Integration Simulation of Intelligent Real-time Optimization Decision Support System for Assembly Line Balancing

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Abstract—**An Intelligent Real-time Optimization Decision Support System (IRODSS) is proposed in this paper. The IRODSS engages its components (i.e. Automatic Unit Production System, Operator Efficiency Prediction Model, Recursive Operator Allocation Optimization Model and Sequential Decision Making Model) through some sort of communication and coordination to collaborate on the real time basis assembly line balancing control. It is an autonomous intelligent system which is able to learn and adapt to changing circumstances independently. It runs continuously and decides for itself when it should perform some activity. In details, it monitors the production and checks its balance status based on real time data collected continuously on each check point. When an imbalance occurs, it will analyze the condition and take actions for line rebalancing based on condition-action rules automatically. The IRODSS is developed in Delphi. The industrial Automatic Unit Production System is simulated using Promodel. This paper thus demonstrates the key technologies of implementing IRODSS to industrial Automatic Unit Production System through integrating Delphi applications with Promodel software. Interactive cooperation between Delphi applications and Promodel software are explained via cross system data communication and file coordination. Results of the integrated IRODSS simulation system are provided as well.**

***Index Terms*—System Integration, Intelligent Decision Support System, Simulation, Automatic Unit Production System, Assembly Line Balancing**

I. Introduction

Nowadays many apparel firms have installed advanced production systems, such as Automatic Unit Production Systems (AUPS). Although AUPS has been installed for production control, their functions for data analysis and decision making are limited. In the apparel industry, the planning and line-balancing decisions are still heavily relied on the production experts. Because the experts make decisions on the basis of their experience and knowledge about the operators' performance, consistent decisions and optimal solutions are difficult to obtain and/or maintain under dynamic and uncertain manufacturing environments. The decision-making process is further complicated by the complexity caused by operator's multiple skills and variant efficiency on different operations.

An intelligent Real-time Optimization Decision Support System (IRODSS) is thus proposed in this paper for assisting production experts in line-rebalancing control in apparel manufacturing with the consideration of the impact of the variance of operator efficiency and other dynamic factors.

The investigation and construction of intelligent systems is part of the science of artificial intelligence (AI) [1-2]. The definition of AI is "the study and design of intelligent system that perceives its environment, adapts to dynamic situations in uncertain environments, and takes actions which maximizes its chances of success [3]".

Developed as a new approach to provide information to managers for making effective decisions, decision support system (DSS) has been receiving extensive attention since the early 1970s [4-8].

With the emergence of AI in the information systems area such question as "how to design intelligent systems to support decision making?" becomes really essential and critical [9]. DSS which performs selected cognitive decision-making functions and is based on artificial intelligence technologies is called Intelligent Decision Support System (IDSS). Besides the general functions of DSS, an IDSS should also be able to provide decision makers with intelligent recommendations and inferences in the ways that human experts normally perform.

Some IDSSs have been designed for supporting assembly line balancing (ALB) problems. For instance, an intelligent microcomputer-based decision support system was designed by Chu et al. [9] to solve line balancing problems. An expert system was proposed by Oh [10] for line balancing using a heuristic and tutorial method, which acted like an expert in an interactive mode. There are intelligent systems developed by other methods, for example, the web-based interactive advisor for assembly line balancing by Jiao et al. [11].

The following weaknesses exist in the previous IDSSs for ALB problems. The dynamic and uncertain factors such as variance of operator efficiency were not taken into account due to the complexity of real time balancing. The decision in operator allocation optimization was seldom improved from the aspect of an accurate operator performance prediction. The systems developed were not intelligent enough to act upon the change of their environments and make time-based decisions to adjust their next behaviors automatically.

The IRODSS to be developed has the following features which make it capable to overcome the weakness of previous

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intelligent systems in line balancing control:

1) Temporal (for time-based decisions): The IRODSS can predict operator efficiency based on large amounts of time-series data on previous stage and then offer the optimal operator allocation solution to improve line balancing control on next stage.
2) Autonomous: It is able to collect data, generate optimal solutions and make operator reallocation or system reconfiguration automatically.
3) Interactive with environment: It monitors the change of the environment (e.g. the change of operator efficiency and flow status) in real time and checks its balance status continuously. Whenever the production line turns unacceptably imbalanced, it takes actions according to the type of conditions.

The core model of IRODSS is developed in Delphi. The process of integrating its components and implementing it to industrial Automatic Unit Production System is simulated using Promodel. The sophisticated functions developed in Delphi thus needs to be called by Promodel. There has been no successful case for that so far. This paper will propose a novel method of simulating the system integration through interactive cooperation between Delphi applications and Promodel software.

System design, including the structure, components and components cooperation procedure will be presented in sectionⅡ. The integration of components by interactive cooperation between Promodel software and Delphi applications will be simulated in sectionⅢ. The simulation result of integrated IRODSS will be provided in section Ⅳ.

II. System Design

A. Structure and components

The intelligent real-time optimization decision support system (IRODSS) is designed to provide functions for both pre and real-time line balancing control in apparel industry. Pre-line balancing control aims to optimize the assembly line configuration before production. Real-time balancing control attempts to make sequential optimization based on the reliable prediction on operator efficiency during production. The framework of implementing the integrated IRODSS system to real application is shown in Figure 1. System components include the Industrial Automatic Unit Production System (Industrial AUPS), Simulated Automatic Unit Production System (Simulated AUPS), Operator Efficiency Prediction (OEP) Model, Recursive Operator Allocation Optimization (ROAO) Model and Sequential Decision Making (SDM) Model. Except the Industrial AUPS, all components are newly proposed models for IRODSS.

Industrial Automatic Unit Production System (Industrial AUPS)

The ALB problem to be addressed is based on an industrial AUPS which produces single products in stochastic processing time with a hybrid line structure. Industrial AUPS has basic functions for data collection and information management. After integration with the IRODSS, intelligent function will be added to the industrial AUPS which makes it able to take sequential decision making actions upon different conditions.

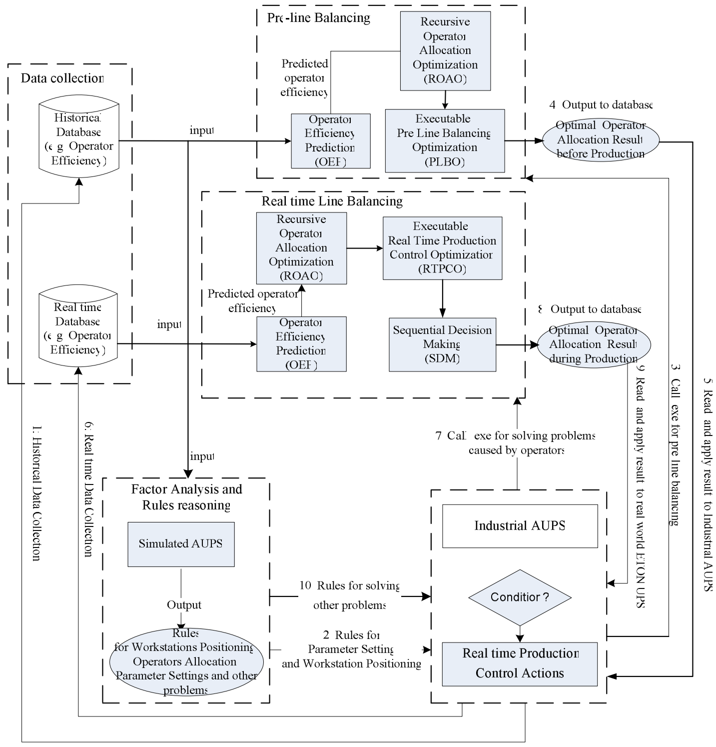

Figure 1 Model of Integrated IRODSS

Simulated Automatic Unit Production System (Simulated AUPS)

The optimal configuration of an assembly line is of critical importance for implementing a cost efficient production system. A study on assembly line configuration optimization is necessary to be carried out by analyzing impacts of relevant factors on production flow and line efficiency and reasoning rules for parameter configuration, workstation layout and operator allocation. The simulated AUPS is thus proposed for above purpose.

Operator Efficiency Prediction (OEP) model

Accurate forecasting of operator efficiency is crucial to supervisors in making operator allocation decisions scientifically. A time series based neural network forecasting model is therefore proposed for predicting the operator performance on next stage based on her/his previous efficiency and skill matrix [12]. Historical data is used for pre-line balancing control, while real time data is collected for prediction during real-time line balancing control.

Recursive Operator Allocation Optimization (ROAO) Model

Optimal operator allocation may lower the variance of operation efficiency and hence improve the balancing status of a production line. A recursive operator allocation optimization (ROAO) model is then developed based on the predicted operator efficiency by OEP model [13-14]. The objective is to maximize the line efficiency, to minimize the standard deviation of operation efficiency and to minimize the operation efficiency waste. The operator allocation belongs to the NP-hard combinatorial optimization field. The recursive algorithms can eliminate the weakness of the conventional

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heuristic procedures in modeling the actual conditions of assembly lines with large problem size and high flexibility.

Sequential Decision Making (SDM) Model

The optimal operator allocation generated by the ROAO model will be used for pre-line balancing first. But even initialized to the optimal balanced status, the assembly line will turn into imbalanced over time due to uncertain operator efficiency. Whenever the imbalance status is beyond the acceptable level, a decision is required for rebalancing the production line. A sequential decision making (SDM) model, thus, is brought forward for solving the continuous line reconfiguration and/or rebalancing problem in real time basis production[15].

B. Procedure of Component Cooperation

All the proposed models are integrated into the IRODSS through interactive cooperation. The following ten steps describe the basic running procedure of the integrated IRODSS system in real application (Step number is shown in Figure 1):

Step 1: The industrial AUPS collects the historical data and stores it into the historical database.

Step2: Based on the input of the historical data, the Simulated AUPS System analyzes factor impact and reasons condition-action rules of parameter setting, workstation/operator allocation and other conditions for system configuration.

Step 3: The industrial AUPS calls the executable file for Pre Line Balancing Optimization (PLBO). This executable file is generated by the Recursive Operator Allocation Optimization (ROAO) algorithm written by Delphi based on the predicted operator efficiency before production.

Step 4: The executable file of PLBO outputs the optimal operator allocation result before production and stores it to database.

Step 5: The optimal operator allocation result before production is read and applied to the industrial AUPS for pre line balancing.

Step 6: The industrial AUPS collects the real time data and stores it to the real time database.

Step 7: When the imbalance occurs, the industrial AUPS will take a proper action based on the condition-action rules. If the imbalance is caused by operator efficiency variance condition, AUPS will call the executable file for Real Time basis Production Control Optimization (RTPCO). This executable file is generated by the ROAO algorithm based on the predicted operator efficiency during production.

Step 8: The executable file of RTPCO generates the Optimal Operator Allocation Result during Production and outputs it into database.

Step 9: The industrial AUPS reads and applies the result for real time line balancing control.

Step 10: If the imbalance is caused by other conditions (e.g. too low in-buffer size, or too high uploading speed), then the industrial AUPS will take a corresponding action (e.g. increasing the in-buffer size or slow down the uploading speed) based on the rules for solving other problems.

The steps from 6 to10 will be repeated sequentially till the end of the production.

III. Integration Simulation through Interactive Cooperation between Delphi and Promodel

The core model of IRODSS is developed in Delphi. The industrial Automatic Unit Production System is simulated using Promodel. The key technologies of integrating the components of IRODSS and implementing them to industrial Automatic Unit Production System will be simulated through interactive cooperation between Delphi applications and Promodel software.

A. Simulation using Promodel

In the present work, simulation model is performed by using the ProModel software. ProModel has modeling construction specifically designed for capturing the dynamic behavior of systems, and it offers a realistic, graphical animation for the system being modeled [16-18].

A simulation system configured with real world data is validated to simulate the industrial AUPS where 31operators, 5operations, and 35 workstations are allocated. The proposed simulation model is not only applied for factor analysis but also for simulating the difficult logics like sequential decision making and operator efficiency changing during real time basis production.

B. Subroutine, XSUB, and dynamic link library (DLL) for system integration

The techniques like subroutine, external subroutine, XSUB, and dynamic link library (DLL) are significant in realizing the integration. ProModel is able to simulate the sequential decision making (SDM) process by creating a subroutine. But it is not able to simulate the function that the ROAO algorithm does. ROAO algorithm is developed in Delphi. For these extended capabilities with more sophisticated commands that ProModel is not capable of doing, an interface with external subroutines located in thirty-two bit Windows DLL files will be provided [19]. A DLL is a special type of executable file used to store functions and resources in a file. It allows useful, commonly used functions and resources to be made available to many applications. Based on above background, this paper proposes the following method for solving the system integration problem: to store the functions and resources of ROAO in Delphi DLL, and to call them for application in Promodel as external subroutine through XSUB. Due to the complexities of Windows programming and the variety of uses for this advanced feature, there is no a successful example of creating the DLL in Delphi that can be called by XSUB. Through trial and error, a successful case for using XSUB to call the DLL created in Delphi is created here. The cooperation details between DLL and XSUB are shown in Figure 2.

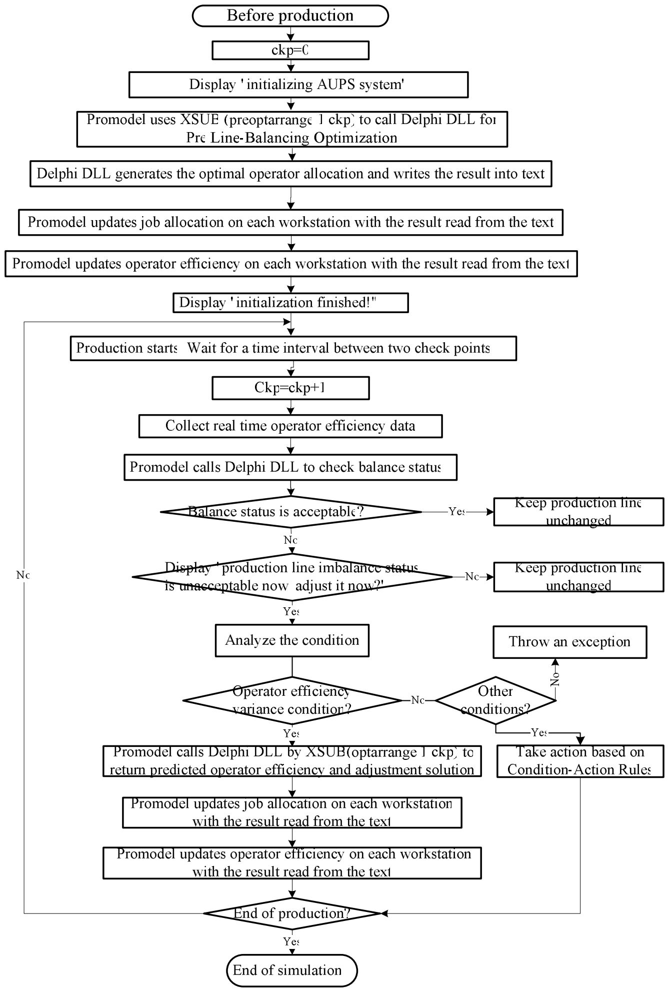

Figure 2 Simulation of Integrating the Proposed IRODSS using Subroutine, XSUB, and DLL

C. *Check points and subroutines for controlling the sequential decision making process*

The real time basis production control demands the production status to be optimized no matter when the imbalance occurs during production. But taking too frequent adjustments may cause operators difficult to be adapted to the changes. The check points are therefore used to cut the production time into fixed intervals so that the adjustment will be made at regular intervals. A subroutine is proposed to simulate the real time adjustment at regular intervals. It includes the following contents: On the time of each check point, the line balance status will be checked. If it is beyond the acceptable level, the XSUB in the subroutine calls the DLL to generate the optimal solution. Then the subroutine reads the generated data and applies it to update the simulation model. The repeat of above process is controlled by a loop, till the end of the production (see Figure 2).

D. *Cross system data communication*

As the elements of the integrated IRODSS system are developed in different languages or tools, a cross system data communication is provided. Figure 3 lists out the language/tool and data store format used for each subsystem. The industrial AUPS for factory management is programmed in C language and its database is Interbase. In this paper, the operator efficiency prediction (OEP) system is proposed using Artificial Neural Network (ANN) and the result is stored in Excel format. The recursive operator allocation optimization (ROAO) algorithm for both Pre and Real-Time Line-Balancing Optimization (LBO) is realized in Delphi language and the result is stored in Access database. The simulation system for integration is developed in Promodel. The data that needs to be read once at the beginning of simulation is stored in Excel and that needs to be updated for several times during simulation is stored in Text format.

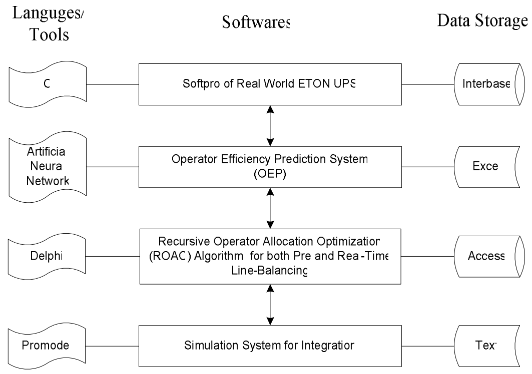

Figure 3 Language and Data Store Format for Each Software

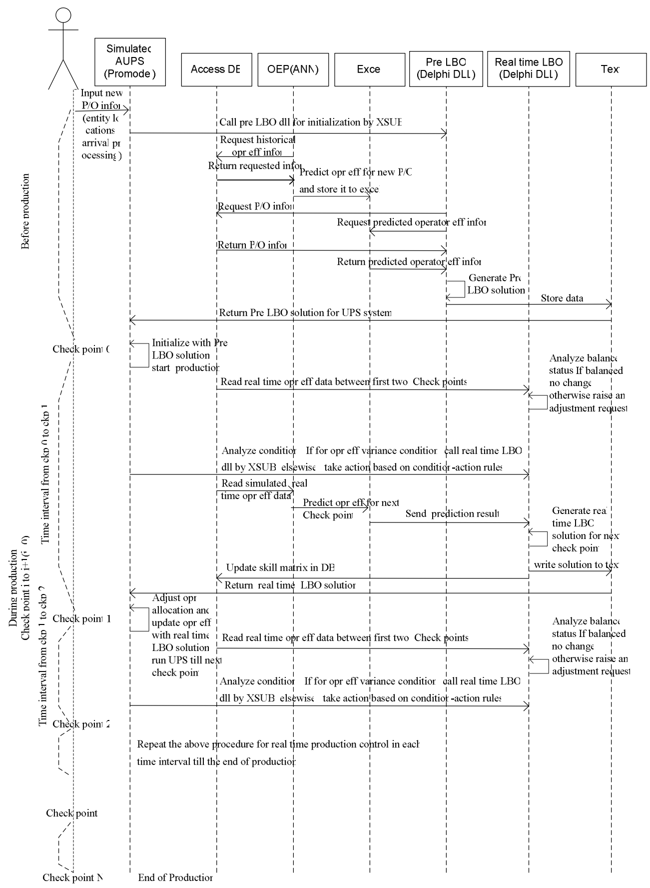

Figure 4 Sequence Diagram of the Data Communication in the Integrated IRODSS Simulation System

The sequence diagram in Figure 4 is the data communication in the integrated simulation system. The left of the Figure4 are two time phases: before production and during production (from check point 0 to N) till the end of production. The phase of during production is further divided into several time intervals by various check points sequentially. The objects listed in Figure 4 are simulated AUPS, OEP, Pre LBO DLL, Real time LBO DLL, and their data storage entities of Access DB, Excel, and Text respectively. The data communication is processed sequentially along the time phase.

E. File Coordination of the Integrated IRODSS Simulation System

The developed IRODSS includes the following files: the Delphi files (i.e. files of project, source code, form and DLL respectively) for pre/real-time line balancing, Promodel simulation files for integration, DLL project's data source and Promodel's external files (see Figure 5). When simulation model calls DLL for pre/real-time line balancing, the DLL is activated to link to its data source and generate corresponding results. The results are exported to Promodel's external files, which will be used by Simulation model for system reconfiguration or rebalancing. The coordination and communication of these files guarantees the smooth running of the whole system.

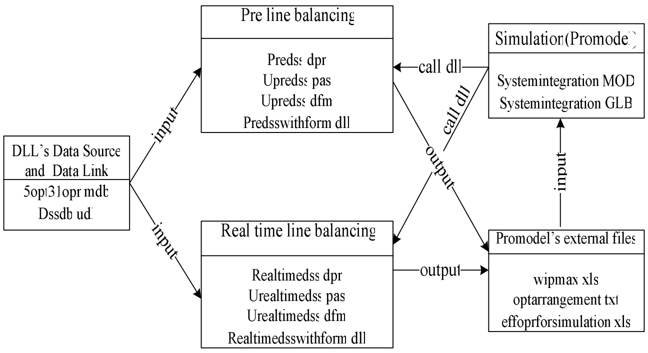

Figure 5 File Coordination in the Integrated IRODSS Simulation System

IV. Results of the Integrated IRODSS Simulation System

The results of running the integrated IRODSS simulation model for both pre line balancing and real time line balancing on different check points are demonstrated as follows.

A. Basic layout

This integrated IRODSS simulation system attempts to keep UPS run normally by avoiding the entity arrival failure and flow congestion, to make UPS run faster by arranging the workstations in operation order and in the shortest distance, and to bring the shortest throughput time by grouping operators optimally and putting the slowest operator the foremost in the same operation. Based on above settings, the simulation is started with an "initializing AUPS" message on the basic layout as shown in Figure 6.

B. Pre line balancing before production

The time interval of each two check points is set to be 30 minutes in this simulation. On check point 0 (i.e. 30 minutes after the beginning of the simulation), XSUB calls Delphi DLL for pre line balancing optimization. The data link is shown in Figure 7and the result of optimal operator allocation solution generated by DLL of ROAO based on historical data is displayed in Figure 8. The simulation model is initialized with the above operator allocation solution and other information like operator efficiency from external files (See Figure 9).

C. Sequential optimization for real time line balancing during production

The production starts after initialization. It continues to run (See Figure 10) till check point 1. A request for line balancing is raised when imbalance occurs due to the variance of operator efficiency on check point 1(Figure 11). If supervisor agrees to accept the adjustment, then Promodel uses XSUB to call Delphi DLL to generate the optimal operator allocation solution and updates the system with the generated result (Figure 12).

After that, the system keeps running till check point 2. The system checks the condition and finds out that the problem is "the workstation in-buffer size is too low" (Figure 13). Consequently, the in-buffer size is adjusted to be higher according to Condition-Action rules.

The system continues to run till check point 3 and the condition is diagnosed to be the variance of operator efficiency problem again. So the XSUB calls the Delphi DLL to generate the optimal operator allocation solution on check point 3 and updates the system with the generated result (Figure 14).

The production is completed before check point 4. The throughput time is 1 hour and 59 minutes. Figure 15 shows the end of simulation.

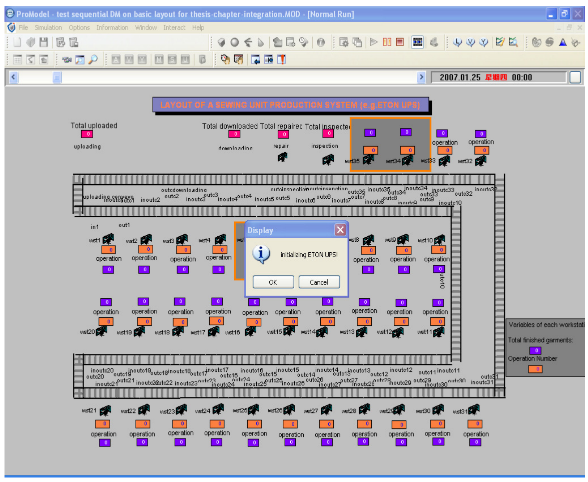

Figure 6 Start the Simulation by Initialization

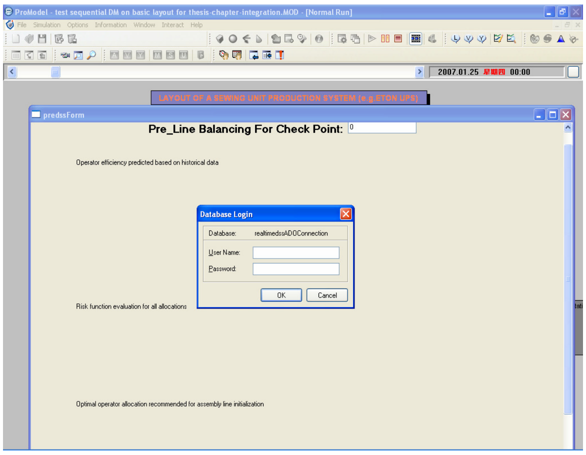

Figure 7 Call DLL for Pre Line Balancing Optimization at Check Point 0

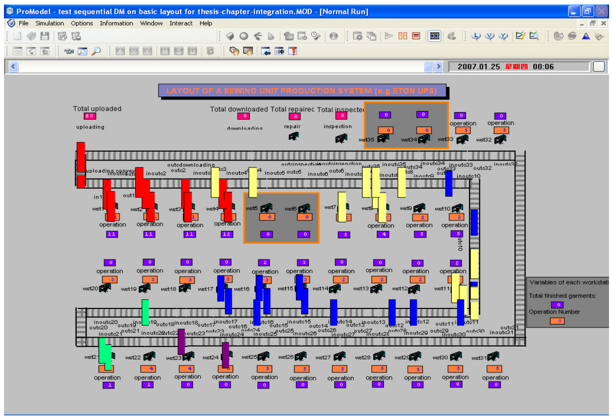

Figure 10 Continue to Run Simulation till Check Point 1

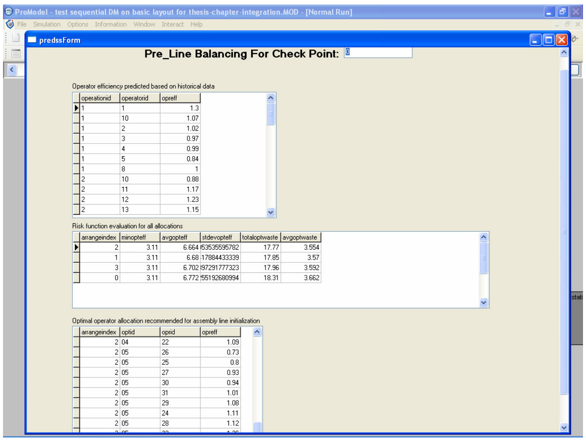

Figure 8 Display the Optimal Operator Allocation Solution on Check Point 0

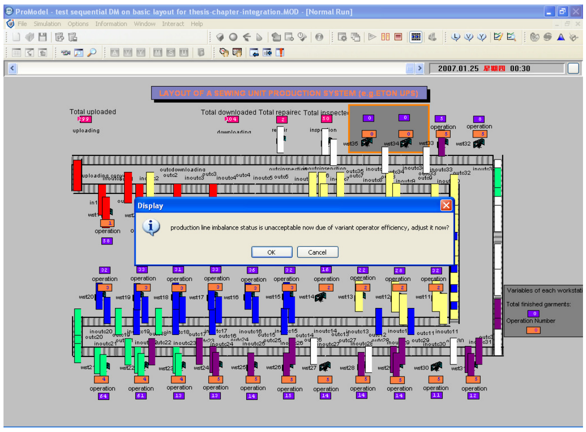

Figure 11 Raise a Request for Line Balancing when Imbalance Occurs due to the Variance of Operator Efficiency on Check Point 1

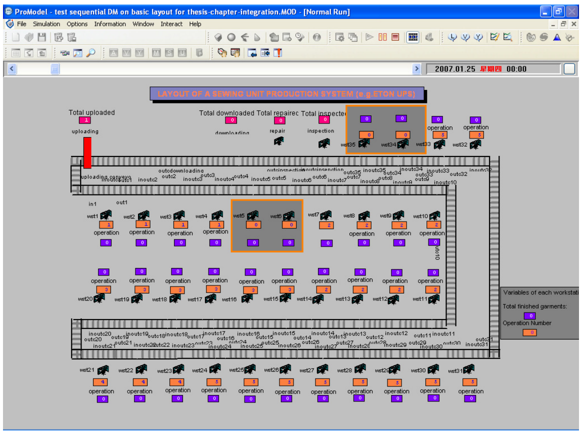

Figure 9 Initialize the Operator Allocation with the Above Result

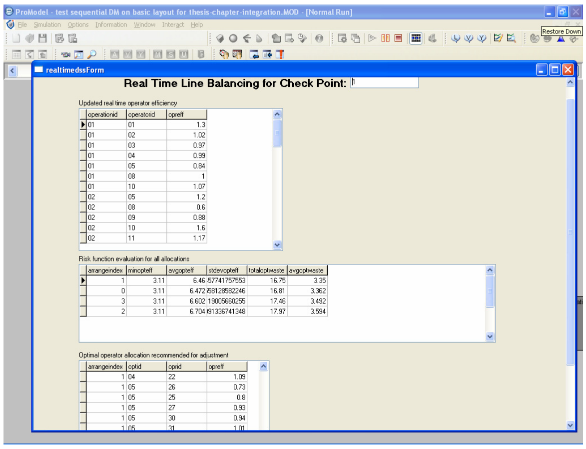

Figure 12 Call DLL to Generate the Optimal Operator Allocation Solution for Check Point 1 and Update the System with the Generated Result; Run System till Check Point 2

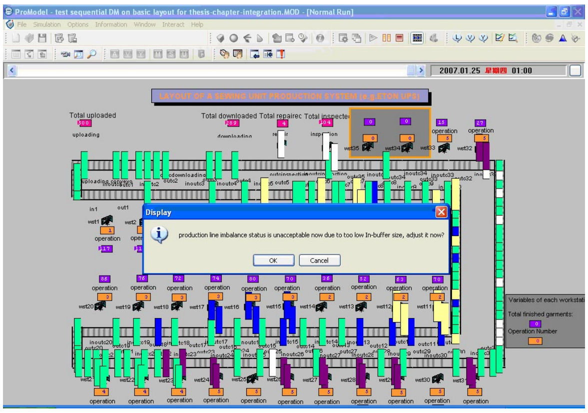

Figure 13 Adjust In-Buffer Size as Production Line Imbalance is Caused by Low In-buffer on Check Point 2; Continue to Run System till Check Point 3

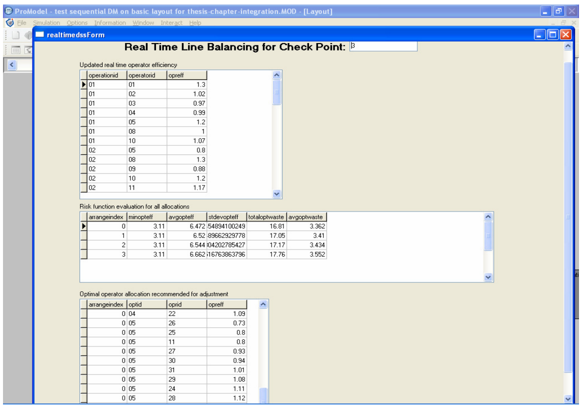

Figure 14 Call DLL to Generate the Optimal Operator Allocation Solution on Check Point 3 and Update the System with the Generated Result

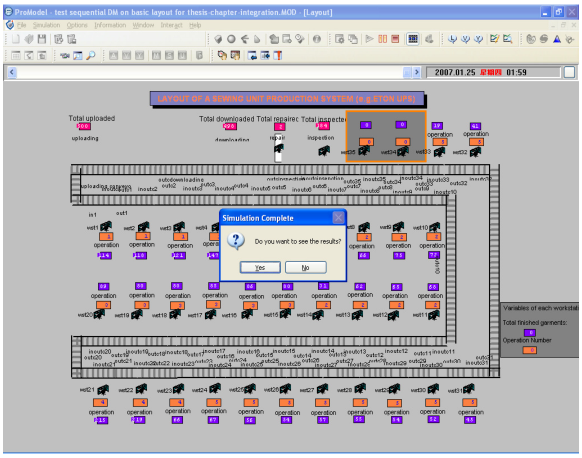

Figure 15 End of Simulation

V. Conclusion

An Intelligent Real-time Optimization Decision Support System (IRODSS) was proposed in this paper to assist the assembly line balancing control in an automatic unit production system (AUPS) by providing optimal resources re-allocation solutions with operator efficiency forecast updates. The integration of various component models, namely, operator efficiency prediction (OEP) model, recursive operator allocation optimization (ROAO) model, and sequential decision making (SDM) model, into IRODSS was simulated through interactive cooperation between Promodel software and Delphi applications. Cross system data communication, file coordination and running results in the integrated simulation system were provided.

This paper has made two major contributions. Firstly, the developed IRODSS can represent the complexity of real situation because it considers different types of uncertainties (e.g. the variance of operator efficiency) that may exist in a dynamic environment. It is an autonomous temporal intelligent system as it is capable of monitoring the change of work environment (i.e. the change of flow line status) and providing time-based decisions to improve the line balance status sequentially and automatically. These features make it different from other expert systems.

Secondly, due to the complexities of Windows programming, there is no a successful example of integrating the Delphi application with Promodel software. This paper provided a successful case for that the first time by creating the DLL in Delphi that can be called by XSUB and calling it in Promodel through XSUB as an external subroutine. Referring to this technology, those extended functions developed in Delphi with more sophisticated commands that ProModel is not capable of doing can be demonstrated in Promodel. Promodel thus becomes a stronger platform which is able to simulate more complicated system integration.

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