

A Lean Manufacturing Implementation Strategy and its Model for Numerical Control Job Shop under Single-piece and Small-batch Production Environment

Ao BAI¹, Ping XIA, Liang ZENG

Institute of Mechanical Manufacturing Technology, China Academy of Engineering Physics, P. R. China

Abstract. Lean Manufacturing (LM) is an advanced manufacturing paradigm which aims at improving the efficiency of production, enhancing the quality of products whereas eliminating various kinds of waste and cost on shop floor. It is obvious that different manufacturing environment or mode needs different lean manufacturing implementation method. In this study, a LM implementation model for Numerical Control (NC) job shop under single-piece and small-batch production environment is proposed and constructed. With the detailed analysis for the characteristics and problems of modern NC job shop, a new and specific structure of LM system is presented. Based on this structure, a LM implementation model is established, this model is made up of problem analysis layer, information platform layer and system application layer. To support the model implementation, an operational procedure is further put forward. Finally, case study in a typical NC job shop from a part fabrication manufacturer is given out to validate the model's availability and possibility. Practical application shows that with the LM adoption and implementation model, the overall efficiency of NC job shop under single-piece and small-batch production environment can be profoundly promoted.

Keywords. lean manufacturing, lean enterprise, NC job shop, discrete shop floor, implementation model, implementation framework, digital manufacturing, single-piece and small-batch production

Introduction

Lean Manufacturing (LM) or Lean Production (LP) is an advanced manufacturing paradigm which was firstly practiced by Toyota Motor Company in its Japan factory since the middle age of 20th century. Now more than half a century has passed, LM still has powerful vitality to be used by various kinds of manufacturing enterprises around the world to achieve their organizational goals and remain competitive in global market.

In general, LM means doing more work with fewer resources for a production organizations or service sectors. So, the standard concept of LM can be described as: LM is an adaptation of mass production in which work is accomplished in less time, in

¹ Corresponding Author: Ao Bai, Postal Mail Box 919/621, Mianyang City, Sichuan Province, P. R. China; E-mail: baiiao1983@126.com, baiiao@caep.cn.

a smaller space, with fewer workers, and with less equipment, and yet achieves higher quality levels in the final product [1]. Based on the successful practice of Toyota Motor Company, many works have been done to adopt and implement LM for different manufacturing enterprises. For example: In literature [2], a LM implementation method considering cellular layout was proposed, and a case study was also given out to validate its feasibility; In literature [3], A LM process case study was discussed to demonstrate production flow analysis through Value Stream Mapping (VSM); In literature [4], a study was made to integrated LM and group technology to shorten production cycle, improve product quality and cut down product cost, thus brought biggest benefits to the whole company; In literature [5], LM principles in remanufacturing industry were given out, and a case study at a toner cartridge remanufacturer was discussed; In literature [6], a LM strategy for hot charge operation of a steel mill was shown, and substantial cost savings could be made once the full benefits of a lean production strategy are considered; In literature [7], a continuous improvement model of LM based on multi-type and small-batch production was established to help enterprises guarantee their survival and achieve their development; In literature [8], a five-stage method was proposed for Chinese enterprises to carry out LM step by step including the tools configured for each stage.

From the above researches, it can be concluded that there is no uniform LM implementation standard, different enterprises need different methods to adopt or realize LM based on their real production mode and conditions. In this study, an implementation reference model of LM just suitable for NC job shop under single-piece and small-batch production environment will be proposed. Single-piece and small-batch production is commonly known for its high flexibility and now widely used in the equipment manufacturing industry, such as ship manufacturing industry, boiler manufacturing industry, steam turbine manufacturing industry, power plant manufacturing industry and petrochemical equipment manufacturing industry.

Unlike other common LM application or implementation in mass production or multi-varieties and small-batch production environment, the core of LM in single-piece and small-batch production is fully using different types of digital technologies or information systems to collect data, integrate information and share knowledge, thus helps NC job shops realize and pursue exact, real-time, quantitative and highly effective manufacturing to achieve their enterprises' lean goals.

The rest of this paper is organized as follows: Section 1 analyzes the characteristics of NC job shop and then proposes a new LM structure as LM implementation strategy. In Section 2, the model of the specific LM system is established, and its main compositions are described in detail. Section 3 contains an operational procedure to help implement LM, and a simple case study from a part fabrication manufacturer is also given out. Finally, Section 4 contains the conclusion.

1. Requirement analysis of NC job shop and the new structure of LM system

As we all know, as an advanced manufacturing paradigm, LM is firstly used in Toyota Motor Company and is generally regarded as being best suitable for mass production mode. The successful implementation of LM is greatly influenced by many factors such as products' feature, production mode, management style, organizational structure or even enterprise's culture. So, it should take different method to implement LM based on the enterprises' real condition or situation. For the NC job shop under single-piece

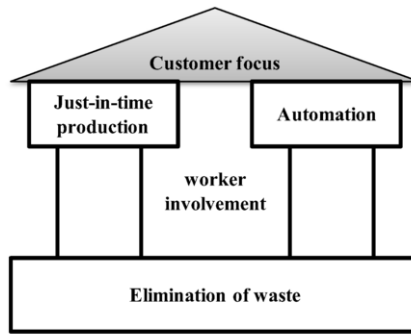
and small-batch production environment, numerical machine tools or equipments are generally installed or deployed follow the so called process concentration principle, the production batch is usually very small (even just one) and most customers' orders are completely new and not standard, and different types of manufacturing resources are need to be prepared before the work starts. Therefore, the overall efficiency of NC job shop under single-piece and small-batch production environment is generally in a low status, and it becomes very difficult to manage and control production tasks execution with less time and fewer resources to satisfy LM requirement.

According to our recent surveys from several typical equipment manufacturing enterprises, at least three main and typical problems are now widely existed in their NC job shops under single-piece and small-batch production environment:

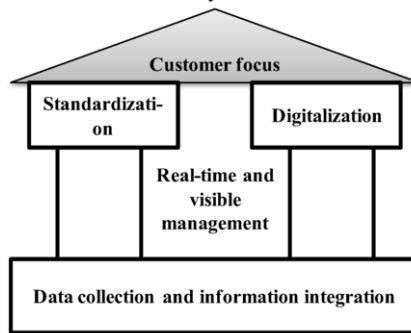
- First, from the perspective of equipment, due to the lack of suitable or optimal cutting parameter for variety products or parts, the efficiency of single numerical machine tool (the numerical machine tool is general equipment in NC job shops) is usually in a low status, so some numerical control machines are easy to become bottleneck nodes to prevent the task or job finishing in a planned time period. What's more, some complex numerical control programs may not be examined and simulated before executing, so sometimes operation accidents may occur to damage the machine tools and bring unnecessary loss.
- Second, from the perspective of resource, waiting time for different manufacturing resources is generally too long, if not well prepared, it's usually very common that the production tasks/jobs have arrived at one work station but the needed manufacturing resources still in warehouse or other places; furthermore, the management of manufacturing resources is just in a mess, the manufacturing resources may be destroyed, overdue or even missed.
- Third, from the perspective of process, the production task is not well arranged and scheduled to balance the work load among different workstations or work centers. Due to a lack of production scheduling systems, the production scheduling process is mainly based on the production managers' skills or experiences, and is generally complex and time-consuming. So facing with a changeable and uncertain customers' requirement, it's usually very hard and difficult to make feasible production plans even for a skillful product manager or expert.

To deal with these three main problems above, it is in great need to take many actions. According to our previous researches and literature reviews, we select Lean Manufacturing as our main way to help promote the efficiency of NC job shop under single-piece and small-batch production environment. The practice way and implementation model of LM in our study is changed and is different from the original way firstly practiced by Toyota Motor Company.

Due to the main problems of NC job shop as mentioned previously, we will use information and digital technologies or tools to realize exact, real-time and effective management towards manufacturing execution process in single-piece and small-batch production environment. Based on this consideration, we will change the structure of traditional LM system from Figure 1.(a) to Figure 1.(b), just as depicted in Figure 1.



(a) The general structure of a traditional lean manufacturing system



(b) The new and specific structure of a lean manufacturing system for numerical control job shop

Figure 1. The change of a lean manufacturing system's structure.

From the top part of figure 1 (Figure 1.(a)), we can see that the foundation of a general or traditional lean manufacturing system is elimination of waste, the core is worker involvement, the two supporting pillars are just-in-time production and automation, and the goal is to satisfy customer's focus or need. Unlike general lean manufacturing system, from the bottom part of figure 2 (Figure 1.(b)), we can see that the foundation of a specific lean manufacturing system for NC job shop in single-piece and small-batch production environment is data collection and information integration, the core is real-time and visible management, the two supporting pillars are standardization and digitalization, but the goal is the same as general lean manufacturing system, just to satisfy customers' focuses or needs.

We will further discuss the two supporting pillars in the specific structure of a lean manufacturing system. Standardization means that every operation in NC job shop should be strictly in accordance with quality management architecture and standard procedure. Due to the complexity of NC job shop and changeable tasks, some workers incline to do jobs in an unconstrained and free manner, which can easily make errors or bring interruption to whole production. So, training workers before beginning working

and make some encouragement or punishment policies are necessary indeed to enforce them follow the standard procedures.

On the other hand, digitalization is also needed to help workers standardize their behaviors. With digitalization technologies and tools, many procedures or business processes can be easily executed in a standard and uniform manner. For example, the correctness of production data or parameter can be guaranteed, the indispensable step may not be omitted, and it will become very convenient to track and trace task because key or important components is tagged and their historical status or activities are recorded in backend database in earlier time. What's more, production managers will obtain more useful information to assist them make quick and right decision to manage and control manufacturing field in a real-time manner.

2. Implementation model of lean manufacturing system

Based on the specific structure of lean manufacturing system in single-piece and small-batch production environment, the implementation model will be presented and further illustrated. The implementation model of lean manufacturing system for NC job shop mainly contains three layers, which are Problem Analysis Layer (PAL), Information Platform Layer (IPL) and System Application Layer (SAL). Each layer has its different role and function, which can be described in detail as follows:

- In Problem Analysis Layer, there are two important strategies to support LM, which are management innovation strategy and technology innovation strategy. With management innovation strategy, business process in NC job shop are diagnosed, optimized and re-engineered, and organization's structure is also rebuilt in order to satisfy the standardization requirement of LM. With technology innovation strategy, information and digital systems are constructed and different kinds of production processes are improved to support the LM's digitalization need.
- In Information Platform Layer, four information platforms are planned and built to support the implementation of LM system under single-piece and small-batch production environment, which are Numerical Processes Optimization and Machine Monitoring Platform (NPOMM-Platform), Manufacturing Resource Quick Preparing and Management Platform (MRQPM-Platform), Production Planning and Scheduling Platform (PPS-Platform) and System Integration Platform (SI-Platform). The goals of each platform are as follows: a) the NPOMM-Platform is to enhance the efficiency of single numerical machine tools; b) the MRQPM-Platform is to shorten the waiting time of various manufacturing resources in job shop; c) the PPS-Platform is to enhance the efficiency of overall production process; d) the SI-Platform is integrate different platform to better exchange the data or information to achieve maximum system performance. According to these four platforms, the LM model in NC job shop can be changed from theory into practice.
- In System Application Layer, different specific information or digital systems are deployed to enhance the efficiencies of machine running, resource delivery and process execution. The details of each information system are

listed in table I. From table I, we can see that different information systems play different roles in LM system to achieve their unique effects. It should be noted that each information system should not work separately from each other, so they must be integrated well and work just as a whole and uniform part.

Beside these three layers above, it should emphasize that the foundation of LM model in NC job shop under single-piece and small-batch production environment is data collection, information integration and knowledge share. According to this foundation, real-time, exact, quantitative and highly effective manufacturing can be easily and conveniently achieved to manage and control NC job shop in a lean way. Obviously, the lean of a manufacturing enterprise is largely depending on its workshop, including fabrication job shop and assembly line. If its NC job shop is lean, it will be great motivation for the lean of overall enterprise.

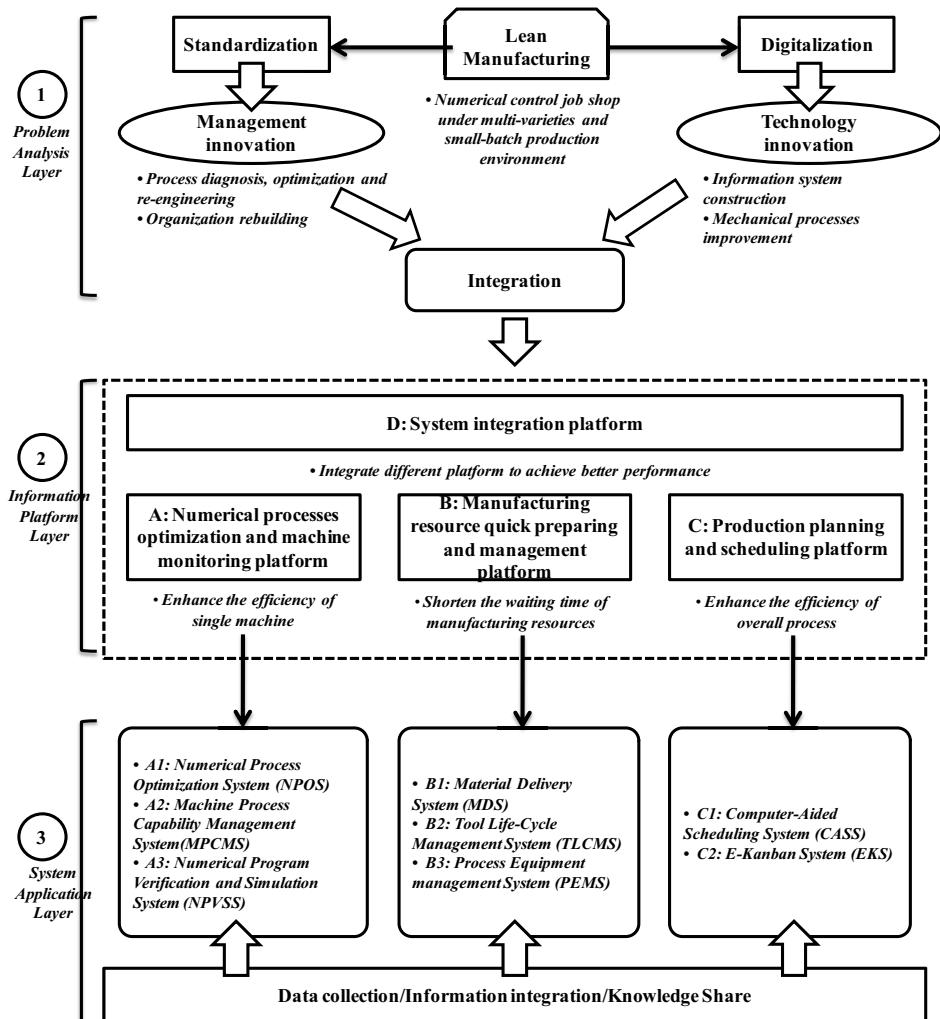


Figure 2. New implementation model of lean manufacturing system for NC job shop.

Table 1. Summaries of information systems supporting lean manufacturing implementation in NC job shop.

Code	Full name		Short name	Managed objects	Functions and roles in lean manufacturing system
A1	Numerical Process Optimization System		NPOS	Equipments/Machines	Optimize the cutting parameters (and store them) to gain high efficiency of machine running
A2	Machine Process Capability Management System		MPCMS	Equipments/Machines	Manage the machines and repair them in a controlled time period to keep machines in a available status
A3	Numerical Program Verification and Simulation System		NPVSS	Equipments/Machines	Verify the correctness of numerical programs to prevent error of programs and avoid damage of machines
B1	Material Delivery System		MDS	Manufacturing resources	Prepare materials and delivery them in a JIT mode
B2	Tool Life-Cycle Management System		TLCMS	Manufacturing resources	Prepare tools and manage their whole lifecycle exactly to avoid the waste of tools
B3	Process Equipment management System		PEMS	Manufacturing resources	Prepare or manage process equipments and delivery them in a JIT mode if one process needs
C1	Computer-Aided Scheduling System		CASS	Manufacturing processes	Generate feasible production orders or tasks and re-schedule them if any abnormal event occurs
C2	E-Kanban System		EKS	Manufacturing processes	Display the information from manufacturing field in a real-time manner to reflect the status of tasks execution

3. Operational procedure of lean manufacturing system and its case study

In order to implement lean manufacturing in modern NC job shop under single-piece and small-batch production environment, we further propose an operational procedure based on the implementation model above. The operational procedure will integrate two parts: general information systems and lean manufacturing-related information systems, just as depicted in Figure 3. The general manufacturing information systems are Production Planning System (PPS), Computer Aided Process Planning (CAPP) system, and Manufacturing Execution System (MES). These three general information systems provide various types of important and basic production-related data to support the running and execution of production orders or tasks in job shop. The lean manufacturing-related information systems are these systems which are proposed in Figure 2. (See detail in table 1) to enhance the efficiency of single machine tool, shorten the waiting time of manufacturing resources and enhance the efficiency of overall process. With the lean manufacturing-related information systems, the execution of production orders or tasks in job shop will be managed, controlled and optimized in a more exact and quantitative manner to realize the lean goal.

Combining general information systems and lean manufacturing-related information systems together, the operational procedure of lean manufacturing in job shop under single-piece and small-batch production environment will be described as follows, which contained four main steps:

- The first step is to accept the two important production instructions from PPS and CAPP simultaneously, which are production task/job information and process rule information;
- Then, in the second step, with MDS, TLCMS and PEMS, the availability of main manufacturing resources such as materials, tools and process equipments which are needed in production processes are carefully checked, if the current manufacturing resources can't satisfy the requirement of production tasks, then manufacturing resources purchase orders or self-production orders will be generated instantly;
- In the third step, different production tasks are scheduled and planed in CASS based on the data from PPS and MES. PPS provides CASS with production planning data (such as material code, material name, required amount, delivery time, special requirements, et al.), and MES provides CASS with production execution status data (such as progress, finished amount, workers' workload, equipments' capacity, et al.). According to this steps, production task/job will be arranged in a more reasonable and feasible style to achieve a shorter production cycle time and a well-balanced workload in every workstation;
- In the forth step, production tasks are executed sequentially in each workstation or work center, at the same time MDS, TLCMS and PEMS delivery the manufacturing resources in a Just-In-Time (JIT) mode without long waiting. In order to promote the performance of numeral machine tools, NPOS, MPCMS and NPVSS also work together to generate optimal cutting parameters and verify the validation of NC program. EKS, a production information display system deployed in manufacturing field, will show the real-time production information or production index to reflect the status of production process. With this information displayed by EKS, production managers or team leaders could take immediate and active action to eliminate the error or deviation between the planned process and real execution process.

By this operational procedure (See detail in figure 3), general information system and lean manufacturing-related information system will be integrated into a whole lean manufacturing system. With this system, the physical items flow can be driven by virtual information flow, and the production execution can be worked in a more exact and effective way, thus the management and control level of NC job shop in single-piece and small-batch production environment can be greatly enhanced.

With this lean manufacturing implementation strategy and its mode, and follow its corresponding operational procedure, a implement lean manufacturing practice have been made for a modern NC job shop under single-piece and small-batch production environment in a typical part fabrication manufacturer. In order to strongly push forward this complex system engineering, a project team are built, which mainly consists of enterprise's top leaders, lean manufacturing experts, common business persons, system analysis persons and system development persons. From the current execution progress of lean manufacturing system implementation, our work is being well controlled and managed, some accomplishments have been made, a exact, effective and quantitative manufacturing have been realized preliminarily. With the

advancement of lean manufacturing project, it is estimated that the work potential and efficiency of NC job shop has enhanced to nearly 10 percent over the past two years.

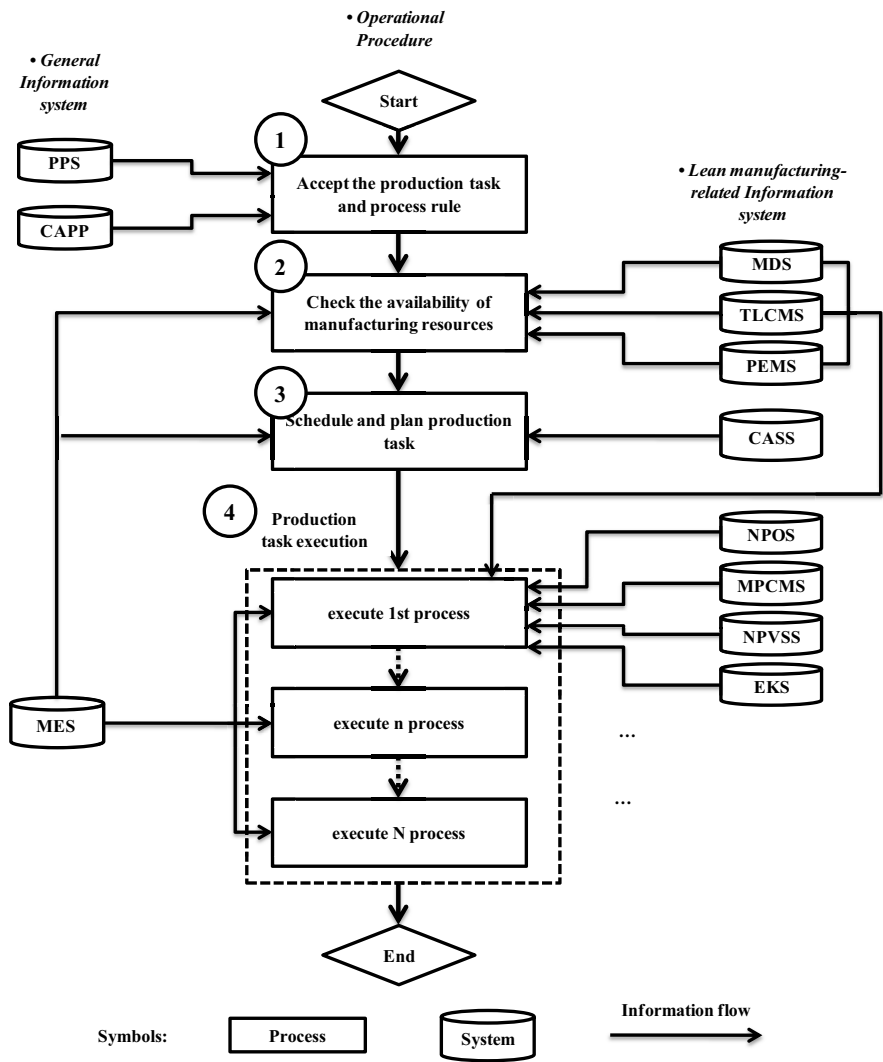


Figure 3. Operational procedure of lean manufacturing system for NC shop floor.

4. Conclusion

With the lean manufacturing model described above, we have started to construct a lean manufacturing prototype system for a typical NC job shop under single-piece and small-batch production environment to achieve exact, effective and quantitative manufacturing, which will be a necessary way to realize lean enterprise for modern discrete manufacturers. Our proposed lean manufacturing system largely adopts the information/digital technology to provide managers or leaders with real-time decision

supporting information to make some quick decisions, and the information flow is used to drive physical items flow in the right time to make everything ready before work starts. According to our lean manufacturing system, the efficiency of a single machine tool can be greatly promoted, the waiting time for different manufacturing resources can be sharply declined and the performance of overall manufacturing business processes can be remarkably improved, thus realize exact manufacturing and high efficiency manufacturing to achieve lean goal, and finally better satisfy the customers' focuses and requirements.

It should be noted that the proposed lean manufacturing model is just suitable for single-piece and small-batch production mode in NC job shop, for other production modes in other manufacturing fields, new and specific lean manufacturing model still need to be carefully explored and practiced based on their real condition or situation. It is still deeply believed that there is no common LM implementation way suitable for all types of manufacturers.

Acknowledgement

The authors would like to thank the support from S&T Special Project of China Academy of Engineering Physics (contract No.9120601) and National Natural Science Foundation of China (contract No.50675201), which give us a good opportunity to implement a specific and unique lean manufacturing system for NC job shop in single-piece and small-batch production mode, and the authors would also like to show great and deep appropriate to other colleagues for their hard and fruitful work.

References

- [1] Mikell P. Groover, *Automation, Production Systems, and Computer-Integrated Manufacturing*, third Ed. Tsinghua University Press, Beijing, 2011.
- [2] L. N. Pattanaik, B. P. Sharma, Implementing lean manufacturing with cellular layout: a case study, *International Journal of Advanced Manufacturing Technology* **42** (2009), 772–779.
- [3] Rahani AR, Muhammad al-Ashraf, Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study, *Procedia Engineering* **41** (2002), 1727–1734.
- [4] Y. Hu, F Ye, Z Fang, A study on the integration of lean production and group technology, *Proc. of the 2000 IEEE International Conference on Management of Innovation and Technology, ICMIT 2000*, Singapore, 839-842.
- [5] J. Ostlin, H Ekholm, Lean Production Principles in Remanufacturing A Case Study at a Toner Cartridge Remanufacturer, *Proc. of the 2007 IEEE International Symposium on Electronics and the Environment, ISEE 2007*, Orlando, 216-221.
- [6] J. Storck, B. Lindberg, A lean production strategy for hot charge operation of a steel mill, *Proc. of the 2007 The IET International Conference on Agile Manufacturing, ICAM 2007*, Durham, 158-167.
- [7] M. F. Tchidi, Z. He, A. R. Agnantounkpatin, The continuous improvement model of Lean Production based on Multi-type and small-batch production, *Proc. of 2009 International Conference on Information Management, Innovation Management and Industrial Engineering, ICIMMIE 2009*, Xi'an, 469-472.
- [8] L. Chen, B. Meng, Research on the Five-stage Method for Chinese Enterprises to Implement Lean Production, *Proc. of 2010 International Conference on Logistics Systems and Intelligent Management, ICLSIM 2010*, Harbin, 1135-1138.