Value stream mapping method for development of a dynamic model of capacity utilization

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Abstract. For multi-product small-scale manufacturing, for example the production of electronic equipment, the searching of methods and tools for production planning is relevant. One of the basic tools for planning is the model of enterprise capacity utilization. The purpose of this research is to develop a model and software allowed the company to calculate the optimal capacity utilization. The paper considers the use of value stream mapping method for development of a manufacturing dynamic model. This method allows creating the interaction logic and collecting data and parameters for each system components. The purpose of the value stream analysis is to find a transit solution from the current production state to a more efficient, which allows loading the production capacity in optimal mode. In the analysis, the manufacturing data of the finished products assembly shop of a radio-electronic enterprise is used. According to the results of use the proposed method, the duration of the assembly process was significantly reduced, which makes it possible to equalize the load of work centers and to reduce the volume of unfinished production.

1. Introduction
The market of specialized electronic equipment is mainly represented by communication stations, radio navigation equipment and other similar high-tech products. Frequent change of products, as well as the constant increase in the number of nomenclature in conditions of high requirements for product quality impose their difficulties on the operational planning of production [1]. To improve production efficiency, operations management should be carried out to achieve the required performance under specified conditions in real time [2]. Such purposes can be achieved by effective operational and calendar-network planning to organize the coordinated interaction of all enterprise shops. This allows organizing the coordinated manufacturing to ensure timely product release in accordance with the established in agreements terms, item, and delivery time with the most complete use of all enterprise resources.

Traditionally, for operational management purposes uses the APS (Advanced Planning and Scheduling) and MES (Manufacturing Execution System) software. The well-known APS and MES software cannot propose an effective solution solving the problem of manufacturing setting (tuning), which is a typical problem in small-scale and multi-product production [3]. The relationships between production planning, maintenance tools and equipment performance is a critical factor. Decision makers have to adapt to the dynamic behavior of the production environment [4]. This creates a demand for a dynamic model that allows making complex decisions under uncertainty while considering alternative solutions.
2. Problem statement
The value stream mapping method for object of research allows creating the interaction logic for each element of the production system, as well as to collect data and parameters for each object of the system too. The lean manufacturing philosophy is used for continuously process improvement and it is based on product value forming. From the business point of view, the cost of a product is defined as what the customer pays for [5]. If the production is exist, the value stream is exist too. The intersection of lean manufacturing and simulation is discussed in some well-known papers [6]. Company of any business scale, from small businesses to large enterprises, use simulation models for logistic networks analyzing, so the mapping technology of this stream is necessary. In manufacturing process, losses can be occured for various reasons. The way for analysis, prevention, optimization and solution search for losses causes is the joint use of value stream mapping method and simulation. The advantage of this approach is it’s helping to maintain or even to decrease the production cost, to eliminate negative factors and unnecessary waste.

The value stream mapping (VSM) is a method for research and design of material and information flows (streams) that are presents itself the customer requirements satisfaction [7]. The VSM diagram shows each stages of material and information stream which are required to fulfill the customer’s order. With VSM it is possible to determine losses in the stream of values and find the solutions for it’s reducing or eliminating. The value stream analysis and VSM-chart design is expressed in the representation of all processes, from tool’s processing of raw materials to delivery products to customer, that is leading to a better understanding of the production process as a whole [8].

3. Object of research
Analyzed manufacturing in the research is JSC «NPP «Radiosvyaz». This enterprise is leading Russian research and development company for radio-communication and navigation equipment. At the same time, for most products due to their complexity, this company is the one (exclusive) supplier. For example, the produced navigation equipment with spatial orientation function has no competitors in Russia and is not inferior to the best foreign analogues. A similar situation is observed in the sphere of tropospheric communication mobile stations. The company is the main manufacturer of this kind of equipment designed to provide communication of remote objects in the conditions of impossibility of using satellite communications. In the Figure 1 is presented a simplified process stream for the manufacturing process specified for JSC «NPP «Radiosvyaz».

![Figure 1. Simplified manufacturing process stream](image-url)
For the research purposes (creating and research VSM diagram), one of the products was chosen – the voltage inverter for radio-communication stations (Figure 2). All manufacturing operations are carried out in assembly shop (Figure 3). The working shift mode for employees is 8 hours. In one working day is one shift.

![Figure 2. The voltage inverter](image1)

![Figure 3. Workshop adjustment area](image2)

4. Development of the VSM diagram

The method of the VSM diagram design is widely reported in the well-known tutorials and monographs [9, 10]. The process of its creation can be described as follows steps: the choice of a product group (family), building a map of the current state of the process, process analysis for the presence of losses (overproduction, excess stocks, transportation, waiting, defects, excessive processing) and bottlenecks. It all completes by the development of the future state map with minimized losses.

Then the future state is modeled, and the simulation results are compared with previous results, the change in the main indicators is assessed. The model obtained as a result is a static object, but our task is to create a dynamic model that allows calculating the optimal utilization of production capacity in real time based on the collected manufacturing data.

In the Tables 1 and 2 are presented data for the manufacturing process of voltage inverter device (Figure 2). The manufacturing process consists of fifteen operations. Operations with 1–15 numbers are the following technological operations according to the technological route of the device:

1. Completing by purchased items.
2. Completing by own production items.
3. Assembly.
4. Installation.
5. Assembly.
6. Installation.
7. Marking.
8. Installation.
9. Control.
10. Adjustment.
11. Technical training.
12. Erasure.
13. Acceptance testing in the quality control area.
14. Presentation, subpaint.
15. Acceptance tests to the customer's representative.

**Table 1. Information of current state VSM (first part)**
Based on the collected manufacturing data, a map of the value stream was developed – the current state (Figure 4). Value added time is 3623 minutes, and lead time is 17406 minutes. Process cycle efficiency is 0.2, which undoubtedly indicates that there are many losses in manufacturing stream. Production losses are so great that the researched manufacturing process obviously needs for optimization. Because of assembly shop is working in one shift for 8 hours, the available time per day is 480 minutes (one hour). The production of voltage inverter needs 36 working days. The demand for this device is 50 units per year, which is impossible with the current capacity.

### Table 2. Information of current state VSM (second part)

| № of operations | Value creation time (min) | Transportation | Control | Changeover | Storage, drying of glue | Number of operators |
|-----------------|---------------------------|---------------|--------|------------|------------------------|-------------------|
| 1, 2, 3, 4, 5, 6, 7, 8 | 10, 12, 476, 354, 60, 1020, 84, 150 | 2, 4, 2, 1, 1, 1, 1 | 0, 0, 0, 0, 0, 0, 0 | 0, 0, 10, 60, 60, 60, 180 | 0, 0, 1440, 1440, 1440, 2880, 4320 | 1, 1, 1, 1, 1, 1, 1 |
| 9, 10, 11, 12, 13, 14, 15 | 100, 155, 447, 120, 150, 160, 180 | 2, 4, 4, 4, 2, 2, 1 | 0, 0, 0, 0, 0, 0, 0 | 60, 75, 40, 60, 60, 60, 60 | 0, 0, 0, 0, 0, 1440, 0 | 1, 1, 2, 1, 2, 1, 2 |

Figure 4. Current state – VSM
Analyzing the chart, it is possible to note that one of the most significant losses is waiting. These type of losses are associated with the waiting personnel resources, the next technological operation, as well as this type of loss includes equipment downtime during uneven loading, lack of necessary materials. One of the main causes of this loss is a violation in the production logistics system and the lack of effective planning.

When mapping a future state VSM diagram, it is necessary to take into attention that identified losses should be reduced as much as possible. It was developed desirable indicators for the manufacturing process parameters, which are presented in Tables 3 and 4. To expand the bottleneck of sequential assembly and installation it has been proposed solutions by parallelized operations 3 and 4. To reduce the cycle time of operations, the 5S system was implemented, and to reduce equipment changeover time, elements of the SMED system were used. Compare the similar indicators of Tables 1 and 2, Tables 3 and 4. The lead time was reduced by 9792 minutes. Process cycle efficiency was increased to 2.1 % instead of 0.2 %. The value of the stream increased in 10 times. Among the losses in the production process, the time of waiting still dominates, but it is primarily due to the peculiarity of the technological process. In Figure 6, the value stream map of the future state is shown.

The data obtained for the future state VSM diagram should be checked for subsequent implementation in production. It is necessary to create a model using simulation methods in the future. The model will have to allow testing the hypothesis without implementing measures directly in the production system.

**Table 3. Information of future state VSM the first part**

| No. of operations | Value creation time | Time during which value is not created | Number of operators |
|-------------------|---------------------|----------------------------------------|---------------------|
|                   | min                 | min                                    | employee           |
| 1                 | 10                  | 2                                      | 1                   |
| 2                 | 12                  | 4                                      | 1                   |
| 3                 | 476                 | 0                                      | 1                   |
| 4                 | 60                  | 1                                      | 1                   |
| 5                 | 1020                | 1                                      | 1                   |
| 6                 | 84                  | 1                                      | 1                   |
| 7                 | 150                 | 1                                      | 1                   |

**Table 4. Information of future state VSM the second part**

| No. of operations | Value creation time | Time during which value is not created | Number of operators |
|-------------------|---------------------|----------------------------------------|---------------------|
|                   | min                 | min                                    | employee           |
| 8                 | 100                 | 2                                      | 1                   |
| 9                 | 155                 | 4                                      | 1                   |
| 10                | 447                 | 4                                      | 2                   |
| 11                | 120                 | 4                                      | 2                   |
| 12                | 150                 | 2                                      | 1                   |
| 13                | 160                 | 1                                      | 1                   |
| 14                | 180                 | 1                                      | 1                   |

|                   | min | min     | min     | min     | min     | min     | min     | min     | min|
|-------------------|-----|---------|---------|---------|---------|---------|---------|---------|-----|
| 8                 | 2   | 4       | 4       | 4       | 2       | 2       | 2       | 1       |    |
| 9                 | 0   | 0       | 0       | 0       | 0       | 0       | 0       | 0       |    |
| 10                | 20  | 15      | 30      | 40      | 40      | 40      | 40      | 40      |    |
| 11                | 0   | 0       | 0       | 0       | 0       | 0       | 1440    | 0       |    |
| 12                | 1   | 2       | 1       | 2       | 1       | 2       | 1       | 2       |    |

|                   | min     | min     | min     | min     | min     | min     | min     | min     | min     |
|-------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 8                 | 2       | 4       | 4       | 4       | 2       | 2       | 2       | 1       |         |
| 9                 | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 1440    | 0       |
| 10                | 20      | 15      | 30      | 40      | 40      | 40      | 40      | 40      |         |
| 11                | 0       | 0       | 0       | 0       | 0       | 0       | 1440    | 0       |         |
| 12                | 1       | 2       | 1       | 2       | 1       | 2       | 1       | 2       |         |
5. Conclusion
The VSM method uses for production processes analyzing and it is an effective method for identifying production losses. The developed map of the current production process state is based on the searching for actions with do not create values. The proposed VSM model of the future state has a set of solutions to minimize manufacturing losses. The simulation is an additional tool that allows visualizing processes and testing the model of the future state. Creating a dynamic model will allow you to use the potential of production. The planned for development software is focused on the collected data of the technological process and it is predicted the maximum possible output for a certain period, with full-use provided the production capacity tools assigned to the shop. A designed cycle time reduction can increase the number of manufactured products at 10 times. If further simulations confirm these results, and the improvement processes are undertaken, the whole organization can be more productive, and the demand can be satisfied with existing capacities.

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