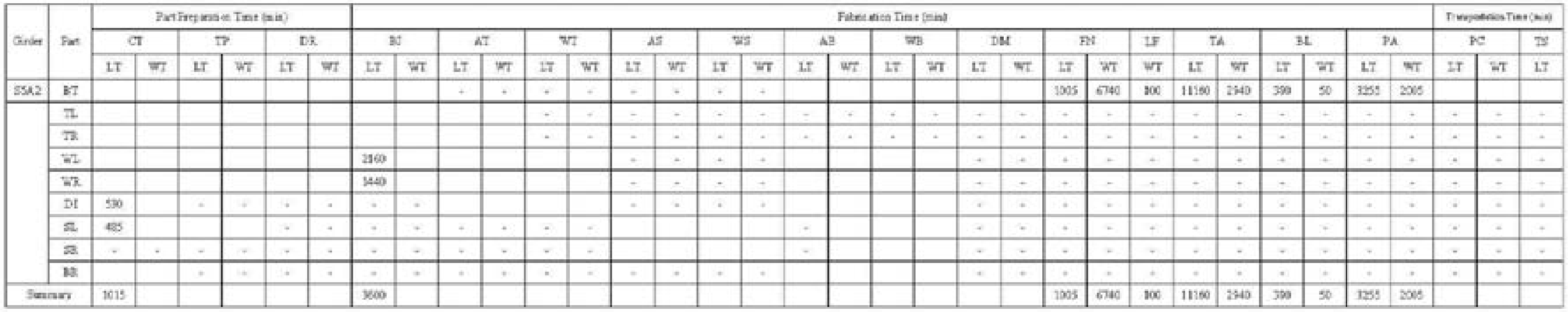
Data transformation

Table B.1 Summary data collection of girder no.S5A1



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BU		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S5A1	BT									-	-	-	-	-	-	-	-									0	11160	2000	660	80	3080	3830			
	TL											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL							1920						-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	95						540						-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	530		-	-	-	-	-	-					-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	485				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1110						2460																		0	11160	2000	660	80	3080	3830			

Table B.2 Summary data collection of girder no.S5A2



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BU		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S5A2	BT									-	-	-	-	-	-	-	-							1005	6740	800	11160	2940	390	50	3255	2065			
	TL											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL							2160						-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR							1440						-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	530		-	-	-	-	-	-					-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	485				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1015						3600																1005	6740	800	11160	2940	390	50	3255	2065			

Table B.3 Summary data collection of girder no.P4A1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P4A1	BT									-	-	-	-	-	-	-	-				475					0	18135	1725	570	130	1065	1925			
	TL											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	150												-	-	-	-				4370	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	150										1440		-	-	-	-				4370	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1140		-	-	-	-	-	-					-	-	-	-				5570	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	310				-	-	-	-	-	-	-	-			2160		-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-				5090	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1750										1440				2160					20025					0	18135	1725	570	130	1065	1925			

Table B.4 Summary data collection of girder no.P4A2

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P4A2	BT	195								-	-	-	-	-	-	-	-			2160						0	17580	2280	630	100	785				
	TL	120						720				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	340										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	185									0			-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	155						2160			1440			-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1140		-	-	-	-	-	-		0			-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	310				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		2445						2880			1440									2160						0	17580	2280	630	100	785				

Table B.5 Summary data collection of girder no.S4A1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FW		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S4A1	ET	210								-	-	-	-	-	-	-	-		5855	1010	600	130	15	1815	910	6665	6345	2400	450	75	1725				
	TL	215										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	170										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	190												-	-	-	-		6615	2640	1610	-		-	-	-	-	-	-	-	-	-	-	-	-
	WR	185												-	-	-	-			4410	560	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	535				-	-	-	-	-	-	-	-					-	7335	1200	3050	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-		1920	3530	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-	4080	720	2120	2850	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1505																4080	30565	13300	12200	130	15	1815	910	6665	6345	2400	450	75	1725				

Table B.6 Summary data collection of girder no.S4A2

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FW		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S4A2	ET	195								-	-	-	-	-	-	-	-		4455	2160						9345	6890	2590	410	70	1860				
	TL	170										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	250										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	210									0	1440		-	-	-	-		0	2160		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	195												-	-	-	-		0	2160		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	510				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-			1440		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1530									0	1440							4455	7920						9345	6890	2590	410	70	1860				

Table B.7 Summary data collection of girder no.P3A1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P3A1	BT	180								-	-	-	-	-	-	-	-			1920	1515	225	45			4575	13875	1380	600	90	2340				
	TL	150						720				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	80						720				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	225						1440			0	1440	2240	-	-	-	-	6640	0	1920	1515	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	180						720			0	2160		-	-	-	-		0	1920	1515	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	790		-	-	-	-	-	-			1440		-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	705				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-				2095	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		2310						3600			0	5040	2240					6640	0	5760	6640	225	45			4575	13875	1380	600	90	2340				

Table B.8 Summary data collection of girder no.P3A2

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P3A2	BT	200								-	-	-	-	-	-	-	-			3120	430	280	285	575	850	2200	13880	2070	500	75	1170				
	TL	130									20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	160										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	145						1440			20	1125	3045	-	-	-	-			3920	530	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	180						1440			0	1200		-	-	-	-			1440	2110	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1185		-	-	-	-	-	-					-	-	-	-			4865	1390	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	705				-	-	-	-	-	-	-	-				85	-			1390	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-			1390	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-		720	4800	6910	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		2705						2880			40	2325	3045				85		720	16465	14150	280	285	575	850	2200	13880	2070	500	75	1170				

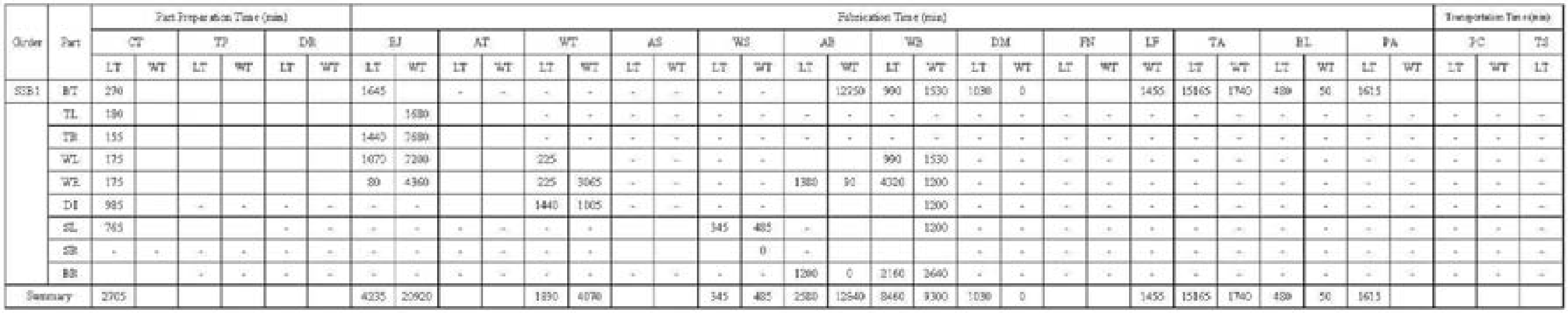
Table B.9 Summary data collection of girder no.S3A1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																										Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S3A1	ET	190								-	-	-	-	-	-	-	-		3470	2570	250	380	1440	1170	1100	10305	4185	1560	510	35	2255				
	TL	240						2160			0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	110						1440	7140	2700	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	190						1440			0	720	3605	-	-	-	-				10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	220						2160	9600			720	720	-	-	-	-			1850	490	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1560		-	-	-	-	-	-			1440		-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	1010				-	-	-	-	-	-	-	-				1215	-		1200	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-		1200	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-			4605	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3520						7200	16740	2700	0	2880	4325				1215		3470	11425	780	380	1440	1170	1100	10305	4185	1560	510	35	2255				

Table B.10 Summary data collection of girder no.S3A2

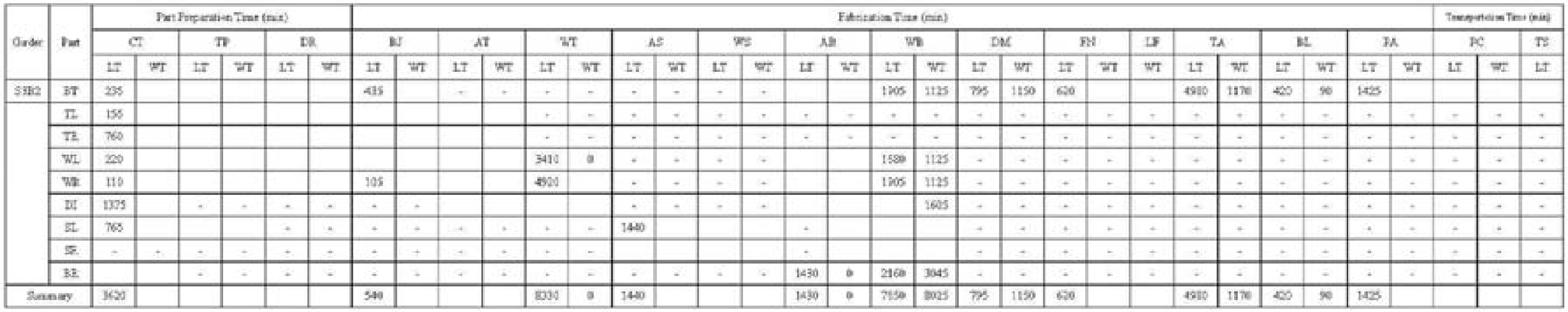
Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																										Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S3A2	ET	180								-	-	-	-	-	-	-	-		4080	1760	90	1090	1380	1200	0	9460	4390	1390	420	65	1645				
	TL	175									240	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	250						720			0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	190									240	185	2935	-	-	-	-		3975	480	1370	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	235						720			0	1920		-	-	-	-		3140	720	1130	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1435		-	-	-	-	-	-					-	-	-	-			4800	410	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	1010				-	-	-	-	-	-	-	-					-			410	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-	3620	1440	410	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BE			-	-	-	-	-	-	-	-	-	-	-	-	-	-	205			3305	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3475						1440			480	2105	2935					205	14815	9200	7125	1090	1380	1200	0	9460	4390	1390	420	65	1645				

Table B.11 Summary data collection of girder no.S3B1



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																										Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S3B1	BT	260						1645		-	-	-	-	-	-	-	-		12250	990	1530	1030	0			1455	15165	1740	480	50	1615				
	TL	190							1680			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TB	155						1440	7680			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	175						1070	7200			225		-	-	-	-			990	1530	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WB	175						80	4360			225	3065	-	-	-	-	1380	90	4320	1200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	985		-	-	-	-	-	-			1440	1005	-	-	-	-				1200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	765				-	-	-	-	-	-	-	-			345	485	-			1200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-				0	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-	1200	0	2160	2640	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		2705						4235	20920			1890	4070			345	485	2580	12540	8460	9300	1030	0			1455	15165	1740	480	50	1615				

Table B.12 Summary data collection of girder no.S3B2



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																										Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S3B2	BT	235						435		-	-	-	-	-	-	-	-			1905	1125	795	1150	620			4980	1170	420	90	1425				
	TL	155										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TB	760										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	220										3410	0	-	-	-	-			1580	1125	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WB	110						105				4920		-	-	-	-			1905	1125	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1375		-	-	-	-	-	-					-	-	-	-				1605	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	765				-	-	-	-	-	-	-	-	1440				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-	1430	0	2160	3045	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3620						540				8330	0	1440				1430	0	7550	8025	795	1150	620			4980	1170	420	90	1425				

Table B.13 Summary data collection of girder no.P3B1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P3B1	ET	390						2800	3470	-	-	-	-	-	-	-	-	4320			990			1380			6360	3000	420	90	2735				
	TL	245						440	4750	750	865	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	305										-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	180						2165	2585	320	670	695	1350	-	-	-	-	1260	5670	1440	720	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	185						720	4940			3260		-	-	-	-	630			720	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1270	10285	-	-	-	-	-	-	50				-	-	-	-				0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	535				-	-	-	-	-	-	-	-	1410				-			720	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-				1090	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-	1640	2670	1440	1920	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3110	10285					6125	16745	1120	1535	3955	1350	1410			1090	7850	8340	2880	5070			1380			6360	3000	420	90	2735				

Table B.14 Summary data collection of girder no.P3B2

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P3B2	ET	390						1320	6000	-	-	-	-	-	-	-	-	2970	7440	2160			1430	190			6300	3480	420	140	1770				
	TL	285						1440	6850	320	270	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	280						380	8450	395	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	185								220	0	1820	1200	-	-	-	-			2160		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	200						720	6970	395	0			-	-	-	-	1440	6720	2160		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1270	8235	-	-	-	-	-	-					-	-	-	-		6240	1440		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	535				-	-	-	-	-	-	-	-	270				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-				240	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-	2640				-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3145	8235					3860	28270	1330	270	1820	1200	270			240	7050	20400	7920			1430	190			6300	3480	420	140	1770				

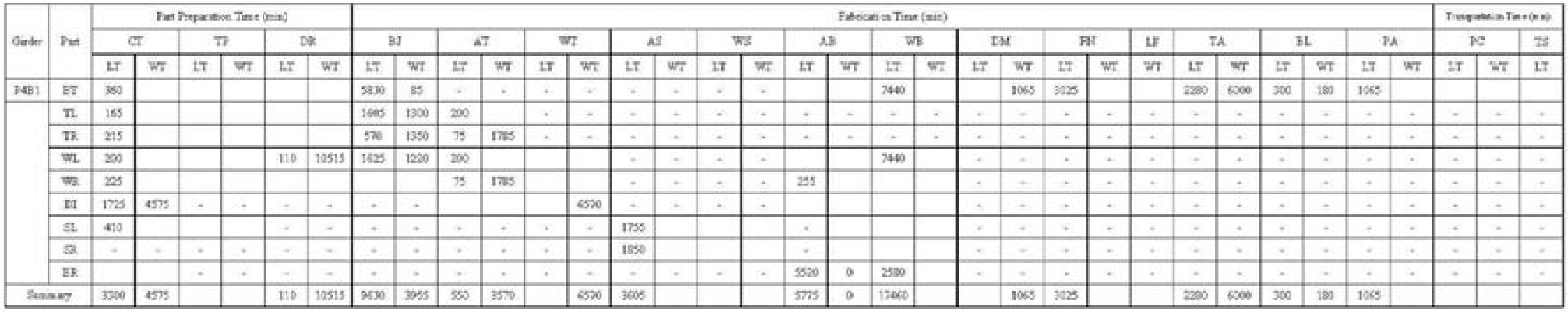
Table B.15 Summary data collection of girder no.S4B1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S4B1	BT	185						1950	1350	-	-	-	-	-	-	-	-			1440	2880						9840	3480	480	130	1700				
	TL	290									600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	620								130		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	155						145			600	210	1180	-	-	-	-				3600	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	160						860	1560	130			100	-	-	-	-	135			2880	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	165				-	-	-	-	-	-	-	-	390				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-	610				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-	2320	0	2330	3190	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1575						2955	2910	260	1200	210	1280	1000				2455	0	3770	12550						9840	3480	480	130	1700				

Table B.16 Summary data collection of girder no.S4B2

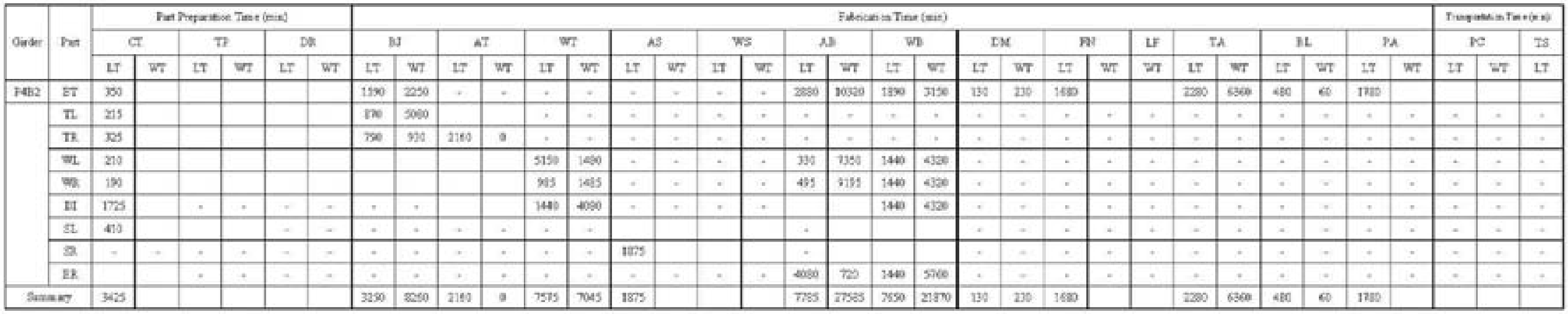
Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S4B2	BT	290						2400	4140	-	-	-	-	-	-	-	-			1200				1200			9840	4440	1080	100	1110				
	TL	270						285	4980	1370	560	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	130						280	4750	135	1485	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	150						340	4435	1370	560	300		-	-	-	-			1200		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	155								135	1485	1020	200	-	-	-	-			1200		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	165				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		1160						3705	13305	3010	4090	1720	200							3600				1200			9840	4440	1080	100	1110				

Table B.17 Summary data collection of girder no.P4B1



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																										Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P4B1	ET	360						5830	85	-	-	-	-	-	-	-	-			7440			1065	3025			2280	6300	300	180	1065				
	TL	165						1605	1300	200		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	215						570	1350	75	1785	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	200				110	10515	1625	1220	200				-	-	-	-			7440		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	225								75	1785			-	-	-	-	255				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1725	4575	-	-	-	-	-	-				4590	-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	410				-	-	-	-	-	-	-	-	1755				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-	1850				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-	5520	0	2580		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3300	4575			110	10515	9630	3955	550	3570		4590	3605				5775	0	17460			1065	3025			2280	6300	300	180	1065				

Table B.18 Summary data collection of girder no.P4B2



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																										Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
P4B2	ET	350						1590	2250	-	-	-	-	-	-	-	-	2880	10320	1890	3150	130	230	1680			2280	6360	480	60	1780				
	TL	215						870	5060			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	325						790	930	2160	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	210										5150	1490	-	-	-	-	330	7350	1440	4320	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	190										985	1465	-	-	-	-	495	9195	1440	4320	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1725		-	-	-	-	-	-			1440	4090	-	-	-	-			1440	4320	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	410				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-	1875				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ER			-	-	-	-	-	-	-	-	-	-	-	-	-	-	4080	720	1440	5760	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3425						3250	8250	2160	0	7575	7045	1875				7785	27585	7650	21870	130	230	1680			2280	6360	480	60	1780				

Table B.19 Summary data collection of girder no.S5B1

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S5B1	BT	250						1430	4320	-	-	-	-	-	-	-	-			1810			905			3090	2880	8160	360	120	1100				
	TL	160						1885	3870			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	160						2150	1215	255	360	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	165						1425	2230			1110	780	-	-	-	-	340	5250			-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	175						1410	1935	255	760	1130		-	-	-	-	135	5850			-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1260		-	-	-	-	-	-				11800	-	-	-	-	10				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	745				-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-	2880	480	3360		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		2915						8300	13370	510	1520	2240	12580					3365	11580	5170			905			3090	2880	8160	360	120	1100				

Table B.20 Summary data collection of girder no.S5B2

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)																									Transportation Time (min)		
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB		DM		FN		LF	TA		BL		PA		PC		TS
		LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT	WT	WT	LT	WT	LT	WT	LT	WT	LT	WT	LT
S5B2	BT	220						2490	4910	-	-	-	-	-	-	-	-	10	5310	670	2990	110	2000	190	1230	3550	2880	7560	350	130	1800				
	TL	155						3030				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR	155						1005				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WL	160						885	1650			835	2475	-	-	-	-	360	2820	1440	2460	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	WR	465						1840	1380			785		-	-	-	-	300			2460	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DI	1260		-	-	-	-	-	-				2550	-	-	-	-	165	4725	1440	1740	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SL	745				-	-	-	-	-	-	-	-	285				-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-					-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BR			-	-	-	-	-	-	-	-	-	-	-	-	-	-		1440	1440	3180	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summary		3160						8600	7940			1620	5025	285				835	14295	4990	12830	110	2000	190	1230	3550	2880	7560	350	130	1800				

Table B.21 Summary data of bottom part

Girder	Part	Part Preparation Time (mins)						Fabrication Time (mins)													
		CT		TP		DB		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	BT			75	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-				
S5A2	BT			75	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-				
P6A1	BT			125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-				675
P6A2	BT	195	0-60, 25	125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-			2160	
S4A1	BT	210	0-60, 25	115	0-120, 45	285	30-3300, 70			-	-	-	-	-	-	-	-		5895	1010	600
S4A2	BT	195	0-60, 25	115	0-120, 45	285	30-3300, 70			-	-	-	-	-	-	-	-		4455	2160	
P5A1	BT	180	0-60, 25	125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-			1920	1515
P5A2	BT	200	0-60, 25	125	0-120, 45	408	30-3300, 70			-	-	-	-	-	-	-	-			3120	430
S3A1	BT	190	0-60, 25	115	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-		3470	2570	250
S3A2	BT	180	0-60, 25	115	0-120, 45	145	30-3300, 70			-	-	-	-	-	-	-	-		4080	1760	90
S3B1	BT	270	0-60, 25	275	0-120, 45	390	30-3300, 70	1645		-	-	-	-	-	-	-	-		12750	990	1330
S3B2	BT	235	0-60, 25	275	0-120, 45	390	30-3300, 70	435		-	-	-	-	-	-	-	-			1905	1125
P5B1	BT	390	0-60, 25	430	0-120, 45	775	30-3300, 70	2800	5470	-	-	-	-	-	-	-	-	4320			990
P5B2	BT	390	0-60, 25	430	0-120, 45	775	30-3300, 70	1320	6000	-	-	-	-	-	-	-	-	2970	7440	2160	
S4B1	BT	185	0-60, 25	310	0-120, 45	775	30-3300, 70	1950	1550	-	-	-	-	-	-	-	-			1440	2880
S4B2	BT	290	0-60, 25	310	0-120, 45	775	30-3300, 70	2400	4140	-	-	-	-	-	-	-	-			1200	
P4B1	BT	360	0-60, 25	430	0-120, 45	775	30-3300, 70	5830	85	-	-	-	-	-	-	-	-			7440	
P4B2	BT	350	0-60, 25	430	0-120, 45	775	30-3300, 70	1590	2250	-	-	-	-	-	-	-	-	2880	10320	1890	3150
S5B1	BT	250	0-60, 25	280	0-120, 45	390	30-3300, 70	1430	4320	-	-	-	-	-	-	-	-			1810	
S5B2	BT	220	0-60, 25	280	0-120, 45	390	30-3300, 70	2490	8910	-	-	-	-	-	-	-	-	10	5310	670	2990
Max	BT	390	60	430	120	775	3300	5830	6000	-	-	-	-	-	-	-	-	4320	12750	7440	3150
Mode	BT	195	25	125	45	775	70	#N/A	#N/A	-	-	-	-	-	-	-	-	#N/A	#N/A	2160	#N/A
Min	BT	180	0	75	0	145	30	435	85	-	-	-	-	-	-	-	-	10	3470	670	90
Mean		285	27	253	50	460	602	3133	3043	-	-	-	-	-	-	-	-	2165	8110	4055	1620
SD		61	10	102	20	182	545	1557	1708	-	-	-	-	-	-	-	-	1244	2679	1954	883

<u>Remark</u> (xx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

Table B.22 Summary data of left top-flange part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DB		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	TL			45	0-120, 45	35	30-3300, 70					-	-	-	-	-	-	-	-	-	-
S5A2	TL			45	0-120, 45	35	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P6A1	TL			45	0-120, 45	95	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P6A2	TL	120	0-60, 25	45	0-120, 45	95	30-3300, 70	720				-	-	-	-	-	-	-	-	-	-
S4A1	TL	215	0-60, 25	45	0-120, 45	65	30-3300, 70					-	-	-	-	-	-	-	-	-	-
S4A2	TL	170	0-60, 25	45	0-120, 45	65	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P5A1	TL	150	0-60, 25	45	0-120, 45	95	30-3300, 70	720				-	-	-	-	-	-	-	-	-	-
P5A2	TL	130	0-60, 25	45	0-120, 45	95	30-3300, 70				20	-	-	-	-	-	-	-	-	-	-
S3A1	TL	240	0-60, 25	45	0-120, 45	35	30-3300, 70	2160			0	-	-	-	-	-	-	-	-	-	-
S3A2	TL	175	0-60, 25	45	0-120, 45	35	30-3300, 70				240	-	-	-	-	-	-	-	-	-	-
S3B1	TL	180	0-60, 25	45	0-120, 45	35	30-3300, 70		1680			-	-	-	-	-	-	-	-	-	-
S3B2	TL	155	0-60, 25	45	0-120, 45	35	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P5B1	TL	245	0-60, 25	90	0-120, 45	50	30-3300, 70	440	6750	750	865	-	-	-	-	-	-	-	-	-	-
P5B2	TL	285	0-60, 25	90	0-120, 45	50	30-3300, 70	1440	6850	320	270	-	-	-	-	-	-	-	-	-	-
S4B1	TL	290	0-60, 25	45	0-120, 45	65	30-3300, 70				600	-	-	-	-	-	-	-	-	-	-
S4B2	TL	270	0-60, 25	45	0-120, 45	65	30-3300, 70	285	4980	1370	560	-	-	-	-	-	-	-	-	-	-
P4B1	TL	165	0-60, 25	110	0-120, 45	110	30-3300, 70	1605	1500	200		-	-	-	-	-	-	-	-	-	-
P4B2	TL	215	0-60, 25	110	0-120, 45	110	30-3300, 70	870	5080			-	-	-	-	-	-	-	-	-	-
S5B1	TL	160	0-60, 25	70	0-120, 45	35	30-3300, 70	1885	3670			-	-	-	-	-	-	-	-	-	-
S5B2	TL	155	0-60, 25	70	0-120, 45	35	30-3300, 70	3080				-	-	-	-	-	-	-	-	-	-
Max	TL	290	60	110	120	110	3300	3080	6850	1370	865	-	-	-	-	-	-	-	-	-	-
Mode	TL	215	25	45	45	35	70	720	#N/A	#N/A	#N/A	-	-	-	-	-	-	-	-	-	-
Min	TL	120	0	45	0	35	30	285	1500	200	0	-	-	-	-	-	-	-	-	-	-
Mean		205	27	78	50	73	602	1683	4075	785	433	-	-	-	-	-	-	-	-	-	-
SD		49	10	19	20	22	545	807	1602	338	250	-	-	-	-	-	-	-	-	-	-

<u>Remark</u> (xx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

Table B.23 Summary data of right top-flange part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	TR			45	0-120, 45	35	30-3300, 70					-	-	-	-	-	-	-	-	-	-
S5A2	TR			45	0-120, 45	35	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P4A1	TR			45	0-120, 45	95	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P4A2	TR	340	0-60, 25	45	0-120, 45	95	30-3300, 70					-	-	-	-	-	-	-	-	-	-
S4A1	TR	170	0-60, 25	45	0-120, 45	65	30-3300, 70					-	-	-	-	-	-	-	-	-	-
S4A2	TR	250	0-60, 25	45	0-120, 45	65	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P3A1	TR	80	0-60, 25	45	0-120, 45	95	30-3300, 70	720				-	-	-	-	-	-	-	-	-	-
P3A2	TR	160	0-60, 25	45	0-120, 45	95	30-3300, 70					-	-	-	-	-	-	-	-	-	-
S3A1	TR	110	0-60, 25	45	0-120, 45	35	30-3300, 70	1440	7140	2700	0	-	-	-	-	-	-	-	-	-	-
S3A2	TR	250	0-60, 25	45	0-120, 45	35	30-3300, 70	720			0	-	-	-	-	-	-	-	-	-	-
S3B1	TR	155	0-60, 25	45	0-120, 45	35	30-3300, 70	1440	7680			-	-	-	-	-	-	-	-	-	-
S3B2	TR	760	0-60, 25	45	0-120, 45	35	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P3B1	TR	305	0-60, 25	110	0-120, 45	110	30-3300, 70					-	-	-	-	-	-	-	-	-	-
P3B2	TR	280	0-60, 25	110	0-120, 45	110	30-3300, 70	380	8450	395	0	-	-	-	-	-	-	-	-	-	-
S4B1	TR	620	0-60, 25	45	0-120, 45	65	30-3300, 70			130		-	-	-	-	-	-	-	-	-	-
S4B2	TR	130	0-60, 25	45	0-120, 45	65	30-3300, 70	280	4750	135	1485	-	-	-	-	-	-	-	-	-	-
P4B1	TR	215	0-60, 25	110	0-120, 45	110	30-3300, 70	570	1350	75	1785	-	-	-	-	-	-	-	-	-	-
P4B2	TR	325	0-60, 25	110	0-120, 45	110	30-3300, 70	790	930	2160	0	-	-	-	-	-	-	-	-	-	-
S5B1	TR	160	0-60, 25	70	0-120, 45	35	30-3300, 70	2150	1215	255	760	-	-	-	-	-	-	-	-	-	-
S5B2	TR	155	0-60, 25	70	0-120, 45	35	30-3300, 70	1005				-	-	-	-	-	-	-	-	-	-
Max	TR	760	60	110	120	110	3300	2150	8450	2700	1785	-	-	-	-	-	-	-	-	-	-
Mode	TR	250	25	45	45	35	70	720	#N/A	#N/A	0	-	-	-	-	-	-	-	-	-	-
Min	TR	80	0	45	0	35	30	280	930	75	0	-	-	-	-	-	-	-	-	-	-
Mean		420	27	78	50	73	602	1215	4690	1388	893	-	-	-	-	-	-	-	-	-	-
SD		196	10	19	20	22	545	540	2171	758	515	-	-	-	-	-	-	-	-	-	-

<u>Remark</u> (xx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

Table B.24 Summary data of left web-flange part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	WL			45	0-120, 45	35	30-3300, 70	1920						-	-	-	-				
S5A2	WL			45	0-120, 45	35	30-3300, 70	2160						-	-	-	-				
P4A1	WL	150	0-60, 25	45	0-120, 45	95	30-3300, 70							-	-	-	-				4370
P4A2	WL	185	0-60, 25	45	0-120, 45	95	30-3300, 70				0			-	-	-	-				
S4A1	WL	190	0-60, 25	45	0-120, 45	65	30-3300, 70							-	-	-	-		6615	2640	1610
S4A2	WL	210	0-60, 25	45	0-120, 45	65	30-3300, 70				0	1440		-	-	-	-		0	2160	
P3A1	WL	225	0-60, 25	45	0-120, 45	95	30-3300, 70	1440			0	1440	2240	-	-	-	-	6640	0	1920	1515
P3A2	WL	145	0-60, 25	45	0-120, 45	95	30-3300, 70	1440			20	1125	3045	-	-	-	-			3020	530
S3A1	WL	190	0-60, 25	45	0-120, 45	35	30-3300, 70	1440			0	720	3605	-	-	-	-				10
S3A2	WL	190	0-60, 25	45	0-120, 45	35	30-3300, 70				240	185	2935	-	-	-	-		3975	480	1370
S3B1	WL	175	0-60, 25	45	0-120, 45	35	30-3300, 70	1070	7200			225		-	-	-	-			990	1530
S3B2	WL	220	0-60, 25	45	0-120, 45	35	30-3300, 70					3410	0	-	-	-	-			1680	1125
P3B1	WL	180	0-60, 25	110	0-120, 45	110	30-3300, 70	2165	2585	320	670	695	1350	-	-	-	-	1260	5670	1440	720
P3B2	WL	185	0-60, 25	110	0-120, 45	110	30-3300, 70			220	0	1820	1200	-	-	-	-			2160	
S4B1	WL	155	0-60, 25	45	0-120, 45	65	30-3300, 70	145			600	210	1110	-	-	-	-				3600
S4B2	WL	150	0-60, 25	45	0-120, 45	65	30-3300, 70	740	4435	1370	560	700		-	-	-	-			1200	
P4B1	WL	200	0-60, 25	110	0-120, 45	110	10515	1625	1220	200				-	-	-	-			7440	
P4B2	WL	210	0-60, 25	110	0-120, 45	110	30-3300, 70					5150	1480	-	-	-	-	330	7350	1440	4320
S5B1	WL	165	0-60, 25	70	0-120, 45	35	30-3300, 70	1425	2230			1110	780	-	-	-	-	240	5250		
S5B2	WL	160	0-60, 25	70	0-120, 45	35	30-3300, 70	885	1650			835	2475	-	-	-	-	360	2820	1440	2460
Max	WL	225	60	110	120	110	10515	2165	7200	1370	670	5150	3605	-	-	-	-	6640	7350	7440	4370
Mode	WL	190	25	45	45	35	70	1440	#N/A	#N/A	0	1440	#N/A	-	-	-	-	#N/A	0	1440	#N/A
Min	WL	145	0	45	0	35	30	145	1220	200	0	185	0	-	-	-	-	240	0	480	10
Mean		185	27	78	50	73	1804	1155	4210	785	335	2668	1803	-	-	-	-	3440	3675	3960	2190
SD		23	10	19	20	22	1748	583	1726	538	195	1435	1041	-	-	-	-	1848	2122	2009	1259

<u>Remark</u> (xx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

Table B.25 Summary data of right web-flange part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	WR	95	0-60, 25	100	0-120, 45	55	30-3300, 70	540						-	-	-	-				
S5A2	WR			100	0-120, 45	55	30-3300, 70	1440						-	-	-	-				
P4A1	WR	150	0-60, 25	100	0-120, 45	110	30-3300, 70					1440		-	-	-	-				4370
P4A2	WR	155	0-60, 25	100	0-120, 45	110	30-3300, 70	2160			1440			-	-	-	-				
S4A1	WR	185	0-60, 25	100	0-120, 45	110	30-3300, 70							-	-	-	-			4410	560
S4A2	WR	185	0-60, 25	100*	0-120, 45	110	30-3300, 70							-	-	-	-		0	2160	
P3A1	WR	180	0-60, 25	100	0-120, 45	110	30-3300, 70	720			0	2160		-	-	-	-		0	1920	1515
P3A2	WR	180	0-60, 25	100	0-120, 45	110	30-3300, 70	1440			0	1200		-	-	-	-			1440	2110
S3A1	WR	220	0-60, 25	100	0-120, 45	55	30-3300, 70	2160	9600			720	720	-	-	-	-			1850	490
S3A2	WR	235	0-60, 25	100	0-120, 45	55	30-3300, 70	720			0	1920		-	-	-	-		3140	720	1130
S3B1	WR	175	0-60, 25	100	0-120, 45	85	30-3300, 70	80	4560			225	3065	-	-	-	-	1380	90	4320	1200
S3B2	WR	110	0-60, 25	100	0-120, 45	85	30-3300, 70	105				4920		-	-	-	-			1005	1125
P5B1	WR	185	0-60, 25	150	0-120, 45	165	30-3300, 70	750	4940			3560		-	-	-	-	630			720
P5B2	WR	200	0-60, 25	150	0-120, 45	165	30-3300, 70	720	6970	395	0			-	-	-	-	1440	6720	2160	
S4B1	WR	160	0-60, 25	100	0-120, 45	165	30-3300, 70	860	1560	150			100	-	-	-	-	135			2880
S4B2	WR	155	0-60, 25	100	0-120, 45	165	30-3300, 70			135	1485	1020	200	-	-	-	-			1700	
P4B1	WR	225	0-60, 25	150	0-120, 45	165	30-3300, 70			75	1785			-	-	-	-	255			
P4B2	WR	190	0-60, 25	150	0-120, 45	165	30-3300, 70					985	1485	-	-	-	-	895	9195	1440	4320
S5B1	WR	175	0-60, 25	100	0-120, 45	85	30-3300, 70	1410	1935	255	760	1130		-	-	-	-	135	5850		
S5B2	WR	465	0-60, 25	100	0-120, 45	85	30-3300, 70	1140	1380			785		-	-	-	-	300			2460
Max	WR	465	60	150	120	165	3300	2160	9600	395	1785	4920	3065	-	-	-	-	1440	9195	4410	4370
Mode	WR	185	25	100	45	110	70	720	#N/A	#N/A	0	#N/A	#N/A	-	-	-	-	135	0	2160	#N/A
Min	WR	95	0	100	0	55	30	80	1380	75	0	225	100	-	-	-	-	135	0	720	490
Mean		280	27	125	50	110	602	1120	5490	235	893	2373	1583	-	-	-	-	788	4598	2565	2430
SD		107	10	14	20	32	545	600	2373	92	515	1355	856	-	-	-	-	377	2654	1065	1120

<u>Remark</u> (xx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

Table B.26 Summary data of diaphragm part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	DI	530		-	-	-	-	-	-					-	-	-	-				
S5A2	DI	530		-	-	-	-	-	-					-	-	-	-				
P4A1	DI	1140		-	-	-	-	-	-					-	-	-	-				5570
P4A2	DI	1140		-	-	-	-	-	-		0			-	-	-	-				
S4A1	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S4A2	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P3A1	DI	790		-	-	-	-	-	-			1440		-	-	-	-				
P3A2	DI	1185		-	-	-	-	-	-					-	-	-	-			4085	1390
S3A1	DI	1560		-	-	-	-	-	-			1440		-	-	-	-				
S3A2	DI	1435		-	-	-	-	-	-					-	-	-	-			4800	410
S3B1	DI	985		-	-	-	-	-	-			1440	1005	-	-	-	-				1200
S3B2	DI	1375		-	-	-	-	-	-					-	-	-	-				1605
P5B1	DI	1270	10285	-	-	-	-	-	-	50				-	-	-	-				0
P5B2	DI	1270	8235	-	-	-	-	-	-					-	-	-	-		6240	1440	
S4B1	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S4B2	DI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P4B1	DI	1725	4575	-	-	-	-	-	-				6570	-	-	-	-				
P4B2	DI	1725		-	-	-	-	-	-			1440	4080	-	-	-	-			1440	4320
S5B1	DI	1260		-	-	-	-	-	-				11800	-	-	-	-	110			
S5B2	DI	1260		-	-	-	-	-	-				2550	-	-	-	-	165	4725	1440	1740
Max	DI	1725	10285	-	-	-	-	-	-	50	0	1440	11800	-	-	-	-	165	6240	4800	5570
Mode	DI	530	#N/A	-	-	-	-	-	-	#N/A	#N/A	1440	#N/A	-	-	-	-	#N/A	#N/A	1440	#N/A
Min	DI	530	4575	-	-	-	-	-	-	50	0	1440	1005	-	-	-	-	110	4725	1440	0
Mean		1128	7430	-	-	-	-	-	-	50	0	1440	6403	-	-	-	-	138	5483	3120	2785
SD		345	1648	-	-	-	-	-	-	0	0	0	3116	-	-	-	-	16	437	970	1608

Table B.27 Summary data of left stiffener part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	SL	243	0-60, 25	115	0-120, 45	-	-	-	-	-	-	-	-					-			
S5A2	SL	243	0-60, 25	100	0-120, 45	-	-	-	-	-	-	-	-					-			
P4A1	SL	155	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-			2160		-			
P4A2	SL	155	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-					-			
S4A1	SL	268	0-60, 25	105	0-120, 45	-	-	-	-	-	-	-	-					-	7335	1200	3050
S4A2	SL	255	0-60, 25	105	0-120, 45	-	-	-	-	-	-	-	-					-			
P3A1	SL	353	0-60, 25	140	0-120, 45	-	-	-	-	-	-	-	-					-			
P3A2	SL	353	0-60, 25	140	0-120, 45	-	-	-	-	-	-	-	-				85	-			1390
S3A1	SL	505	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-				1215	-		1200	10
S3A2	SL	505	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-					-			410
S3B1	SL	383	0-60, 25	85	0-120, 45	-	-	-	-	-	-	-	-			345	485	-			1200
S3B2	SL	383	0-60, 25	95	0-120, 45	-	-	-	-	-	-	-	-	1440	60-240, 150			-			
P3B1	SL	268	0-60, 25	75	0-120, 45	-	-	-	-	-	-	-	-	1410	60-240, 150			-			720
P3B2	SL	268	0-60, 25	90	0-120, 45	-	-	-	-	-	-	-	-	270	60-240, 150			-			
S4B1	SL	83	0-60, 25	75	0-120, 45	-	-	-	-	-	-	-	-	390	60-240, 150			-			
S4B2	SL	83	0-60, 25	75	0-120, 45	-	-	-	-	-	-	-	-					-			
P4B1	SL	205	0-60, 25	85	0-120, 45	-	-	-	-	-	-	-	-	1755	60-240, 150			-			
P4B2	SL	205	0-60, 25	85	0-120, 45	-	-	-	-	-	-	-	-					-			
S5B1	SL	373	0-60, 25	95	0-120, 45	-	-	-	-	-	-	-	-					-			
S5B2	SL	373	0-60, 25	95	0-120, 45	-	-	-	-	-	-	-	-	785	60-240, 150			-			
Max	SL	505	60	140	120	-	-	-	-	-	-	-	-	1755	240	2160	1215	-	7335	1200	3050
Mode	SL	268	25	125	45	-	-	-	-	-	-	-	-	#N/A	150	#N/A	#N/A	-	#N/A	1200	#N/A
Min	SL	83	0	75	0	-	-	-	-	-	-	-	-	270	60	345	85	-	7335	1200	10
Mean		294	27	108	50	-	-	-	-	-	-	-	-	1013	150	1253	650	-	7335	1200	1530
SD		122	10	19	20	-	-	-	-	-	-	-	-	429	52	524	326	-	0	0	878

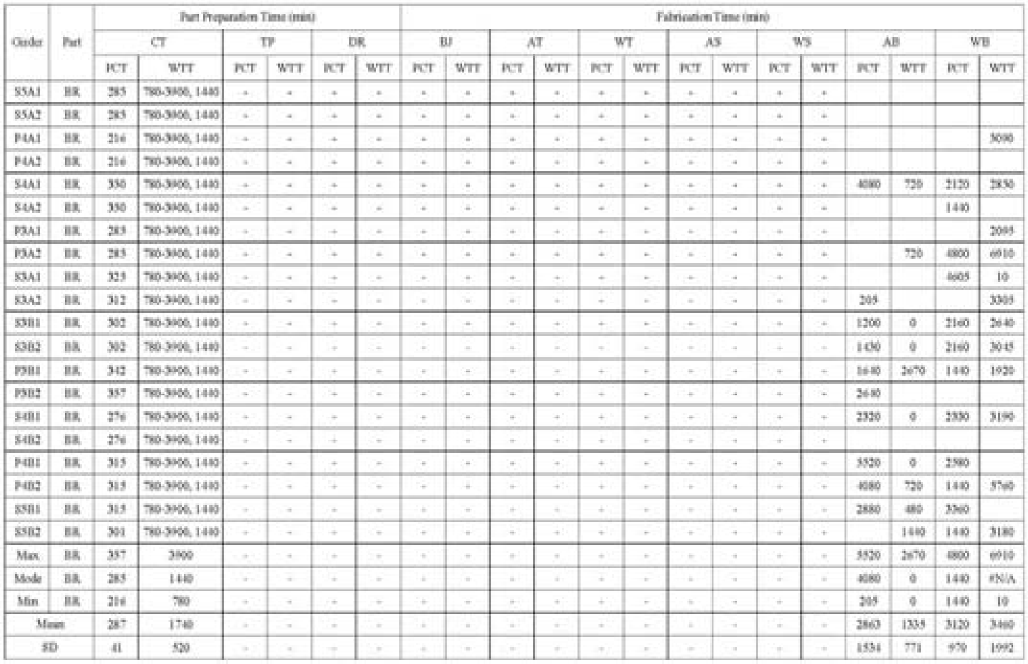
Remark (xx-xxx, xx) represent minimum, maximum, and average values from interview.

Table B.28 Summary data of right stiffener part

Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	SR	243	0-60, 25	115	0-120, 45	-	-	-	-	-	-	-	-					-			
S5A2	SR	243	0-60, 25	100	0-120, 45	-	-	-	-	-	-	-	-					-			
P4A1	SR	155	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-					-			
P4A2	SR	155	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-					-			
S4A1	SR	268	0-60, 25	105	0-120, 45	-	-	-	-	-	-	-	-					-		1920	3530
S4A2	SR	255	0-60, 25	105	0-120, 45	-	-	-	-	-	-	-	-					-			
P3A1	SR	353	0-60, 25	140	0-120, 45	-	-	-	-	-	-	-	-					-			
P3A2	SR	353	0-60, 25	140	0-120, 45	-	-	-	-	-	-	-	-					-			1390
S3A1	SR	505	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-					-		1200	10
S3A2	SR	505	0-60, 25	125	0-120, 45	-	-	-	-	-	-	-	-					-	3620	1440	410
S3B1	SR	383	0-60, 25	85	0-120, 45	-	-	-	-	-	-	-	-			720-1440, 900	0	-			
S3B2	SR	383	0-60, 25	95	0-120, 45	-	-	-	-	-	-	-	-					-			
P3B1	SR	268	0-60, 25	75	0-120, 45	-	-	-	-	-	-	-	-			720-1440, 900	1090	-			
P3B2	SR	268	0-60, 25	90	0-120, 45	-	-	-	-	-	-	-	-			720-1440, 900	240	-			
S4B1	SR	83	0-60, 25	75	0-120, 45	-	-	-	-	-	-	-	-	610	60-240, 150			-			
S4B2	SR	83	0-60, 25	75	0-120, 45	-	-	-	-	-	-	-	-					-			
P4B1	SR	205	0-60, 25	85	0-120, 45	-	-	-	-	-	-	-	-	1850	60-240, 150			-			
P4B2	SR	205	0-60, 25	85	0-120, 45	-	-	-	-	-	-	-	-	1875	60-240, 150			-			
S5B1	SR	373	0-60, 25	95	0-120, 45	-	-	-	-	-	-	-	-					-			
S5B2	SR	373	0-60, 25	95	0-120, 45	-	-	-	-	-	-	-	-					-			
Max	SR	505	60	140	120	-	-	-	-	-	-	-	-	1875	240	1440	1090	-	3620	1920	3530
Mode	SR	268	25	125	45	-	-	-	-	-	-	-	-	#N/A	150	900	#N/A	-	#N/A	#N/A	#N/A
Min	SR	83	0	75	0	-	-	-	-	-	-	-	-	610	60	720	0	-	3620	1200	10
Mean		294	27	108	50	-	-	-	-	-	-	-	-	1245	150	960	545	-	3620	1560	1770
SD		122	10	19	20	-	-	-	-	-	-	-	-	365	30	120	515	-	0	208	1916

Remark (xxx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

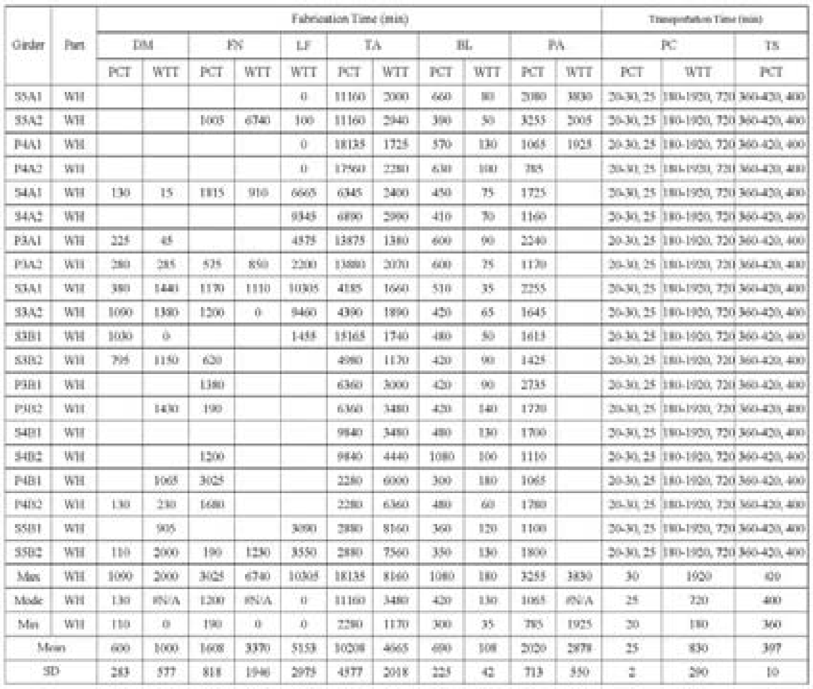
Table B.29 Summary data of bracing part



Girder	Part	Part Preparation Time (min)						Fabrication Time (min)													
		CT		TP		DR		BJ		AT		WT		AS		WS		AB		WB	
		PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT
S5A1	BR	285	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
S5A2	BR	285	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
P4A1	BR	216	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-				3090
P4A2	BR	216	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
S4A1	BR	350	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4080	720	2120	2830
S4A2	BR	350	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1440	
P3A1	BR	285	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-				2095
P3A2	BR	285	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-		720	4800	6910
S3A1	BR	325	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-			4605	10
S3A2	BR	312	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	205			3305
S3B1	BR	302	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1200	0	2160	2640
S3B2	BR	302	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1430	0	2160	3045
P3B1	BR	342	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1640	2670	1440	1920
P3B2	BR	357	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2640			
S4B1	BR	276	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2320	0	2330	3190
S4B2	BR	276	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
P4B1	BR	315	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3520	0	2580	
P4B2	BR	315	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4080	720	1440	5760
S5B1	BR	315	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2880	480	3360	
S5B2	BR	301	780-3900, 1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1440	1440	3180
Max	BR	357	3900	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3520	2670	4800	6910
Mode	BR	285	1440	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4080	0	1440	#N/A
Min	BR	216	780	-	-	-	-	-	-	-	-	-	-	-	-	-	-	205	0	1440	10
Mean		287	1740	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2863	1335	3120	3460
SD		41	520	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1534	771	970	1992

Remark (xxx-xxxx, xxxx) represent minimum, maximum, and average values from interview.

Table B.30 Summary data of whole part



Girder	Part	Fabrication Time (min)											Transportation Time (min)		
		DM		FN		LF	TA		BL		PA		PC		TS
		PCT	WTT	PCT	WTT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT	WTT	PCT
S5A1	WH					0	11160	2000	660	80	2080	3830	20-30, 25	180-1920, 720	360-420, 400
S5A2	WH			1005	6740	100	11160	2940	390	50	3255	2005	20-30, 25	180-1920, 720	360-420, 400
P4A1	WH					0	18135	1725	570	130	1065	1925	20-30, 25	180-1920, 720	360-420, 400
P4A2	WH					0	17560	2280	630	100	785		20-30, 25	180-1920, 720	360-420, 400
S4A1	WH	130	15	1815	910	6665	6345	2400	450	75	1725		20-30, 25	180-1920, 720	360-420, 400
S4A2	WH					9345	6890	2990	410	70	1160		20-30, 25	180-1920, 720	360-420, 400
P3A1	WH	225	45			4575	13875	1380	600	90	2240		20-30, 25	180-1920, 720	360-420, 400
P3A2	WH	280	285	575	850	2200	13880	2070	600	75	1170		20-30, 25	180-1920, 720	360-420, 400
S3A1	WH	380	1440	1170	1110	10305	4185	1660	510	35	2255		20-30, 25	180-1920, 720	360-420, 400
S3A2	WH	1090	1380	1200	0	9460	4390	1890	420	65	1645		20-30, 25	180-1920, 720	360-420, 400
S3B1	WH	1030	0			1455	15165	1740	480	50	1615		20-30, 25	180-1920, 720	360-420, 400
S3B2	WH	795	1150	620			4980	1170	420	90	1425		20-30, 25	180-1920, 720	360-420, 400
P3B1	WH			1380			6360	3000	420	90	2735		20-30, 25	180-1920, 720	360-420, 400
P3B2	WH		1430	190			6360	3480	420	140	1720		20-30, 25	180-1920, 720	360-420, 400
S4B1	WH						9840	3480	480	130	1700		20-30, 25	180-1920, 720	360-420, 400
S4B2	WH			1200			9840	4440	1080	100	1110		20-30, 25	180-1920, 720	360-420, 400
P4B1	WH		1065	3025			2280	6000	300	180	1065		20-30, 25	180-1920, 720	360-420, 400
P4B2	WH	130	230	1680			2280	6360	480	60	1780		20-30, 25	180-1920, 720	360-420, 400
S5B1	WH		905			3090	2880	8160	360	120	1100		20-30, 25	180-1920, 720	360-420, 400
S5B2	WH	110	2000	190	1230	3550	2880	7560	350	130	1800		20-30, 25	180-1920, 720	360-420, 400
Max	WH	1090	2000	3025	6740	10305	18135	8160	1080	180	3255	3830	30	1920	420
Mode	WH	130	#N/A	1200	#N/A	0	11160	3480	420	130	1065	#N/A	25	720	400
Min	WH	110	0	190	0	0	2280	1170	300	35	785	1925	20	180	360
Mean		600	1000	1608	3370	5153	10208	4665	690	108	2020	2878	25	830	397
SD		283	577	818	1946	2975	4577	2018	225	42	713	550	2	290	10

Remark (xxx-xxxx, xxx) represent minimum, maximum, and average values from interview.

APPENDIX C

Simulation source code

Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
/********************************************************************************
/STROBOSCOPE Simulation Program by Mr Worawut Srisdom
/********************************************************************************
/Steel Box Girder Bridge Fabrication Process - CTP-WT (Current) Base R2 Combine Case1
/********************************************************************************

/Problem Decision Variables
VARIABLE    NumberofRawBT               91;       /Bottom part Raw Material               91
VARIABLE    NumberofRawTL               27;       /Left Top Flange part Raw Material      27
VARIABLE    NumberofRawTR               24;       /Right Top Flange part Raw Material     24
VARIABLE    NumberofRawWL               65;       /Left Web Flange part Raw Material      65
VARIABLE    NumberofRawWR               65;       /Right Web Flange part Raw Material     65
VARIABLE    NumberofRawDI               10;       /Diaphragm part Raw Material            10
VARIABLE    NumberofRawSL               10;       /Left Stiffener part Raw Material       13
VARIABLE    NumberofRawSR               10;       /Right Stiffener part Raw Material      13

VARIABLE    NumberofCTPStation           2;       /                                       2
VARIABLE    NumberofCTPMachine           1;       /machines per Cut Plate Station         1
VARIABLE    NumberofCTPWorker            2;       /persons per Cut Plate Machine

VARIABLE    NumberofTPStation            4;       /                                       4
VARIABLE    NumberofTPMachine            2;       /machines per Taper Station             1
VARIABLE    NumberofTPWorker             1;       /persons per Taper Machine

VARIABLE    NumberofDRStation            3;       /                                       3
VARIABLE    NumberofDRMachine            1;       /machines per Drill Station             1
VARIABLE    NumberofDRWorker             3;       /person per Drill Machine

VARIABLE    NumberofBJStation            3;       /                                       3
VARIABLE    NumberofBJMachine            2;       /machines per Butt Joint Station        2
VARIABLE    NumberofBJWorker             2;       /person per Butt Joint Machine

VARIABLE    NumberofATStation            8;       /                                       8
VARIABLE    NumberofATMachine            1;       /machines per Assembly T-Shape station  1
VARIABLE    NumberofATWorker             4;       /persons per Assembly T-Shape Machine

VARIABLE    NumberofWTStation            8;       /                                       8
VARIABLE    NumberofWTMachine            4;       /machines per Assembly T-Shape Station  4
VARIABLE    NumberofWTWorker             1;       /persons per Assembly T-Shape Machine

/Assembly Variables
VARIABLE    BT_perRMP                    3;       /Amount of Bottom Part per Raw Material
VARIABLE    MeanBTperGirder           4.65;       /Mean Bottom Part per Girder
VARIABLE    SDBTperGirder             0.67;       /SD Bottom Part per Girder

VARIABLE    TL_perRMP                    4;       /Amount of Left-Top Part per Raw Material
VARIABLE    MeanTLperGirder           3.50;       /Mean Left-Top Part per Girder
VARIABLE    SDTLperGirder             0.33;       /SD Left-Top Part per Girder

VARIABLE    TR_perRMP                    4;       /Amount of Right-Top Part per Raw Material
VARIABLE    MeanTRperGirder           3.50;       /Mean Right-Top Part per Girder
VARIABLE    SDTRperGirder             0.33;       /SD Right-Top Part per Girder

VARIABLE    WL_perRMP                    2;       /Amount of Left-Web Part per Raw Material
VARIABLE    MeanWLperGirder           3.20;       /Mean Left-Web Part per Girder
VARIABLE    SDWLperGirder             0.17;       /SD Left-Web Part per Girder

VARIABLE    WR_perRMP                    3;       /Amount of Right-Web Part per Raw Material
VARIABLE    MeanWRperGirder           3.20;       /Mean Right-Web Part per Girder
VARIABLE    SDWRperGirder             0.17;       /SD Right-Web Part per Girder

VARIABLE    DI_perRMP                    4;       /Amount of Diaphragm Part per Raw Material
```

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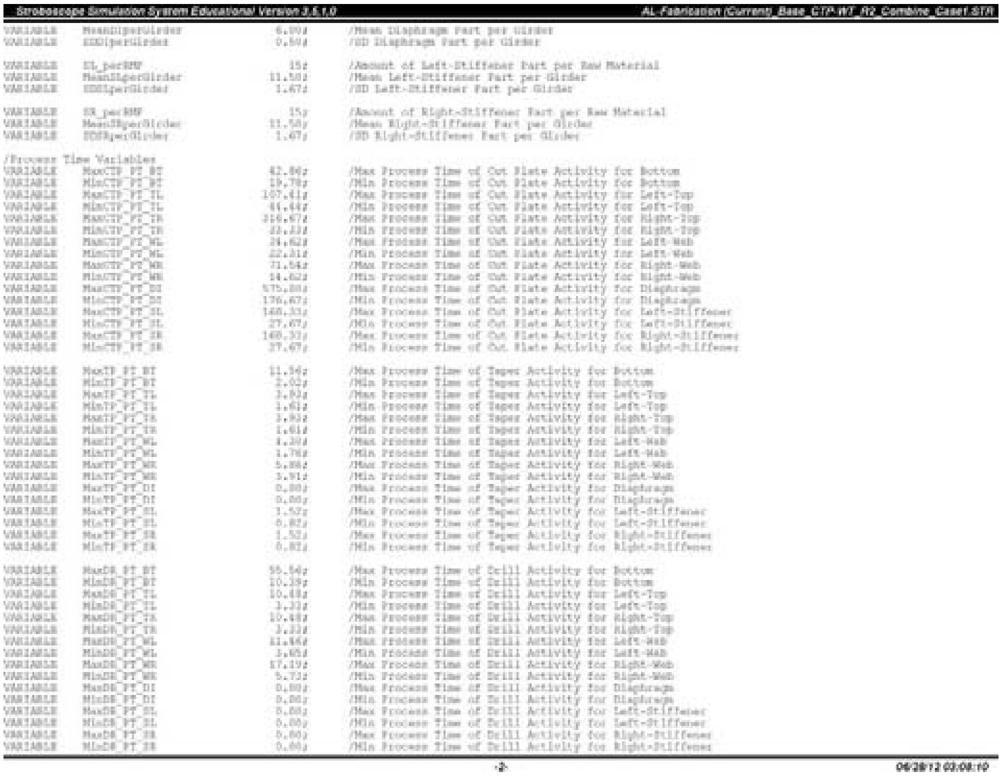
Figure C.1 Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
VARIABLE    MeanDIperGirder           6.00;       /Mean Diaphragm Part per Girder
VARIABLE    SDDIperGirder             0.50;       /SD Diaphragm Part per Girder

VARIABLE    SL_perRMP                   15;       /Amount of Left-Stiffener Part per Raw Material
VARIABLE    MeanSLperGirder          11.50;       /Mean Left-Stiffener Part per Girder
VARIABLE    SDSLperGirder             1.67;       /SD Left-Stiffener Part per Girder

VARIABLE    SR_perRMP                   15;       /Amount of Right-Stiffener Part per Raw Material
VARIABLE    MeanSRperGirder          11.50;       /Mean Right-Stiffener Part per Girder
VARIABLE    SDSRperGirder             1.67;       /SD Right-Stiffener Part per Girder

/Process Time Variables
VARIABLE    MaxCTP_PT_BT             42.86;       /Max Process Time of Cut Plate Activity for Bottom
VARIABLE    MinCTP_PT_BT             19.78;       /Min Process Time of Cut Plate Activity for Bottom
VARIABLE    MaxCTP_PT_TL            107.41;       /Max Process Time of Cut Plate Activity for Left-Top
VARIABLE    MinCTP_PT_TL             44.44;       /Min Process Time of Cut Plate Activity for Left-Top
VARIABLE    MaxCTP_PT_TR            116.67;       /Max Process Time of Cut Plate Activity for Right-Top
VARIABLE    MinCTP_PT_TR             33.33;       /Min Process Time of Cut Plate Activity for Right-Top
VARIABLE    MaxCTP_PT_WL             24.62;       /Max Process Time of Cut Plate Activity for Left-Web
VARIABLE    MinCTP_PT_WL             22.31;       /Min Process Time of Cut Plate Activity for Left-Web
VARIABLE    MaxCTP_PT_WR             71.54;       /Max Process Time of Cut Plate Activity for Right-Web
VARIABLE    MinCTP_PT_WR             14.62;       /Min Process Time of Cut Plate Activity for Right-Web
VARIABLE    MaxCTP_PT_DI            575.00;       /Max Process Time of Cut Plate Activity for Diaphragm
VARIABLE    MinCTP_PT_DI            176.67;       /Min Process Time of Cut Plate Activity for Diaphragm
VARIABLE    MaxCTP_PT_SL            168.33;       /Max Process Time of Cut Plate Activity for Left-Stiffener
VARIABLE    MinCTP_PT_SL             27.67;       /Min Process Time of Cut Plate Activity for Left-Stiffener
VARIABLE    MaxCTP_PT_SR            168.33;       /Max Process Time of Cut Plate Activity for Right-Stiffener
VARIABLE    MinCTP_PT_SR             27.67;       /Min Process Time of Cut Plate Activity for Right-Stiffener

VARIABLE    MaxTP_PT_BT              11.56;       /Max Process Time of Taper Activity for Bottom
VARIABLE    MinTP_PT_BT               2.02;       /Min Process Time of Taper Activity for Bottom
VARIABLE    MaxTP_PT_TL               3.83;       /Max Process Time of Taper Activity for Left-Top
VARIABLE    MinTP_PT_TL               1.61;       /Min Process Time of Taper Activity for Left-Top
VARIABLE    MaxTP_PT_TR               3.83;       /Max Process Time of Taper Activity for Right-Top
VARIABLE    MinTP_PT_TR               1.61;       /Min Process Time of Taper Activity for Right-Top
VARIABLE    MaxTP_PT_WL               4.30;       /Max Process Time of Taper Activity for Left-Web
VARIABLE    MinTP_PT_WL               1.76;       /Min Process Time of Taper Activity for Left-Web
VARIABLE    MaxTP_PT_WR               5.88;       /Max Process Time of Taper Activity for Right-Web
VARIABLE    MinTP_PT_WR               3.91;       /Min Process Time of Taper Activity for Right-Web
VARIABLE    MaxTP_PT_DI               0.00;       /Max Process Time of Taper Activity for Diaphragm
VARIABLE    MinTP_PT_DI               0.00;       /Min Process Time of Taper Activity for Diaphragm
VARIABLE    MaxTP_PT_SL               1.52;       /Max Process Time of Taper Activity for Left-Stiffener
VARIABLE    MinTP_PT_SL               0.82;       /Min Process Time of Taper Activity for Left-Stiffener
VARIABLE    MaxTP_PT_SR               1.52;       /Max Process Time of Taper Activity for Right-Stiffener
VARIABLE    MinTP_PT_SR               0.82;       /Min Process Time of Taper Activity for Right-Stiffener

VARIABLE    MaxDR_PT_BT              55.56;       /Max Process Time of Drill Activity for Bottom
VARIABLE    MinDR_PT_BT              10.39;       /Min Process Time of Drill Activity for Bottom
VARIABLE    MaxDR_PT_TL              10.48;       /Max Process Time of Drill Activity for Left-Top
VARIABLE    MinDR_PT_TL               3.33;       /Min Process Time of Drill Activity for Left-Top
VARIABLE    MaxDR_PT_TR              10.48;       /Max Process Time of Drill Activity for Right-Top
VARIABLE    MinDR_PT_TR               3.33;       /Min Process Time of Drill Activity for Right-Top
VARIABLE    MaxDR_PT_WL              11.46;       /Max Process Time of Drill Activity for Left-Web
VARIABLE    MinDR_PT_WL               3.65;       /Min Process Time of Drill Activity for Left-Web
VARIABLE    MaxDR_PT_WR              17.19;       /Max Process Time of Drill Activity for Right-Web
VARIABLE    MinDR_PT_WR               5.73;       /Min Process Time of Drill Activity for Right-Web
VARIABLE    MaxDR_PT_DI               0.00;       /Max Process Time of Drill Activity for Diaphragm
VARIABLE    MinDR_PT_DI               0.00;       /Min Process Time of Drill Activity for Diaphragm
VARIABLE    MaxDR_PT_SL               0.00;       /Max Process Time of Drill Activity for Left-Stiffener
VARIABLE    MinDR_PT_SL               0.00;       /Min Process Time of Drill Activity for Left-Stiffener
VARIABLE    MaxDR_PT_SR               0.00;       /Max Process Time of Drill Activity for Right-Stiffener
VARIABLE    MinDR_PT_SR               0.00;       /Min Process Time of Drill Activity for Right-Stiffener
```

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Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)

Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
VARIABLE    MaxBJ_PT_BT              971.67;     /Max Process Time of Butt Joint Activity for Bottom
VARIABLE    MinBJ_PT_BT               72.50;     /Min Process Time of Butt Joint Activity for Bottom
VARIABLE    MaxBJ_PT_TL              513.33;     /Max Process Time of Butt Joint Activity for Left-Top
VARIABLE    MinBJ_PT_TL               47.50;     /Min Process Time of Butt Joint Activity for Left-Top
VARIABLE    MaxBJ_PT_TR              358.33;     /Max Process Time of Butt Joint Activity for Right-Top
VARIABLE    MinBJ_PT_TR               46.67;     /Min Process Time of Butt Joint Activity for Right-Top
VARIABLE    MaxBJ_PT_WL              360.83;     /Max Process Time of Butt Joint Activity for Left-Web
VARIABLE    MinBJ_PT_WL               24.17;     /Min Process Time of Butt Joint Activity for Left-Web
VARIABLE    MaxBJ_PT_WR              340.00;     /Max Process Time of Butt Joint Activity for Right-Web
VARIABLE    MinBJ_PT_WR               13.33;     /Min Process Time of Butt Joint Activity for Right-Web
VARIABLE    MaxBJ_PT_DI                0.00;     /Max Process Time of Butt Joint Activity for Diaphragm
VARIABLE    MinBJ_PT_DI                0.00;     /Min Process Time of Butt Joint Activity for Diaphragm
VARIABLE    MaxBJ_PT_SL                0.00;     /Max Process Time of Butt Joint Activity for Left-Stiffener
VARIABLE    MinBJ_PT_SL                0.00;     /Min Process Time of Butt Joint Activity for Left-Stiffener
VARIABLE    MaxBJ_PT_SR                0.00;     /Max Process Time of Butt Joint Activity for Right-Stiffener
VARIABLE    MinBJ_PT_SR                0.00;     /Mode Process Time of Butt Joint Activity for Right-Stiffener

VARIABLE    MaxAT_PT_BT                0.00;     /Max Process Time of Assembly T-Shape Activity for Bottom
VARIABLE    MinAT_PT_BT                0.00;     /Min Process Time of Assembly T-Shape Activity for Bottom
VARIABLE    MaxAT_PT_TL              171.25;     /Max Process Time of Assembly T-Shape Activity for Left-Top
VARIABLE    MinAT_PT_TL               25.00;     /Min Process Time of Assembly T-Shape Activity for Left-Top
VARIABLE    MaxAT_PT_TR              137.50;     /Max Process Time of Assembly T-Shape Activity for Right-Top
VARIABLE    MinAT_PT_TR                9.38;     /Min Process Time of Assembly T-Shape Activity for Right-Top
VARIABLE    MaxAT_PT_WL              171.25;     /Max Process Time of Assembly T-Shape Activity for Left-Web
VARIABLE    MinAT_PT_WL               25.00;     /Min Process Time of Assembly T-Shape Activity for Left-Web
VARIABLE    MaxAT_PT_WR               49.38;     /Max Process Time of Assembly T-Shape Activity for Right-Web
VARIABLE    MinAT_PT_WR                9.38;     /Min Process Time of Assembly T-Shape Activity for Right-Web
VARIABLE    MaxAT_PT_DI               16.67;     /Max Process Time of Assembly T-Shape Activity for Diaphragm
VARIABLE    MinAT_PT_DI               16.67;     /Min Process Time of Assembly T-Shape Activity for Diaphragm
VARIABLE    MaxAT_PT_SL              585.00;     /Max Process Time of Assembly T-Shape Activity for Left-Stiffener
VARIABLE    MinAT_PT_SL               90.00;     /Min Process Time of Assembly T-Shape Activity for Left-Stiffener
VARIABLE    MaxAT_PT_SR              620.00;     /Max Process Time of Assembly T-Shape Activity for Right-Stiffener
VARIABLE    MinAT_PT_SR              203.33;     /Min Process Time of Assembly T-Shape Activity for Right-Stiffener

VARIABLE    MaxWT_PT_BT                0.00;     /Max Process Time of Weld T-Shape Activity for Bottom
VARIABLE    MinWT_PT_BT                0.00;     /Min Process Time of Weld T-Shape Activity for Bottom
VARIABLE    MaxWT_PT_TL               80.47;     /Max Process Time of Weld T-Shape Activity for Left-Top
VARIABLE    MinWT_PT_TL                2.89;     /Min Process Time of Weld T-Shape Activity for Left-Top
VARIABLE    MaxWT_PT_TR               76.58;     /Max Process Time of Weld T-Shape Activity for Right-Top
VARIABLE    MinWT_PT_TR                3.52;     /Min Process Time of Weld T-Shape Activity for Right-Top
VARIABLE    MaxWT_PT_WL               80.47;     /Max Process Time of Weld T-Shape Activity for Left-Web
VARIABLE    MinWT_PT_WL                2.89;     /Min Process Time of Weld T-Shape Activity for Left-Web
VARIABLE    MaxWT_PT_WR               76.58;     /Max Process Time of Weld T-Shape Activity for Right-Web
VARIABLE    MinWT_PT_WR                3.52;     /Min Process Time of Weld T-Shape Activity for Right-Web
VARIABLE    MaxWT_PT_DI              480.00;     /Max Process Time of Weld T-Shape Activity for Diaphragm
VARIABLE    MinWT_PT_DI              480.00;     /Min Process Time of Weld T-Shape Activity for Diaphragm
VARIABLE    MaxWT_PT_SL              240.00;     /Max Process Time of Weld T-Shape Activity for Left-Stiffener
VARIABLE    MinWT_PT_SL               38.33;     /Min Process Time of Weld T-Shape Activity for Left-Stiffener
VARIABLE    MaxWT_PT_SR              140.00;     /Max Process Time of Weld T-Shape Activity for Right-Stiffener
VARIABLE    ModeWT_PT_SR             100.00;     /Mode Process Time of Weld T-Shape Activity for Right-Stiffener
VARIABLE    MinWT_PT_SR               80.00;     /Min Process Time of Weld T-Shape Activity for Right-Stiffener

/Working Time Variables
VARIABLE    MeanWorkingTime          684.00;     /Mean Working Time per Day in Minutes
VARIABLE    SDWorkingTime             84.00;     /SD Working Time per Day in Minutes

/Amount of Gliders
VARIABLE    NumberofGlider               20;     /Total Glider Production

/*****************************************************************************
```

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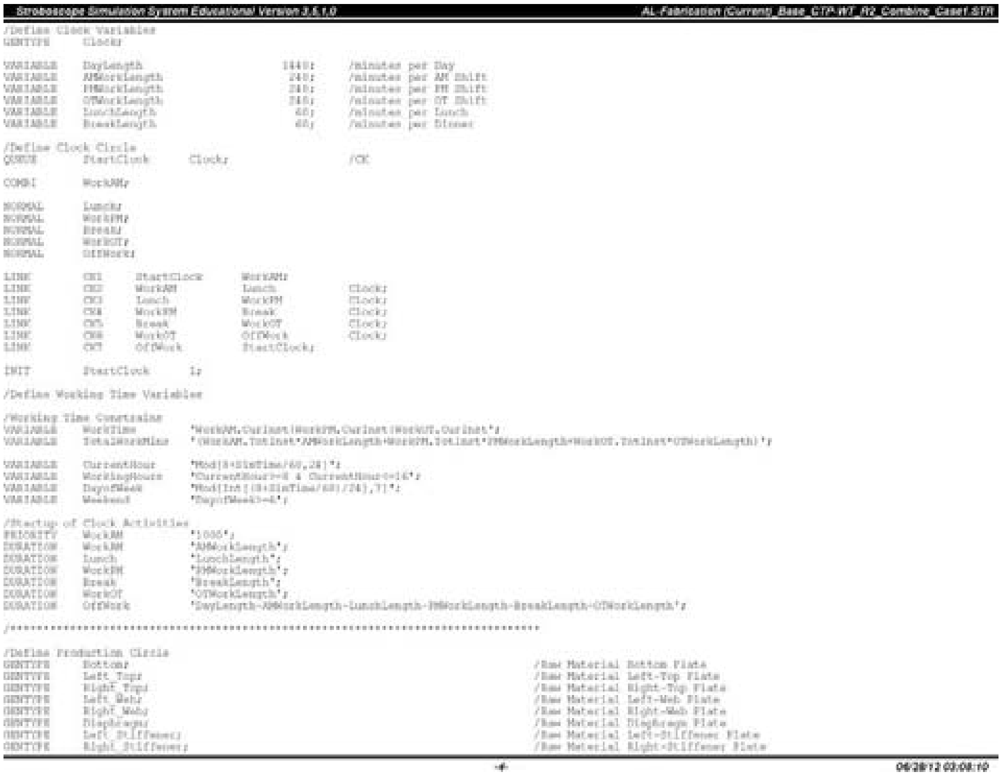
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
/Define Clock Variables
GENTYPE     Clock;

VARIABLE    DayLength                       1440;     /minutes per Day
VARIABLE    AMWorkLength                     240;     /minutes per AM Shift
VARIABLE    PMWorkLength                     240;     /minutes per PM Shift
VARIABLE    OTWorkLength                     240;     /minutes per OT Shift
VARIABLE    LunchLength                       60;     /minutes per Lunch
VARIABLE    BreakLength                       60;     /minutes per Dinner

/Define Clock Circle
QUEUE       StartClock      Clock;                   /CK

COMBI       WorkAM;

NORMAL      Lunch;
NORMAL      WorkPM;
NORMAL      Break;
NORMAL      WorkOT;
NORMAL      OffWork;

LINE        CK1    StartClock      WorkAM;
LINE        CK2    WorkAM          Lunch           Clock;
LINE        CK3    Lunch           WorkPM          Clock;
LINE        CK4    WorkPM          Break           Clock;
LINE        CK5    Break           WorkOT          Clock;
LINE        CK6    WorkOT          OffWork         Clock;
LINE        CK7    OffWork         StartClock;

INIT        StartClock      1;

/Define Working Time Variables

/Working Time Constrains
VARIABLE    WorkTime        'WorkAM.CurInst|WorkPM.CurInst|WorkOT.CurInst';
VARIABLE    TotalWorkMins   '(WorkAM.TotInst*AMWorkLength+WorkPM.TotInst*PMWorkLength+WorkOT.TotInst*OTWorkLength)';

VARIABLE    CurrentHour     'Mod(8+SimTime/60,24)';
VARIABLE    WorkingHours    'CurrentHour>=8 & CurrentHour<=16';
VARIABLE    DayofWeek       'Mod(Int((8+SimTime/60)/24),7)';
VARIABLE    Weekend         'DayofWeek>=6';

/Startup of Clock Activities
PRIORITY    WorkAM          '1000';
DURATION    WorkAM          'AMWorkLength';
DURATION    Lunch           'LunchLength';
DURATION    WorkPM          'PMWorkLength';
DURATION    Break           'BreakLength';
DURATION    WorkOT          'OTWorkLength';
DURATION    OffWork         'DayLength-AMWorkLength-LunchLength-PMWorkLength-BreakLength-OTWorkLength';

/*****************************************************************************

/Define Production Circle
GENTYPE     Bottom;                                                     /Raw Material Bottom Plate
GENTYPE     Left_Top;                                                   /Raw Material Left-Top Plate
GENTYPE     Right_Top;                                                  /Raw Material Right-Top Plate
GENTYPE     Left_Web;                                                   /Raw Material Left-Web Plate
GENTYPE     Right_Web;                                                  /Raw Material Right-Web Plate
GENTYPE     Diaphragm;                                                  /Raw Material Diaphragm Plate
GENTYPE     Left_Stiffener;                                             /Raw Material Left-Stiffener Plate
GENTYPE     Right_Stiffener;                                            /Raw Material Right-Stiffener Plate
```

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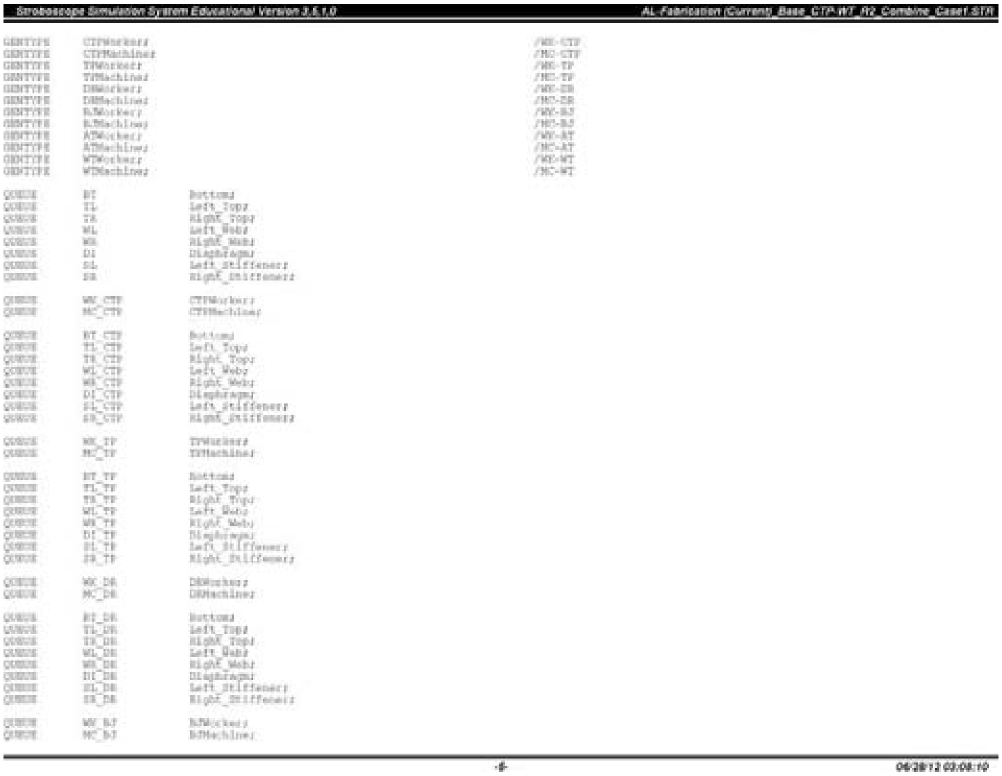
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0   AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
GENTYPE     CTPWorker;                                             /WK-CTP
GENTYPE     CTPMachine;                                            /MC-CTP
GENTYPE     TPWorker;                                              /WK-TP
GENTYPE     TPMachine;                                             /MC-TP
GENTYPE     DRWorker;                                              /WK-DR
GENTYPE     DRMachine;                                             /MC-DR
GENTYPE     BJWorker;                                              /WK-BJ
GENTYPE     BJMachine;                                             /MC-BJ
GENTYPE     ATWorker;                                              /WK-AT
GENTYPE     ATMachine;                                             /MC-AT
GENTYPE     WTWorker;                                              /WK-WT
GENTYPE     WTMachine;                                             /MC-WT

QUEUE       BT              Bottom;
QUEUE       TL              Left_Top;
QUEUE       TR              Right_Top;
QUEUE       WL              Left_Web;
QUEUE       WR              Right_Web;
QUEUE       DI              Diaphragm;
QUEUE       SL              Left_Stiffener;
QUEUE       SR              Right_Stiffener;

QUEUE       WK_CTP          CTPWorker;
QUEUE       MC_CTP          CTPMachine;

QUEUE       BT_CTP          Bottom;
QUEUE       TL_CTP          Left_Top;
QUEUE       TR_CTP          Right_Top;
QUEUE       WL_CTP          Left_Web;
QUEUE       WR_CTP          Right_Web;
QUEUE       DI_CTP          Diaphragm;
QUEUE       SL_CTP          Left_Stiffener;
QUEUE       SR_CTP          Right_Stiffener;

QUEUE       WK_TP           TPWorker;
QUEUE       MC_TP           TPMachine;

QUEUE       BT_TP           Bottom;
QUEUE       TL_TP           Left_Top;
QUEUE       TR_TP           Right_Top;
QUEUE       WL_TP           Left_Web;
QUEUE       WR_TP           Right_Web;
QUEUE       DI_TP           Diaphragm;
QUEUE       SL_TP           Left_Stiffener;
QUEUE       SR_TP           Right_Stiffener;

QUEUE       WK_DR           DRWorker;
QUEUE       MC_DR           DRMachine;

QUEUE       BT_DR           Bottom;
QUEUE       TL_DR           Left_Top;
QUEUE       TR_DR           Right_Top;
QUEUE       WL_DR           Left_Web;
QUEUE       WR_DR           Right_Web;
QUEUE       DI_DR           Diaphragm;
QUEUE       SL_DR           Left_Stiffener;
QUEUE       SR_DR           Right_Stiffener;

QUEUE       WK_BJ           BJWorker;
QUEUE       MC_BJ           BJMachine;
```

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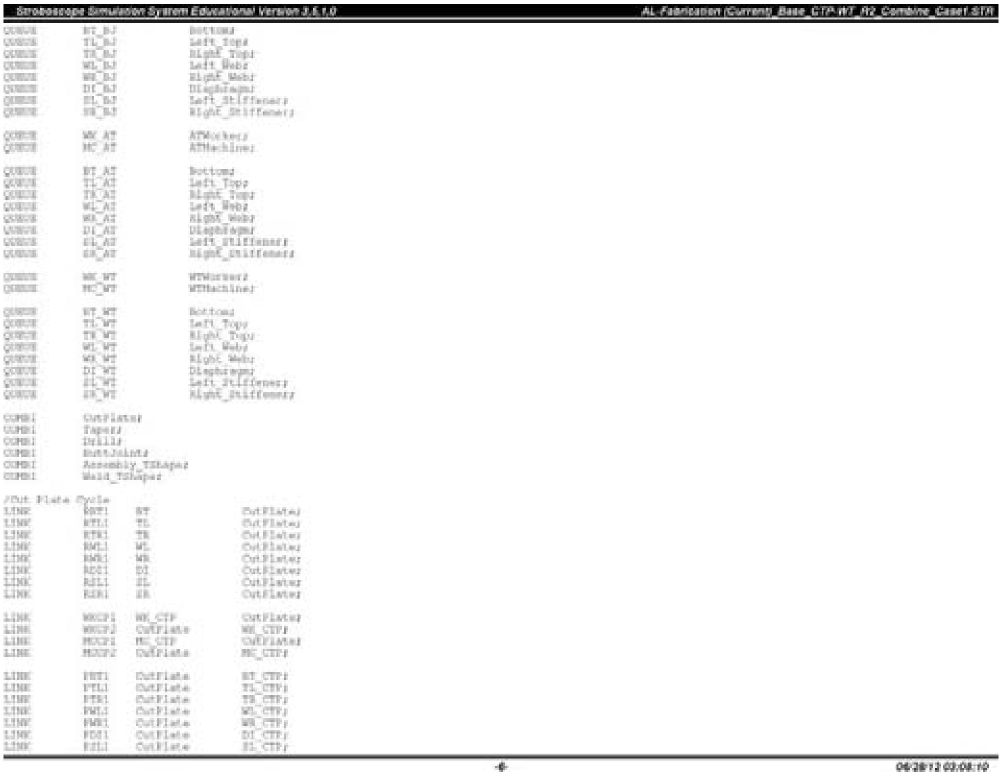
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0   AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
QUEUE       BT_BJ           Bottom;
QUEUE       TL_BJ           Left_Top;
QUEUE       TR_BJ           Right_Top;
QUEUE       WL_BJ           Left_Web;
QUEUE       WR_BJ           Right_Web;
QUEUE       DI_BJ           Diaphragm;
QUEUE       SL_BJ           Left_Stiffener;
QUEUE       SR_BJ           Right_Stiffener;

QUEUE       WK_AT           ATWorker;
QUEUE       MC_AT           ATMachine;

QUEUE       BT_AT           Bottom;
QUEUE       TL_AT           Left_Top;
QUEUE       TR_AT           Right_Top;
QUEUE       WL_AT           Left_Web;
QUEUE       WR_AT           Right_Web;
QUEUE       DI_AT           Diaphragm;
QUEUE       SL_AT           Left_Stiffener;
QUEUE       SR_AT           Right_Stiffener;

QUEUE       WK_WT           WTWorker;
QUEUE       MC_WT           WTMachine;

QUEUE       BT_WT           Bottom;
QUEUE       TL_WT           Left_Top;
QUEUE       TR_WT           Right_Top;
QUEUE       WL_WT           Left_Web;
QUEUE       WR_WT           Right_Web;
QUEUE       DI_WT           Diaphragm;
QUEUE       SL_WT           Left_Stiffener;
QUEUE       SR_WT           Right_Stiffener;

COMBI       CutPlate;
COMBI       Taper;
COMBI       Drill;
COMBI       ButtJoint;
COMBI       Assembly_TShape;
COMBI       Weld_TShape;

/Cut Plate Cycle
LINK        RBT1    BT              CutPlate;
LINK        RTL1    TL              CutPlate;
LINK        RTR1    TR              CutPlate;
LINK        RWL1    WL              CutPlate;
LINK        RWR1    WR              CutPlate;
LINK        RDI1    DI              CutPlate;
LINK        RSL1    SL              CutPlate;
LINK        RSR1    SR              CutPlate;

LINK        WKCP1   WK_CTP          CutPlate;
LINK        WKCP2   CutPlate        WK_CTP;
LINK        MCCP1   MC_CTP          CutPlate;
LINK        MCCP2   CutPlate        MC_CTP;

LINK        FBT1    CutPlate        BT_CTP;
LINK        FTL1    CutPlate        TL_CTP;
LINK        FTR1    CutPlate        TR_CTP;
LINK        FWL1    CutPlate        WL_CTP;
LINK        FWR1    CutPlate        WR_CTP;
LINK        FDI1    CutPlate        DI_CTP;
LINK        FSL1    CutPlate        SL_CTP;
```

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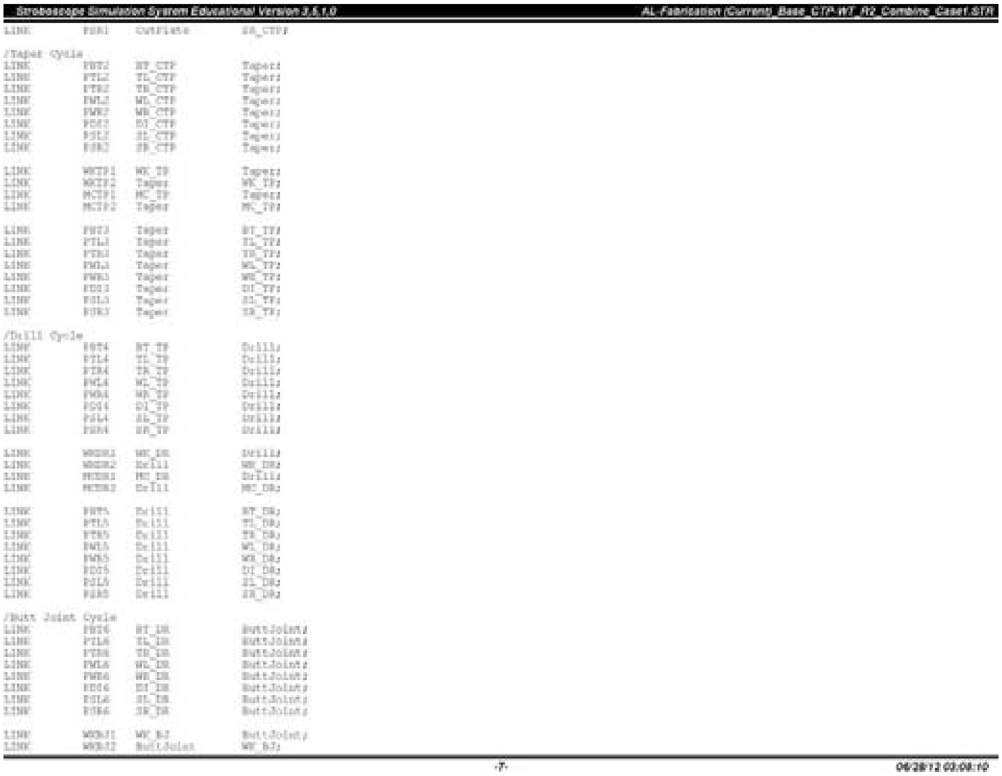
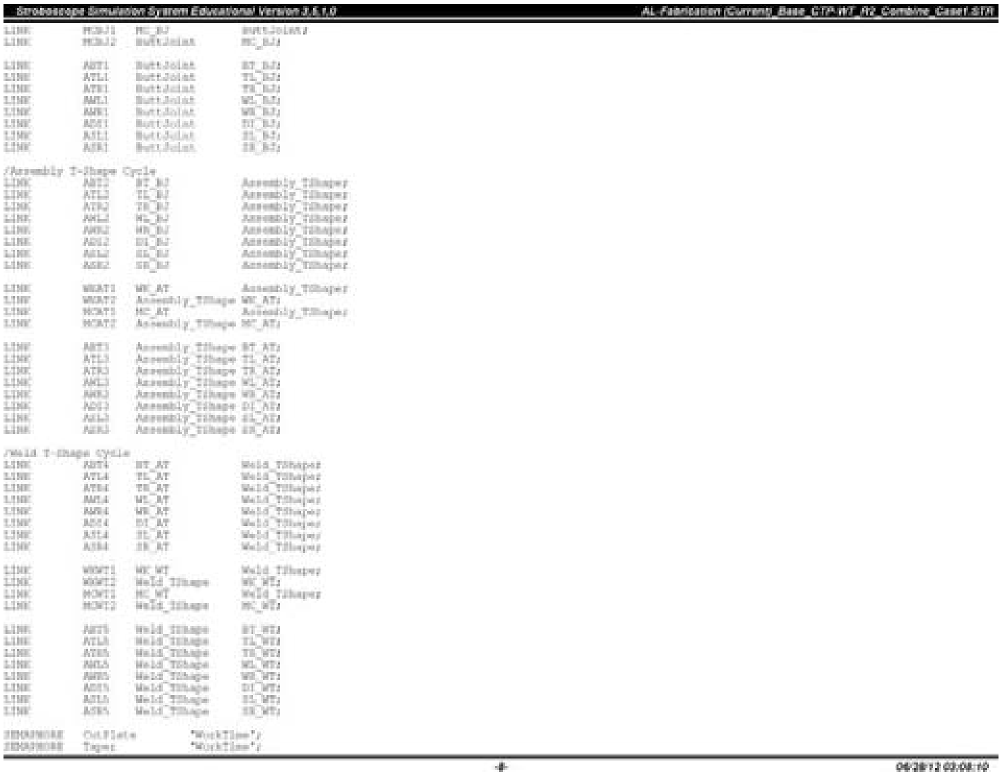
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



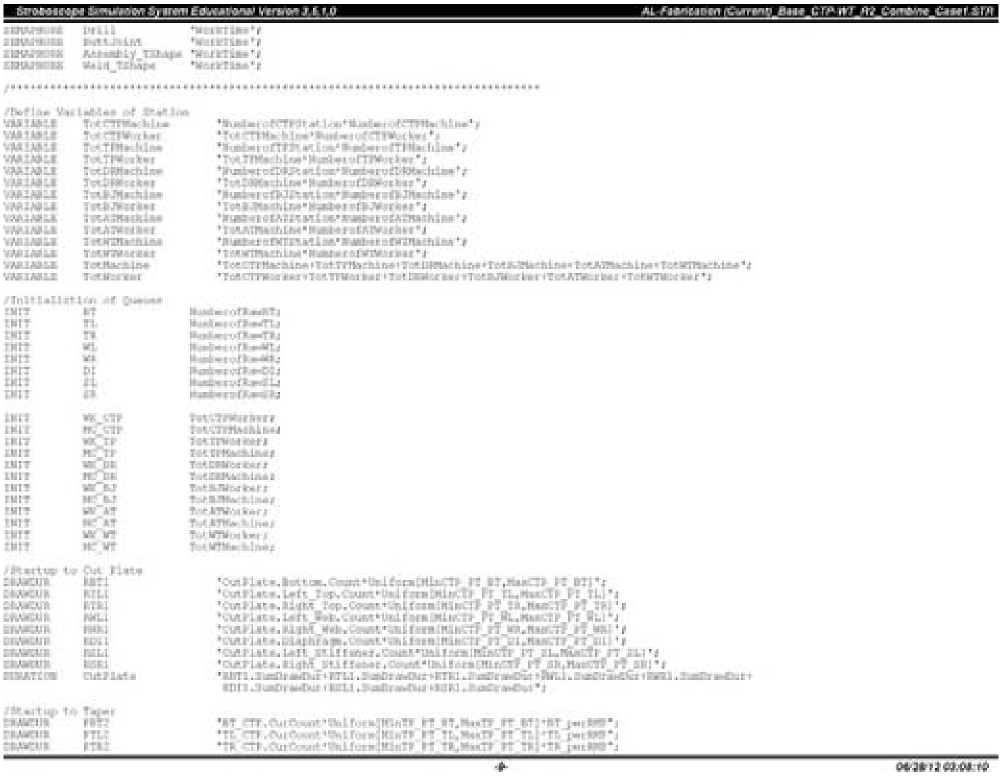
```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR
LINK          FSR1    CutPlate        SR_CTP;

/Taper Cycle
LINK          FBT2    BT_CTP          Taper;
LINK          FTL2    TL_CTP          Taper;
LINK          FTR2    TR_CTP          Taper;
LINK          FWL2    WL_CTP          Taper;
LINK          FWR2    WR_CTP          Taper;
LINK          FDI2    DI_CTP          Taper;
LINK          FSL2    SL_CTP          Taper;
LINK          FSR2    SR_CTP          Taper;

LINK          WKTP1   WK_TP           Taper;
LINK          WKTP2   Taper           WK_TP;
LINK          MCTP1   MC_TP           Taper;
LINK          MCTP2   Taper           MC_TP;

LINK          FBT3    Taper           BT_TP;
LINK          FTL3    Taper           TL_TP;
LINK          FTR3    Taper           TR_TP;
LINK          FWL3    Taper           WL_TP;
LINK          FWR3    Taper           WR_TP;
LINK          FDI3    Taper           DI_TP;
LINK          FSL3    Taper           SL_TP;
LINK          FSR3    Taper           SR_TP;

/Drill Cycle
LINK          FBT4    BT_TP           Drill;
LINK          FTL4    TL_TP           Drill;
LINK          FTR4    TR_TP           Drill;
LINK          FWL4    WL_TP           Drill;
LINK          FWR4    WR_TP           Drill;
LINK          FDI4    DI_TP           Drill;
LINK          FSL4    SL_TP           Drill;
LINK          FSR4    SR_TP           Drill;

LINK          WKDR1   WK_DR           Drill;
LINK          WKDR2   Drill           WK_DR;
LINK          MCDR1   MC_DR           Drill;
LINK          MCDR2   Drill           MC_DR;

LINK          FBT5    Drill           BT_DR;
LINK          FTL5    Drill           TL_DR;
LINK          FTR5    Drill           TR_DR;
LINK          FWL5    Drill           WL_DR;
LINK          FWR5    Drill           WR_DR;
LINK          FDI5    Drill           DI_DR;
LINK          FSL5    Drill           SL_DR;
LINK          FSR5    Drill           SR_DR;

/Butt Joint Cycle
LINK          FBT6    BT_DR           ButtJoint;
LINK          FTL6    TL_DR           ButtJoint;
LINK          FTR6    TR_DR           ButtJoint;
LINK          FWL6    WL_DR           ButtJoint;
LINK          FWR6    WR_DR           ButtJoint;
LINK          FDI6    DI_DR           ButtJoint;
LINK          FSL6    SL_DR           ButtJoint;
LINK          FSR6    SR_DR           ButtJoint;

LINK          WKBJ1   WK_BJ           ButtJoint;
LINK          WKBJ2   ButtJoint       WK_BJ;
                                       -7-                                   06/28/12 03:08:10
```

Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



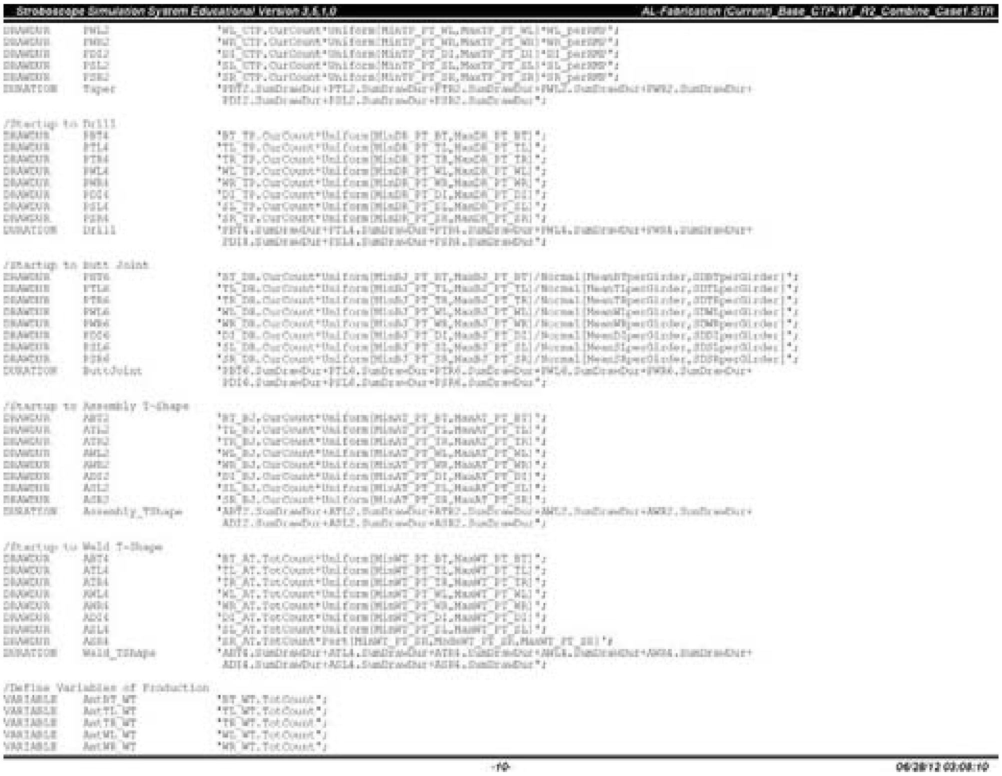
```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR
LINK          MCBJ1   MC_BJ           ButtJoint;
LINK          MCBJ2   ButtJoint       MC_BJ;

LINK          ABT1    ButtJoint       BT_BJ;
LINK          ATL1    ButtJoint       TL_BJ;
LINK          ATR1    ButtJoint       TR_BJ;
LINK          AWL1    ButtJoint       WL_BJ;
LINK          AWR1    ButtJoint       WR_BJ;
LINK          ADI1    ButtJoint       DI_BJ;
LINK          ASL1    ButtJoint       SL_BJ;
LINK          ASR1    ButtJoint       SR_BJ;

/Assembly T-Shape Cycle
LINK          ABT2    BT_BJ           Assembly_TShape;
LINK          ATL2    TL_BJ           Assembly_TShape;
LINK          ATR2    TR_BJ           Assembly_TShape;
LINK          AWL2    WL_BJ           Assembly_TShape;
LINK          AWR2    WR_BJ           Assembly_TShape;
LINK          ADI2    DI_BJ           Assembly_TShape;
LINK          ASL2    SL_BJ           Assembly_TShape;
LINK          ASR2    SR_BJ           Assembly_TShape;

LINK          WKAT1   WK_AT           Assembly_TShape;
LINK          WKAT2   Assembly_TShape WK_AT;
LINK          MCAT1   MC_AT           Assembly_TShape;
LINK          MCAT2   Assembly_TShape MC_AT;

LINK          ABT3    Assembly_TShape BT_AT;
LINK          ATL3    Assembly_TShape TL_AT;
LINK          ATR3    Assembly_TShape TR_AT;
LINK          AWL3    Assembly_TShape WL_AT;
LINK          AWR3    Assembly_TShape WR_AT;
LINK          ADI3    Assembly_TShape DI_AT;
LINK          ASL3    Assembly_TShape SL_AT;
LINK          ASR3    Assembly_TShape SR_AT;

/Weld T-Shape Cycle
LINK          ABT4    BT_AT           Weld_TShape;
LINK          ATL4    TL_AT           Weld_TShape;
LINK          ATR4    TR_AT           Weld_TShape;
LINK          AWL4    WL_AT           Weld_TShape;
LINK          AWR4    WR_AT           Weld_TShape;
LINK          ADI4    DI_AT           Weld_TShape;
LINK          ASL4    SL_AT           Weld_TShape;
LINK          ASR4    SR_AT           Weld_TShape;

LINK          WKWT1   WK_WT           Weld_TShape;
LINK          WKWT2   Weld_TShape     WK_WT;
LINK          MCWT1   MC_WT           Weld_TShape;
LINK          MCWT2   Weld_TShape     MC_WT;

LINK          ABT5    Weld_TShape     BT_WT;
LINK          ATL5    Weld_TShape     TL_WT;
LINK          ATR5    Weld_TShape     TR_WT;
LINK          AWL5    Weld_TShape     WL_WT;
LINK          AWR5    Weld_TShape     WR_WT;
LINK          ADI5    Weld_TShape     DI_WT;
LINK          ASL5    Weld_TShape     SL_WT;
LINK          ASR5    Weld_TShape     SR_WT;

SEMAPHORE     CutPlate        'WorkTime';
SEMAPHORE     Taper           'WorkTime';
                                       -8-                                   06/28/12 03:08:10
```

Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



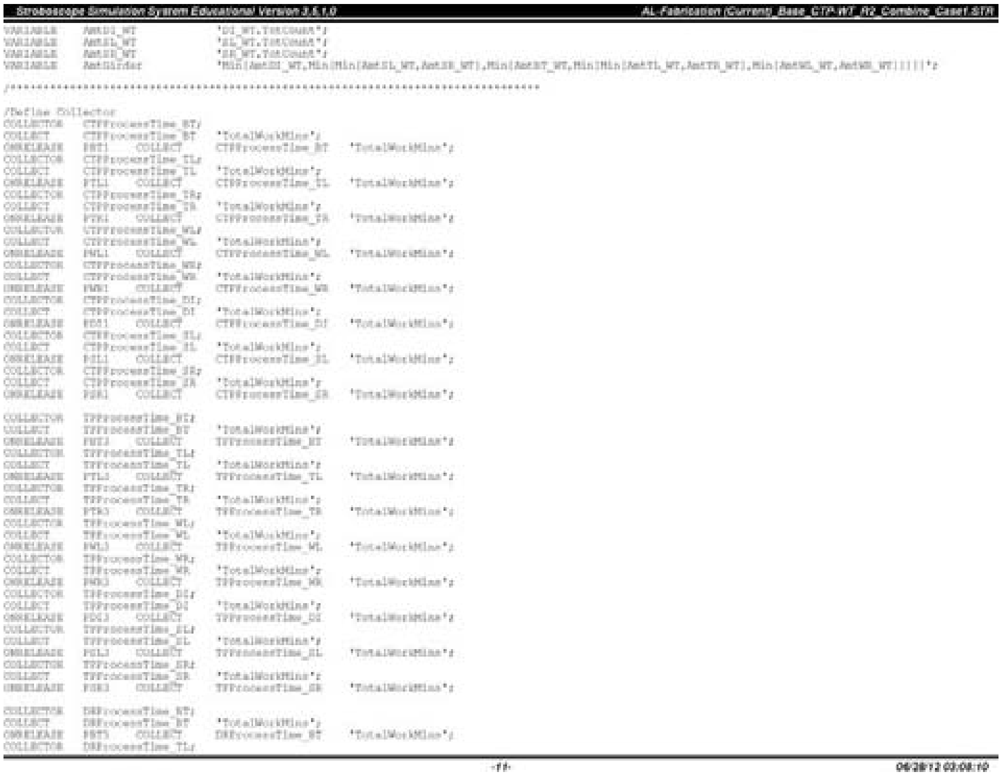
```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR
SEMAPHORE   Drill           'WorkTime';
SEMAPHORE   ButtJoint       'WorkTime';
SEMAPHORE   Assembly_TShape 'WorkTime';
SEMAPHORE   Weld_TShape     'WorkTime';

/*******************************************************************************

/Define Variables of Station
VARIABLE    TotCTPMachine       'NumberofCTPStation*NumberofCTPMachine';
VARIABLE    TotCTPWorker        'TotCTPMachine*NumberofCTPWorker';
VARIABLE    TotTPMachine        'NumberofTPStation*NumberofTPMachine';
VARIABLE    TotTPWorker         'TotTPMachine*NumberofTPWorker';
VARIABLE    TotDRMachine        'NumberofDRStation*NumberofDRMachine';
VARIABLE    TotDRWorker         'TotDRMachine*NumberofDRWorker';
VARIABLE    TotBJMachine        'NumberofBJStation*NumberofBJMachine';
VARIABLE    TotBJWorker         'TotBJMachine*NumberofBJWorker';
VARIABLE    TotATMachine        'NumberofATStation*NumberofATMachine';
VARIABLE    TotATWorker         'TotATMachine*NumberofATWorker';
VARIABLE    TotWTMachine        'NumberofWTStation*NumberofWTMachine';
VARIABLE    TotWTWorker         'TotWTMachine*NumberofWTWorker';
VARIABLE    TotMachine          'TotCTPMachine+TotTPMachine+TotDRMachine+TotBJMachine+TotATMachine+TotWTMachine';
VARIABLE    TotWorker           'TotCTPWorker+TotTPWorker+TotDRWorker+TotBJWorker+TotATWorker+TotWTWorker';

/Initializtion of Queues
INIT        BT              NumberofRawBT;
INIT        TL              NumberofRawTL;
INIT        TR              NumberofRawTR;
INIT        WL              NumberofRawWL;
INIT        WR              NumberofRawWR;
INIT        DI              NumberofRawDI;
INIT        SL              NumberofRawSL;
INIT        SR              NumberofRawSR;

INIT        WK_CTP          TotCTPWorker;
INIT        MC_CTP          TotCTPMachine;
INIT        WK_TP           TotTPWorker;
INIT        MC_TP           TotTPMachine;
INIT        WK_DR           TotDRWorker;
INIT        MC_DR           TotDRMachine;
INIT        WK_BJ           TotBJWorker;
INIT        MC_BJ           TotBJMachine;
INIT        WK_AT           TotATWorker;
INIT        MC_AT           TotATMachine;
INIT        WK_WT           TotWTWorker;
INIT        MC_WT           TotWTMachine;

/Startup to Cut Plate
DRAWDUR     RBT1                'CutPlate.Bottom.Count*Uniform[MinCTP_PT_BT,MaxCTP_PT_BT]';
DRAWDUR     RTL1                'CutPlate.Left_Top.Count*Uniform[MinCTP_PT_TL,MaxCTP_PT_TL]';
DRAWDUR     RTR1                'CutPlate.Right_Top.Count*Uniform[MinCTP_PT_TR,MaxCTP_PT_TR]';
DRAWDUR     RWL1                'CutPlate.Left_Web.Count*Uniform[MinCTP_PT_WL,MaxCTP_PT_WL]';
DRAWDUR     RWR1                'CutPlate.Right_Web.Count*Uniform[MinCTP_PT_WR,MaxCTP_PT_WR]';
DRAWDUR     RDI1                'CutPlate.Diaphragm.Count*Uniform[MinCTP_PT_DI,MaxCTP_PT_DI]';
DRAWDUR     RSL1                'CutPlate.Left_Stiffener.Count*Uniform[MinCTP_PT_SL,MaxCTP_PT_SL]';
DRAWDUR     RSR1                'CutPlate.Right_Stiffener.Count*Uniform[MinCTP_PT_SR,MaxCTP_PT_SR]';
DURATION    CutPlate            'RBT1.SumDrawDur+RTL1.SumDrawDur+RTR1.SumDrawDur+RWL1.SumDrawDur+RWR1.SumDrawDur+
                                 RDI1.SumDrawDur+RSL1.SumDrawDur+RSR1.SumDrawDur';

/Startup to Taper
DRAWDUR     FBT2                'BT_CTP.CurCount*Uniform[MinTP_PT_BT,MaxTP_PT_BT]*BT_perRMP';
DRAWDUR     FTL2                'TL_CTP.CurCount*Uniform[MinTP_PT_TL,MaxTP_PT_TL]*TL_perRMP';
DRAWDUR     FTR2                'TR_CTP.CurCount*Uniform[MinTP_PT_TR,MaxTP_PT_TR]*TR_perRMP';
                                          -9-                                                    06/28/12 03:08:10
```

Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR
DRAWDUR     FWL2                'WL_CTP.CurCount*Uniform[MinTP_PT_WL,MaxTP_PT_WL]*WL_perRMP';
DRAWDUR     FWR2                'WR_CTP.CurCount*Uniform[MinTP_PT_WR,MaxTP_PT_WR]*WR_perRMP';
DRAWDUR     FDI2                'DI_CTP.CurCount*Uniform[MinTP_PT_DI,MaxTP_PT_DI]*DI_perRMP';
DRAWDUR     FSL2                'SL_CTP.CurCount*Uniform[MinTP_PT_SL,MaxTP_PT_SL]*SL_perRMP';
DRAWDUR     FSR2                'SR_CTP.CurCount*Uniform[MinTP_PT_SR,MaxTP_PT_SR]*SR_perRMP';
DURATION    Taper               'FBT2.SumDrawDur+FTL2.SumDrawDur+FTR2.SumDrawDur+FWL2.SumDrawDur+FWR2.SumDrawDur+
                                 FDI2.SumDrawDur+FSL2.SumDrawDur+FSR2.SumDrawDur';

/Startup to Drill
DRAWDUR     FBT4                'BT_TP.CurCount*Uniform[MinDR_PT_BT,MaxDR_PT_BT]';
DRAWDUR     FTL4                'TL_TP.CurCount*Uniform[MinDR_PT_TL,MaxDR_PT_TL]';
DRAWDUR     FTR4                'TR_TP.CurCount*Uniform[MinDR_PT_TR,MaxDR_PT_TR]';
DRAWDUR     FWL4                'WL_TP.CurCount*Uniform[MinDR_PT_WL,MaxDR_PT_WL]';
DRAWDUR     FWR4                'WR_TP.CurCount*Uniform[MinDR_PT_WR,MaxDR_PT_WR]';
DRAWDUR     FDI4                'DI_TP.CurCount*Uniform[MinDR_PT_DI,MaxDR_PT_DI]';
DRAWDUR     FSL4                'SL_TP.CurCount*Uniform[MinDR_PT_SL,MaxDR_PT_SL]';
DRAWDUR     FSR4                'SR_TP.CurCount*Uniform[MinDR_PT_SR,MaxDR_PT_SR]';
DURATION    Drill               'FBT4.SumDrawDur+FTL4.SumDrawDur+FTR4.SumDrawDur+FWL4.SumDrawDur+FWR4.SumDrawDur+
                                 FDI4.SumDrawDur+FSL4.SumDrawDur+FSR4.SumDrawDur';

/Startup to Butt Joint
DRAWDUR     FBT6                'BT_DR.CurCount*Uniform[MinBJ_PT_BT,MaxBJ_PT_BT]/Normal[MeanBTperGirder,SDBTperGirder]';
DRAWDUR     FTL6                'TL_DR.CurCount*Uniform[MinBJ_PT_TL,MaxBJ_PT_TL]/Normal[MeanTLperGirder,SDTLperGirder]';
DRAWDUR     FTR6                'TR_DR.CurCount*Uniform[MinBJ_PT_TR,MaxBJ_PT_TR]/Normal[MeanTRperGirder,SDTRperGirder]';
DRAWDUR     FWL6                'WL_DR.CurCount*Uniform[MinBJ_PT_WL,MaxBJ_PT_WL]/Normal[MeanWLperGirder,SDWLperGirder]';
DRAWDUR     FWR6                'WR_DR.CurCount*Uniform[MinBJ_PT_WR,MaxBJ_PT_WR]/Normal[MeanWRperGirder,SDWRperGirder]';
DRAWDUR     FDI6                'DI_DR.CurCount*Uniform[MinBJ_PT_DI,MaxBJ_PT_DI]/Normal[MeanDIperGirder,SDDIperGirder]';
DRAWDUR     FSL6                'SL_DR.CurCount*Uniform[MinBJ_PT_SL,MaxBJ_PT_SL]/Normal[MeanSLperGirder,SDSLperGirder]';
DRAWDUR     FSR6                'SR_DR.CurCount*Uniform[MinBJ_PT_SR,MaxBJ_PT_SR]/Normal[MeanSRperGirder,SDSRperGirder]';
DURATION    ButtJoint           'FBT6.SumDrawDur+FTL6.SumDrawDur+FTR6.SumDrawDur+FWL6.SumDrawDur+FWR6.SumDrawDur+
                                 FDI6.SumDrawDur+FSL6.SumDrawDur+FSR6.SumDrawDur';

/Startup to Assembly T-Shape
DRAWDUR     ABT2                'BT_BJ.CurCount*Uniform[MinAT_PT_BT,MaxAT_PT_BT]';
DRAWDUR     ATL2                'TL_BJ.CurCount*Uniform[MinAT_PT_TL,MaxAT_PT_TL]';
DRAWDUR     ATR2                'TR_BJ.CurCount*Uniform[MinAT_PT_TR,MaxAT_PT_TR]';
DRAWDUR     AWL2                'WL_BJ.CurCount*Uniform[MinAT_PT_WL,MaxAT_PT_WL]';
DRAWDUR     AWR2                'WR_BJ.CurCount*Uniform[MinAT_PT_WR,MaxAT_PT_WR]';
DRAWDUR     ADI2                'DI_BJ.CurCount*Uniform[MinAT_PT_DI,MaxAT_PT_DI]';
DRAWDUR     ASL2                'SL_BJ.CurCount*Uniform[MinAT_PT_SL,MaxAT_PT_SL]';
DRAWDUR     ASR2                'SR_BJ.CurCount*Uniform[MinAT_PT_SR,MaxAT_PT_SR]';
DURATION    Assembly_TShape     'ABT2.SumDrawDur+ATL2.SumDrawDur+ATR2.SumDrawDur+AWL2.SumDrawDur+AWR2.SumDrawDur+
                                 ADI2.SumDrawDur+ASL2.SumDrawDur+ASR2.SumDrawDur';

/Startup to Weld T-Shape
DRAWDUR     ABT4                'BT_AT.TotCount*Uniform[MinWT_PT_BT,MaxWT_PT_BT]';
DRAWDUR     ATL4                'TL_AT.TotCount*Uniform[MinWT_PT_TL,MaxWT_PT_TL]';
DRAWDUR     ATR4                'TR_AT.TotCount*Uniform[MinWT_PT_TR,MaxWT_PT_TR]';
DRAWDUR     AWL4                'WL_AT.TotCount*Uniform[MinWT_PT_WL,MaxWT_PT_WL]';
DRAWDUR     AWR4                'WR_AT.TotCount*Uniform[MinWT_PT_WR,MaxWT_PT_WR]';
DRAWDUR     ADI4                'DI_AT.TotCount*Uniform[MinWT_PT_DI,MaxWT_PT_DI]';
DRAWDUR     ASL4                'SL_AT.TotCount*Uniform[MinWT_PT_SL,MaxWT_PT_SL]';
DRAWDUR     ASR4                'SR_AT.TotCount*Pert[MinWT_PT_SR,ModeWT_PT_SR,MaxWT_PT_SR]';
DURATION    Weld_TShape         'ABT4.SumDrawDur+ATL4.SumDrawDur+ATR4.SumDrawDur+AWL4.SumDrawDur+AWR4.SumDrawDur+
                                 ADI4.SumDrawDur+ASL4.SumDrawDur+ASR4.SumDrawDur';

/Define Variables of Production
VARIABLE    AmtBT_WT            'BT_WT.TotCount';
VARIABLE    AmtTL_WT            'TL_WT.TotCount';
VARIABLE    AmtTR_WT            'TR_WT.TotCount';
VARIABLE    AmtWL_WT            'WL_WT.TotCount';
VARIABLE    AmtWR_WT            'WR_WT.TotCount';
                                          -10-                                                   06/28/12 03:08:10
```

Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
VARIABLE    AmtDI_WT          'DI_WT.TotCount';
VARIABLE    AmtSL_WT          'SL_WT.TotCount';
VARIABLE    AmtSR_WT          'SR_WT.TotCount';
VARIABLE    AmtGirder         'Min(AmtDI_WT,Min(Min(AmtSL_WT,AmtSR_WT),Min(AmtBT_WT,Min(Min(AmtTL_WT,AmtTR_WT),Min(AmtWL_WT,AmtWR_WT)))))';

/*******************************************************************************

/Define Collector
COLLECTOR   CTPProcessTime_BT;
COLLECT     CTPProcessTime_BT    'TotalWorkMins';
ONRELEASE   PBT1     COLLECT     CTPProcessTime_BT    'TotalWorkMins';
COLLECTOR   CTPProcessTime_TL;
COLLECT     CTPProcessTime_TL    'TotalWorkMins';
ONRELEASE   PTL1     COLLECT     CTPProcessTime_TL    'TotalWorkMins';
COLLECTOR   CTPProcessTime_TR;
COLLECT     CTPProcessTime_TR    'TotalWorkMins';
ONRELEASE   PTR1     COLLECT     CTPProcessTime_TR    'TotalWorkMins';
COLLECTOR   CTPProcessTime_WL;
COLLECT     CTPProcessTime_WL    'TotalWorkMins';
ONRELEASE   PWL1     COLLECT     CTPProcessTime_WL    'TotalWorkMins';
COLLECTOR   CTPProcessTime_WR;
COLLECT     CTPProcessTime_WR    'TotalWorkMins';
ONRELEASE   PWR1     COLLECT     CTPProcessTime_WR    'TotalWorkMins';
COLLECTOR   CTPProcessTime_DI;
COLLECT     CTPProcessTime_DI    'TotalWorkMins';
ONRELEASE   PDI1     COLLECT     CTPProcessTime_DI    'TotalWorkMins';
COLLECTOR   CTPProcessTime_SL;
COLLECT     CTPProcessTime_SL    'TotalWorkMins';
ONRELEASE   PSL1     COLLECT     CTPProcessTime_SL    'TotalWorkMins';
COLLECTOR   CTPProcessTime_SR;
COLLECT     CTPProcessTime_SR    'TotalWorkMins';
ONRELEASE   PSR1     COLLECT     CTPProcessTime_SR    'TotalWorkMins';

COLLECTOR   TPProcessTime_BT;
COLLECT     TPProcessTime_BT     'TotalWorkMins';
ONRELEASE   PBT3     COLLECT     TPProcessTime_BT     'TotalWorkMins';
COLLECTOR   TPProcessTime_TL;
COLLECT     TPProcessTime_TL     'TotalWorkMins';
ONRELEASE   PTL3     COLLECT     TPProcessTime_TL     'TotalWorkMins';
COLLECTOR   TPProcessTime_TR;
COLLECT     TPProcessTime_TR     'TotalWorkMins';
ONRELEASE   PTR3     COLLECT     TPProcessTime_TR     'TotalWorkMins';
COLLECTOR   TPProcessTime_WL;
COLLECT     TPProcessTime_WL     'TotalWorkMins';
ONRELEASE   PWL3     COLLECT     TPProcessTime_WL     'TotalWorkMins';
COLLECTOR   TPProcessTime_WR;
COLLECT     TPProcessTime_WR     'TotalWorkMins';
ONRELEASE   PWR3     COLLECT     TPProcessTime_WR     'TotalWorkMins';
COLLECTOR   TPProcessTime_DI;
COLLECT     TPProcessTime_DI     'TotalWorkMins';
ONRELEASE   PDI3     COLLECT     TPProcessTime_DI     'TotalWorkMins';
COLLECTOR   TPProcessTime_SL;
COLLECT     TPProcessTime_SL     'TotalWorkMins';
ONRELEASE   PSL3     COLLECT     TPProcessTime_SL     'TotalWorkMins';
COLLECTOR   TPProcessTime_SR;
COLLECT     TPProcessTime_SR     'TotalWorkMins';
ONRELEASE   PSR3     COLLECT     TPProcessTime_SR     'TotalWorkMins';

COLLECTOR   DRProcessTime_BT;
COLLECT     DRProcessTime_BT     'TotalWorkMins';
ONRELEASE   PBT5     COLLECT     DRProcessTime_BT     'TotalWorkMins';
COLLECTOR   DRProcessTime_TL;
```

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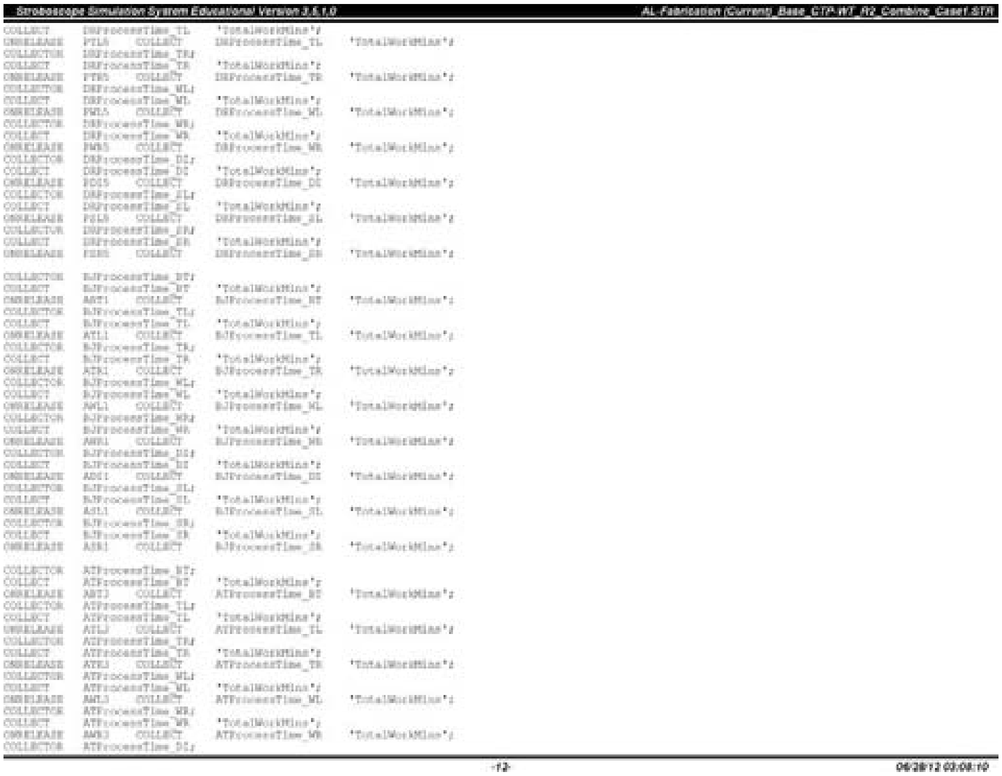
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
COLLECT     DRProcessTime_TL     'TotalWorkMins';
ONRELEASE   PTL5     COLLECT     DRProcessTime_TL     'TotalWorkMins';
COLLECTOR   DRProcessTime_TR;
COLLECT     DRProcessTime_TR     'TotalWorkMins';
ONRELEASE   PTR5     COLLECT     DRProcessTime_TR     'TotalWorkMins';
COLLECTOR   DRProcessTime_WL;
COLLECT     DRProcessTime_WL     'TotalWorkMins';
ONRELEASE   PWL5     COLLECT     DRProcessTime_WL     'TotalWorkMins';
COLLECTOR   DRProcessTime_WR;
COLLECT     DRProcessTime_WR     'TotalWorkMins';
ONRELEASE   PWR5     COLLECT     DRProcessTime_WR     'TotalWorkMins';
COLLECTOR   DRProcessTime_DI;
COLLECT     DRProcessTime_DI     'TotalWorkMins';
ONRELEASE   PDI5     COLLECT     DRProcessTime_DI     'TotalWorkMins';
COLLECTOR   DRProcessTime_SL;
COLLECT     DRProcessTime_SL     'TotalWorkMins';
ONRELEASE   PSL5     COLLECT     DRProcessTime_SL     'TotalWorkMins';
COLLECTOR   DRProcessTime_SR;
COLLECT     DRProcessTime_SR     'TotalWorkMins';
ONRELEASE   PSR5     COLLECT     DRProcessTime_SR     'TotalWorkMins';

COLLECTOR   BJProcessTime_BT;
COLLECT     BJProcessTime_BT     'TotalWorkMins';
ONRELEASE   ABT1     COLLECT     BJProcessTime_BT     'TotalWorkMins';
COLLECTOR   BJProcessTime_TL;
COLLECT     BJProcessTime_TL     'TotalWorkMins';
ONRELEASE   ATL1     COLLECT     BJProcessTime_TL     'TotalWorkMins';
COLLECTOR   BJProcessTime_TR;
COLLECT     BJProcessTime_TR     'TotalWorkMins';
ONRELEASE   ATR1     COLLECT     BJProcessTime_TR     'TotalWorkMins';
COLLECTOR   BJProcessTime_WL;
COLLECT     BJProcessTime_WL     'TotalWorkMins';
ONRELEASE   AWL1     COLLECT     BJProcessTime_WL     'TotalWorkMins';
COLLECTOR   BJProcessTime_WR;
COLLECT     BJProcessTime_WR     'TotalWorkMins';
ONRELEASE   AWR1     COLLECT     BJProcessTime_WR     'TotalWorkMins';
COLLECTOR   BJProcessTime_DI;
COLLECT     BJProcessTime_DI     'TotalWorkMins';
ONRELEASE   ADI1     COLLECT     BJProcessTime_DI     'TotalWorkMins';
COLLECTOR   BJProcessTime_SL;
COLLECT     BJProcessTime_SL     'TotalWorkMins';
ONRELEASE   ASL1     COLLECT     BJProcessTime_SL     'TotalWorkMins';
COLLECTOR   BJProcessTime_SR;
COLLECT     BJProcessTime_SR     'TotalWorkMins';
ONRELEASE   ASR1     COLLECT     BJProcessTime_SR     'TotalWorkMins';

COLLECTOR   ATProcessTime_BT;
COLLECT     ATProcessTime_BT     'TotalWorkMins';
ONRELEASE   ABT3     COLLECT     ATProcessTime_BT     'TotalWorkMins';
COLLECTOR   ATProcessTime_TL;
COLLECT     ATProcessTime_TL     'TotalWorkMins';
ONRELEASE   ATL3     COLLECT     ATProcessTime_TL     'TotalWorkMins';
COLLECTOR   ATProcessTime_TR;
COLLECT     ATProcessTime_TR     'TotalWorkMins';
ONRELEASE   ATR3     COLLECT     ATProcessTime_TR     'TotalWorkMins';
COLLECTOR   ATProcessTime_WL;
COLLECT     ATProcessTime_WL     'TotalWorkMins';
ONRELEASE   AWL3     COLLECT     ATProcessTime_WL     'TotalWorkMins';
COLLECTOR   ATProcessTime_WR;
COLLECT     ATProcessTime_WR     'TotalWorkMins';
ONRELEASE   AWR3     COLLECT     ATProcessTime_WR     'TotalWorkMins';
COLLECTOR   ATProcessTime_DI;
```

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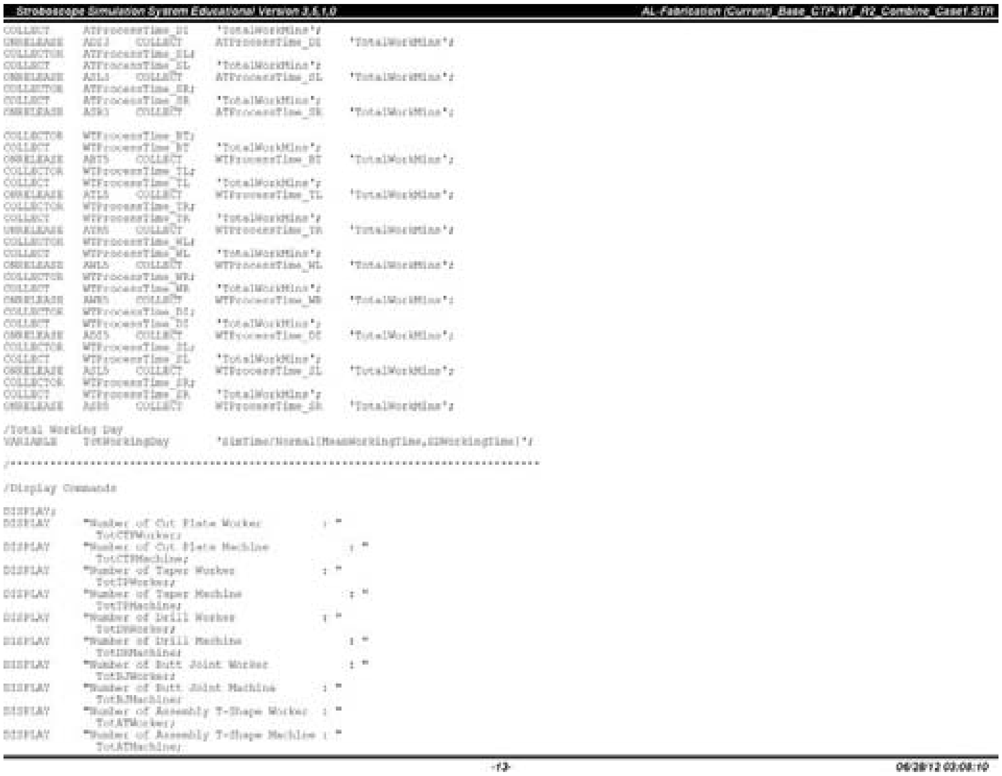
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
COLLECT      ATProcessTime_DS    'TotalWorkMins';
ONRELEASE    ADS3     COLLECT     ATProcessTime_DS     'TotalWorkMins';
COLLECTOR    ATProcessTime_SL;
COLLECT      ATProcessTime_SL    'TotalWorkMins';
ONRELEASE    ASL3     COLLECT     ATProcessTime_SL     'TotalWorkMins';
COLLECTOR    ATProcessTime_SR;
COLLECT      ATProcessTime_SR    'TotalWorkMins';
ONRELEASE    ASR3     COLLECT     ATProcessTime_SR     'TotalWorkMins';

COLLECTOR    WTProcessTime_BT;
COLLECT      WTProcessTime_BT    'TotalWorkMins';
ONRELEASE    ABT5     COLLECT     WTProcessTime_BT     'TotalWorkMins';
COLLECTOR    WTProcessTime_TL;
COLLECT      WTProcessTime_TL    'TotalWorkMins';
ONRELEASE    ATL5     COLLECT     WTProcessTime_TL     'TotalWorkMins';
COLLECTOR    WTProcessTime_TR;
COLLECT      WTProcessTime_TR    'TotalWorkMins';
ONRELEASE    ATR5     COLLECT     WTProcessTime_TR     'TotalWorkMins';
COLLECTOR    WTProcessTime_WL;
COLLECT      WTProcessTime_WL    'TotalWorkMins';
ONRELEASE    AWL5     COLLECT     WTProcessTime_WL     'TotalWorkMins';
COLLECTOR    WTProcessTime_WR;
COLLECT      WTProcessTime_WR    'TotalWorkMins';
ONRELEASE    AWR5     COLLECT     WTProcessTime_WR     'TotalWorkMins';
COLLECTOR    WTProcessTime_DS;
COLLECT      WTProcessTime_DS    'TotalWorkMins';
ONRELEASE    ADS5     COLLECT     WTProcessTime_DS     'TotalWorkMins';
COLLECTOR    WTProcessTime_SL;
COLLECT      WTProcessTime_SL    'TotalWorkMins';
ONRELEASE    ASL5     COLLECT     WTProcessTime_SL     'TotalWorkMins';
COLLECTOR    WTProcessTime_SR;
COLLECT      WTProcessTime_SR    'TotalWorkMins';
ONRELEASE    ASR5     COLLECT     WTProcessTime_SR     'TotalWorkMins';

/Total Working Day
VARIABLE     TotWorkingDay       'SimTime/Normal[MeanWorkingTime,SDWorkingTime]';

/*******************************************************************************

/Display Commands

DISPLAY;
DISPLAY      "Number of Cut Plate Worker           : "
               TotCTPWorker;
DISPLAY      "Number of Cut Plate Machine              : "
               TotCTPMachine;
DISPLAY      "Number of Taper Worker               : "
               TotTPWorker;
DISPLAY      "Number of Taper Machine                  : "
               TotTPMachine;
DISPLAY      "Number of Drill Worker               : "
               TotDRWorker;
DISPLAY      "Number of Drill Machine                  : "
               TotDRMachine;
DISPLAY      "Number of Butt Joint Worker              : "
               TotBJWorker;
DISPLAY      "Number of Butt Joint Machine         : "
               TotBJMachine;
DISPLAY      "Number of Assembly T-Shape Worker    : "
               TotATWorker;
DISPLAY      "Number of Assembly T-Shape Machine : "
               TotATMachine;
```

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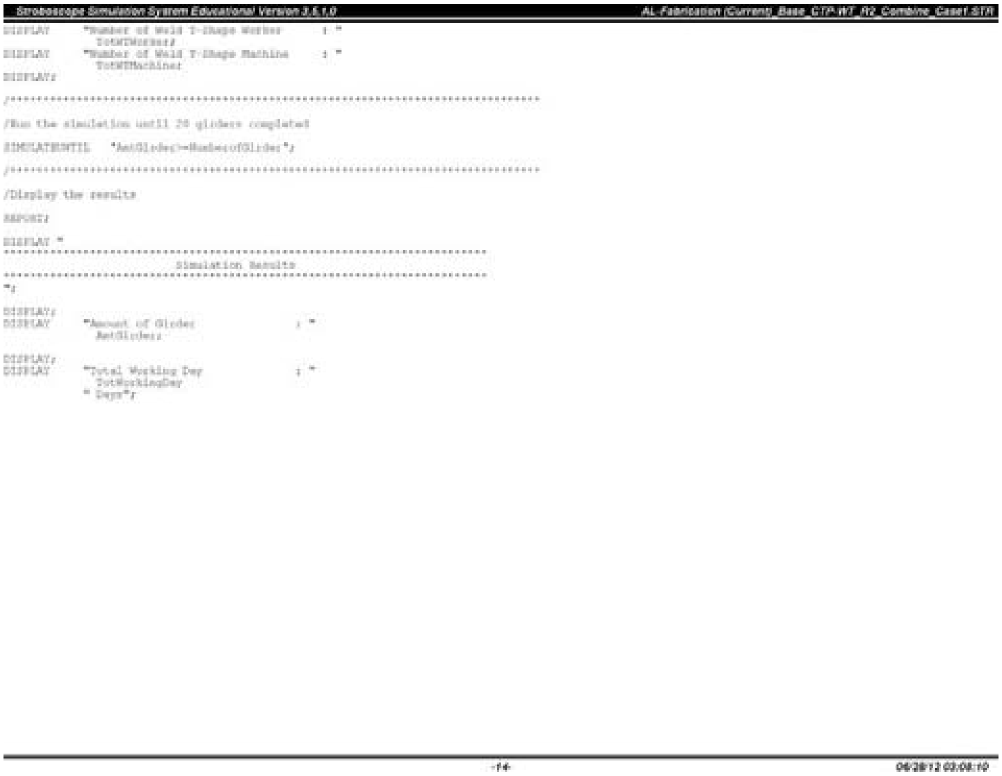
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_CTP-WT_R2_Combine_Case1.STR

```
DISPLAY      "Number of Weld T-Shape Worker        : "
               TotWTWorker;
DISPLAY      "Number of Weld T-Shape Machine       : "
               TotWTMachine;
DISPLAY;

/*******************************************************************************

/Run the simulation until 20 gliders completed

SIMULATEUNTIL    'AmtGlider>=NumberofGlider';

/*******************************************************************************

/Display the results

REPORT;

DISPLAY "
*************************************************************************
                         Simulation Results
*************************************************************************
";

DISPLAY;
DISPLAY      "Amount of Glider                  : "
               AmtGlider;

DISPLAY;
DISPLAY      "Total Working Day                 : "
               TotWorkingDay
             " Days";
```

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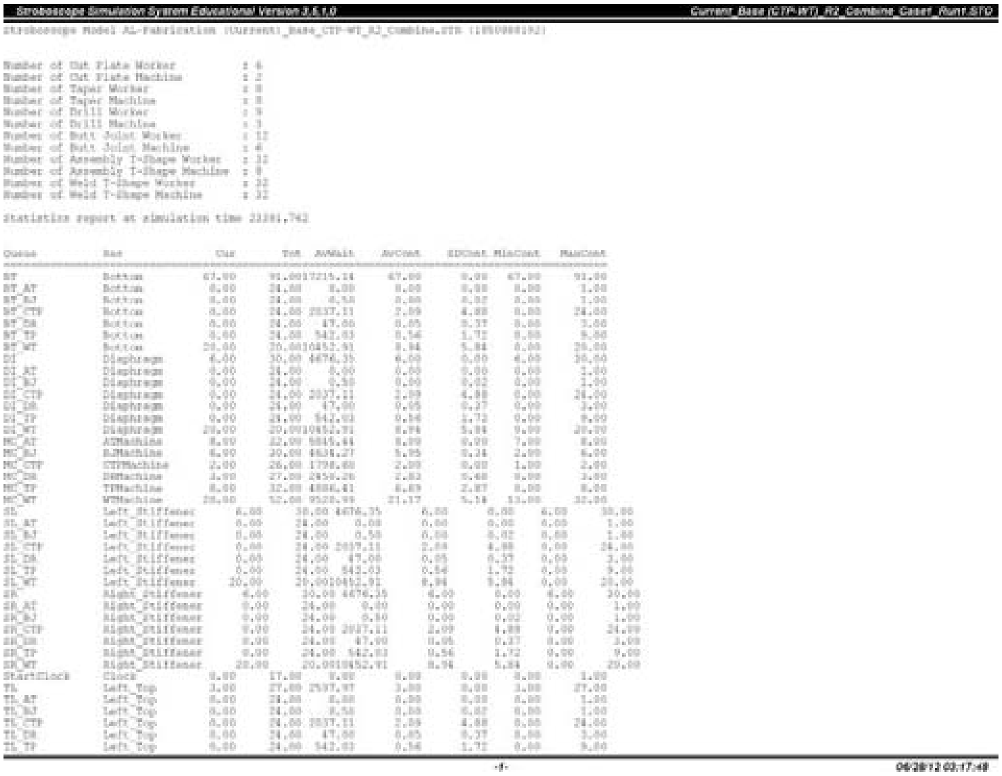
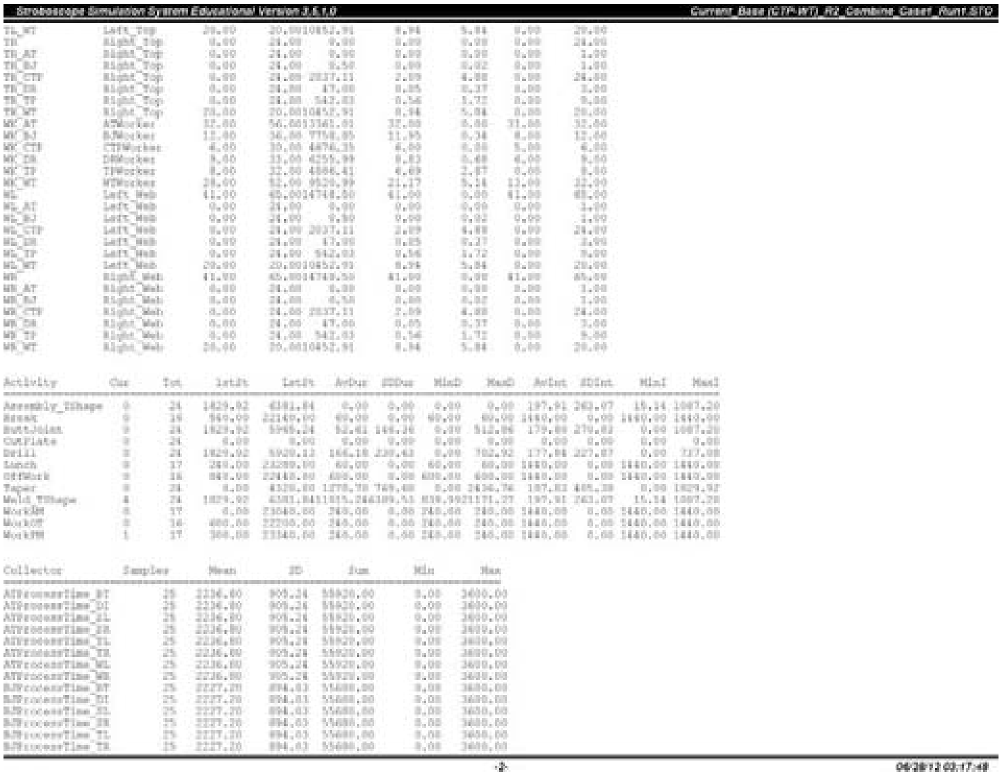
Figure C.1 (Cont.) Simulation input source code (CTP-WT case no.1)



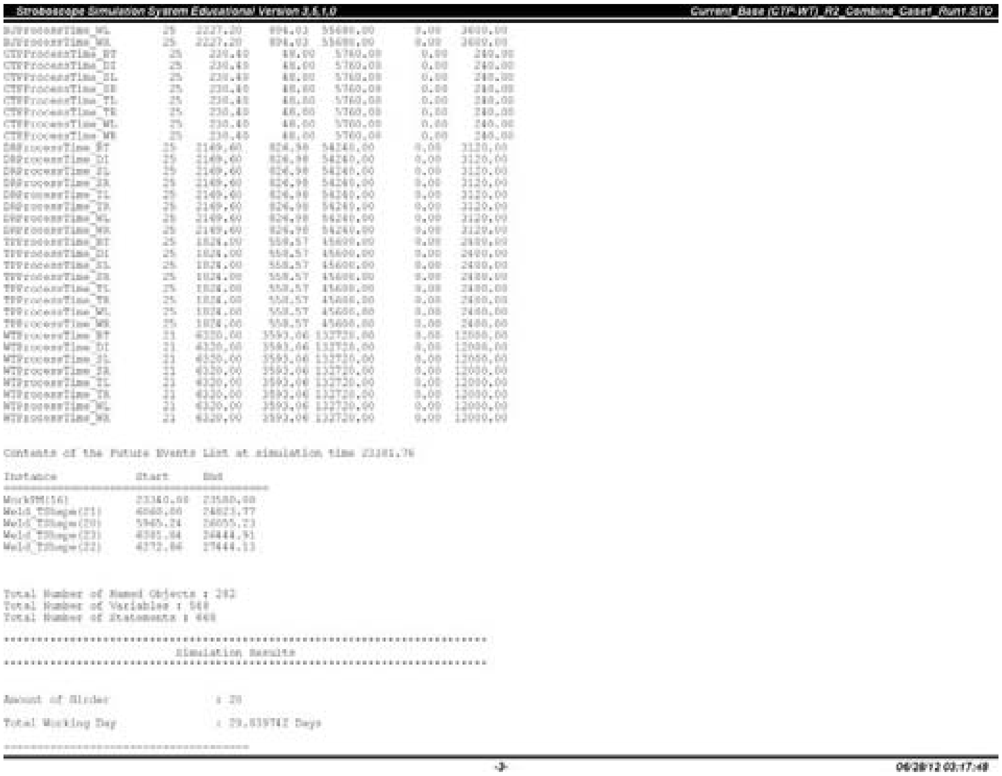
```
Stroboscope Simulation System Educational Version 3.5.1.0                    Current_Base (CTP-WT)_R2_Combine_Case1_Run1.STO
Stroboscope Model AL-Fabrication (Current)_Base_CTP-WT_R2_Combine.STB (1850988192)

Number of Cut Plate Worker          : 6
Number of Cut Plate Machine         : 2
Number of Taper Worker              : 8
Number of Taper Machine             : 8
Number of Drill Worker              : 9
Number of Drill Machine             : 3
Number of Butt Joint Worker         : 12
Number of Butt Joint Machine        : 6
Number of Assembly T-Shape Worker   : 32
Number of Assembly T-Shape Machine  : 8
Number of Weld T-Shape Worker       : 32
Number of Weld T-Shape Machine      : 32

Statistics report at simulation time 22281.762

Queue         Res                Cur      Tot  AvWait     AvCont   SDCont MinCont   MaxCont
=========================================================================================
BT            Bottom           67.00    91.0017215.14     67.00     0.00   67.00     91.00
BT_AT         Bottom            0.00    24.00    0.00      0.00     0.00    0.00      1.00
BT_BJ         Bottom            0.00    24.00    0.50      0.00     0.02    0.00      1.00
BT_CTP        Bottom            0.00    24.00 2037.11      2.09     4.88    0.00     24.00
BT_DR         Bottom            0.00    24.00   47.00      0.05     0.37    0.00      3.00
BT_TP         Bottom            0.00    24.00  542.03      0.56     1.72    0.00      9.00
BT_WT         Bottom           20.00    20.0010452.91      8.94     5.84    0.00     20.00
DI            Diaphragm         6.00    30.00 4676.35      6.00     0.00    6.00     30.00
DI_AT         Diaphragm         0.00    24.00    0.00      0.00     0.00    0.00      1.00
DI_BJ         Diaphragm         0.00    24.00    0.50      0.00     0.02    0.00      1.00
DI_CTP        Diaphragm         0.00    24.00 2037.11      2.09     4.88    0.00     24.00
DI_DR         Diaphragm         0.00    24.00   47.00      0.05     0.37    0.00      3.00
DI_TP         Diaphragm         0.00    24.00  542.03      0.56     1.72    0.00      9.00
DI_WT         Diaphragm        20.00    20.0010452.91      8.94     5.84    0.00     20.00
MC_AT         ATMachine         8.00    22.00 5845.44      8.00     0.00    7.00      8.00
MC_BJ         BJMachine         6.00    20.00 4634.27      5.95     0.24    2.00      6.00
MC_CTP        CTPMachine        2.00    26.00 1798.60      2.00     0.00    1.00      2.00
MC_DR         DRMachine         3.00    27.00 2858.26      2.82     0.48    0.00      3.00
MC_TP         TPMachine         8.00    32.00 4886.41      6.69     2.87    0.00      8.00
MC_WT         WTMachine        28.00    52.00 9528.99     21.17     5.14   13.00     32.00
SL            Left_Stiffener       6.00     30.00 4676.35      6.00      0.00    6.00     30.00
SL_AT         Left_Stiffener       0.00     24.00    0.00      0.00      0.00    0.00      1.00
SL_BJ         Left_Stiffener       0.00     24.00    0.50      0.00      0.02    0.00      1.00
SL_CTP        Left_Stiffener       0.00     24.00 2037.11      2.09      4.88    0.00     24.00
SL_DR         Left_Stiffener       0.00     24.00   47.00      0.05      0.37    0.00      3.00
SL_TP         Left_Stiffener       0.00     24.00  542.03      0.56      1.72    0.00      9.00
SL_WT         Left_Stiffener      20.00     20.0010452.91      8.94      5.84    0.00     20.00
SR            Right_Stiffener      6.00     30.00 4676.35      6.00      0.00    6.00     30.00
SR_AT         Right_Stiffener      0.00     24.00    0.00      0.00      0.00    0.00      1.00
SR_BJ         Right_Stiffener      0.00     24.00    0.50      0.00      0.02    0.00      1.00
SR_CTP        Right_Stiffener      0.00     24.00 2037.11      2.09      4.88    0.00     24.00
SR_DR         Right_Stiffener      0.00     24.00   47.00      0.05      0.37    0.00      3.00
SR_TP         Right_Stiffener      0.00     24.00  542.03      0.56      1.72    0.00      9.00
SR_WT         Right_Stiffener     20.00     20.0010452.91      8.94      5.84    0.00     20.00
StartClock    Clock             0.00    17.00    0.00      0.00     0.00    0.00      1.00
TL            Left_Top          3.00    27.00 2597.97      3.00     0.00    3.00     27.00
TL_AT         Left_Top          0.00    24.00    0.00      0.00     0.00    0.00      1.00
TL_BJ         Left_Top          0.00    24.00    0.50      0.00     0.02    0.00      1.00
TL_CTP        Left_Top          0.00    24.00 2037.11      2.09     4.88    0.00     24.00
TL_DR         Left_Top          0.00    24.00   47.00      0.05     0.37    0.00      3.00
TL_TP         Left_Top          0.00    24.00  542.03      0.56     1.72    0.00      9.00
                                                  -1-                                       06/28/12 03:17:48
```

Figure C.2 Simulation output source code (CTP-WT case no.1)



```
Stroboscope Simulation System Educational Version 3.5.1.0                    Current_Base (CTP-WT)_R2_Combine_Case1_Run1.STO
TL_WT         Left_Top         20.00    20.0010452.91      8.94     5.84    0.00     20.00
TR            Right_Top         0.00    24.00    0.00      0.00     0.00    0.00     24.00
TR_AT         Right_Top         0.00    24.00    0.00      0.00     0.00    0.00      1.00
TR_BJ         Right_Top         0.00    24.00    0.50      0.00     0.02    0.00      1.00
TR_CTP        Right_Top         0.00    24.00 2037.11      2.09     4.88    0.00     24.00
TR_DR         Right_Top         0.00    24.00   47.00      0.05     0.37    0.00      3.00
TR_TP         Right_Top         0.00    24.00  542.03      0.56     1.72    0.00      9.00
TR_WT         Right_Top        20.00    20.0010452.91      8.94     5.84    0.00     20.00
WK_AT         ATWorker         32.00    56.0013361.01     32.00     0.00   31.00     32.00
WK_BJ         BJWorker         12.00    36.00 7758.85     11.95     0.34    8.00     12.00
WK_CTP        CTPWorker         6.00    30.00 4676.35      6.00     0.00    5.00      6.00
WK_DR         DRWorker          9.00    33.00 4255.99      8.83     0.48    6.00      9.00
WK_TP         TPWorker          8.00    32.00 4886.41      6.69     2.87    0.00      8.00
WK_WT         WTWorker         28.00    52.00 9528.99     21.17     5.14   12.00     32.00
WL            Left_Web         41.00    65.0014748.50     41.00     0.00   41.00     65.00
WL_AT         Left_Web          0.00    24.00    0.00      0.00     0.00    0.00      1.00
WL_BJ         Left_Web          0.00    24.00    0.50      0.00     0.02    0.00      1.00
WL_CTP        Left_Web          0.00    24.00 2037.11      2.09     4.88    0.00     24.00
WL_DR         Left_Web          0.00    24.00   47.00      0.05     0.37    0.00      3.00
WL_TP         Left_Web          0.00    24.00  542.03      0.56     1.72    0.00      9.00
WL_WT         Left_Web         20.00    20.0010452.91      8.94     5.84    0.00     20.00
WR            Right_Web        41.00    65.0014748.50     41.00     0.00   41.00     65.00
WR_AT         Right_Web         0.00    24.00    0.00      0.00     0.00    0.00      1.00
WR_BJ         Right_Web         0.00    24.00    0.50      0.00     0.02    0.00      1.00
WR_CTP        Right_Web         0.00    24.00 2037.11      2.09     4.88    0.00     24.00
WR_DR         Right_Web         0.00    24.00   47.00      0.05     0.37    0.00      3.00
WR_TP         Right_Web         0.00    24.00  542.03      0.56     1.72    0.00      9.00
WR_WT         Right_Web        20.00    20.0010452.91      8.94     5.84    0.00     20.00

Activity         Cur    Tot     1stSt     LstSt   AvDur  SDDur    MinD     MaxD   AvInt  SDInt     MinI     MaxI
=================================================================================================================
Assembly_TShape   0     24   1829.92   4381.84    0.00   0.00    0.00     0.00  197.91 263.07    15.14  1087.20
Break             0     16    960.00  22140.00   60.00   0.00   60.00    60.00 1440.00   0.00  1440.00  1440.00
ButtJoint         0     24   1829.92   5965.24   52.41 146.26    0.00   512.86  179.88 270.82     0.00  1087.20
CutPlate          0     24      0.00      0.00    0.00   0.00    0.00     0.00    0.00   0.00     0.00     0.00
Drill             0     24   1829.92   5920.12  166.18 230.42    0.00   702.92  177.84 227.87     0.00   737.08
Lunch             0     17    240.00  22280.00   60.00   0.00   60.00    60.00 1440.00   0.00  1440.00  1440.00
OffWork           0     16    840.00  22440.00  600.00   0.00  600.00   600.00 1440.00   0.00  1440.00  1440.00
Taper             0     24      0.00   4320.00 1278.78 749.48    0.00  2436.76  187.83 405.38     0.00  1829.92
Weld_TShape       4     24   1829.92   4381.8411815.246389.51 838.9921171.27  197.91 263.07    15.14  1087.20
WorkAM            0     17      0.00  21040.00  240.00   0.00  240.00   240.00 1440.00   0.00  1440.00  1440.00
WorkOT            0     16    480.00  22200.00  240.00   0.00  240.00   240.00 1440.00   0.00  1440.00  1440.00
WorkPM            1     17    300.00  22340.00  240.00   0.00  240.00   240.00 1440.00   0.00  1440.00  1440.00

Collector              Samples      Mean        SD        Sum         Min        Max
===================================================================================
ATProcessTime_BT            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_DI            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_SL            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_SR            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_TL            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_TR            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_WL            25   2236.80    905.24   55920.00        0.00    3600.00
ATProcessTime_WR            25   2236.80    905.24   55920.00        0.00    3600.00
BJProcessTime_BT            25   2227.20    894.03   55680.00        0.00    3600.00
BJProcessTime_DI            25   2227.20    894.03   55680.00        0.00    3600.00
BJProcessTime_SL            25   2227.20    894.03   55680.00        0.00    3600.00
BJProcessTime_SR            25   2227.20    894.03   55680.00        0.00    3600.00
BJProcessTime_TL            25   2227.20    894.03   55680.00        0.00    3600.00
BJProcessTime_TR            25   2227.20    894.03   55680.00        0.00    3600.00
                                                  -2-                                       06/28/12 03:17:48
```

Figure C.2 (Cont.) Simulation output source code (CTP-WT case no.1)



```
Stroboscope Simulation System Educational Version 3.5.1.0                Current_Base (CTP-WT)_R2_Combine_Case1_Run1.STO
BJProcessTime_WL        25   2227.20    894.03  55680.00      0.00   3600.00
BJProcessTime_WR        25   2227.20    894.03  55680.00      0.00   3600.00
CTPProcessTime_BT        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_DI        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_DL        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_DR        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_TL        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_TR        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_WL        25    230.40     48.00   5760.00      0.00    240.00
CTPProcessTime_WR        25    230.40     48.00   5760.00      0.00    240.00
DRProcessTime_BT        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_DI        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_DL        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_DR        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_TL        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_TR        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_WL        25   2169.60    826.98  54240.00      0.00   3120.00
DRProcessTime_WR        25   2169.60    826.98  54240.00      0.00   3120.00
TPProcessTime_BT        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_DI        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_DL        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_DR        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_TL        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_TR        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_WL        25   1824.00    558.57  45600.00      0.00   2400.00
TPProcessTime_WR        25   1824.00    558.57  45600.00      0.00   2400.00
WTProcessTime_BT        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_DI        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_DL        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_DR        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_TL        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_TR        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_WL        21   6320.00   3593.06 132720.00      0.00  12000.00
WTProcessTime_WR        21   6320.00   3593.06 132720.00      0.00  12000.00

Contents of the Future Events List at simulation time 23181.76

Instance             Start      End
=============================================
WorkTM(16)           23340.00  23580.00
Weld_TShape(21)      6060.00   24823.77
Weld_TShape(20)      5965.24   26055.23
Weld_TShape(23)      6381.84   26444.91
Weld_TShape(22)      6272.86   27444.13


Total Number of Named Objects : 282
Total Number of Variables : 548
Total Number of Statements : 468

*********************************************************************
                        Simulation Results
*********************************************************************

Amount of Girder                 : 20

Total Working Day                : 29.039742 Days

====================================
                                                   -3-                                  06/28/12 03:17:48
```

Figure C.2 (Cont.) Simulation output source code (CTP-WT case no.1)

```
Stroboscope Simulation System Educational Version 3.5.1.0                Current_Base (CTP-WT)_R2_Combine_Case1_Run1.STO
Execution    Time = 0.125 seconds

                                                   -4-                                  06/28/12 03:17:48
```

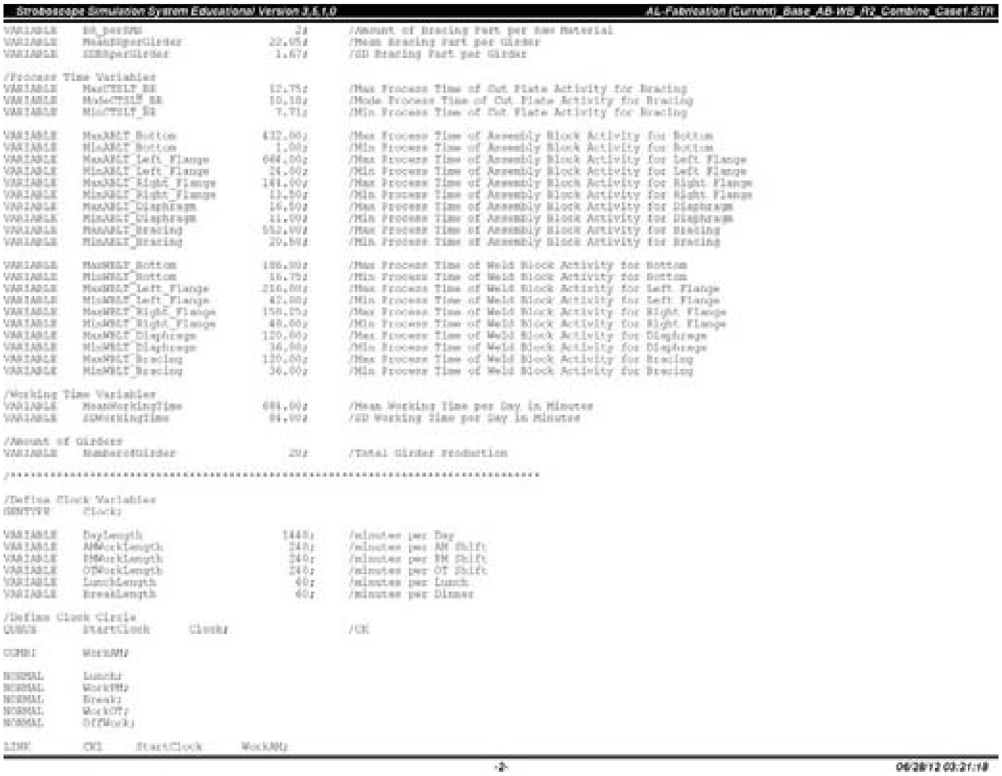
Figure C.2 (Cont.) Simulation output source code (CTP-WT case no.1)

Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR

```
/*******************************************************************************
/STROBOSCOPE Simulation Program by Mr Worawut Srisdom
/*******************************************************************************
/Steel Box Girder Bridge Fabrication Process - AB-WB (Current) Base (R2) Combine Case1
/*******************************************************************************

/Problem Decision Variables
VARIABLE    NumberofRawBT                91;      /Bottom part Raw Material              91
VARIABLE    NumberofRawTL                27;      /Left Top Flange part Raw Material     27
VARIABLE    NumberofRawTR                24;      /Right Top Flange part Raw Material    24
VARIABLE    NumberofRawWL                65;      /Left Web Flange part Raw Material     65
VARIABLE    NumberofRawWR                65;      /Right Web Flange part Raw Material    65
VARIABLE    NumberofRawDI                30;      /Diaphragm part Raw Material           10
VARIABLE    NumberofRawSL                30;      /Left Stiffener part Raw Material      13
VARIABLE    NumberofRawSR                30;      /Right Stiffener part Raw Material     13
VARIABLE    NumberofRawBR               140;      /Bracing part Raw Material             10

VARIABLE    NumberofCTSStation            2;      /                                      2
VARIABLE    NumberofCTSMachine            2;      /machines per Cut Shape Station        2
VARIABLE    NumberofCTSWorker             2;      /persons per Cut Shape Machine

VARIABLE    NumberofABStation            10;      /                                      10
VARIABLE    NumberofABMachine             1;      /machines per Assembly Block Station   2
VARIABLE    NumberofABWorker              4;      /persons per Assembly Block Machine

VARIABLE    NumberofWBStation            10;      /                                      10
VARIABLE    NumberofWBMachine             4;      /machines per Assembly Block Station   2
VARIABLE    NumberofWBWorker              1;      /persons per Assembly Block Machine

/Assembly Variables
VARIABLE    BT_perRMP                     3;      /Amount of Bottom Part per Raw Material
VARIABLE    MeanBTperGirder            1.65;      /Mean Bottom Part per Girder
VARIABLE    SDBTperGirder              0.67;      /SD Bottom Part per Girder

VARIABLE    TL_perRMP                     6;      /Amount of Left-Top Part per Raw Material
VARIABLE    MeanTLperGirder            3.50;      /Mean Left-Top Part per Girder
VARIABLE    SDTLperGirder              0.33;      /SD Left-Top Part per Girder

VARIABLE    TR_perRMP                     6;      /Amount of Right-Top Part per Raw Material
VARIABLE    MeanTRperGirder            3.50;      /Mean Right-Top Part per Girder
VARIABLE    SDTRperGirder              0.33;      /SD Right-Top Part per Girder

VARIABLE    WL_perRMP                     3;      /Amount of Left-Web Part per Raw Material
VARIABLE    MeanWLperGirder            3.20;      /Mean Left-Web Part per Girder
VARIABLE    SDWLperGirder              0.17;      /SD Left-Web Part per Girder

VARIABLE    WR_perRMP                     3;      /Amount of Right-Web Part per Raw Material
VARIABLE    MeanWRperGirder            3.20;      /Mean Right-Web Part per Girder
VARIABLE    SDWRperGirder              0.17;      /SD Right-Web Part per Girder

VARIABLE    DI_perRMP                     4;      /Amount of Diaphragm Part per Raw Material
VARIABLE    MeanDIperGirder            6.00;      /Mean Diaphragm Part per Girder
VARIABLE    SDDIperGirder              0.50;      /SD Diaphragm Part per Girder

VARIABLE    SL_perRMP                    15;      /Amount of Left-Stiffener Part per Raw Material
VARIABLE    MeanSLperGirder           11.50;      /Mean Left-Stiffener Part per Girder
VARIABLE    SDSLperGirder              1.67;      /SD Left-Stiffener Part per Girder

VARIABLE    SR_perRMP                    15;      /Amount of Right-Stiffener Part per Raw Material
VARIABLE    MeanSRperGirder           11.50;      /Mean Right-Stiffener Part per Girder
VARIABLE    SDSRperGirder              1.67;      /SD Right-Stiffener Part per Girder
```

-1- 06/28/12 03:21:18

Figure C.3 Simulation input source code (AB-WB case no.1)

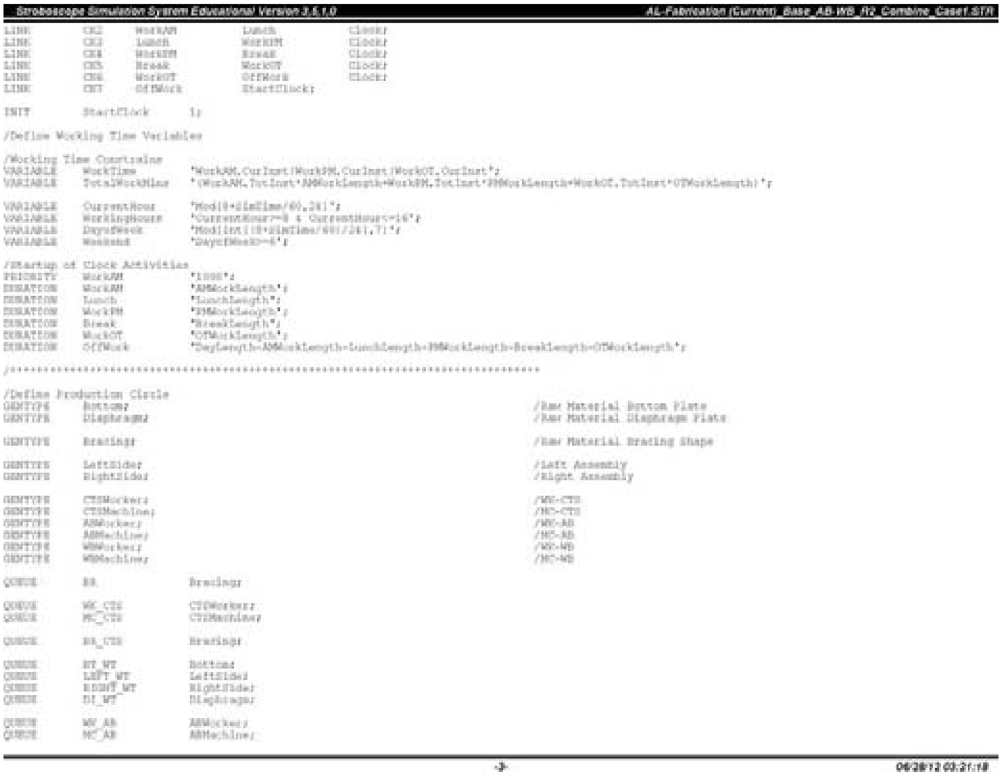


Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR

```
VARIABLE    BR_perRMP                     2;      /Amount of Bracing Part per Raw Material
VARIABLE    MeanBRperGirder           22.05;      /Mean Bracing Part per Girder
VARIABLE    SDBRperGirder              1.67;      /SD Bracing Part per Girder

/Process Time Variables
VARIABLE    MaxCTSLT_BR               12.75;      /Max Process Time of Cut Plate Activity for Bracing
VARIABLE    ModeCTSLT_BR              10.10;      /Mode Process Time of Cut Plate Activity for Bracing
VARIABLE    MinCTSLT_BR                7.71;      /Min Process Time of Cut Plate Activity for Bracing

VARIABLE    MaxABLT_Bottom           432.00;      /Max Process Time of Assembly Block Activity for Bottom
VARIABLE    MinABLT_Bottom             1.00;      /Min Process Time of Assembly Block Activity for Bottom
VARIABLE    MaxABLT_Left_Flange      684.00;      /Max Process Time of Assembly Block Activity for Left Flange
VARIABLE    MinABLT_Left_Flange       24.00;      /Min Process Time of Assembly Block Activity for Left Flange
VARIABLE    MaxABLT_Right_Flange     141.00;      /Max Process Time of Assembly Block Activity for Right Flange
VARIABLE    MinABLT_Right_Flange      13.50;      /Min Process Time of Assembly Block Activity for Right Flange
VARIABLE    MaxABLT_Diaphragm         16.50;      /Max Process Time of Assembly Block Activity for Diaphragm
VARIABLE    MinABLT_Diaphragm         11.00;      /Min Process Time of Assembly Block Activity for Diaphragm
VARIABLE    MaxABLT_Bracing          552.00;      /Max Process Time of Assembly Block Activity for Bracing
VARIABLE    MinABLT_Bracing           29.50;      /Min Process Time of Assembly Block Activity for Bracing

VARIABLE    MaxWBLT_Bottom           186.00;      /Max Process Time of Weld Block Activity for Bottom
VARIABLE    MinWBLT_Bottom            16.75;      /Min Process Time of Weld Block Activity for Bottom
VARIABLE    MaxWBLT_Left_Flange      216.00;      /Max Process Time of Weld Block Activity for Left Flange
VARIABLE    MinWBLT_Left_Flange       42.00;      /Min Process Time of Weld Block Activity for Left Flange
VARIABLE    MaxWBLT_Right_Flange     158.25;      /Max Process Time of Weld Block Activity for Right Flange
VARIABLE    MinWBLT_Right_Flange      48.00;      /Min Process Time of Weld Block Activity for Right Flange
VARIABLE    MaxWBLT_Diaphragm        120.00;      /Max Process Time of Weld Block Activity for Diaphragm
VARIABLE    MinWBLT_Diaphragm         36.00;      /Min Process Time of Weld Block Activity for Diaphragm
VARIABLE    MaxWBLT_Bracing          120.00;      /Max Process Time of Weld Block Activity for Bracing
VARIABLE    MinWBLT_Bracing           36.00;      /Min Process Time of Weld Block Activity for Bracing

/Working Time Variables
VARIABLE    MeanWorkingTime          684.00;      /Mean Working Time per Day in Minutes
VARIABLE    SDWorkingTime             84.00;      /SD Working Time per Day in Minutes

/Amount of Girders
VARIABLE    NumberofGirder               20;      /Total Girder Production

/*******************************************************************************

/Define Clock Variables
GENTYPE     Clock;

VARIABLE    DayLength                  1440;     /minutes per Day
VARIABLE    AMWorkLength                240;     /minutes per AM Shift
VARIABLE    PMWorkLength                240;     /minutes per PM Shift
VARIABLE    OTWorkLength                240;     /minutes per OT Shift
VARIABLE    LunchLength                  60;     /minutes per Lunch
VARIABLE    BreakLength                  60;     /minutes per Dinner

/Define Clock Circle
QUEUE       StartClock      Clock;               /CK

COMBI       WorkAM;

NORMAL      Lunch;
NORMAL      WorkPM;
NORMAL      Break;
NORMAL      WorkOT;
NORMAL      OffWork;

LINK        CK1     StartClock      WorkAM;
```

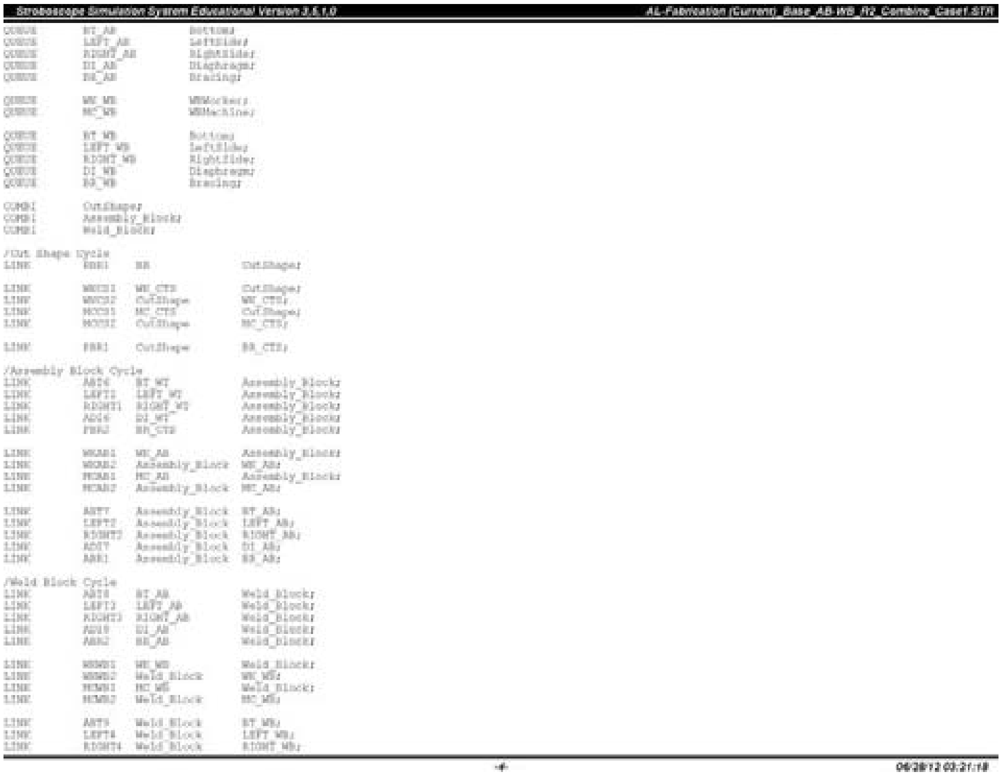
-2- 06/28/12 03:21:18

Figure C.3 (Cont.) Simulation input source code (AB-WB case no.1)



```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR
LINK        CK2     WorkAM          Lunch           Clock;
LINK        CK3     Lunch           WorkPM          Clock;
LINK        CK4     WorkPM          Break           Clock;
LINK        CK5     Break           WorkOT          Clock;
LINK        CK6     WorkOT          OffWork         Clock;
LINK        CK7     OffWork         StartClock;

INIT        StartClock      1;

/Define Working Time Variables

/Working Time Constrains
VARIABLE    WorkTime        'WorkAM.CurInst|WorkPM.CurInst|WorkOT.CurInst';
VARIABLE    TotalWorkMins   '(WorkAM.TotInst*AMWorkLength+WorkPM.TotInst*PMWorkLength+WorkOT.TotInst*OTWorkLength)';

VARIABLE    CurrentHour     'Mod(8+SimTime/60,24)';
VARIABLE    WorkingHours    'CurrentHour>=8 & CurrentHour<=16';
VARIABLE    DayofWeek       'Mod(Int((8+SimTime/60)/24),7)';
VARIABLE    Weekend         'DayofWeek>=6';

/Startup of Clock Activities
PRIORITY    WorkAM          '1000';
DURATION    WorkAM          'AMWorkLength';
DURATION    Lunch           'LunchLength';
DURATION    WorkPM          'PMWorkLength';
DURATION    Break           'BreakLength';
DURATION    WorkOT          'OTWorkLength';
DURATION    OffWork         'DayLength-AMWorkLength-LunchLength-PMWorkLength-BreakLength-OTWorkLength';

/*****************************************************************************

/Define Production Circle
GENTYPE     Bottom;                                                     /Raw Material Bottom Plate
GENTYPE     Diaphragm;                                                  /Raw Material Diaphragm Plate

GENTYPE     Bracing;                                                    /Raw Material Bracing Shape

GENTYPE     LeftSide;                                                   /Left Assembly
GENTYPE     RightSide;                                                  /Right Assembly

GENTYPE     CTSWorker;                                                  /WK-CTS
GENTYPE     CTSMachine;                                                 /MC-CTS
GENTYPE     ABWorker;                                                   /WK-AB
GENTYPE     ABMachine;                                                  /MC-AB
GENTYPE     WBWorker;                                                   /WK-WB
GENTYPE     WBMachine;                                                  /MC-WB

QUEUE       BR              Bracing;

QUEUE       WK_CTS          CTSWorker;
QUEUE       MC_CTS          CTSMachine;

QUEUE       BR_CTS          Bracing;

QUEUE       BT_WT           Bottom;
QUEUE       LEFT_WT         LeftSide;
QUEUE       RIGHT_WT        RightSide;
QUEUE       DI_WT           Diaphragm;

QUEUE       WK_AB           ABWorker;
QUEUE       MC_AB           ABMachine;
                                        -3-                                                                06/28/12 03:21:18
```

Figure C.3 (Cont.) Simulation input source code (AB-WB case no.1)



```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR
QUEUE       BT_AB           Bottom;
QUEUE       LEFT_AB         LeftSide;
QUEUE       RIGHT_AB        RightSide;
QUEUE       DI_AB           Diaphragm;
QUEUE       BR_AB           Bracing;

QUEUE       WK_WB           WBWorker;
QUEUE       MC_WB           WBMachine;

QUEUE       BT_WB           Bottom;
QUEUE       LEFT_WB         LeftSide;
QUEUE       RIGHT_WB        RightSide;
QUEUE       DI_WB           Diaphragm;
QUEUE       BR_WB           Bracing;

COMBI       CutShape;
COMBI       Assembly_Block;
COMBI       Weld_Block;

/Cut Shape Cycle
LINK        RBR1    BR              CutShape;

LINK        WKCS1   WK_CTS          CutShape;
LINK        WKCS2   CutShape        WK_CTS;
LINK        MCCS1   MC_CTS          CutShape;
LINK        MCCS2   CutShape        MC_CTS;

LINK        FBR1    CutShape        BR_CTS;

/Assembly Block Cycle
LINK        ABT6    BT_WT           Assembly_Block;
LINK        LEFT1   LEFT_WT         Assembly_Block;
LINK        RIGHT1  RIGHT_WT        Assembly_Block;
LINK        ADI6    DI_WT           Assembly_Block;
LINK        FBR2    BR_CTS          Assembly_Block;

LINK        WKAB1   WK_AB           Assembly_Block;
LINK        WKAB2   Assembly_Block  WK_AB;
LINK        MCAB1   MC_AB           Assembly_Block;
LINK        MCAB2   Assembly_Block  MC_AB;

LINK        ABT7    Assembly_Block  BT_AB;
LINK        LEFT2   Assembly_Block  LEFT_AB;
LINK        RIGHT2  Assembly_Block  RIGHT_AB;
LINK        ADI7    Assembly_Block  DI_AB;
LINK        ABR1    Assembly_Block  BR_AB;

/Weld Block Cycle
LINK        ABT8    BT_AB           Weld_Block;
LINK        LEFT3   LEFT_AB         Weld_Block;
LINK        RIGHT3  RIGHT_AB        Weld_Block;
LINK        ADI8    DI_AB           Weld_Block;
LINK        ABR2    BR_AB           Weld_Block;

LINK        WKWB1   WK_WB           Weld_Block;
LINK        WKWB2   Weld_Block      WK_WB;
LINK        MCWB1   MC_WB           Weld_Block;
LINK        MCWB2   Weld_Block      MC_WB;

LINK        ABT9    Weld_Block      BT_WB;
LINK        LEFT4   Weld_Block      LEFT_WB;
LINK        RIGHT4  Weld_Block      RIGHT_WB;
                                        -4-                                                                06/28/12 03:21:18
```

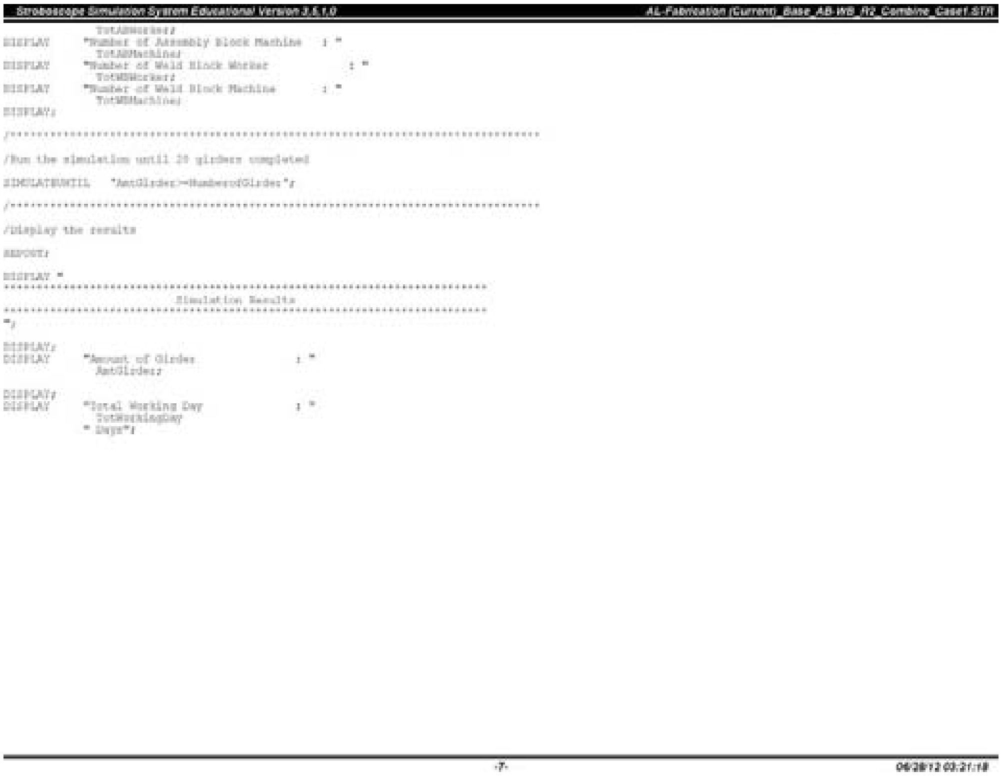
Figure C.3 (Cont.) Simulation input source code (AB-WB case no.1)

```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR
LINK        ADI9    Weld_Block      DI_WB;
LINK        ABR3    Weld_Block      BR_WB;

SEMAPHORE   CutShape        'WorkTime';
SEMAPHORE   Assembly_Block  'WorkTime';
SEMAPHORE   Weld_Block      'WorkTime';

/*********************************************************************************

/Define Variables of Station
VARIABLE    TotCTSMachine        'NumberofCTSStation*NumberofCTSMachine';
VARIABLE    TotCTSWorker         'TotCTSMachine*NumberofCTSWorker';
VARIABLE    TotABMachine         'NumberofABStation*NumberofABMachine';
VARIABLE    TotABWorker          'TotABMachine*NumberofABWorker';
VARIABLE    TotWBMachine         'NumberofWBStation*NumberofWBMachine';
VARIABLE    TotWBWorker          'TotWBMachine*NumberofWBWorker';
VARIABLE    TotMachine           'TotCTSMachine+TotABMachine+TotWBMachine';
VARIABLE    TotWorker            'TotCTSWorker+TotABWorker+TotWBWorker';

/Define Amount of Material
VARIABLE    Bottom_ASM      'NumberofRawBT*BT_perRMP/Normal[MeanBTperGirder,SDBTperGirder]';
VARIABLE    Left_ASM        'Min[Min[NumberofRawTL*TL_perRMP/Normal[MeanTLperGirder,SDTLperGirder],
                             NumberofRawWL*WL_perRMP/Normal[MeanWLperGirder,SDWLperGirder]],
                             NumberofRawSL*SL_perRMP/Normal[MeanSLperGirder,SDSLperGirder]]';
VARIABLE    Right_ASM       'Min[Min[NumberofRawTR*TR_perRMP/Normal[MeanTRperGirder,SDTRperGirder],
                             NumberofRawWR*WR_perRMP/Normal[MeanWRperGirder,SDWRperGirder]],
                             NumberofRawSR*SR_perRMP/Normal[MeanSRperGirder,SDSRperGirder]]';
VARIABLE    Diaphragm_ASM   'NumberofRawDI*DI_perRMP/Normal[MeanDIperGirder,SDDIperGirder]';

/Initializtion of Queues
INIT        BT_WT           Bottom_ASM;
INIT        LEFT_WT         Left_ASM;
INIT        RIGHT_WT        Right_ASM;
INIT        DI_WT           Diaphragm_ASM;

INIT        BR              NumberofRawBR;

INIT        WK_CTS          TotCTSWorker;
INIT        MC_CTS          TotCTSMachine;
INIT        WK_AB           TotABWorker;
INIT        MC_AB           TotABMachine;
INIT        WK_WB           TotWBWorker;
INIT        MC_WB           TotWBMachine;

/Startup to Cut Shape
DRAWDUR     RBR1                'CutShape.Bracing.Count*Pert[MinCTSLT_BR,ModeCTSLT_BR,MaxCTSLT_BR]';
DURATION    CutShape            'RBR1.SumDrawDur';

/Startup to Assembly Block
DRAWDUR     ABT6                'Assembly_Block.Bottom.Count*Uniform[MinABLT_Bottom,MaxABLT_Bottom]';
DRAWDUR     LEFT1               'Assembly_Block.LeftSide.Count*Uniform[MinABLT_Left_Flange,MaxABLT_Left_Flange]';
DRAWDUR     RIGHT1              'Assembly_Block.RightSide.Count*Uniform[MinABLT_Right_Flange,MaxABLT_Right_Flange]';
DRAWDUR     ADI6                'Assembly_Block.Diaphragm.Count*Uniform[MinABLT_Diaphragm,MaxABLT_Diaphragm]';
DRAWDUR     FBR2                'BR_CTS.CurCount*Uniform[MinABLT_Bracing,MaxABLT_Bracing]*BR_perRMP/Normal[MeanBRperGirder,SDBRperGirder]';
DURATION    Assembly_Block      'ABT6.SumDrawDur+LEFT1.SumDrawDur+RIGHT1.SumDrawDur+ADI6.SumDrawDur+FBR2.SumDrawDur';

/Startup to Weld Block
DRAWDUR     ABT8                'BT_AB.CurCount*Uniform[MinWBLT_Bottom,MaxWBLT_Bottom]';
DRAWDUR     LEFT3               'LEFT_AB.CurCount*Uniform[MinWBLT_Left_Flange,MaxWBLT_Left_Flange]';
DRAWDUR     RIGHT3              'RIGHT_AB.CurCount*Uniform[MinWBLT_Right_Flange,MaxWBLT_Right_Flange]';
DRAWDUR     ADI8                'DI_AB.CurCount*Uniform[MinWBLT_Diaphragm,MaxWBLT_Diaphragm]';
DRAWDUR     ABR2                'BR_AB.CurCount*Uniform[MinWBLT_Bracing,MaxWBLT_Bracing]';
                                          -5-                                              06/28/12 03:21:18
```

Figure C.3 (Cont.) Simulation input source code (AB-WB case no.1)

```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR
DURATION    Weld_Block          'ABT8.SumDrawDur+LEFT3.SumDrawDur+RIGHT3.SumDrawDur+ADI8.SumDrawDur+ABR2.SumDrawDur';

/Define Variables of Production
VARIABLE    AmtBT_WB            'BT_WB.TotCount';
VARIABLE    AmtLEFT_WB          'LEFT_WB.TotCount';
VARIABLE    AmtRIGHT_WB         'RIGHT_WB.TotCount';
VARIABLE    AmtDI_WB            'DI_WB.TotCount';
VARIABLE    AmtBR_WB            'BR_WB.TotCount';
VARIABLE    AmtGirder           'Min[AmtBT_WB,Min[Min[AmtLEFT_WB,AmtRIGHT_WB],Min[AmtDI_WB,AmtBR_WB]]]';

/*********************************************************************************

/Define Collector
COLLECTOR   CTSProcessTime_BR;
COLLECT     CTSProcessTime_BR       'TotalWorkMins';
ONRELEASE   FBR1     COLLECT        CTSProcessTime_BR       'TotalWorkMins';

COLLECTOR   ABProcessTime_Bottom;
COLLECT     ABProcessTime_Bottom    'TotalWorkMins';
ONRELEASE   ABT7     COLLECT        ABProcessTime_Bottom    'TotalWorkMins';
COLLECTOR   ABProcessTime_LeftSide;
COLLECT     ABProcessTime_LeftSide  'TotalWorkMins';
ONRELEASE   LEFT2    COLLECT        ABProcessTime_LeftSide  'TotalWorkMins';
COLLECTOR   ABProcessTime_RightSide;
COLLECT     ABProcessTime_RightSide 'TotalWorkMins';
ONRELEASE   RIGHT2   COLLECT        ABProcessTime_RightSide 'TotalWorkMins';
COLLECTOR   ABProcessTime_Diaphragm;
COLLECT     ABProcessTime_Diaphragm 'TotalWorkMins';
ONRELEASE   ADI7     COLLECT        ABProcessTime_Diaphragm 'TotalWorkMins';
COLLECTOR   ABProcessTime_Bracing;
COLLECT     ABProcessTime_Bracing   'TotalWorkMins';
ONRELEASE   ABR1     COLLECT        ABProcessTime_Bracing   'TotalWorkMins';

COLLECTOR   WBProcessTime_Bottom;
COLLECT     WBProcessTime_Bottom    'TotalWorkMins';
ONRELEASE   ABT9     COLLECT        WBProcessTime_Bottom    'TotalWorkMins';
COLLECTOR   WBProcessTime_LeftSide;
COLLECT     WBProcessTime_LeftSide  'TotalWorkMins';
ONRELEASE   LEFT4    COLLECT        WBProcessTime_LeftSide  'TotalWorkMins';
COLLECTOR   WBProcessTime_RightSide;
COLLECT     WBProcessTime_RightSide 'TotalWorkMins';
ONRELEASE   RIGHT4   COLLECT        WBProcessTime_RightSide 'TotalWorkMins';
COLLECTOR   WBProcessTime_Diaphragm;
COLLECT     WBProcessTime_Diaphragm 'TotalWorkMins';
ONRELEASE   ADI9     COLLECT        WBProcessTime_Diaphragm 'TotalWorkMins';
COLLECTOR   WBProcessTime_Bracing;
COLLECT     WBProcessTime_Bracing   'TotalWorkMins';
ONRELEASE   ABR3     COLLECT        WBProcessTime_Bracing   'TotalWorkMins';

/Total Working Day
VARIABLE    TotWorkingDay       'SimTime/Normal[MeanWorkingTime,SDWorkingTime]';

/*********************************************************************************

/Display Commands

DISPLAY;
DISPLAY     "Number of Cut Shape Worker          : "
              TotCTSWorker;
DISPLAY     "Number of Cut Shape Machine           : "
              TotCTSMachine;
DISPLAY     "Number of Assembly Block Worker       : "
                                          -6-                                              06/28/12 03:21:18
```

Figure C.3 (Cont.) Simulation input source code (AB-WB case no.1)


Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_AB-WB_R2_Combine_Case1.STR

```
            TotABWorker;
DISPLAY     "Number of Assembly Block Machine   : "
            TotABMachine;
DISPLAY     "Number of Weld Block Worker            : "
            TotWBWorker;
DISPLAY     "Number of Weld Block Machine      : "
            TotWBMachine;
DISPLAY;

/*****************************************************************************

/Run the simulation until 20 girders completed

SIMULATEUNTIL    "AmtGirder>=NumberofGirder";

/*****************************************************************************

/Display the results

REPORT;

DISPLAY "
************************************************************************
                         Simulation Results
************************************************************************
";

DISPLAY;
DISPLAY     "Amount of Girder                : "
            AmtGirder;

DISPLAY;
DISPLAY     "Total Working Day               : "
            TotWorkingDay
          " Days";
```

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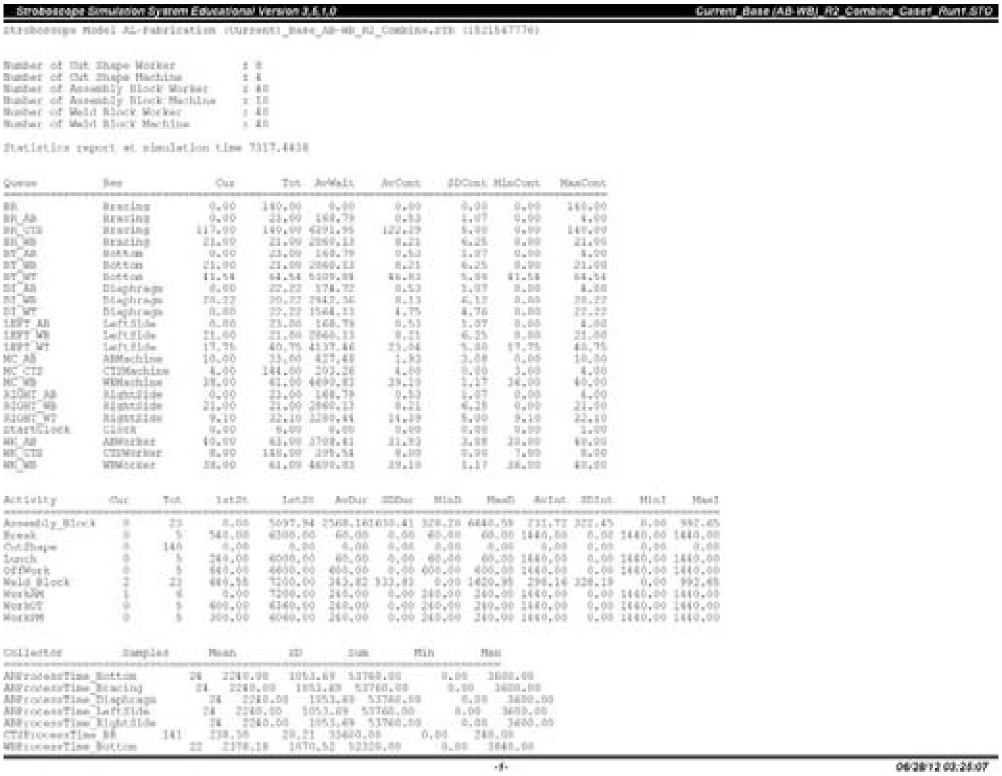
Figure C.3 (Cont.) Simulation input source code (AB-WB case no.1)


Stroboscope Simulation System Educational Version 3.5.1.0 Current_Base (AB-WB)_R2_Combine_Case1_Run1.STO

```
Stroboscope Model AL-Fabrication (Current)_Base_AB-WB_R2_Combine.STR (1521547776)


Number of Cut Shape Worker          : 8
Number of Cut Shape Machine         : 4
Number of Assembly Block Worker     : 40
Number of Assembly Block Machine    : 10
Number of Weld Block Worker         : 40
Number of Weld Block Machine        : 40

Statistics report at simulation time 7317.4438

Queue          Res               Cur        Tot   AvWait     AvCont    SDCont  MinCont   MaxCont
==================================================================================================
BR             Bracing          0.00     140.00     0.00       0.00      0.00     0.00    140.00
BR_AB          Bracing          0.00      23.00   168.79       0.53      1.07     0.00      4.00
BR_CTS         Bracing        117.00     140.00  4291.95     122.29      5.00     0.00    140.00
BR_WB          Bracing         21.00      23.00  2860.13       8.21      6.25     0.00     21.00
BT_AB          Bottom           0.00      23.00   168.79       0.53      1.07     0.00      4.00
BT_WB          Bottom          21.00      23.00  2860.13       8.21      6.25     0.00     21.00
BT_WT          Bottom          41.54      64.54  5309.88      46.83      5.58    41.54     64.54
DI_AB          Diaphragm        0.00      22.22   174.72       0.53      1.07     0.00      4.00
DI_WB          Diaphragm       20.22      20.22  2942.36       8.13      6.12     0.00     20.22
DI_WT          Diaphragm        0.00      22.22  1544.13       4.75      4.76     0.00     22.22
LEFT_AB        LeftSide         0.00      23.00   168.79       0.53      1.07     0.00      4.00
LEFT_WB        LeftSide        21.00      21.00  2860.13       8.21      6.25     0.00     21.00
LEFT_WT        LeftSide        17.75      40.75  4137.46      23.04      5.80    17.75     40.75
MC_AB          ABMachine       10.00      33.00   427.48       1.93      3.08     0.00     10.00
MC_CTS         CTSMachine       4.00     144.00   203.28       4.00      0.00     3.00      4.00
MC_WB          WBMachine       38.00      61.00  4690.83      29.19      1.17    34.00     40.00
RIGHT_AB       RightSide        0.00      23.00   168.79       0.53      1.07     0.00      4.00
RIGHT_WB       RightSide       21.00      21.00  2860.13       8.21      6.25     0.00     21.00
RIGHT_WT       RightSide        9.10      32.10  3290.44      14.39      5.00     9.10     32.10
StartClock     Clock            0.00       0.00     0.00       0.00      0.00     0.00      1.00
WK_AB          ABWorker        40.00      63.00  3708.41      21.93      3.08    33.00     40.00
WK_CTS         CTSWorker        8.00     148.00   295.58       8.00      0.20     7.00      8.00
WK_WB          WBWorker        38.00      61.00  4690.83      29.19      1.17    38.00     40.00

Activity        Cur     Tot     1stSt     LstSt    AvDur  SDDur    MinD     MaxD    AvInt  SDInt     MinI     MaxI
=====================================================================================================================
Assembly_Block    0      23      0.00   5097.94  2568.161650.41  328.28 6640.55   231.77 322.45     0.00   992.65
Break             0       5    540.00   6300.00    60.00   0.00   60.00    60.00  1440.00   0.00  1440.00  1440.00
CutShape          0     140      0.00      0.00     0.00   0.00    0.00     0.00     0.00   0.00     0.00     0.00
Lunch             0       5    240.00   6000.00    60.00   0.00   60.00    60.00  1440.00   0.00  1440.00  1440.00
OffWork           0       5    840.00   6600.00   600.00   0.00  600.00   600.00  1440.00   0.00  1440.00  1440.00
Weld_Block        2      23    444.55   7200.00   343.82 533.83    0.00  1620.95   298.16 328.19     0.00   992.65
WorkAM            1       6      0.00   7200.00   240.00   0.00  240.00   240.00  1440.00   0.00  1440.00  1440.00
WorkOT            0       5    600.00   6360.00   240.00   0.00  240.00   240.00  1440.00   0.00  1440.00  1440.00
WorkPM            0       5    300.00   6060.00   240.00   0.00  240.00   240.00  1440.00   0.00  1440.00  1440.00

Collector             Samples       Mean          SD        Sum         Min         Max
=========================================================================================
ABProcessTime_Bottom         24   2240.00   1053.69  53760.00       0.00   3600.00
ABProcessTime_Bracing         24   2240.00   1053.69  53760.00       0.00   3600.00
ABProcessTime_Diaphragm         24   2240.00   1053.69  53760.00       0.00   3600.00
ABProcessTime_LeftSide         24   2240.00   1053.69  53760.00       0.00   3600.00
ABProcessTime_RightSide         24   2240.00   1053.69  53760.00       0.00   3600.00
CTSProcessTime_BR       141    238.30     28.21  33600.00       0.00    240.00
WBProcessTime_Bottom         22   2378.18   1670.52  52320.00       0.00   3840.00
```

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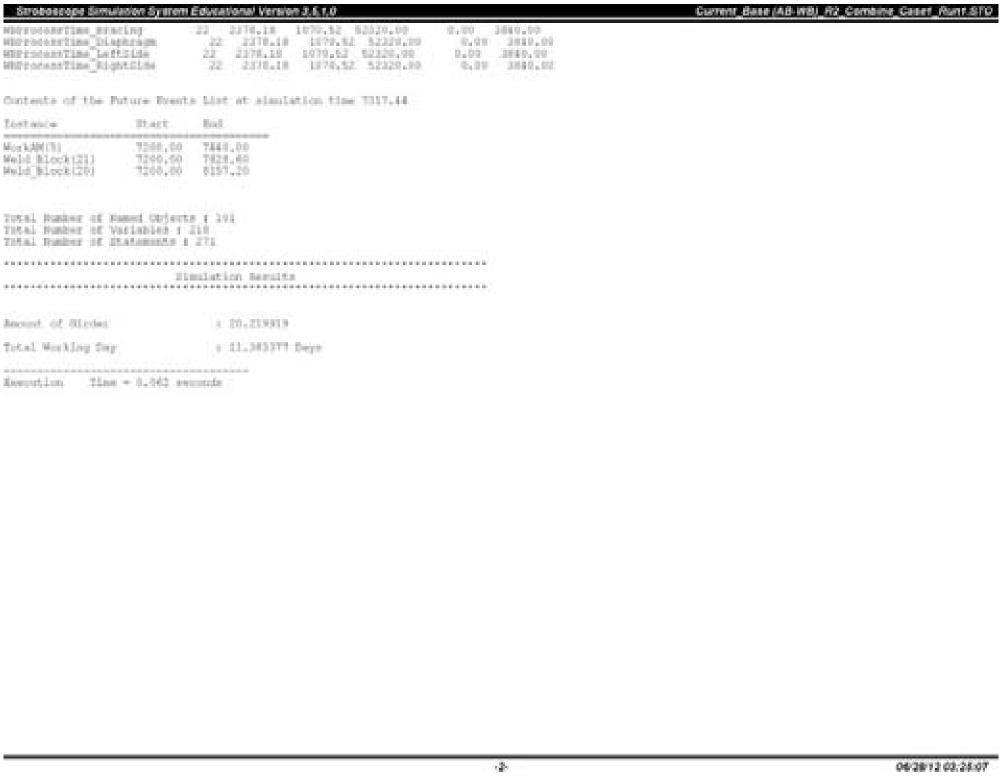
Figure C.4 Simulation output source code (AB-WB case no.1)

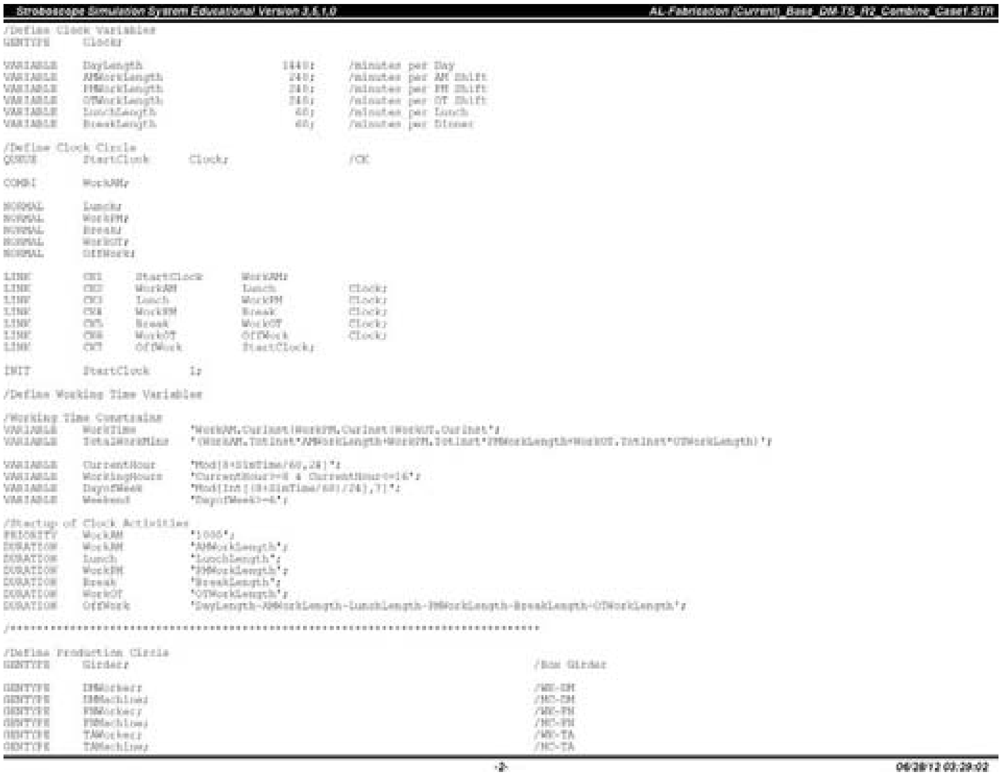


```
Stroboscope Simulation System Educational Version 3.5.1.0          Current_Base (AB-WB)_R2_Combine_Case1_Run1.STO
WBProcessTime_Bracing         22   2378.18   1070.52  52320.00       0.00   3840.00
WBProcessTime_Diaphragm         22   2378.18   1070.52  52320.00       0.00   3840.00
WBProcessTime_LeftSide        22   2378.18   1070.52  52320.00       0.00   3840.00
WBProcessTime_RightSide         22   2378.18   1070.52  52320.00       0.00   3840.00

Contents of the Future Events List at simulation time 7317.44

Instance            Start      End
===========================================
WorkAM(5)           7200.00   7440.00
Weld_Block(21)      7200.00   7828.80
Weld_Block(20)      7200.00   8157.20


Total Number of Named Objects : 191
Total Number of Variables : 218
Total Number of Statements : 271

*******************************************************************************
                            Simulation Results
*******************************************************************************


Amount of Girder                   : 20.219919

Total Working Day                  : 11.383377 Days

----------------------------------------
Execution    Time = 0.042 seconds

                                                    -2-                             06/28/12 03:25:07
```

Figure C.4 (Cont.) Simulation output source code (AB-WB case no.1)

```
Stroboscope Simulation System Educational Version 3.5.1.0     AL-Fabrication (Current)_Base_DM-TS_R2_Combine_Case1.STR
/*******************************************************************************
/STROBOSCOPE Simulation Program by Mr Worawat Srisdom
/*******************************************************************************
/Steel Box Girder Bridge Fabrication Process - DM-TS (Current) Base (R2) Combine Case1
/*******************************************************************************

/Problem Decision Variables
VARIABLE    NumberofDMStation            10;      /                                                   10
VARIABLE    NumberofDMMachine             2;      /machines per Dimension Station                     1
VARIABLE    NumberofDMWorker              1;      /persons per Dimension Machine

VARIABLE    NumberofFNStation             2;      /                                                   2
VARIABLE    NumberofFNMachine             1;      /machines per Finishing Station (Overhead Crane)    2
VARIABLE    NumberofFNWorker              5;      /persons per Finishing Machine

VARIABLE    NumberofTAStation             6;      /                                                   6
VARIABLE    NumberofTAMachine             2;      /machines per Trial Assembly Station (Gantry Crane) 2
VARIABLE    NumberofTAWorker              5;      /persons per Trial Assembly Machine

VARIABLE    NumberofBLStation             1;      /                                                   1
VARIABLE    NumberofBLMachine             3;      /machines per Blasting Station                      3
VARIABLE    NumberofBLWorker              1;      /persons per Blasting Machine

VARIABLE    NumberofPAStation             4;      /                                                   4
VARIABLE    NumberofPAMachine             3;      /machines per Painting Station                      3
VARIABLE    NumberofPAWorker              1;      /person per Painting Machine

VARIABLE    NumberofPCStation             5;      /                                                   5
VARIABLE    NumberofPCMachine             1;      /machines per Packing Station                       2
VARIABLE    NumberofPCWorker              2;      /persons per Packing Machine

VARIABLE    NumberofTSStation             1;      /                                                   1
VARIABLE    NumberofTSMachine            10;      /machines per Packing Station                       10
VARIABLE    NumberofTSWorker              4;      /persons per Packing Machine

/Amount of Girders
VARIABLE    NumberofGirder               20;      /Total Girder Production

/Process Time Variables
VARIABLE    MaxDM_Girder              54.50;      /Max Process Time of Dimension Activity for Whole Girder
VARIABLE    MinDM_Girder               5.50;      /Min Process Time of Dimension Activity for Whole Girder
VARIABLE    MaxFN_Girder            1512.50;      /Max Process Time of Finishing Activity for Whole Girder
VARIABLE    MinFN_Girder              95.00;      /Min Process Time of Finishing Activity for Whole Girder
VARIABLE    MaxTA_Girder            1511.25;      /Max Process Time of TrialAssembly Activity for Whole Girder
VARIABLE    MinTA_Girder             190.00;      /Min Process Time of TrialAssembly Activity for Whole Girder
VARIABLE    MaxBL_Girder             360.00;      /Max Process Time of Blasting Activity for Whole Girder
VARIABLE    MinBL_Girder             100.00;      /Min Process Time of Blasting Activity for Whole Girder
VARIABLE    MaxPA_Girder             271.25;      /Max Process Time of Painting Activity for Whole Girder
VARIABLE    MinPA_Girder              65.42;      /Min Process Time of Painting Activity for Whole Girder
VARIABLE    MaxPC_Girder               6.00;      /Max Process Time of Packing Activity for Whole Girder
VARIABLE    ModePC_Girder              5.00;      /Mode Process Time of Packing Activity for Whole Girder
VARIABLE    MinPC_Girder               4.00;      /Min Process Time of Packing Activity for Whole Girder
VARIABLE    MaxTS_Girder             182.00;      /Max Process Time of Transportation Activity for Whole Girder
VARIABLE    ModeTS_Girder             72.00;      /Mode Process Time of Transportation Activity for Whole Girder
VARIABLE    MinTS_Girder              18.00;      /Min Process Time of Transportation Activity for Whole Girder

/Working Time Variables
VARIABLE    MeanWorkingTime          684.00;      /Mean Working Time per Day in Minutes
VARIABLE    SDWorkingTime             84.00;      /SD Working Time per Day in Minutes

/*******************************************************************************

                                                    -1-                             06/28/12 03:29:02
```

Figure C.5 Simulation input source code (DM-TS case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 **AL-Fabrication (Current)_Base_DM-TS_R2_Combine_Case1.STR**

```
/Define Clock Variables
GENTYPE     Clock;

VARIABLE    DayLength                   1440;     /minutes per Day
VARIABLE    AMWorkLength                 240;     /minutes per AM Shift
VARIABLE    PMWorkLength                 240;     /minutes per PM Shift
VARIABLE    OTWorkLength                 240;     /minutes per OT Shift
VARIABLE    LunchLength                   60;     /minutes per Lunch
VARIABLE    BreakLength                   60;     /minutes per Dinner

/Define Clock Circle
QUEUE       StartClock      Clock;                /CK

COMBI       WorkAM;

NORMAL      Lunch;
NORMAL      WorkPM;
NORMAL      Break;
NORMAL      WorkOT;
NORMAL      OffWork;

LINK        CK1     StartClock      WorkAM;
LINK        CK2     WorkAM          Lunch           Clock;
LINK        CK3     Lunch           WorkPM          Clock;
LINK        CK4     WorkPM          Break           Clock;
LINK        CK5     Break           WorkOT          Clock;
LINK        CK6     WorkOT          OffWork         Clock;
LINK        CK7     OffWork         StartClock;

INIT        StartClock      1;

/Define Working Time Variables

/Working Time Constrains
VARIABLE    WorkTime        'WorkAM.CurInst|WorkPM.CurInst|WorkOT.CurInst';
VARIABLE    TotalWorkMins   '(WorkAM.TotInst*AMWorkLength+WorkPM.TotInst*PMWorkLength+WorkOT.TotInst*OTWorkLength)';

VARIABLE    CurrentHour     'Mod(8+SimTime/60,24)';
VARIABLE    WorkingHours    'CurrentHour>=8 & CurrentHour<=16';
VARIABLE    DayofWeek       'Mod(Int((8+SimTime/60)/24),7)';
VARIABLE    Weekend         'DayofWeek>=6';

/Startup of Clock Activities
PRIORITY    WorkAM          '1000';
DURATION    WorkAM          'AMWorkLength';
DURATION    Lunch           'LunchLength';
DURATION    WorkPM          'PMWorkLength';
DURATION    Break           'BreakLength';
DURATION    WorkOT          'OTWorkLength';
DURATION    OffWork         'DayLength-AMWorkLength-LunchLength-PMWorkLength-BreakLength-OTWorkLength';

/******************************************************************************

/Define Production Circle
GENTYPE     Girder;                                                 /Box Girder

GENTYPE     DMWorker;                                               /WK-DM
GENTYPE     DMMachine;                                              /MC-DM
GENTYPE     FNWorker;                                               /WK-FN
GENTYPE     FNMachine;                                              /MC-FN
GENTYPE     TAWorker;                                               /WK-TA
GENTYPE     TAMachine;                                              /MC-TA
```

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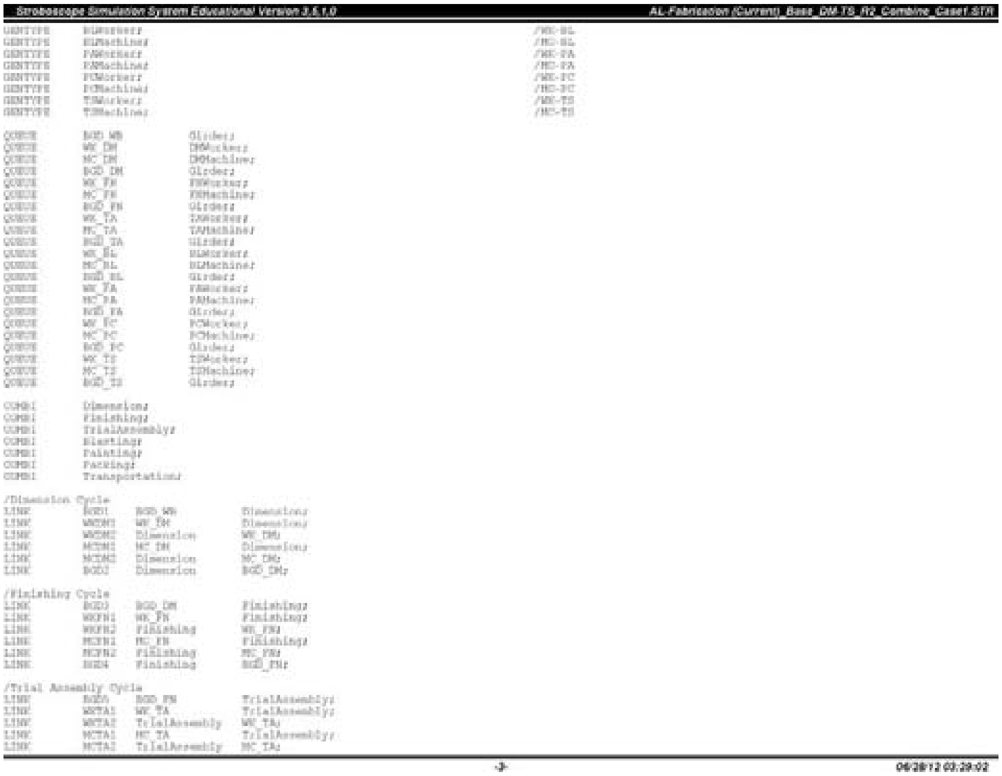
Figure C.5 (Cont.) Simulation input source code (DM-TS case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 **AL-Fabrication (Current)_Base_DM-TS_R2_Combine_Case1.STR**

```
GENTYPE     BLWorker;                                               /WK-BL
GENTYPE     BLMachine;                                              /MC-BL
GENTYPE     PAWorker;                                               /WK-PA
GENTYPE     PAMachine;                                              /MC-PA
GENTYPE     PCWorker;                                               /WK-PC
GENTYPE     PCMachine;                                              /MC-PC
GENTYPE     TSWorker;                                               /WK-TS
GENTYPE     TSMachine;                                              /MC-TS

QUEUE       BGD_WH          Girder;
QUEUE       WK_DM           DMWorker;
QUEUE       MC_DM           DMMachine;
QUEUE       BGD_DM          Girder;
QUEUE       WK_FN           FNWorker;
QUEUE       MC_FN           FNMachine;
QUEUE       BGD_FN          Girder;
QUEUE       WK_TA           TAWorker;
QUEUE       MC_TA           TAMachine;
QUEUE       BGD_TA          Girder;
QUEUE       WK_BL           BLWorker;
QUEUE       MC_BL           BLMachine;
QUEUE       BGD_BL          Girder;
QUEUE       WK_PA           PAWorker;
QUEUE       MC_PA           PAMachine;
QUEUE       BGD_PA          Girder;
QUEUE       WK_PC           PCWorker;
QUEUE       MC_PC           PCMachine;
QUEUE       BGD_PC          Girder;
QUEUE       WK_TS           TSWorker;
QUEUE       MC_TS           TSMachine;
QUEUE       BGD_TS          Girder;

COMBI       Dimension;
COMBI       Finishing;
COMBI       TrialAssembly;
COMBI       Blasting;
COMBI       Painting;
COMBI       Packing;
COMBI       Transportation;

/Dimension Cycle
LINK        BGD1    BGD_WH          Dimension;
LINK        WKDM1   WK_DM           Dimension;
LINK        WKDM2   Dimension       WK_DM;
LINK        MCDM1   MC_DM           Dimension;
LINK        MCDM2   Dimension       MC_DM;
LINK        BGD2    Dimension       BGD_DM;

/Finishing Cycle
LINK        BGD3    BGD_DM          Finishing;
LINK        WKFN1   WK_FN           Finishing;
LINK        WKFN2   Finishing       WK_FN;
LINK        MCFN1   MC_FN           Finishing;
LINK        MCFN2   Finishing       MC_FN;
LINK        BGD4    Finishing       BGD_FN;

/Trial Assembly Cycle
LINK        BGD5    BGD_FN          TrialAssembly;
LINK        WKTA1   WK_TA           TrialAssembly;
LINK        WKTA2   TrialAssembly   WK_TA;
LINK        MCTA1   MC_TA           TrialAssembly;
LINK        MCTA2   TrialAssembly   MC_TA;
```

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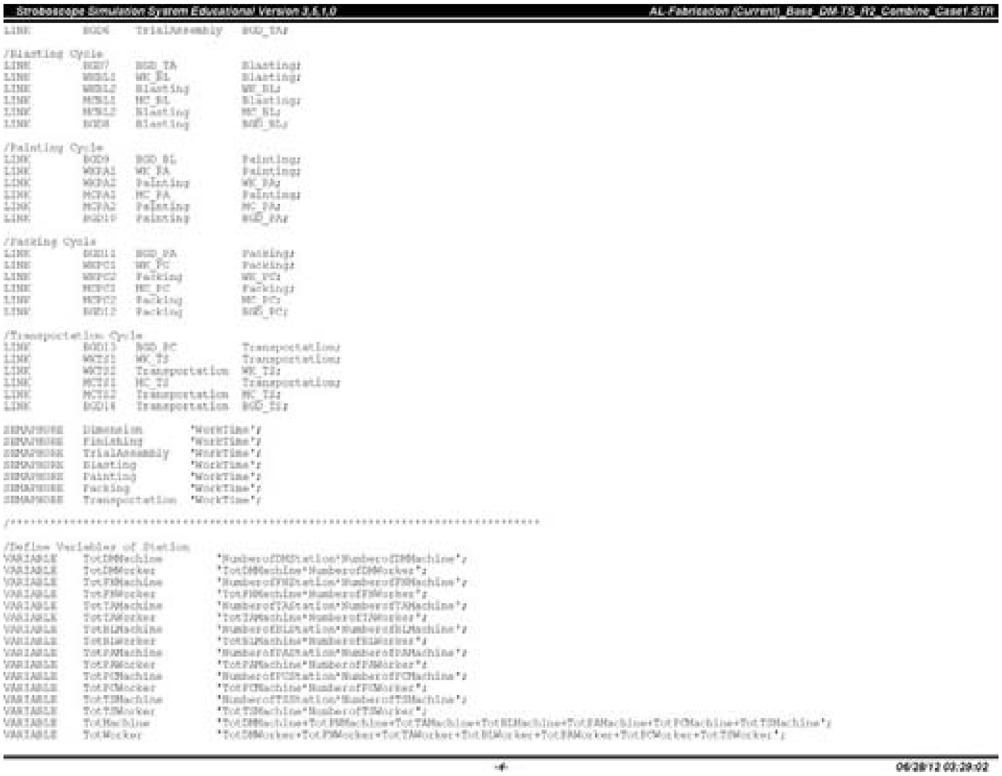
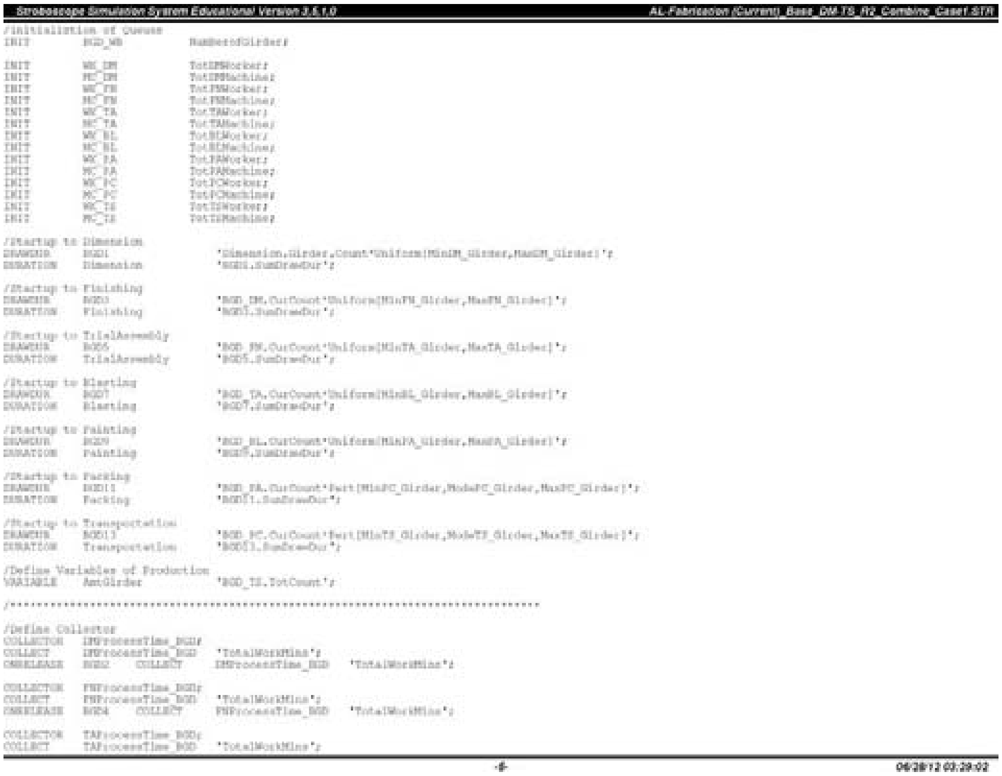
Figure C.5 (Cont.) Simulation input source code (DM-TS case no.1)



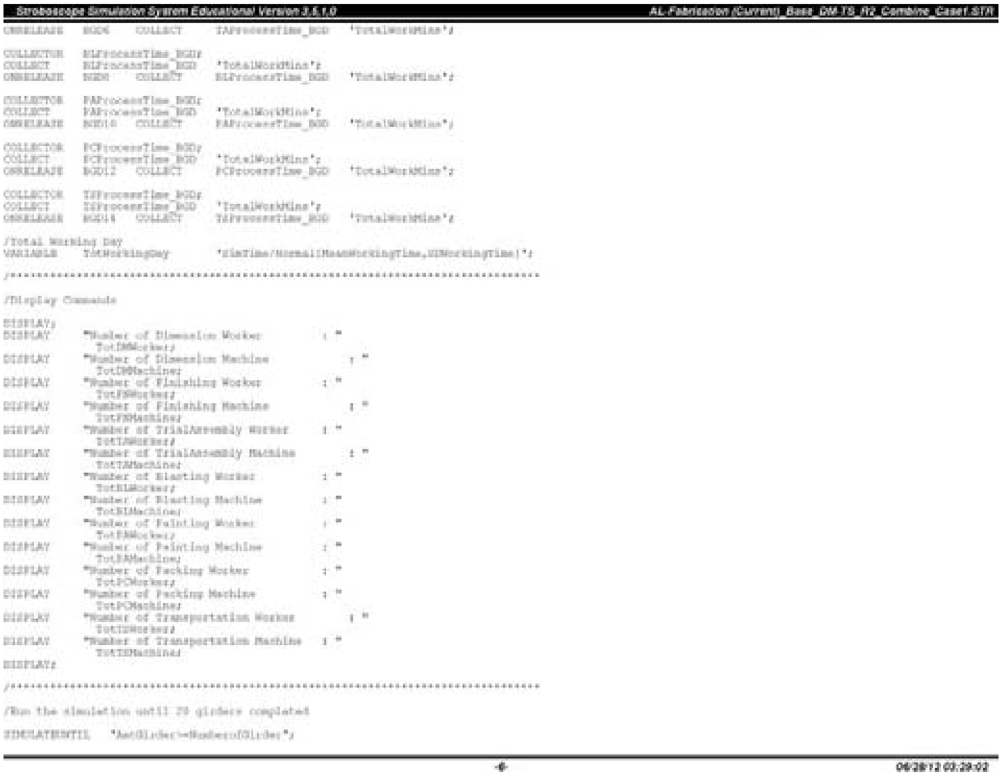
```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_DM-TS_R2_Combine_Case1.STR
LINK        BGD6    TrialAssembly   BGD_TA;

/Blasting Cycle
LINK        BGD7    BGD_TA          Blasting;
LINK        WKBL1   WK_BL           Blasting;
LINK        WKBL2   Blasting        WK_BL;
LINK        MCBL1   MC_BL           Blasting;
LINK        MCBL2   Blasting        MC_BL;
LINK        BGD8    Blasting        BGD_BL;

/Painting Cycle
LINK        BGD9    BGD_BL          Painting;
LINK        WKPA1   WK_PA           Painting;
LINK        WKPA2   Painting        WK_PA;
LINK        MCPA1   MC_PA           Painting;
LINK        MCPA2   Painting        MC_PA;
LINK        BGD10   Painting        BGD_PA;

/Packing Cycle
LINK        BGD11   BGD_PA          Packing;
LINK        WKPC1   WK_PC           Packing;
LINK        WKPC2   Packing         WK_PC;
LINK        MCPC1   MC_PC           Packing;
LINK        MCPC2   Packing         MC_PC;
LINK        BGD12   Packing         BGD_PC;

/Transportation Cycle
LINK        BGD13   BGD_PC          Transportation;
LINK        WKTS1   WK_TS           Transportation;
LINK        WKTS2   Transportation  WK_TS;
LINK        MCTS1   MC_TS           Transportation;
LINK        MCTS2   Transportation  MC_TS;
LINK        BGD14   Transportation  BGD_TS;

SEMAPHORE   Dimension       'WorkTime';
SEMAPHORE   Finishing       'WorkTime';
SEMAPHORE   TrialAssembly   'WorkTime';
SEMAPHORE   Blasting        'WorkTime';
SEMAPHORE   Painting        'WorkTime';
SEMAPHORE   Packing         'WorkTime';
SEMAPHORE   Transportation  'WorkTime';

/*******************************************************************************

/Define Variables of Station
VARIABLE    TotDMMachine        'NumberofDMStation*NumberofDMMachine';
VARIABLE    TotDMWorker         'TotDMMachine*NumberofDMWorker';
VARIABLE    TotFMMachine        'NumberofFMStation*NumberofFMMachine';
VARIABLE    TotFMWorker         'TotFMMachine*NumberofFMWorker';
VARIABLE    TotTAMachine        'NumberofTAStation*NumberofTAMachine';
VARIABLE    TotTAWorker         'TotTAMachine*NumberofTAWorker';
VARIABLE    TotBLMachine        'NumberofBLStation*NumberofBLMachine';
VARIABLE    TotBLWorker         'TotBLMachine*NumberofBLWorker';
VARIABLE    TotPAMachine        'NumberofPAStation*NumberofPAMachine';
VARIABLE    TotPAWorker         'TotPAMachine*NumberofPAWorker';
VARIABLE    TotPCMachine        'NumberofPCStation*NumberofPCMachine';
VARIABLE    TotPCWorker         'TotPCMachine*NumberofPCWorker';
VARIABLE    TotTSMachine        'NumberofTSStation*NumberofTSMachine';
VARIABLE    TotTSWorker         'TotTSMachine*NumberofTSWorker';
VARIABLE    TotMachine          'TotDMMachine+TotFMMachine+TotTAMachine+TotBLMachine+TotPAMachine+TotPCMachine+TotTSMachine';
VARIABLE    TotWorker           'TotDMWorker+TotFMWorker+TotTAWorker+TotBLWorker+TotPAWorker+TotPCWorker+TotTSWorker';
                                        -4-                                                            06/28/12 03:29:02
```

Figure C.5 (Cont.) Simulation input source code (DM-TS case no.1)



```
Stroboscope Simulation System Educational Version 3.5.1.0          AL-Fabrication (Current)_Base_DM-TS_R2_Combine_Case1.STR
/Initialization of Queues
INIT        BGD_WB          NumberofGirder;

INIT        WK_DM           TotDMWorker;
INIT        MC_DM           TotDMMachine;
INIT        WK_FM           TotFMWorker;
INIT        MC_FM           TotFMMachine;
INIT        WK_TA           TotTAWorker;
INIT        MC_TA           TotTAMachine;
INIT        WK_BL           TotBLWorker;
INIT        MC_BL           TotBLMachine;
INIT        WK_PA           TotPAWorker;
INIT        MC_PA           TotPAMachine;
INIT        WK_PC           TotPCWorker;
INIT        MC_PC           TotPCMachine;
INIT        WK_TS           TotTSWorker;
INIT        MC_TS           TotTSMachine;

/Startup to Dimension
DRAWDUR     BGD1                'Dimension.Girder.Count*Uniform[MinDM_Girder,MaxDM_Girder]';
DURATION    Dimension           'BGD1.SumDrawDur';

/Startup to Finishing
DRAWDUR     BGD3                'BGD_DM.CurCount*Uniform[MinFM_Girder,MaxFM_Girder]';
DURATION    Finishing           'BGD3.SumDrawDur';

/Startup to TrialAssembly
DRAWDUR     BGD5                'BGD_FM.CurCount*Uniform[MinTA_Girder,MaxTA_Girder]';
DURATION    TrialAssembly       'BGD5.SumDrawDur';

/Startup to Blasting
DRAWDUR     BGD7                'BGD_TA.CurCount*Uniform[MinBL_Girder,MaxBL_Girder]';
DURATION    Blasting            'BGD7.SumDrawDur';

/Startup to Painting
DRAWDUR     BGD9                'BGD_BL.CurCount*Uniform[MinPA_Girder,MaxPA_Girder]';
DURATION    Painting            'BGD9.SumDrawDur';

/Startup to Packing
DRAWDUR     BGD11               'BGD_PA.CurCount*Pert[MinPC_Girder,ModePC_Girder,MaxPC_Girder]';
DURATION    Packing             'BGD11.SumDrawDur';

/Startup to Transportation
DRAWDUR     BGD13               'BGD_PC.CurCount*Pert[MinTS_Girder,ModeTS_Girder,MaxTS_Girder]';
DURATION    Transportation      'BGD13.SumDrawDur';

/Define Variables of Production
VARIABLE    AmtGirder           'BGD_TS.TotCount';

/*******************************************************************************

/Define Collector
COLLECTOR   DMProcessTime_BGD;
COLLECT     DMProcessTime_BGD   'TotalWorkMins';
ONRELEASE   BGD2    COLLECT     DMProcessTime_BGD   'TotalWorkMins';

COLLECTOR   FMProcessTime_BGD;
COLLECT     FMProcessTime_BGD   'TotalWorkMins';
ONRELEASE   BGD4    COLLECT     FMProcessTime_BGD   'TotalWorkMins';

COLLECTOR   TAProcessTime_BGD;
COLLECT     TAProcessTime_BGD   'TotalWorkMins';
                                        -5-                                                            06/28/12 03:29:02
```

Figure C.5 (Cont.) Simulation input source code (DM-TS case no.1)



Stroboscope Simulation System Educational Version 3.5.1.0 AL-Fabrication (Current)_Base_DM-TS_R2_Combine_Case1.STR

```
ONRELEASE    BGD6    COLLECT      TAProcessTime_BGD    'TotalWorkMins';

COLLECTOR    BLProcessTime_BGD;
COLLECT      BLProcessTime_BGD    'TotalWorkMins';
ONRELEASE    BGD8    COLLECT      BLProcessTime_BGD    'TotalWorkMins';

COLLECTOR    PAProcessTime_BGD;
COLLECT      PAProcessTime_BGD    'TotalWorkMins';
ONRELEASE    BGD10   COLLECT      PAProcessTime_BGD    'TotalWorkMins';

COLLECTOR    PCProcessTime_BGD;
COLLECT      PCProcessTime_BGD    'TotalWorkMins';
ONRELEASE    BGD12   COLLECT      PCProcessTime_BGD    'TotalWorkMins';

COLLECTOR    TSProcessTime_BGD;
COLLECT      TSProcessTime_BGD    'TotalWorkMins';
ONRELEASE    BGD14   COLLECT      TSProcessTime_BGD    'TotalWorkMins';

/Total Working Day
VARIABLE     TotWorkingDay        'SimTime/Normal[MeanWorkingTime,SDWorkingTime]';

/*******************************************************************************

/Display Commands

DISPLAY;
DISPLAY      "Number of Dimension Worker          : "
               TotDMWorker;
DISPLAY      "Number of Dimension Machine              : "
               TotDMMachine;
DISPLAY      "Number of Finishing Worker          : "
               TotFNWorker;
DISPLAY      "Number of Finishing Machine              : "
               TotFNMachine;
DISPLAY      "Number of TrialAssembly Worker      : "
               TotTAWorker;
DISPLAY      "Number of TrialAssembly Machine          : "
               TotTAMachine;
DISPLAY      "Number of Blasting Worker           : "
               TotBLWorker;
DISPLAY      "Number of Blasting Machine          : "
               TotBLMachine;
DISPLAY      "Number of Painting Worker           : "
               TotPAWorker;
DISPLAY      "Number of Painting Machine          : "
               TotPAMachine;
DISPLAY      "Number of Packing Worker            : "
               TotPCWorker;
DISPLAY      "Number of Packing Machine           : "
               TotPCMachine;
DISPLAY      "Number of Transportation Worker          : "
               TotTSWorker;
DISPLAY      "Number of Transportation Machine    : "
               TotTSMachine;
DISPLAY;

/*******************************************************************************

/Run the simulation until 20 gliders completed

SIMULATEUNTIL    'AmtGlider>=NumberofGlider';
```

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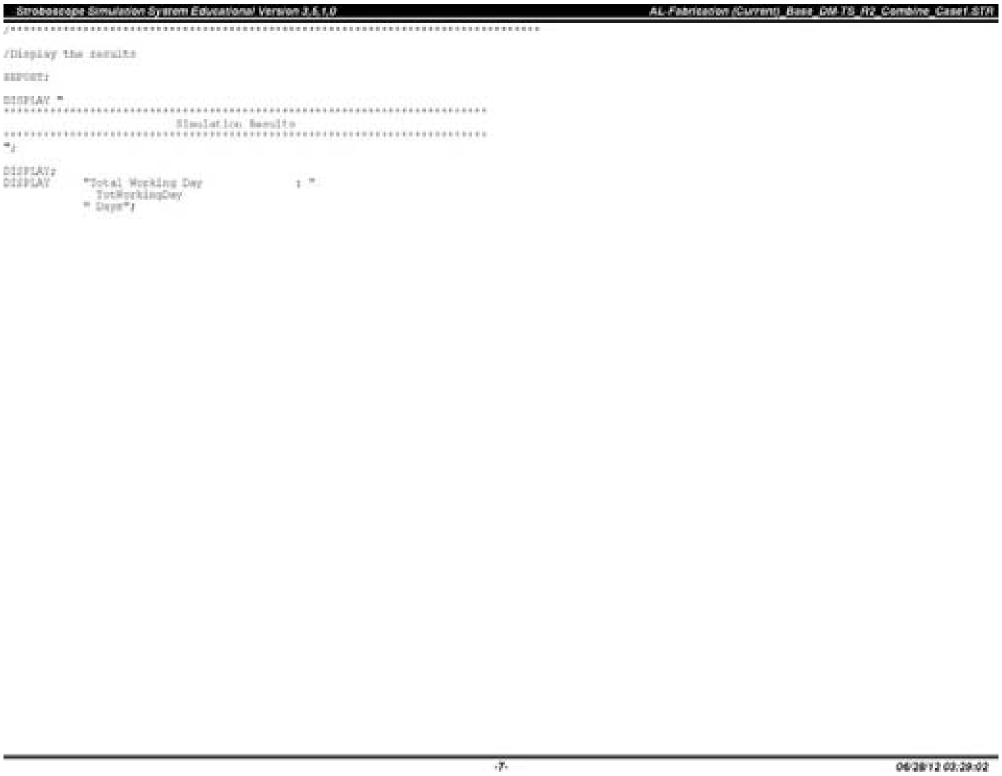
Figure C.5 (Cont.) Simulation input source code (DM-TS case no.1)



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```
/*******************************************************************************

/Display the results

REPORT;

DISPLAY "
*************************************************************************
                         Simulation Results
*************************************************************************
";

DISPLAY;
DISPLAY      "Total Working Day                   : "
               TotWorkingDay
             " Days";
```

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Figure C.5 (Cont.) Simulation input source code (DM-TS case no.1)

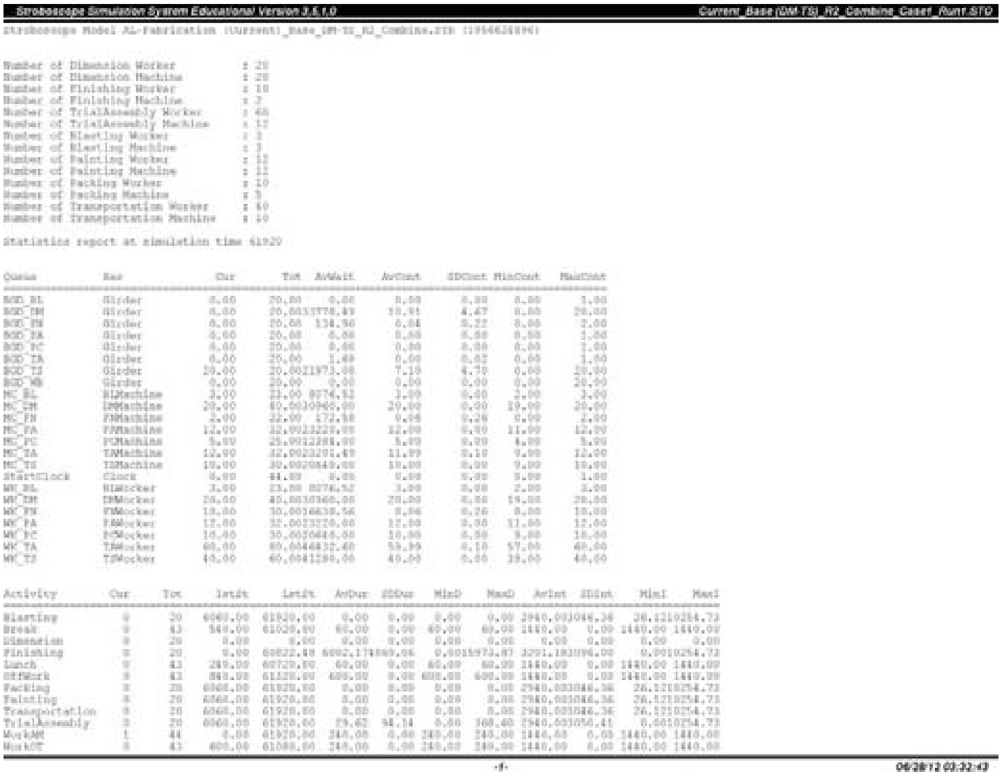

Figure C.6 Simulation output source code (DM-TS case no.1)

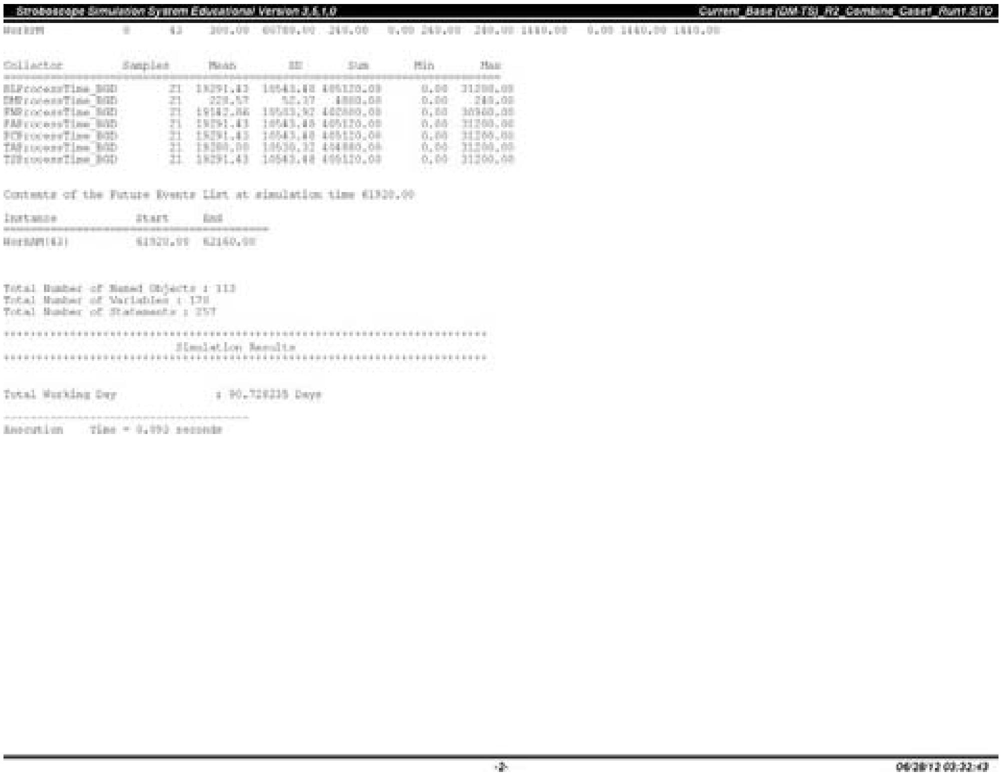

Figure C.6 (Cont.) Simulation output source code (DM-TS case no.1)

VITAE

Worawat Sriudom was born on October 26th, 1982 in Nonthaburi, Thailand. He received his Bachelor's Degree of Engineering in Civil Engineering from Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang in 2003. After graduation, he has been employed under position of Design Engineer by ITALIAN-THAI DEVELOPMENT Public Co., Ltd. In 2008 he continued with Master Degree studies of Infrastructure in Civil Engineering, Department of Civil Engineering, Chulalongkorn University.

About proceeding of this research was published on 24th KKCNN Symposium at Hyogo, Japan on December 2011 and he got excellent presentation prize from this event. Currently, he is Freelancer Civil Engineer to work for structural design and shop drawing along with construction project.