Design and Construction of Lean Production Line for a Typical Control System Product

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Abstract. With the progress of supply-side structural reform and economic development capability shifting and upgrading in the new era, manufacturing enterprises are facing new opportunities and challenges in the process of R&D and production. In order to meet the needs of this requirement, many traditional manufacturing enterprises keep cultivating new core competitiveness through management reforms. Based on the practice in design and construction of a lean assembly unit production line for a high-mix-low-volume control system product, the author sums up the method, process and tools for this kind of lean assembly line, serving as a reference for other manufacturing enterprises committed to comprehensively enhancing the level of manufacturing and operation, and promoting the formation of manufacturing and operating control abilities suitable for the current developing stage of the enterprise.

Introduction

Due to the historical development reasons like weak industry foundation, Chinese traditional manufacturing enterprises presents typical characteristics—diverse product forms, low standardization and modularization, high-mix-low-volume. The production process relies heavily on manual labor. Personnel working around diverse products, parts delivery and outsourcing process completely depend on the person responsible for assembly. The difficulty and complexity of the whole production organization are caused by many reasons, such as multi-variety mixed loading on the site, unbalanced production pace, frequent quality problems. It’s difficult to adapt to the new requirements of modernization with the traditional production mode[1]. Faced with such challenges, it is necessary to change the traditional single-worker responsibility production mode and apply the lean management ideas to establish a lean assembly line based on unitization and informationization[2].

This paper bases on the design and construction of lean production line for a control system products in practice, and proposes a set of typical lean unit production line design and construction methods according to top-level ideas of “lean process, optimized workstation, mobility creation, effective management and control, independent evolution”. It discusses value analysis on break spots, slow spots and blind spots, production line load calculation, production line layout adjustment, tooling equipment automation, material transportation route optimization, process standardization and visualization. And it also expounds the application of lean ideas in typical high-mix-low-volume assembly production process.
Lean Unitized Assembly Line Design and Construction Implementation Method

Establish Integrated Product Team

Integrated Product Team (Referred to as IPT) is a small group full of complementary skills. All the members share common goals, standards of conduct and working methods. They mainly play three different roles: Product/Process Engineer (PE), Industrial Engineer (IE) and Governor of Line (GL). PE works on the optimization of assembly efficiency, quality and cost, responsible for how products are assembled optimally; IE is based on the optimization of capability, mobility and efficiency, responsible for how to perfectly integrate the process plan/process procedure with the line; GL is responsible for re-analysis and improvement through feedback to PE and IE of the production control plan and variation source, responsible for a stable and high quality of the product. With IPT, a combination of PE, IE and GL, the process (consisting of route, parameter, equipment and document) standardization is gradually formed.

Determine Construction Route

In the actual operation process, in order to ensure the continuity of production, the target selection strategy is to select a line of products with high similarity and strong possibility of grouping to optimize the design. According to the production plan and historical data analysis, combined with future product development prospects, to consider the production capacity of the product and the economy of input and output comprehensively, and to select typical products for lean production line construction pilot. This thesis selects a typical control system product shown in Figure 2.

The main function of this kind of product is to realize the on/off, switch and adjust functions of the product by flipping the switches and other devices, and to realize the control input and status output by transmitting information such as the status of the device through lights and luminous block. The product structure mainly consists of supporting board, panel, installation board, shell, printed board, switches, luminous blocks, lights, protective covers and other devices and structural components.

The main features of this production line are: high-mix-low-volume, short switching period of production, mixed production of multi-model products, diverse assembly processes, transporting dependent on assembly process, involving mechanical processing, surface painting and other processes, making it difficult to control.
Combined with the actual situation, the design and construction route of the assembly line is determined as shown in Figure 3. It mainly includes key definitions such as target definition, process lean, layout design, material design, standard operation, unit control, and autonomous operation etc.

Identify Product Families, Develop Typical Process Routes, and Specify Target Definitions

Combining Product-Quantity (PQ) analysis with Product-Route (PR) analysis, a simple and feasible method for determining the design object of lean assembly unit is proposed, namely the Product-Quantity-Route analysis (referred to as PQR Analysis). It is used to determine product family, main process and main product of lean assembly unit, and to determine the production planning control mode of different products of the same family [3].

Using the product family matrix analysis method shown in Table 1 to determine the product family, and following the “80/20 Rule”, which means different products must have more than 80% of the same process, and the products can be classified into same family. The 3 types of control system products shown in the table have 7 assembly processes on the line. Through matrix analysis, all the 3 products involve riveting, metering, welding debugging resistance, joint welding, pressure feeding needle, assembly. And the number of same processes exceeds 80% of the total number of processes. Therefore, these three products can be classified into the same product family, and the same process route can be prepared.

For each product of a family, despite of its structures, its process routes shall be expanded, merged, uniformly named, and adopt Precedence Analysis method. Precedence Analysis method is to find out whether it is parallel operation or serial operation between processes. Parallel operation
refers to sequent operations can be carried out at the same time, while serial operation refers to an operation can only be performed after the previous one is completed. Therefore the process standard path can be determined, and finally forms a typical process route of the production line, providing theoretical basis for subsequent production line balance.

**Carry out Process Lean**

To carry out process standardization, visualization and electronization can realize lean process. Refers to process standardization and visualization, there are some problems can be found in original files: enormous text, fewer graph illustration, mixed material bills, hard for operators to understand, etc. So improve the visual process template, compile manual, and standardize and refine the terms. At the same time, it is required that each process must be attached with assembly graphic presenting assembly procedures from multiple views. What’s more, material information solely required for this process shall be provided in order to facilitate the understanding of operators. For process informationization, CAPP is introduced, combined with process layout, information system introduction is carried out. Legal and effective documents are formed through online approval and signing. The effective documents are uploaded to the station terminal via CAPP, so that operator can check the operation process of the corresponding workstation through the all-in-one monitor for each post.

![Figure 4. Effect Comparisons on Standardization and Visualization.](image)

**Carrying out Production Line Layout Design to Achieve Dynamic Balance**

The layout design of the production line can be carried out according to the design process shown in Figure 5. It is necessary to determine the effective working time of each shift, and select the typical products to balance the line. For each shift, effective working time is generally 6.5 hours. It is calculated by cutting the time spending in pre-shift meeting, intermission and 6S effort from planned working time (8h/shift). In order to realize pace flow production in the lean unit production, it is necessary to adjust the operation content or workload of each process according to the tact time, and follow the steps of “cancel, merge, rearrange and simplify” to make the time of each process as close as possible. By taking the operator configuration and the assignment of workstation into consideration, the balance of production line is finally realized.

![Figure 5. Design Process of Production Line Layout.](image)

Combining the typical process route, re-arrange station design, plan a mutually assistant and dynamically balanced assembly workstation, the production assembly of the whole product is divided into three stages according to the process route: early stage, middle stage and later stage. Early stage is production preparation; middle period is the assembly (①screwing→②③joint welding→④pressure delivery→⑤coating and final assembly), and the last period is ⑥final
inspection and submission period. During each operation period, the corresponding personnel are assigned to operate at the corresponding station. After one operation of one product is completed, the product is transferred to the next workstation personnel for the next process operation. In addition, the next process personnel should first check the assembly quality of the previous process before operation, and conduct mutual inspection among the processes, so as to find and solve problems in time.

After the station design, the work content of each workstation will be assigned, observed and record the actual assembly time of each workstation to analyze the assembly time of each process. Since Workstation 1 has to screw lots of parts and takes up large space, 2 same workstations are set up under the charge of Operator 1. For the long assembly process (such as ② welding), set up two same workstations, which are completed by two operators, who can help each other. Workstation 2 (welding), 3 (joint welding) and 4 (pressure delivery) all need to refer product manual to process the cables, but the process time is different, and operators 2, 3 and 4 can form a mutual aid group. Operators 5 and 6 of workstation 5 (final assembly) and 6 (final inspection) form a second mutual aid group with operator 1 to achieve dynamic balance in accordance with product assembly characteristics. The comparison of the working hours of each station before and after dynamic balancing is shown in Figure 6.

Through reasonable layout and staff coordination, the final workstation layout is shown in Figure 7, which has four typical highlights: (1) Invisible "competition" can be formed between operators/workstations, which is conducive to improving efficiency; (2) Cross-station coordinated operation, which promotes dynamic balance of production lines and helps cut assembly cycle; (3) Launch production on workstation mode, production post is specialized, and the assembly quality of the previous and later stations is checked, which can find problems in time and improve the stability of assembly quality. (4) Production preparation goes ahead of schedule, external transfer process and receiving/dispatching materials are managed in a unified manner, which can reduce waiting time.

![Figure 6. Comparison of The Working Hours of Each Station Before and After Dynamic Balancing.](image)

![Figure 7. Workstation Layout.](image)

Establishing Line-side Logistics to Achieve a New Efficient Logistics Mode

The original backward management mode is to store the materials of a product in one or two containers after the preliminary materials classification, which is managed by each employee who is responsible for the assembly of the product. Parts, semi-finished products and finished products are usually mixed, causing confusion in product assembly state management. In order to solve such
problems, the line-side logistics is established around the “workstation” of the assembly operation area, as shown in Figure 8, the material is more convenient to be taken, and the production line is divided into the riveting area, preparation area, work-in-progress area, the waiting for the power-on area, the submitting area, office area, regular meeting area, etc., to ensure that the production line is “material partitioned, areas identified and objects correlated”.

![Line-Side Logistics Diagram](image)

**Figure 8. Line-Side Logistics Diagram.**

Line-side logistics management follows four principles: (1) Proper container and capacity: capacity and quantity of standard container determines the batch size; (2) Position is flow: material location indicates its status and flow direction, which is convenient for tracking; (3) Nearby position: All items, parts, or tools needed for work are placed near the operator (point of use). The most commonly used items are the nearest, less used items are appropriately placed farther, and the least used items are stored far away but with easy access; (4) Operate by signal: The material flow is triggered by a certain signal. The production preparation and product assembly can be carried out according to the daily production plan. Record material in and out in real time on the board, and record material receipt/delivery and product status on the board.

**Implement Standard Operations Comprehensively**

Standard Operating Procedure (SOP) [4] includes technician, operator, planner standard operations, etc. Through the standardization of the process system and forms, it can comprehensively achieve operation standardization. For example, technician drafts process documents according to typical process routes, SOP and standardized languages; apply the solidified SOP and typical process to the site, and let the operator of corresponding station adopt the best practice to solidify skills. Forms used in the production process are unified so as to avoid missing elements.

**Establishing a Quick Response Mechanism to Improve the Efficiency of Unit Control**

**Establishing a Quick Processing Mechanism for on-site Problems.** Various problems can occur every day in the assembly. Original problem-solving mode is when encountering a problem, operator fills in “Correction Form of Product Problem (Fault)” and sent it to the process manager, who completed the registration and assigned different field engineers. Long processing cycle and frequent movement of the operator make great impact on the smoothness of the line.

After improvement, a new on-site problem solving mode is formed according to the characteristics of the line. That is when the operator encounters a problem, he report to the line manager at the first time. Line manager initially screen and classify the problem according to the problem nature. In table 2, Problem 1 and 6 are handled by line manager, and 2-5 are handled by the industrial engineer. In addition, line manager can make overall management according to the operation plan, timely supervise and urge the progress, and promote the solution to the problem.
Table 2. Classification of On-Site Problems.

| Number | Problem Classification               | Description                                                                 |
|--------|--------------------------------------|-----------------------------------------------------------------------------|
| 1      | Lack of materials                    | The actual issued quantity of materials is inconsistent with the quantity shown on the issued material list |
| 2      | Wrong materials, mixed materials     | Physical is inconsistent with process requirements or has multiple states   |
| 3      | Parts quality problems               | Defective parts can't be assembled or can't meet the process requirements after assembly, appearance defects |
| 4      | Process data problems                | Process error, ambiguous description, unable to guide smooth assembly        |
| 5      | Fixture equipment, etc.              | Abnormal tooling, fixtures, equipment                                       |
| 6      | Others                               | Plan conflicts, product backlog, etc.                                       |

Combined with the priority of actual demand, the process is transferred step by step to form a full-process closed cycle of “line manager preliminary screening → on-site engineer processing → on-site engineer feedback → normal assembly → product engineer solidifying process” as shown in Figure 9.

**Unified Scheduling thought and Processes to Effectively Control Production.** In order to ensure that the output targets are met to its maximum extent with limited resources, and production is effectively controlled, IPT team sorts out the full assembly cycle of the products in the production line, forming a unified scheduling thought and process as shown in Figure 10. Which is, according to the production cycle and Bill of Materials (BOM), the production management department will decompose the product requirements into component requirements and parts requirements through Material Requirement Planning (MRP) calculation to form a quarterly rolling delivery plan [5]. According to it, the assembly plant forms a monthly production plan and locks it. Through layer-by-layer decomposition and refinement, it is implemented as the production line week node plan and the daily scheduling plan. Line operators complete the work tasks as planned to ensure the delivery requirements[6].

**Independent Evolution, Continuous Improvement**

After the completion of the production line, it is necessary to form a continuous improvement ability that can independently evolve, so as to continuously solve new problems in the operation process and continuously improve the output efficiency and quality. Take feeding cycle shortening by optimization of material maintenance and scrapping process as an example.
IPT team changes the material maintenance process from the traditional paper signature approval to electronic approval, which increases the frequency of approval and reduces the circulation. The feeding maintenance cycle is shortened by one day on average. IPT team continuously improve the on-site material scrapping process, changing Office Automation (OA) and Enterprise Resource Planning (ERP) process, which are shifted from serial to parallel, reducing the on-site material scrapping process from an average of 30 days to 3 days.

![Figure 11. On-Site Scrapping and Feeding before Improvement.](image)

![Figure 12. On-Site Scrapping and Feeding after Improvement.](image)

Establishing Staff Training and Assessment Methods

The operation of the line is inseparable from the operator, whose skill level determines assembly speed of the line and quality of the products. Establish staff skill matrix, carried out skill trainings according to staff skill level and workstation’s skill requirements. In order to prevent the training from being a mere formality, examination will be arranged after training, and final results will be published. Operators with high scores will be given with material rewards to fully mobilize the enthusiasm of staff. In addition, the line performance evaluation mechanism is also established. The product delivery time rate and the one-time pass rate are used to guide the establishment of operator's reward and punishment system, and the operational errors in daily work are also included in the assessment method to enhance the operator's responsibility.

Line Effectiveness

After a year of trial and data statistics, annual output of the line has increased from 1,226 in 2015 to 2,308 in 2016, monthly per capita output increased from 29 to 43, the utilization rate of working hours increased from 68% in 2015 to 96% in 2016. All the performance indicators of this line have been significantly improved.
Conclusions

This paper introduces the design and construction process of a lean unitized assembly line of an enterprise control system product, and summarizes a feasible path for the design and construction of a lean unitized assembly line. Through lean process, optimized production line layout, improved production line logistics, information flow, and increased production line implementation, the quantity and quality of assembled products have been effectively improved, and customer satisfaction has been greatly improved. At the same time, through continuous and orderly promotion, the company's production on-site management has been gradually promoted from extensive to fine, from rule of man to rule of law, from function-oriented to process-driven, and raises the transformation and upgrading of enterprises to lean enterprises.

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