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# COLLABORATIVE PROCESS PLANNING AND FLOW ANALYSIS FOR AUTOMOTIVE ASSEMBLY SHOPS

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**ABSTRACT**–To maintain competitiveness in the modern automotive market, it is important to carry out process planning concurrently with new car development processes. Process planners need to make decisions concurrently and collaboratively in order to reduce manufacturing preparation time for developing a new car. Automated generation of a simulation model by using the integrated process plan database can reduce time consumed for carrying out a simulation and allow a consistent model to be used throughout. In this research, we developed a web-based system for concurrent and collaborative process planning and flow analysis for an automotive general assembly using web, database, and simulation technology. A single integrated database is designed to automatically generate simulation models from process plans without having to rework the data. This system enables process planners to evaluate their decisions quickly, considering various factors, and easily share their opinions with others. By using this collaborative system, time and cost put into the assembly process planning can be reduced and the reliability of the process plan would be improved.

**KEY WORDS :** Assembly, Collaborative engineering, Process planning

## 1. INTRODUCTION

As customer demand is very diverse and global competitions among automotive companies are becoming more and more aggressive, an automotive company need to find new paradigms and technologies in order to rapidly develop diverse new cars (Crabb, 1998). An automotive general assembly shop consists of many sub-assembly lines, workstations, workers and components to be assembled. A process planner decides assembly methods, locations, sequences, tools, equipments, the number of workers and time that should be needed for each operation in the general assembly lines. In addition to making these decisions, the planners must maintain an overall balance and consider several prerequisites of the lines.

Considering the wideness and complexity of automotive manufacturing, the process planning task for an automotive general assembly is generally divided into several sub-tasks and performed by several process planners. Since every process planner is responsible for deliberating on only a limited number of equipments, workers and parts, it is necessary for him or her to have access to the data of other planners at real time, and all of these planners need to be fully aware of the current status on parts and of every operation in the assembly line. Thus, information management and collaboration environments are essential for reliable and effective process planning.

Most previous researches on assembly process planning dealt with line balancing problems, because this line balancing problem was one of the most difficult issues in this field. The main issue is to find a way to distribute the total workload as evenly as possible among workers. The largest-candidate rule, the Kilbridge and Wester's method, and the ranked positional weights method are the conventional methods that have been effective tools for the line balancing, and there are also many heuristic methods (Groover, 2001). For example, R. Klein and A. Scholl proposed a branch and bound procedure to solve the balancing problem for a single assembly line and a given number of stations (Klein and Scholl, 1996). Rubinovitz and Levitin (1995) developed a genetic algorithm for the generation of multiple solutions to the assembly line balancing problem. Driscoll and Thilakawardana (2001) introduced a new compound expression for the line balancing difficulty and project index, and compared this new measure with existing measures. They finally presented a new software for the assembly line balancing with the proposed measure.

Process planners need to evaluate whether their decision is valid or not. There are many factors to be

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considered in evaluating a process plan such as workplace arrangement, storage space, material handling, material allocation, material flow, etc. as well as line balancing and cycle time. The evaluation process helps a planner to understand if the process plan and the production system are in compliance with each other. A simulation model for the purpose of evaluation can be generated based on the decision made by the engineers, but it is cumbersome to build a simulation model as preparation of the data and building the model itself involve redundant tasks, which in turn means that the whole process is time consuming. Another problem to this simulation model is the inconsistency between the information used for building simulation model and the data from process plan due to its frequent modification. Therefore, it is essential of integrate process planning and simulation in order to solve this problem caused by such discrepancies. Such an integrated environment enables process planners to automatically generate a simulation model from process plan information so that they can make use of a consistent digital model and reduce the model development time.

Some examples of such integration can be summarized as follows. Sly and Moorthy (2001) suggested an automated integration of the facility layout and simulation technologies using SDX (Simulation Data Exchange). Mecklenburg (2001) also used SDX for integration of layout and simulation to enable virtual factory. Randell and Bolmsjö (2001) have automatically generated and driven the simulation model from production planning database. Bruner (2001) has presented a single integrated environment for workplace planning.

In this research, we present a web-based collaborative process planning system and an integrated process flow analysis system for automotive general assembly. To achieve effective information sharing and collaboration in the process planning, we analyzed and improved the business workflow of the process planning activities, and the design database schema and application software in web environments. We used FactoryFlow® as a tool for simulating and analyzing production flow. A single integrated database is used for process planning and flow analysis so as to minimize the building time of analysis models, and consequently, avoid data redundancy and inconsistency. This also makes it possible to automatically extract the information for simulation directly from the process planning system.

This process planning and flow analysis system driven by the integrated database enables many dispersed planers to perform process planning on their own web browsers in concurrent and collaborative manners with the help of simulation technology. Using this system, the business workflow of the process planning activities would be improved.

## 2. ENGINEERING COLLABORATION FOR PROCESS PLANNING IN AN AUTOMOTIVE GENERAL ASSEMBLY SYSTEM

This research is focused on process planning in automotive general assembly shops. The automotive general assembly shops have the following characteristics:

a) Most of the works are done by human workers, the performance of which are largely dependent on their experiences and skills.

b) Process planning is difficult, and it involves a lot of works and consumes a lot of time due to the fact that the assembly processes are very extensive and complex.

c) Listing, arranging, and analyzing the processes require very enormous works that optimization and data management are extremely difficult.

d) Process Planners who are physically distributed need to gather and exchange their opinions to make process plans due to the vastness and complexity of assembly processes.

e) Validity and effectiveness in process planning by vast number of people are important.

Process planning for the general assembly line is directly connected with the overall production planning, and is performed by many process planners simultaneously. They must consider many factors such as line balancing, cycle time, storage space, material handling, material allocation, material flow, etc. Due to the complicated business workflow and complex engineering problems in each process planning activity, the manufacturing preparation for the general assembly is a big obstacle for realizing rapid development of a new car. Thus, a business process re-engineering for achieving collaboration in process planning is required, and also it is crucial to realize an environment that can support the new business process.

The process planners need to make the following plans that decide process flow in an automotive general assembly:

a) Processes and sequence that comply with precedents

b) Part and material allocation for each process

c) Part and material flow based on the allocation

d) Overall performance such as manufacturability and throughput

The assembly process in the automotive general assembly system consists of work elements, unit works and assembly operations. A work element is the minimum unit of the assembly operation and a unit work is a set of work elements. The general process planning steps include 1) determining work elements; 2) assigning work elements to a specific unit work; 3) deploying unit works into an assembly operation; 4) checking balance of the workload and prerequisites; and 5) modifying and rearranging unbalanced processes. Such check procedures mainly depend on balancing and cycle time at that time, and processes and sequence are determined in this manner. Process planners need to consider other factors, which are mentioned above, in order to make plans for part and material allocation, and part and material flow.

In other words, process planning in the automotive general assembly consists of such enormous and complicated jobs that involve the participation of many people from various departments in the business. So, there is a need for an efficient process planning environment that will allow the many physically dispersed planners to work together, share their opinions with one another, and be able to make quick decisions. However, currently such processes are being carried out separately and in a manner where decisions are made successively from one department to another. As the business workflow moves from departments to departments, there are instances of information inconsistency between such departments as well as redundant works being conducted due to the isolation between departments. Those result in more engineering changes, and waste of time and cost for manufacturing preparation for new car development.

An efficient environment for collaborative process planning is the solution to overcoming this problem. Such an environment would enable many dispersed process planners from various departments to participate in the decision-making process starting from the early stages of process planning. Although there would be some engineering changes at the early stages, it gradually decreases as the process proceeds on. Therefore, time and cost for manufacturing preparation are reduced, and reliability of the process plan is improved (Crabb, 1998).

Once the planners decide on the processes and on what needs to be done next based on prerequisites such as cycle time and line balancing, they need to do part allocation and develop part flow plans in accordance with these processes. The automotive business has always depended on the experiences of the engineers. Repetitious trial and errors are inevitable. So, it takes a long time due to the frequent modifications made to the final plan. Analysis and evaluation of the plan by simulation technology help making a more accurate and reliable plan for part allocation and part flow that are less dependent on the experiences. However, it is time-consuming and redundant jobs to build simulation models. And it is so hard to build a revised simulation model to accommodate any modifications.

By automated generation of simulation models to form the integrated process plan database, the above problem can be solved. That is, it enables process planners to perform simulation at the same time as when process plans are being developed. Planners can also make better plans for part allocation and part flow directly after they analyze and evaluate their decisions using simulation technology. In other words, they can make more accurate decisions at the early stage of process planning. This will, in turn reduce time and cost.

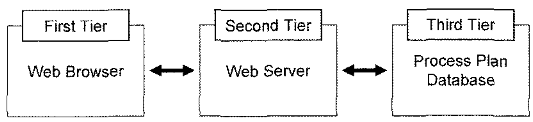


Figure 1. 3-tiered architecture of the process planning system.

Such an environment requires two things: 1) an integrated process plan database that includes all of the information to build simulation models; 2) an application that extracts a simulation model automatically and immediately from the database.

## 3. COLLABORATIVE PROCESS PLANNING USING WEB TECHNOLOGY

To establish a collaborative process planning environment, 3-tiered architecture was adopted. 3-tier architecture, which is more subdivided as compared to a 2-tiered architecture, can make a system highly efficient, expansible, flexible, and easy to develop and maintain. Figure 1 shows the 3-tier architecture.

A new software, which is not familiar to users, could be a big obstacle for users even though it is very effective. The first tier should be easy to use and understand; it takes charge of user interface that deals with various kinds of information in easy form. A web browser is a suitable option. As it is well known among users, it would not be necessary to learn how to use it.

The database that can store users' inputs and outputs forms the third tier. The database should contain all the information of products, assembly processes and resources in the general assembly lines.

Web server forms the second tier between users and database. It is separated from the database, and thus, it dynamically serves the right information from database to users whenever it is requested.

Web technology is the most suitable method to develop a collaborative process planning system as a 3-tier architecture. It is already a widely spread medium, which means it is inexpensive, universal, and familiar. And time is saved for training in case of using an new system. Many dispersed users can exchange their opinions and share information just by accessing into web server through the web browser in their desktop.

## 4. CONCURRENT PROCESS FLOW ANALYSIS BY THE INTEGRATED DATABASE

After deciding on the process and sequence in which such process should be proceed, process planners need to perform process flow analysis in order to evaluate the plan, and to develop part allocation and part flow plans, which requires simulation to be performed. The database for process flow analysis should be integrated with the process plan database so that the analysis system can utilize accurate and up-to-date information of products, processes, and resources that constructs simulation models. A web application builds the simulation model automatically in real time from the database when users request for it. Figure 2 shows the 3-tiered architecture of this system.

Process planners make process plans collaboratively considering prerequisites such as cycle time and line balancing. The information is stored in the integrated database. The web server builds the simulation models immediately from the integrated database according to the planners' requests for the next process planning activities. Simulation engineers then retrieve the models from the web server and perform the necessary simulation. After simulation, the analysis results are stored into the database through the web server so that process planners can refer to the results and make the appropriate changes to the plans. In addition, process flow analysis can be performed concurrently using web, database, and simulation technology. This concurrent and collaborative environment enables many dispersed process planners from various departments to participate in the process planning activities from the early stage and to eventually build a reliable process plan.

## 5. WEB-BASED COLLABORATIVE PROCESS PLANNING SYSTEM

Figure 3 shows the structure of the proposed system.

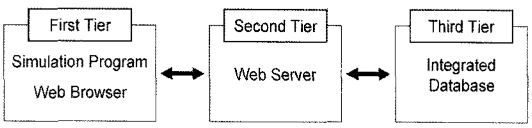


Figure 2. 3-tiered architecture of the process flow analysis system.

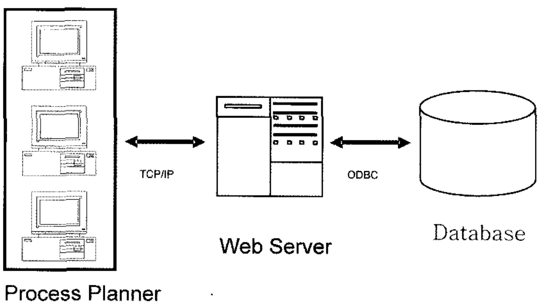


Figure 3. Structure of web-based collaborative process planning system.

Users need not install any software other than the web browser on their desktop. This means they already know how to use the system for the most part and time is not wasted to learn it. By using the web browser to access web server, they can input various kinds of information and inquire the decisions of other people collaboratively.

The Apache HTTP Server is selected as the web server. Web application is developed by PHP (2004) to respond to users' requests and manage the database. PHP is a widely used scripting language that is especially suited for web development and can be embedded into HTML. It does not impose a burden on clients and it is executed on server side in real time. It can compose interactive web pages and show dynamically accurate information that users want to see. The web server presents functions and logics that should be provided by the system. Using PHP, each application can be developed by each page; therefore it is not difficult to add a new function or modify existing ones. The web server can retrieve any information from users, process it by proper logics, call the database by ODBC (Open Database Connectivity) in order to store or extract the information, and present it to users in a proper form.

Microsoft® SQL Server™ 2000 is selected as DBMS. A database should include all the information of products, assembly processes and resources in the general assembly lines. It also includes user information so that only authorized personnel can access this system. Each user is classified because there are certain functions that must be managed by only persons in high ranks.

This system has the following functions:

a) Registration and update of preconditions and operations

b) Operation arrangement, shift, and partition

c) Operation time inquiry

## 6. CONCURRENT PROCESS FLOW ANALYSIS SYSTEM FOR COLLABORATIVE PROCESS PLANNING

Once process planners decide the process and on the next steps that need to be taken using the above system, they need to evaluate their plan and make plans for part allocation and part flow with the help of simulation technology. Figure 4 shows the structure of the combined system. After process planners have made a tentative plan and built a simulation model based on the plan, simulation engineers can download the model using their web browser. They then analyze the model and upload the results to the web server so that other planners can refer to the results and make appropriate changes to their plans.

A web application, also developed by PHP, automatically generates the simulation model in real time by

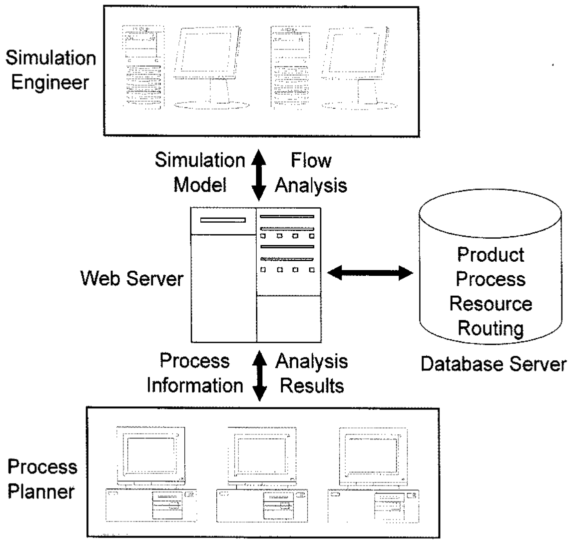


Figure 4. Structure of the entire system.

users' requests. It gathers the information needed for building a simulation model from the database through ODBC. The database also stores the analysis results grouped into each simulation model. An integrated database with the existing process plan database was designed to obtain up-to-date information, i.e., to prevent data redundancy and inconsistency.

FactoryFlow® (2002) and FactoryCAD® were selected as tools for analyzing the model. FactoryFlow® is not a DES (Discrete Event Simulation) package and it does not perform a stochastic simulation. However, it can be used for performing a deterministic flow simulation and it is useful enough for developing plans for part allocation and part flow with FactoryCAD®. In addition, FactoryFlow® makes it possible to readily identify:

a) Critical paths
b) Potential flow bottlenecks
c) Production flow efficiency
d) Storage space requirements
e) Material handling requirements

The database stores most information including product, process, and resource information. Process planners have to supplement parts routing information to build simulation models. AutoCAD® or FactoryCAD® layout drawings of the assembly shop also need to be prepared. The generated models can be imported into FactoryFlow® and readily analyzed. The analysis results are stored in HTML documents or layout drawings, and distributed through the web server so that process planners can refer to them and exchange their opinions in their web browser. In this way, planners can evaluate their plans and decide plans for part allocation and part flow, i.e., the number and size of containers and racks, their locations, storage space, material handling devices, and paths for the parts that will be put into each process. Finally, many dispersed planners or departments can gather from the early stage and make reliable decisions using this collaborative and concurrent process flow analysis system.

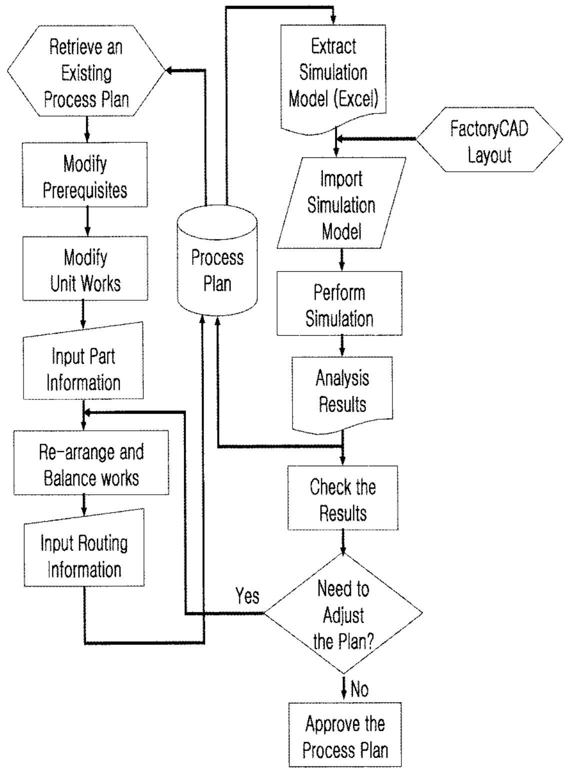


Figure 5. Business workflow of process planning using the proposed system.

## 7. SYSTEM IMPLEMENTATIONS

A web-based collaborative process planning and process flow analysis system is proposed in this research. Figure 5 shows the business workflow of process planning using the proposed system.

### 7.1. Process Planning System

The first task is to copy an existing process plan, which is already stored in the database, as shown in Figure 6. Process planners bring a process plan of the existing car which is the most similar to the new car among existing process plans. It is known that generally 30–50% of unit works are needed to make modifications in new car developments. Therefore, copying an existing process plan from the database can greatly reduce the time for process planning.

The next task is to edit basic conditions of the copied process plan. Prerequisites such as cycle time, critical

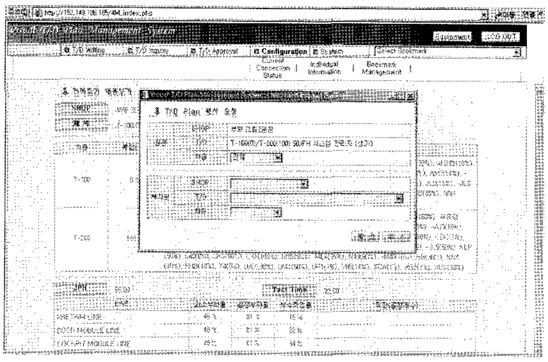

Figure 6. Copying an existing process plan.

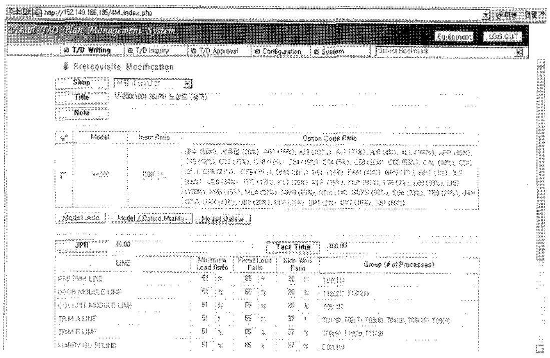

Figure 7. Modifying prerequisites.

load ratio, JPH, additional operation time should be modified for the new car, as shown in Figure 7.

Determining new unit works and modifying existing unit works, which are necessary for a new model, is the next task. Figure 8 shows the step of editing a unit work and its work elements. Operation time for a unit work is decided here using standard time information stored in the database.

The next task is to input part information for each unit work. Figure 9 shows editing parts and their numbers that need to be incorporated into each unit work.

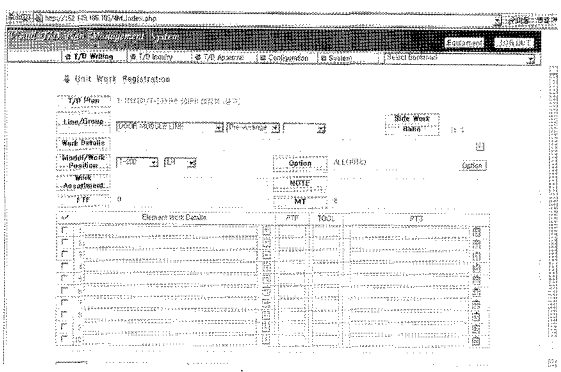

Figure 8. Determining new unit works and modifying existing unit works.

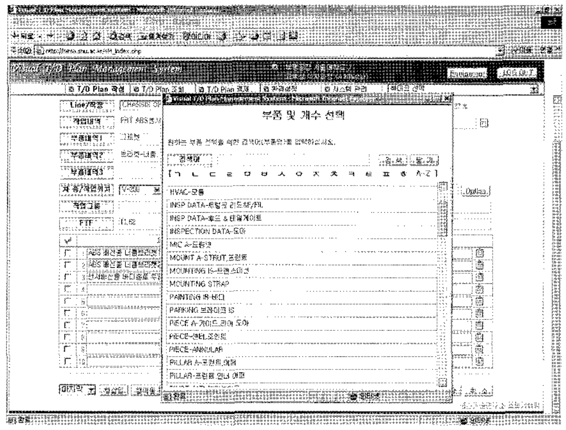

Figure 9. Editing part information for each unit work.

The next task is to assign unit works to each workstation and to perform line balancing. Whenever a new unit work is assigned into workstations, the operation time of each process is calculated, and line balancing is automatically checked by the supporting software. The process planner can also check the balancing result by a graph-styled measure when they deploy a new unit work or move particular unit works. Figure 10 shows the screen for assigning unit works and results of the line balancing using bar graph-styled measures. The blue bar represents the line balancing results of the workstation that are performing in a satisfactory manner, and the yellow one means that the workstation show less operation time than the minimum cycle time and notifies that it is possible to assign more unit works. The red bar means that the process has too many unit works. Therefore, unit works of the workstation in the red signal should be shifted to other assembly processes or workstations. The process plan is tentatively approved if the process plan suffices line balancing and all prerequisites after several reassignment.

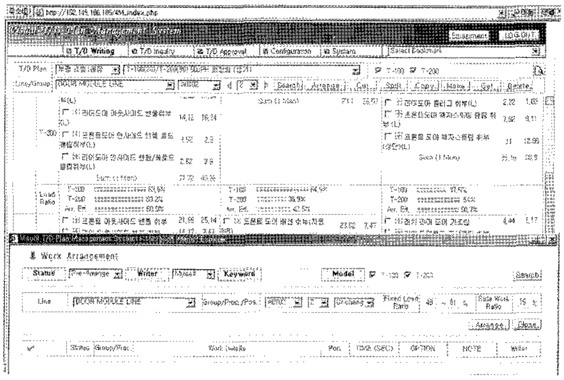

Figure 10. Assigning unit works to each workstation and checking line balancing.

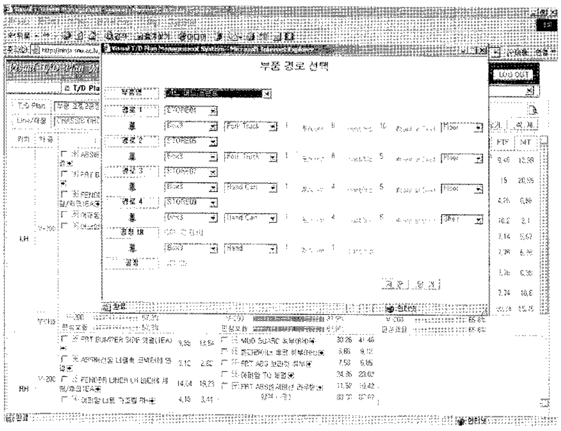

Figure 11. Editing routing information of the parts put into each unit work assigned to an assembly process.

Figure 12. List of the simulation models and their analysis results.

7.2. Process Flow Analysis System

After the process planners decide on the process, sequence, and location, they need to input part routing information. Figure 11 shows routing information of the parts that are put into each unit work assigned to an assembly process. The part routing information consists of paths, containers, material handling equipments, quantities, and storage types.

After assigning unit works and deciding part routing information, process planners can immediately export the data from the database. Now all of the data to generate simulation models are stored in the database. The process flow analysis system automatically generates a Microsoft® Excel file, which meets a given format of FactoryFlow®, directly from the data that process planners have made. After a planner has made a simulation model file in a form of a spreadsheet file, everyone can download the model file, as shown in Figure 12. After preparing AutoCAD® or FactoryCAD® layout drawing of the assembly shop, simulation engineers import the spreadsheet data file to FactoryFlow®, build a model immediately using the file, and then analyze it. Figure 12 shows the list of the models extracted from the database.

HTML documents and drawings that contain the analysis results are attached to each model. Process planners can refer to these results in their web browser, exchange their opinions, modify their plans, and decide on the part allocation and part flow plans. In this way, process planners can easily evaluate and modify their decision with the help of the analysis tool using the single integrated database. Thus time-consuming problem, data redundancy, and model inconsistency are resolved. Repeated processes of this model building and analysis do not take up any additional time. Rather, it helps process planners to make more reliable decision.

This system presents some kind of analysis results; path analysis, complete flow results, material handling device utilization, activity point utilization, storage space analysis, etc.

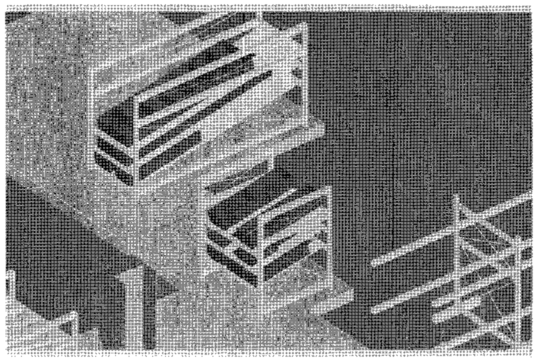

Figure 13. Making plans for part allocation using FactoryFlow® and FactoryCAD®.

Figure 13 shows part allocation activity by FactoryFlow® and FactoryCAD®. It shows a developed plan for racks and storage space based on the information of the volume and quantities of containers that contain parts for a workstation.

Figure 14 shows part flow planning by FactoryFlow®. It shows material flow in the facility layout and the result

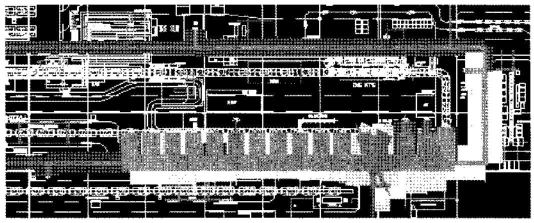

Figure 14. Making plans for part flow using FactoryFlow®.

of path analysis such as critical path. Figure 15 shows complete flow results that keep records of routing, material handling device, travel time, cost, and distance for each part.

## 8. CASE STUDY–BUSINESS PROCESS REENGINEERING FOR PROCESS PLANNING IN NEW CAR DEVELOPMENTS

This research was performed and applied to a Korean automotive company. The general assembly system of the company produces two types of car and has 9 sub-lines, more than 280 workstations, almost 400 workers and at least 1,800 parts to be assembled. The cycle time of each assembly operation is 36–60 seconds.

To build the most effective process planning environments, it is important to analyze the current (as-is) business workflow and to find the new (to-be) business workflow after applying developed environments. IDEF, which is a methodology for workflow modeling and analysis, is used in this research. To analyze the business workflow for new car developments, we focused on several engineering activities from the styling stage to the SOP (Start of Production). We investigated engineering documents and manuals, and conducted interviews and organized meetings with process planning experts of the company. Figure 16 shows a part of the business workflow for the manufacturing preparation activities in new car developments related to the general assembly process planning.

### 8.1. Business Process Reengineering of Process Planning

The existing business workflow for process planning is composed of many activities as shown in Figure 17. The first activity is to prepare a list of unit works and to assign each unit work into a certain process. In this activity, the process planner refers to related information such as a parts list, previous process plans for existing car models,

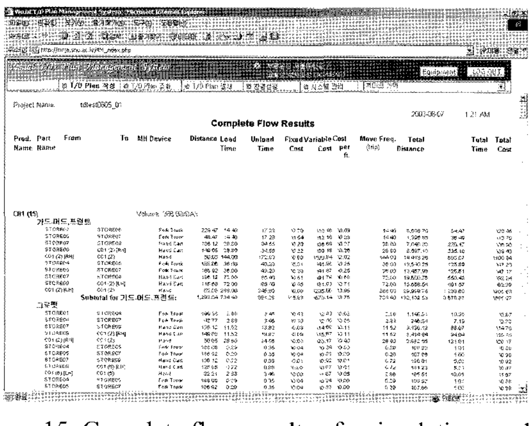


Figure 15. Complete flow results of a simulation model.

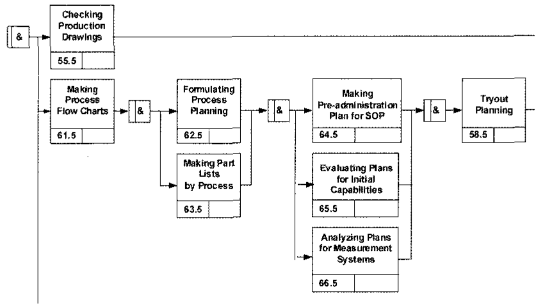


Figure 16. Part of the business workflow for manufacturing preparation activities.

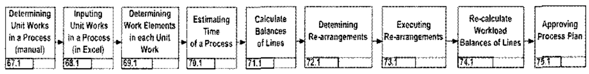


Figure 17. Existing business workflow of process planning for general assembly.

and prerequisites such as JPH (Job Per Hour), critical load ratio and number of workers. During this activity, they cooperate to assign unit works throughout the entire lines and workstations.

The second activity is to input unit works into a spreadsheet file in order to exchange the results. Referring to unit works and work elements, the third activity is to determine work elements for each unit work. The next task is to estimate operation time. The operation time of a unit work is the sum of operation times of work elements, and the operation time of a process is the sum of operation times of unit works incorporated into the process. In order to calculate the operation time, the process planner must be able to search for a standard operation time of each work element. And then, he or she modifies the operation time by considering real situations such as difficulties of assembly, options of a car and auxiliary operation times.

The fifth activity is workload balancing, which is the most complicated task. The process planner checks whether the operation time of a certain process satisfies time-based prerequisites. If the calculated operation time is longer than the prerequisite cycle time, the process planner should move unit works to other workstations, or assign more workers to that process. Since each planner cannot make these decisions alone, they make and share a common list of these non-determined processes and unit works.

The sixth activity is to check a common list and to communicate together and discuss how to handle the non-determined processes and unit works on it. After exchanging opinions with other planners by meetings or telephones, they make decisions and discuss whether to move a unit work, to split a unit work or to assign additional workers in the process. Due to the problems arising from geographical distribution of working units, it is difficult and time consuming to make decisions.

The seventh task is to reassign unit works, and the next is workload balancing as described in the fifth activity. The process planner iterates the above activities until a satisfying proper workload balance of lines is achieved and all prerequisites are met. The final step is to approve the newly made process plan.

In our research, the process planning was time consuming and complicated because the company was not provided with an efficient collaboration environment. To solve this problem, we applied the web-based collaborative process planning system. We improved the business workflow using this system. The system is currently being used in one of the Korean automotive companies, and more than 20 general assembly process plans for 4 assembly shops have shown good results. Through information sharing and collaborative process planning, the engineering hours for the process planning were reduced from 8 MM (man-month) to 4 MM. The reliability and the quality of resulting process plans were also improved.

### 8.2. Business Process Reengineering of Part Allocation and Part Flow Planning

Figure 18 shows a brief IDEF0 model of the existing

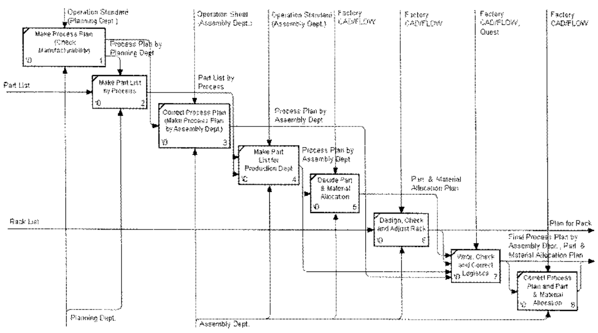


Figure 18. Existing business workflow of part allocation activity.

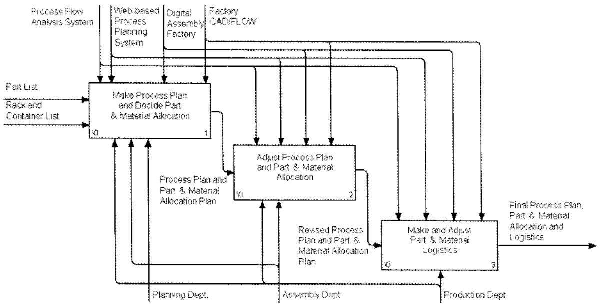


Figure 19. New business workflow of part allocation activity.

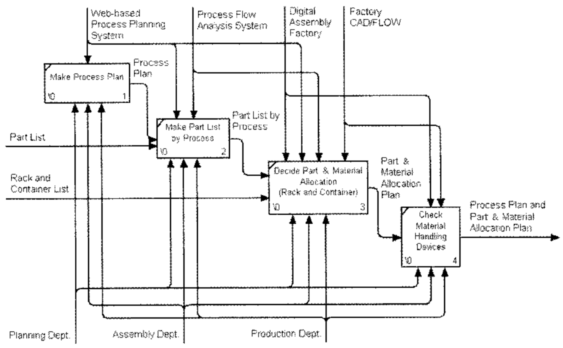


Figure 20. The early stage of new business workflow in detail.

business workflow of part allocation activity. In the past, each department had to repeat redundant jobs due to lack of collaboration. Works were repeated as the process passed through departments. This isolation among departments made the decision less reliable and caused information inconsistency among them. In addition, the decision was not reliable because it only depended on engineers' experiences, without testing it by simulation. Naturally, the business workflow needed change.

Figure 19 shows a brief IDEF0 model of the new business workflow of part allocation activity. The three departments used the same collaborative system. Using the collaborative system, all of them could participate in the decision-making process and share information with others. Therefore, many of the decisions could be made in the early stage as shown in Figure 20, and less reworks were needed as the process progressed. Also the system solved the redundancy and inconsistency problem and made the decision more reliable using simulation technology.

## 9. CONCLUSIONS

In this research, a new business workflow and supporting environments were designed to reduce the manufacturing preparation time of new car developments. A web-based collaborative process planning and process flow analysis system for the automotive general assembly was developed with web, database, and simulation technology. The collaborative environment, using a single integrated database, automatically builds simulation models and helps process planners to evaluate their decisions. It supports other process planning activities, i.e., part allocation and part flow planning as process planners share the simulation results with other planners or departments.

This system covers decisions of processes and sequences, part allocation, and part flow plan at present. It should be expanded to support further process planning activities. To evaluate the overall performance, such as manufacturability and throughput, DES and ergonomic simulation should be performed. New applications have to be developed to automatically generate DES or ergonomic simulation models in real time, and database schema also has to be changed to include additional information that the new simulation models require. Fortunately, this system is highly expansible. 3-tier architecture is suitable for modification and expansion of the system. A new application can be developed separately by making just a few web pages on the web server using PHP. Furthermore, it is not difficult to make modification of the database schema because the database is separated from web applications.

Through this system, business process re-engineering of the existing workflow saves time and cost, and enhances reliability in the general assembly process planning. The integrated database and connection with the collaborative process planning system is expected to enable every personnel to use a consistent digital model for the automotive factory.

## REFERENCES

Bruner, A. (2001). Workplace planning in a collaborative manufacturing environment. *IIE Annual Conf.*, Dallas, TX, May 20–23. 307–312.

Crabb, H. C. (1998). *The Virtual Engineer.* ASME Press. New York.

Driscoll, J. and Thilakawardana, D. (2001). "The definition of assembly line balancing difficulty and evaluation of balance solution quality. *Robotics and Computer-Integrated Manufacturing* **17, 1,** 81–86.

*FactoryFlow 7.0 Class Guide* (2002). Electronic Data Systems Inc. New York.

Groover, M. P. (2001). *Automation Production Systems, and Computer-Integrated Manufacturing*. 2nd Edn.. Prentice Hall. New Jersey.

Klein, R. and Scholl, A. (1996). Maximizing the production rate in simple assembly line balancing - A branch and bound procedure. *European J. Operational Research* **91, 2,** 367–385.

Mecklenburg, K. (2001). Seamless integration of layout and simulation. *Proc. 2001 Winter Simulation Conf.* 1487–1491.

PHP (2004). *Hypertext Preprocessor.* URL: http://www.php.net

Randell, L. G. and Bolmsjö, G. S. (2001). Database driven factory simulation: a proof-of-concept demonstrator. *Proc. 2001 Winter Simulation Conf.*, 977–983.

Rubinovitz, J. and Levitin, G. (1995). Genetic algorithm for assembly line balancing. *Int. J. Production Economics* **41, 1-3,** 343–354.

Sly, D. and Moorthy, S. (2001). Simulation data exchange (SDX) implementation and use. *Proc. 2001 Winter Simulation Conf.*, 1473–1477.