Yury Klochkov

Albina Gazizulina[1]

Kunnummal Muralidharan

LEAN SIX SIGMA FOR SUSTAINABLE BUSINESS PRACTICES: A CASE STUDY AND STANDARDISATION

Abstract: Lean Six Sigma (LSS) modifies the DMAIC approach by emphasizing speed. Lean focuses on streamlining a process by identifying and removing non-value added steps. A leaned production process eliminates waste. The target metrics, which affect any business include zero wait time, zero inventory, scheduling using customer pull, cutting batch sizes to improve flow, line balancing, and reducing overall process time. Lean Six Sigma's goal is to produce quality products that meet customer requirements as efficiently and effectively as possible. In this article, we present various Lean performance characteristics that can be effectively used for improving a sustainable business process through a case study.

Keywords: Quality improvement, Environmental Management system, Qualitative statistics, Six Sigma

1. Introduction

Lean is a quality improvement philosophy, began with Japanese automobile manufacturing in the 1960s, and was popularized by Womack et al. (1990) in "The Machine that Changed the World". The Machine that Changed the World is essentially the story of the Toyota way of manufacturing automobiles. The characteristics of Lean, sometimes referred to as Toyotaism, are that materials flow 'like water' from the supplier through the production process onto the customer with little if any stock of raw materials or components in warehouses, no buffer stocks of materials and part finished goods between stages of the manufacturing process and no output stock of finished goods (Andreeva et al., 2014). This 'just in time' (JIT) approach requires that materials arrive from dedicated suppliers on the factory floor at the right stage of production just when required, and

when the production process is completed it is shipped directly to the customer (Antony et al., 2012a, 2012b).

For any business to sustain, there must available a strong business leadership, manpower knowledge and technology. That too, people working with LSS projects, should bring complete transparency on the positive and negative aspects of the environmental issues they are addressing through the project. The *environmental management standards* (EMS) were first developed as a response to new environmental regulations being imposed on companies. Environmental management has both short term and long term consequences, affecting the current performance and long term sustainability of businesses. Carbon management is relatively a new part of this process, gaining in significance in light of the climate change threat (Walley & Whiltehead, 1994). It is important to create one comprehensive environmental strategy

[1] Corresponding author: Albina Gazizulina
Email: albinagazizulina@gmail.com

and understand the potential trade-offs between its constituent parts. Thus EMS is a structured framework for managing an organizations significant impact on the environment (Borovkov et al., 2017; Burkovsky et al., 2012; Shymchenko et al., 2017). These impacts can include waste, emissions, energy use, transport and consumption of materials and increasingly, climate change factors (Ganguly, 2012).

It is important to note that the advantage of introducing LSS by many authors is primarily noted for solving problems such as reducing defective products, increasing customer satisfaction, improving product quality, increasing efficiency, and reducing time spending (Naidu, 2011).

The article is meant for business organizations promoting Lean activities, professionals working in Six Sigma projects, consultants and academicians. In the next section, we discuss some important aspects of LSS and their benefits (Grechnikov et al., 1999). The activity tools necessary for implementing LSS in sustainable business practices are discussed. In the article discusses the sustainable issues of businesses. The performance indicators addressed through LSS are presented in section 3 and 4. The 5 section ends with a conclusion and discussion.

2. Methodology

2.1. Lean Six Sigma

The operating philosophy of lean is to eliminate waste through continuous improvement (see Womack and Jones, 1996). By waste, we mean unnecessarily long cycle times, or waiting times between value-added work activities. Waste can also include rework, scrap, and excess inventory. Rework and scrap are often the result of excess variability, so there is an obvious connection between Six Sigma and lean. As we know, a business process is a series of interconnected sub processes. The tools and focus of Six Sigma is to fix processes,

whereas, Lean concentrates on the interconnection between the processes. The central theme of Six Sigma is defect reduction. The root causes of the defects are examined and improvement efforts are focused on those causes. In Lean Six Sigma the emphasis is indirect in that defects can cause delays to occur. George (2003) provided a good introduction to how lean and Six Sigma work together. According to Muir (2006), the two philosophies can be summed up as: "Reduce the time it takes to deliver a defect-free product or service to the customer". It is not the question of whether the customer wants it right or quickly, but both (Corbett, 2011).

The value-added activities in a lean manufacturing can be achieved through:
- Defining value from the client's perspective
- Identify the value stream
- Only make what the client pulls
- Keep the flow moving continuously and
- Always improve the process

The important metrics associated with LSS:
- Process cycle efficiency
- Process cycle time
- Work-in-progress
- Throughput rate

The Six Sigma process improvement goes with the philosophy of DMAIC techniques. In LSS, it develops with the identification of the problems and ends with retaining the benefits of the program. Thus the steps followed in LSS are R-DMAIC-S, where R stands for Recognize and S stands for sustain (Delgado et al., 2010). It is important to identify the significant gaps in a business problem by articulating the business strategy. This will decide what the management wants to deliver. Once a Six Sigma project completes through the DMAIC procedure, the management will be able to identify the tangible benefits coming out of the project and its immediate impact can be assessed for retaining similar such projects.

In order to achieve the required target, a process flow is necessary to establish. A perfect process has continuous flow as products, services and knowledge are transformed continuously without delay from step to step (Jeyaraman & Teo, 2010). A flow is created by eliminating queues and stops and improving process flexibility & reliability. The other aspects of establishing the continuous flow is by identifying the value added and non-valued activities in a process. Any activities that add no value to the client are by definition "waste". The mapping of all activities and steps according to its time of occurrence required bringing a product, service or capability to the client is called *Value Stream Mapping* (VSM).

Thus implementing Lean will address waste and its root causes. Waste points us to problems within the system. Lean also focuses on efficient use of equipment and people and minimizes issues by standardizing work. A lean cost model says that decreased cost always lead to increased profit. Hence, the tools for both philosophies differ depending on the business issue to be resolved.

2.2. Lean production

Lean production involves each employee in the process of optimizing the business and maximizing market orientation (custom production). The goals of lean manufacturing are:

- reduction of labor costs approximately twice;
- reduction of production and storage areas;
- shortening of the terms of development of new products;
- guarantee of delivery of products to the customer;
- maximum quality with minimum cost.

The starting point of lean production is value. Value is the utility inherent in the product in terms of the end user (Chiarini, 2011, 2012). The product is created by the manufacturer as a result of a number of actions: some of these actions add value from the point of view of the consumer, and the rest are simply necessary in accordance with the organization of the production process. In order to determine the value of an action, it is necessary to ask the end user if he is ready to pay the manufacturer for doing this action (Naidu, 2011).

In accordance with the concept of lean production, all activities of the enterprise can be classified as follows:

- actions that add value;
- actions that do not add value:
- actions that cannot be removed from the development, ordering and manufacturing processes;
- actions that can and should be immediately eliminated.

Everything that does not add value to the consumer, from the point of view of lean manufacturing, is classified as loss, and must be eliminated. Lean production is the identification and elimination of losses, and the first part of this task is the detection of losses, it is often no less complex than the second is their elimination (Hoerl & Gardner, 2010; Hoerl & Snee, 2010).

Losses are any activities that consume resources, but do not add value to the product from the point of view of the end user. All losses can be classified into 2 categories: losses of the first kind are actions that cannot be abandoned under existing conditions. For example, a control operation, payroll to employees of the company, etc. These actions cannot be removed; they can only be optimized. The loss of the second kind is possible and necessary to eliminate. There are seven types of losses of the second kind:

1. Overproduction. The production of more products is faster or earlier than is required for the next production stage. It is most often a consequence of production, based not on demand, but on supply (Papic, 2007; Kozlovskiy & Aydarov, 2017). There are losses from overproduction, like:

- premature consumption of raw materials;
- excessive stock increase;
- increase in used areas;
- increase in the percentage of deductions;
- increase in transport and administrative costs.

One of the principles of lean production is the pulling of the product; it is a cascading production system, in which a supplier upstream does nothing until the consumer below does not inform him. The best way to understand and feel the logic and advantages of drawing a product is to start dancing from a real consumer who needs a real product, to go through all the steps necessary to give him what he wants. When the customer's order initiates the launch of the entire system, the speed of the work at each stage turns out to be exactly equal to the clock time. Time tact is the time for which you need to produce the next product for the consumer. The time of the bar is equal to the ratio of the planned time to the consumer demand.

$$T\_tact = (Actual\ Time\ Fund) / (Purchase\ Order) \qquad (1)$$

2. Waiting in queues. Queue time is the time that the product is idle in the queue in anticipation of the next stage of design, ordering or production.

There is planned downtime:
- adjustment of equipment;
- scheduled maintenance;
- holding meetings;
- regulated breaks;

There is unplanned downtime:
- breakage of equipment;
- lack of materials;
- absenteeism;
- supervision of the work of the machine.

Losses of waiting time arise when people, operations or partially finished products are forced to wait for further action, information or materials. Bad planning, vendor non-availability, communication problems and imperfection of inventory management lead to downtime, which cost us time and money (Kansal & Singhal, 2017). The presence of variations in the duration of performance of individual jobs generates the effect of queues and the accumulation of unfinished products (Vinodh et al., 2011).

3. Transportation. This is the unnecessary movement of personnel, products, materials and equipment that do not add value to the process. Workers often make unnecessary movements from their site to the shop floor and back and also walk around unnecessary equipment (Pepper & Spedding, 2010). Such displacements can be eliminated and this can speed up the process. This is one of the most unpleasant losses for ordinary personnel and for management, since the time spent and idle time deprives the majority of production processes, making the labor of workers heavier (Demidenko et al., 2017). Despite the fact that most of the production processes were initially developed taking into account the minimization of unnecessary movements, basically this is one of the largest sources of losses that occur imperceptibly and lead to failures (Ryan, 2011).

4. Excessive processing. Losses from excessive processing arise in the production of products or services with higher consumer qualities than it is claimed by the buyer and for which he agrees to pay (Muralidharan, 2015). This leads to:
- increased internal rejection;
- more expensive tool;
- more qualified staff.

Adding functionality that does not have value in the eyes of the consumer does not improve the product or process. The lack of information about how consumers use products or services often contributes to the addition of unnecessary functionality, in which, according to the manufacturer, customers need or desire them.

5. Excess of stocks. Excessive amount of raw materials, work in progress, finished products, spare parts stored in warehouses and between processing stages is common. Losses hiding in surplus stocks are fraught with a host of unpleasant quality problems, such as alteration and defects, labor or production planning problems, excessive lead times, problems with suppliers etc. To contain excessive reserves, freezing capital and requiring payment of bank interest, is too expensive. Excess stocks reduce the return on investment in labor and raw material (Glouschenkov et al., 1997).

6. Excessive movements. Getting rid of unnecessary movements in the performance of work is the main task of specialists in the scientific organization of labor. System 5S is a workplace management system based on visual control (Golenko-Ginzburg et al., 1999). It includes five principles, each of which in Japanese begins with the letter "C" (it should be "S"). Seiri is to separate the necessary tools, parts and documents from unnecessary in order to remove the latter away. Seiton is to arrange (and mark) the parts and tools in the workplace so that they are comfortable to work with. Seiso is to keep the workplace clean. Seiketsu is to perform Seiri regularly, Seiton and Seiso in order to maintain the workplace in perfect condition. Sitsuke is to make the performance of the first four "C" (it should be "S") habits, the standard of work.

7. Incomplete use of knowledge and creativity of employees harms the Planning processes, knowledge, suggestions and needs of immediate performers.

2.3. 5S

5S is a workplace organization system that allows to significantly increase the efficiency and manageability of the operating area, improve the corporate culture, increase labor productivity and save time.

The 5S system includes the following:

Seiri also means sorting means that you are releasing the workplace from everything that is not needed when performing current production operations. Workers and managers often do not have the habit of getting rid of objects that are no longer needed for work, keeping them nearby "for every fire case." This usually leads to unacceptable confusion or to creating obstacles to movement in the work area (Hilton & Sohal, 2012). Removing unnecessary items and putting things in order at the workplace improves the culture and safety of work. To more clearly demonstrate how much excess accumulated in the workplace, you can hang a red label (checkbox) for each candidate for removal from the work area.

All employees are involved in sorting and identifying items that they

- be immediately taken out, discarded, disposed of;
- should be moved to a more suitable place for storage;
- must be left behind and their places must be created and marked for them.

It is necessary to clearly identify the "red label zone" of items with red flags and carefully monitor it. Items that remain intact for more than 30 days are subject to recycling, sale or disposal.

Seiton also means straightens means to identify and designate a "home" for each item needed in the work area. In order to streamline processes and reduce the production cycle, it is extremely important to always leave the necessary items in the same places assigned to them. This is a key condition for minimizing the time spent on unproductive searches (Nemavhola & Ramdass, 2017).

Seiso also means cleaning (keeping clean) means providing the equipment and workstation with a neatness sufficient for monitoring and maintaining it constantly. Cleaning at the beginning and / or at the end

of each shift provides immediate identification of potential problems that can halt the work or even cause the entire site, workshop or factory to stop (Setijono et al., 2012).

Seiketsu also means standardization is a method by which stability can be achieved by performing the procedures of the first three stages of 5S. This means developing a checklist that is understandable and easy to use (Karthi et al., 2011). Think about the necessary standards for cleanliness of equipment and workplaces, and everyone in the organization should know how important is this for overall success (Snee, 2010).

Shitsuke also means sustain means that the implementation of established procedures has become a habit. They are Defects. It interrupts production and diverts itself from material and human resources (Laureani et al., 2010; Setijono et al., 2012). Losses due to defects or the need for an alteration arise when there is no reliable preventive system, including the methods of yet-yoke-built-in error protection and a focused process of constant improvement-kaizen (Niemeijer et al., 2010). Each time, having made a mistake while working with the product and transferring it to the next operation of the process, or even worse, to the consumer, we put up with the alteration as an integral part of the process. We lose money twice when we produce, collect or repair something, while the consumer pays us for a product or service only once (Salah et al., 2010).

2.4. Lean manufacturing

The introduction of lean manufacturing is proposed to reduce the cost of the product and to increase the efficiency of the resources of the enterprise. It is proposed to implement lean manufacturing in the following sequence:

- output;
- storage and delivery of finished products;
- purchases;

- marketing and design of production processes;
- infrastructure and production environnent management;
- management of equipment and accessories;
- human resources management (Timans et al., 2012).

3. Analysis and Results Body of the paper

3.1. Case study

The aim of this case study is to increase the efficiency of the production process of the water pump housing KVN 21073-13007015, due to the application of the lean manufacturing concept.

To achieve this goal, it is necessary to solve the following tasks:

- determine the value for the consumer in the production process of the water pump housing;
- analyze the casting process of KVN 21073-13007015 in terms of losses;
- introduce elements of lean production;
- assess the economic efficiency of measures to implement lean production;
- evaluate the factors of working conditions and the intensity of the engineer's work process on quality.

This solution should help the organization to enter new markets, namely, first of all, to start cooperation with the following organizations:

- FORD;
- Schneider Electric;
- Peugeot Citroen;
- Closed Joint-Stock Company "Samara Experimental Plant of Aluminum Alloys". Short name: CJSC"SamZAS".

The main consumer of CJSC "SamZAS" products are currently Russian automobile and machine-building factories (Figure 1).

They are: CJSC "TZA" - the supplier of JSC "AVTOVAZ"; Open Society "Ulyanovsk motor factory"; OJSC Yaroslavl Motor factory; OJSC "Kazan MCO"; CJSC SoyuzGidravlika (Belgorod); CJSC UralElectro (Mednogorsk), etc.
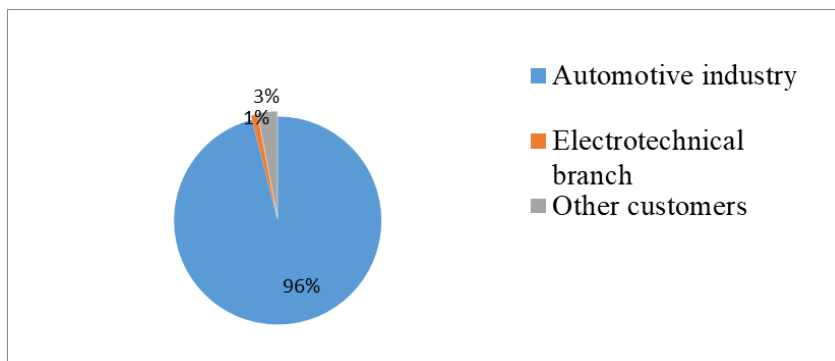

Figure 1. Structure of consumption of products by industry.

At present, CJSC "SamZAS" is a medium-sized enterprise with 300 employees, specializing in the processing of scrap and non-ferrous metal waste and the production of high-quality aluminum alloys and castings of varying complexity, obtained by injection molding and chill molding. The technologies used are injection molding, chill casting, as well as machining of non-ferrous metal products. Injection molding is the process of obtaining castings by feeding the melt into the pressing chamber and injecting it into the cavity of the mold at high speed and under high pressure (Golod & Dobosh, 2017).

The production of alloys is carried out in melting complexes on the basis of reflecting furnaces of various capacities. This allows the production of more than 45 different grades of foundry aluminum alloys (Figures 2 and 3). They are: Ak12M2, DIN 226, AK5M2, AK9M2 etc.

Taking into account the needs of customers, the enterprise produces more than a third of its alloys with narrower chemical composition limits than in the nationwide standards. A flexible production and sales structure allow not only to execute large orders, but, if necessary, to carry out small smelting (Balashova & Gromova, 2017a, 2017b, 2017c).

Figure 2. Aluminum alloys

The castings (Figure 4) are produced on CJSC "SamZAS" on injection molding machines (MLD) of the following models: 711A07, 711A08, 711I09, DC500 Toshiba, CLOO250 Vihorlat-polak, CLOO160 Vihorlat-polak. As the charge materials, aluminum alloys are used, both from own production and purchased from other manufacturers of aluminum alloys.

Figure 3. Storage of aluminum alloys

Figure 4. Factory products are castings

The focus on quality and the related task of standardizing business processes are perceived by management as important tasks of the current period. In 2015 the factory audited the quality management system. In September 2016 the Dutch firm conducted an Inspection of the Factory Management System for compliance with the requirements of the international standard ISO 9001. During the audit, the dynamics of management was analyzed and the processes of the company's QMS were tested in accordance with the KEMA verification program.

In accordance with the ISO 9001 standard, a process approach is applied at the enterprise (Panyukov & Kozlovskiy, 2014, Zhgulev et al., 2018). In accordance with this approach, the organization identified 17 processes. The list of these processes is given in Table 1. The order of interaction of these processes is shown in Figure 5.

Table 1. List of QMS processes implemented at CJSC "SamZAS

Process code	Process name	Process manager (owner)
1	2	3
Organizational and management processes		
O-1	QMS analysis. Continuous improvement	Executive Director
Production processes		
Pp-1.1	Analysis of the contract (alloys)	Head of sales department of alloys
Pp -1.2	Analysis of the contract (casting)	Head of sales department of shaped casting
Pp -2	Procurement management	Head of purchase department
Pp -3.1	Planning and Production of Alloys	Head of smelting and casting shop
Pp -3.2	Planning and Production of Castings	Head of the department of shaped casting
Pp -4.1	Control and testing of alloys	Head of laboratory (alloys)
Pp -4.2	Inspection and testing of castings	Head of technical control department
Pp -5.1	Warehousing and shipment of finished products (alloys)	Head of sales department of alloys
Pp -5.2	Warehousing and shipment of finished products (castings)	Head of sales department for shaped casting
Pp -6.1	Assessment of customer satisfaction (alloys)	Head of sales department of alloys
Pp -6.2	Assessment of customer satisfaction (casting)	Head of sales department for shaped casting
Supporting processes		
Sp-1	Documentation management	Quality engineer
Sp -2	Internal audit	Quality engineer
Sp -3	Personnel Management	Head of Administrative Department
Sp -4	Ensuring production of infrastructure and production environment	Technical Director
Sp -5	Metrological support	Head of technical control department

Consider the process of output. We will determine which production technologies will be subjected to changes in the first place.

CJSC "SamZas" produces products of 60 items. The aim of the project is to increase the efficiency of the production process of KVN 21073-1307015 due to the application of the concept of lean manufacturing. To achieve the goal, it is necessary to solve the following tasks:

1) Determine the value for the consumer in the production process KVN 21073-1307015;
2) To analyze the process of casting the body of the water pump KVN 21073-1307015 in terms of losses;
3) Introduce elements of lean manufacturing in the process of casting the body of the water pump KVN 21073-1307015;
4) To organize the work place;
5) Develop a draft standard on the organization of the workplace in accordance with the requirements of the 5S system;
6) Calculate the economic efficiency of measures to introduce elements of lean manufacturing;

Analyze and evaluate the working conditions of the severity and intensity of the labor process.
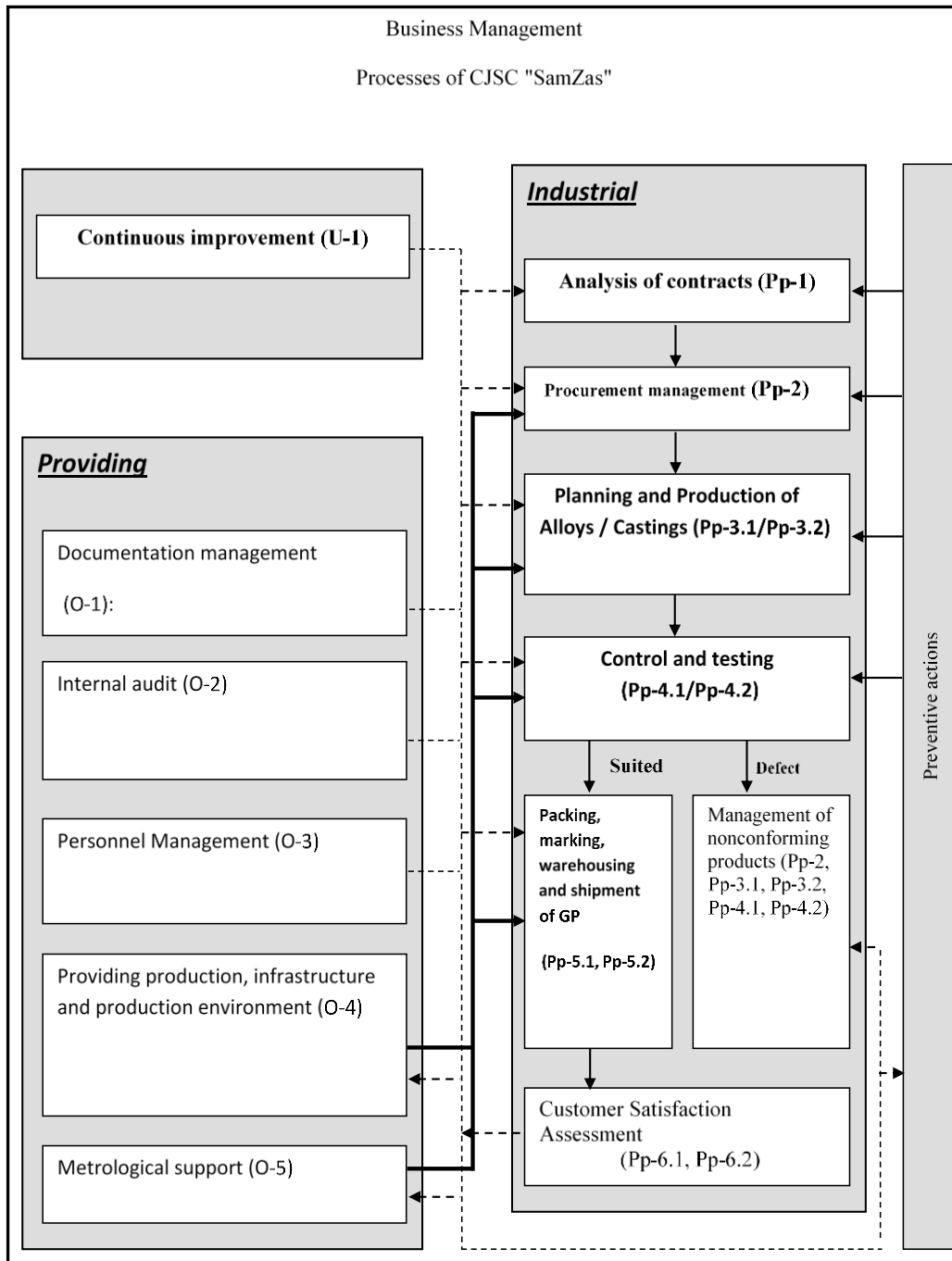
Figure 5. Scheme of interaction of processes of CJSC "SamZAS"

In the next section we have to discuss the overall improvement required in respect of various components in the system.

It is a water pump housing KVN 21073-1307015 (needs revision)

A water pump is available for cars. It is designed to ensure the circulation of antifreeze in the cooling system of the car and meets the requirements for products of the highest quality category (Rudskoy et al., 2018; Vasilyev, et.al.,2018; Kodzhaspirov & Rudskoi, 2017). The productivity of water pumps installed on cars is 15-17 m3 / h.

The water pump (Figure 6) is manufactured in a single version for the assembly of cars supplied to the domestic market and for export, including to countries with tropical climate. The pump is designed to operate the car at an ambient temperature from minus 40 °C to plus 45° C and humidity up to 90% at a temperature of 27°C. The design of the water pump, the materials used ensure its efficiency in the operation of a car with a mileage resource of 160000 km.

Figure 6. Water pump

The main element is the hull. The body of the water pump (Figure 7) is a monolithic body having an internal opening with coaxial annular surfaces.

Figure 7. Water pump housing 21073-1307015

3.2. Analysis of technological process

It is formation of a plan for analyzing the technological process of casting the hull of a water pump from the position of the concept of lean production. Improving the quality of the water pump housing will be achieved by reducing the cost price. Firstly, we will analyze the technological process according to the following plan:

1) Analysis of the casting process in terms of loads.
2) Analysis of the casting process from the point of view of overproduction.
3) Analysis of the casting process from the standpoint of expectations in the queues.
4) Analysis of the casting process in terms of transportation.
5) Analysis of the casting process from the point of view of excessive processing.
6) Analysis of the casting process in terms of stocks.
7) Analysis of the casting process from the point of view of unnecessary movements.
8) Analysis of the casting process in terms of defects.
9) Analysis of the casting process in terms of equipment downtime.

Analysis of the technological process from the point of view of the concept of lean production

The process of manufacturing the body of the water pump 21073-1307015 consists of the following operations:
- metal preparation,
- casting of the water pump housing,
- chipping,
- shot blasting.

Analysis of the technological process in terms of load distribution

Consider the level of loading of the casters in relation to the loading of equipment. In accordance with the casting process shown in Table 2, we determine the level of loading of the foundry.

In Table 3 we will enter the data received in the casting shop. We find that the foundry works 37seconds, then 30 seconds is expected to yield the finished casting, and then another, running 27 seconds.

Table 2. Technological process of casting the body of the water pump 21073-1307015

№	Processes	The norms of time, seconds
1	Treatment of the chamber with grease lubrication.	2
2	Treat the mold surface with an oil-based lubricant for molds.	8
3	Treat the mold surface with a water-based lubricant for molds.	8
4	In the compression chamber, load a granular lubricant for press-pairs using a measuring spoon or an auto-dos.	7
5	Press the two buttons to command the beginning of the cycle.	2
6	Having waited for the permission of pouring with the help of a ladle to pour metal into the pouring window of the chamber of pressing.	8
7	Press the "Pressing" button to fill the mold with metal.	2
8	At the end of the crystallization time of the casting and ejectors operation.	30
9	Extract the bush with ticks.	2
10	Putting the bush castings on the table to make a visual quality control. The presence of nonslitins, chips, cracks, inclusions, junctions, breaks, defects in base surfaces, marking of castings, etc. is not allowed.	16
11	Separate the castings from the gating system and rinsers, guided by the CCI 11-021.	7
12	Incomplete castings, gates, rinsers, discarded in a container for flaw	1
13	Put the annual castings in containers for presentation to the control	1
14	In total	94

Table 3. The level of loading of the caster with respect to the injection molding machine

Detail number	The name of detail	Injection Molding Machine	Machine time, second	Time of man, second	Download level
21073-1307015-81	Water Pump Housing	DC-500	67	64	96%

Analysis of the technological process from the point of view of overproduction

Time tact is the time for which you need to produce the next product for the consumer. Daily output according to the data of the department of labor and wages is 340 items per shift. Using formula 2.1, calculate the time of the measure.

The customer's order for the year is:

$N\_year = 160000$ pieces

The actual time fund is:

$$F = n*f (t\_shift-t\_break) *3600; \quad (2)$$

Where,
n = 249 days-number of working days per year;
f = 2-number of shifts;
t _shifts= 12h-duration of the shift;
t _break= 1h-time for lunch break.
t _ (tech. break) = 1h-time for a technical break.

Then,

$$F = 249 \cdot 2 \cdot (12-2) \cdot 3600 = 17928000 \text{ sec.}$$

Thus, the clock time will be equal to:

$$t \_tact = 17{,}928{,}000 / 160000 = 112 \text{ seconds.}$$

With a clock time of t_tact = 112 seconds, the change in output is:

$$N \_shifts \text{ (as it should be)} = (t\_shifts - t\_break) / T\_tact \cdot 3600 = (12-2) / 112 \cdot 3600 = 321 \text{ products.}$$

Thus, in the shift is produced at 340 - 321 = 19 products more than the consumer demands.

Analysis of the technological process in terms of expectations in queues

The presence of variations in the duration of individual work produces the effect of queues and the accumulation of unfinished products. To assess this type of loss, we present in Table 4 the performance at each operation of the process of manufacturing the body of the water pump 21073-1307015.

Table 4. Performance on each process

Process	Number of people	Man / hours per shift	Operation cycle time, sec.	Productivity, pieces
Casting	1	9,5	94	363
Stump	1	10	15	2400
Shot blasting	1	10	5,8	6,206
Control, kit (packing)	1	10	90	400

Thus, it can be concluded that before the operation, control, set (packing) are formed stocks of unfinished products, and before operations, stump, shot blasting must be done, because these operations have much more performance than the previous ones.

Analysis of the technological process from the point of view of transportation

The greatest losses are due to the fact that the casters' duties are not only the process of casting, but also the search for free packaging for finished castings and packaging for flaw, and their transportation to the workplace and from the workplace.

Analysis of the technological process from the point of view of excessive processing

Packaging is an operation that does not add value to the product. But it is necessary, since the water pump housing after its manufacture must be transported from Samara to Tolyatti. To maintain the integrity of the product, the water pump housing must be packed in a container of 1000 pieces.

Analysis of the technological process from the point of view of reserves

In view of the fact that the duration and quantity of equipment for each operation is different, then to complete the production plan it is necessary to do the rework.

The stocks of the output of the water pump housing (KVN) 2112-1307015 are shown in Figure 8. It is seen that January reports high inventory loss (Kovalenko, et al., 2018; Sokolitsyn, et al., 2017).
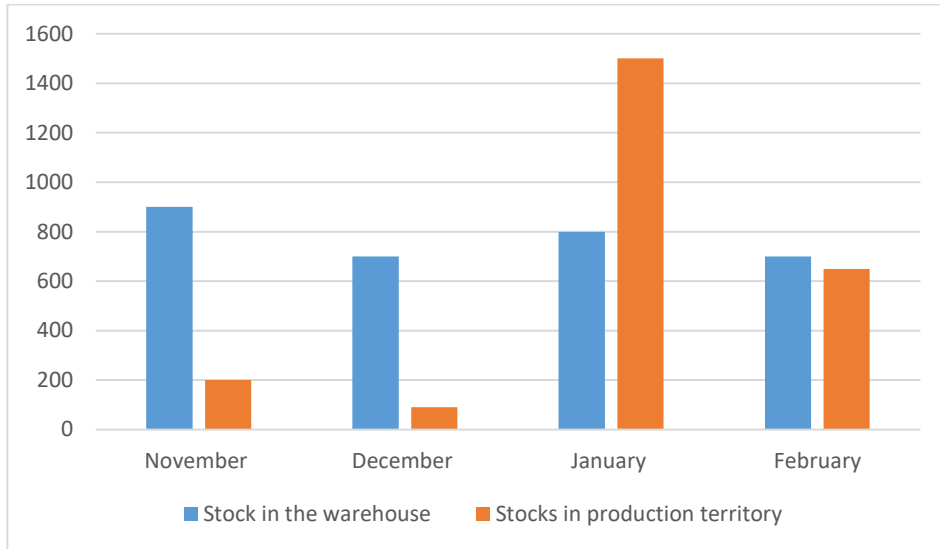

Figure 8. Inventories of manufactured products KVN 21073-1307015 from November to February

Any excess inventory in the organization is a loss. Storage of such reserves requires additional areas, they can adversely affect safety, cluttering the aisles and production areas. These reserves may be generally unnecessary and obsolete with a change in demand for products. Lean production requires a radical change in views on stocks (Sokolitsyn et al., 2017). The presence of excess stocks means the need for additional efforts to manage them; it can inhibit the flow of other production processes, as it is necessary in search of the necessary to turn piles of papers and materials.

To eliminate this type of loss, it is required:

- produce at each site or workplace only the quantity of products that are required by consumers located downstream of the production stream;
- standardize the planning of production sites and their loading;
- ensure that all necessary inputs are received for the subsequent sections

of the production process at the appointed time and do not allow delays in further promotion of materials on the production process.

Analysis of the technological process in terms of unnecessary movements

Any movement that is not required for the successful execution of the operation in question is a loss. Such movements are considered one of the forms of loss, since every movement that is made must increase the added value of the product or service. The inefficient organization of the work process and the incorrect layout of workplaces serve as the causes of unnecessary movements of performers such as walking, holding, bending, etc. With the existing layout of the caster's workplace, the worker runs the path equal to 8m and spends a time of 94 seconds per cycle of production of the casting of the water pump housing 21073-1307015.

Consider actions to export empty packagings for finished castings and for flaw:
1) Packagings are filled;
2) It will be necessary to transport the full packagings to another place in order to take empty packagings;
3) Lead empty containers;
4) Put them in place under the packaging for ready castings and for flaw.

Time costs for the above actions are 5 minutes.

Analysis of the technological process from the point of view of defects

Table 5 shows an analysis of the external reject for the product of the water pump housing 21073-1307015.

Table 5. Analysis of the external reject for the product body of the water pump 21073 - 1307015 from May 2015 to March 2016.

Period	May	June	July	August	September	October
Processed	19683	13669	16665	16428	18697	12566
Defect	300	255	327	363	339	169
Defect per cent	1,50%	1,83%	1,92%	2,16%	1,78%	1,33%
ppm	15 013	18 314	19 244	21 619	17 808	13 271
Period	November	December	January	February	March	
Processed	10669	25496	21090	15972	10517	
Defect	251	516	397	377	176	
Defect per cent	2,30%	1,98%	1,85%	2,31%	1,65%	
ppm	22 985	19 837	18 476	23 060	16 459	

From this analysis, we can conclude that the average level of ppm in the enterprise for the product of the body of the water pump 21073-1307015 is 18735, which corresponds to 3.6 short terms sigma level.

Analysis of the casting process in terms of equipment downtime

Downtime is the time lost in production as a result of planned or unplanned stops. Planned downtime is adjustment of equipment; scheduled maintenance; meetings; and regulated breaks (Radchenko & Petrochenko, 2017). The Unplanned downtime is equipment failure, lack of materials, absenteeism, and monitoring the work of the machine. Table 6 presents the idle time of MLD from November to February.

Table 6. Downtime of MLD DS-500 from November to February

Downtime	Downtime	Actual Time	Downtime, %	Cause of repair
November	5	51	9,80	Cleaning of metallization
December	6	265	2,26	Destruction by an oblique guide
	5	265	1,89	replacement fuse, no electrical.
	1,25	265	0,47	Compressor repair
	0,5	265	0,19	Cleaning of metallization
January	1	103	0,93	Destruction by an oblique guide
February	1	110	0,91	Cleaning of metallization

3.3. Implementation of lean manufacturing procedure

Developing a Value Flow (Stream) Map

The main tool that allows you to get an idea of the flow of material and information and gives you the opportunity to see production processes is the value stream map. A value stream is all activities, with or without added value, that exist to make the products from raw materials to the consumer. In the flow there are operations that add value and operations that do not add value.

Activities that add value are:
1) Change in the magnitude, shape or properties of the material / product or information;
2) Acceptance from the first presentation;
3) The buyer agrees to pay.

Activities that do not add value includes: An activity that requires time and resources, but does not fulfill the requirements of all 3 conditions.

Eliminating transactions that do not add value is a very important step because it has a significant impact on your company's net income. Value is the utility inherent in the product from the point of view of the end user. In order to determine the value of the action, it is necessary to ask the end user if he is ready to pay the manufacturer for doing this action.

In Figure 9, we represent the matrix 3P (the definition of value from the point of view of the consumer), which shows the operations for which the buyer is ready to pay.

	Operation	Product processing	Warehousing	Transportation	Control	Increases product value
1	Obtaining metal from the supplier			∨		
2	Control of incoming products				∨	
3	Storage of products		∨			
4	Transfer of products to the production site			∨		
5	Storage of products		∨			
6	Placing on a production line			∨		
7	Smelt a metal	∨				∨
8	Pressure casting	∨				∨
9	Transfer to storage			∨		
10	Hoard up to fettling		∨			
11	Serve products to presses			∨		
12	Fettling	∨				∨
13	Transfer to storage			∨		

Figure 9. Matrix 3P (definition of value from the point of view of the consumer)

In Figure 10 (see Appendix), we will depict a value stream that represents all activities with or without added value that exist to produce products through the main streams.

The value stream map helps:

- Visualize the entire flow of products, not a single process
- To see several types of losses in the flow
- Quickly see opportunities to improve flow
- Link material and information flows

The goals of creating a value stream map are:

1) Maintenance of production of products (value) on the order of clients;
2) Reduction of costs and simultaneous improvement of quality;
3) Elimination of losses of time, labor, materials, space (shortening the duration of order production and production costs).

The main indicator of efficiency is the speed of the process of creating value. Production efficiency is the ratio of the processing time to the lead time of the order.

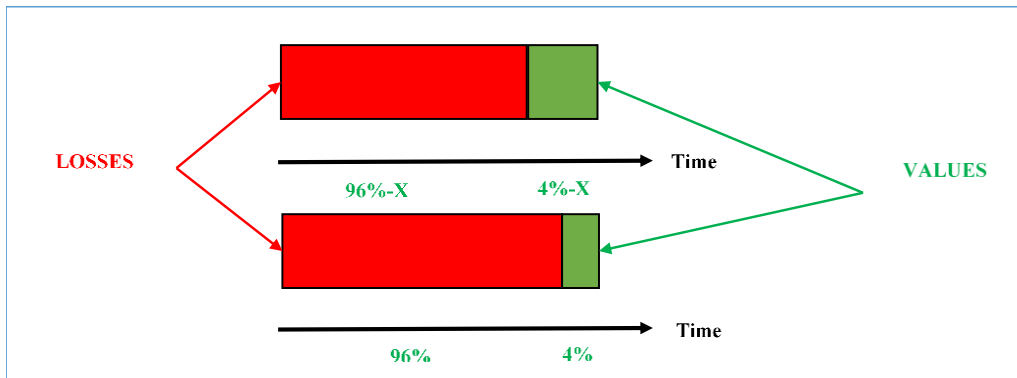$E = 50406 / ((13.99 \times 24 \times 60 \times 60) + 50406) \times 100\% = 4\%$.

Figure 11. Correlation of time

Load distribution of casters

In accordance with the existing technological process, the caster works for 37 seconds, then waits 30 seconds for the finished casting to exit, and then 27 seconds still work. Consider the technological process of casting the body of the water pump (Table 2). You need to convert the wait time during the creation of the value. To do this, consider the actions of the caster after the output of the finished casting (Table 7).

Table 7. Operations of the caster after the output of the finished casting

№	The name of the operation	Time, sec
13	Take steel fixer's pliers	1
14	Take press mold	1
15	Put press mold	1
16	Control castings, remove gates	22
17	Remove gates and marriage	1
18	Put the finished casting	1

As a result of the analysis of the caster's action, it was decided: to carry out operations (control of the finished casting, removal of rejects and sprues, laying of the finished castings in containers) during the next cycle of the injection molding machine. As a result, the casting cycle time was shortened, and, consequently, productivity increased. Thus, we reduced the waiting time for the caster from 30 seconds to 3 seconds, and therefore reduced the cycle time from 94 seconds to 70 seconds.

Calculation of the number of casters

When calculating the number of workers, add 10% to the cycle time. This is the insurance stock of time for unforeseen circumstances.

$$K\_p = T\_c / T\_tact \cdot k\_p; \qquad (3)$$

where
$k\_п = 1,1$ - safety time reserve;
$K\_p = 70/112 \cdot 1,1 = 0,9$ people.
Accept $K\_p = 1$ person.

Development of the KANBAN system

The work of foundry workers will be carried out as follows. The caster needs 2 packs: for finished castings and for flaw. According to the KANBAN system, we need 4 containers. Two will be in the workplace of the caster, the other two will be from the auxiliary worker, who will take the containers to the warehouse, hand over to the dispatcher, and then take empty containers from the dispatcher.

The caster will put ready castings and flaw into the necessary containers. After the containers are filled, it will move them from the workplace to the passage. This will be a signal for the auxiliary worker that the container is full.

Layout Development

To reduce losses due to unnecessary movement, it is necessary to develop a spaghetti diagram. The spaghetti chart is the trajectory that the product (operator) describes, moving along the value stream.

Taking into account all proposed measures, we will present in Figure 8 (there is no spaghetti diagram) a spaghetti diagram reflecting the totality of all movements of semi-finished products and the subsequent movement of the finished product. Moving semi-finished products are reduced to a minimum (Melović et al., 2016). Moving the semi-finished product is 276 m.

3.4. Streamlining

Analysis of the workplace

The workplace of the caster consists of an injection molding machine, transfer furnace, 5 packs (for water-emulsion grease, oil lubrication, and granulated grease, for waste and for finished castings) and 2 tables. For packagings with lubricants, a hose is attached to the other end, which is a gun, which is used to spray the lubricant onto the mold and press-pair (Kartashevskiy et al., 2015). With such a layout of the workplace, the caster passes the path equal to 8m and spends a time equal to 94 seconds.

Sorting

Since there is no standard place for items in the work area, the caster has to spend time searching for the desired object. Also in the workplace are many items that are not needed by the caster. In order to shorten the time for finding the right things, we will sort the items that are at the caster's workstation for "necessary constantly", "necessary" and "unnecessary". Enter the data in Table 8.

Table 8. Sorting items

Necessary constantly	Necessary	Unnecessary
1. Water-emulsion grease	1. Control casting	1. Flange
2. Oil-based lubrication	2. Nut	2. Sealing harness
3. Lubricated granular for press pairs	3. Screw	3. Saw tape
4. Grease for the pressing chamber	4. The wrench	4. Spring nut
5. The atomizer	5. Pliers	5. Steam pipe
6. Paste for molds		6. Supply hose
7. Towel		7. Outlet hose
8. Gloves		8. Electric screwdriver
9. Steelfixer's pliers		9. Charger for electric
10. Piling bucket		screwdriver
11. Punched plate		
12. Aluminum melt		
13. Water pump housing		
14. Waste		
15. The pistol		

On the unnecessary items, we will put a red label and transfer them to the quarantine zone.

Rational location

"Necessary constantly" items should be placed on the table. The items "necessary" will be placed on the bottom shelf of the table.

In Figure 12, we will depict the caster's desktop.

As a result of the analysis, it was decided to leave in the workplace instead of two, one table. Since after the sorting stage, unnecessary things were removed, and the remaining items can be placed on one table.
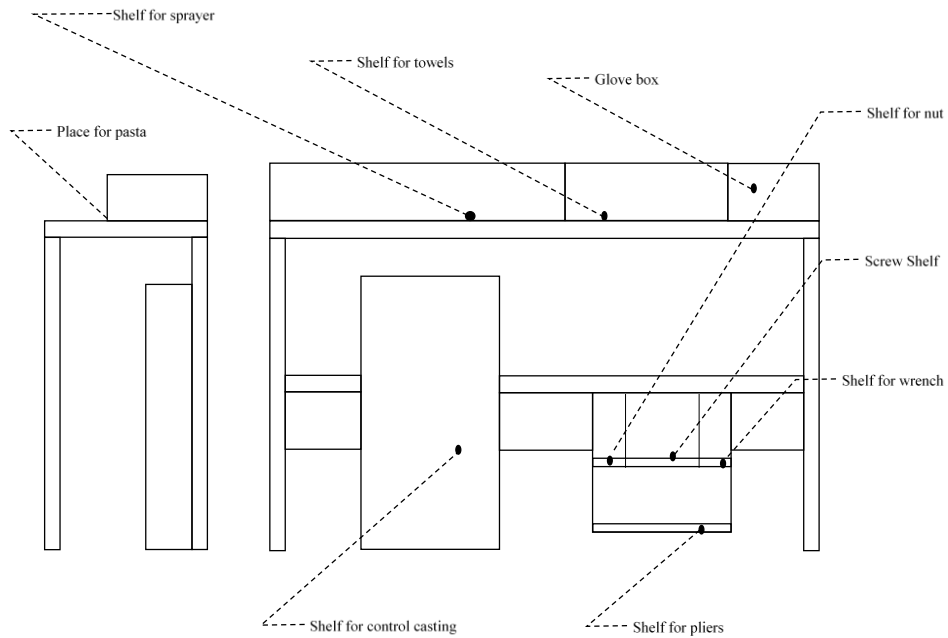

Figure 12. The working table of the caster

Define the container in which the components will be stored in the assembly area (Table 9).

For the rational placement of items in the workplace, it is necessary to take into account all operations performed by the caster. The following decisions were made:

1) Install packagings with lubricants near MLD;
2) Place the hook for the pistols on the MLD on the right side of the tar;
3) Place the hook for the steelfixer's pliers on the MLD on the right side of the grease container;
4) Place the hook for the noise on the dispenser;
5) Place the hook for the ladle on the dispenser;
6) Install waste containers at the work table;
7) Install the container for the finished casting on the left side of the table;
8) Set the cabinet for the quarantine zone in the left corner of the workplace;
9) Install the container for the grease lubrication of the pressing chamber on the MLD (Rybin et al., 2017).

Thus, the workplace consists of: a die casting machine, a working table, a transfer furnace, 6 packs (for waste, for a finished casting of a water pump housing, for lubrication on a water basis, for lubrication on an oil basis, for lubrication on a refined basis, for grease lubrication of the pressing chamber), 4 hooks and a quarantine zone.

Table 9. Packaging for objects

Name of the component	Tare dimensions			Number of units in a container
	Length	Width	Height	
Ready-made casting of the water pump housing	3000	2800	1500	300
Waste	2700	2300	1400	700
Water-emulsion grease	285	220	410	20 liter
Oil-based grease (MS)	285	220	410	20 liter
Grease granulated for press pairs (HS)	15	15	30	1,5 liter
Lubrication for pressing chamber	5	5	15	0,5 liter

Containers for finished castings should be green (green RAL 6032), and containers for rejection of red (red RAL 3020). Also, they must be inscribed in black (black RAL 5040): "READY CASTING", "FLAW", respectively. The zone for the location of the container for the finished casting should be selected with a dashed line (5 cm thick, 20 cm in length, 10 cm between the lines) in blue (RAL 5017 blue) with a protrusion from the edge of the container by 100 mm. The zone for the location of the packaging for marriage should be marked with a dashed line (5 cm thick, 20 cm in length, 10 cm between the lines) in red (red RAL 3020) with a ledge from the edge of the container by 100 mm. The quarantine zone should be separated by a solid line 5 cm thick red (red RAL 3020) with a ledge from the edge of the cabinet at 100mm. The signal area of the KANBAN should be highlighted with a yellow line (yellow RAL 1023) 5 cm thick with a ledge from the edge of the container by 100 mm.

Due to the fact that the pistols are on the same hook near the MLD, the caster can simultaneously take both guns and take turns lubricating the mold. As a result, time will be saved. We enter in Table 10 the distances to which the caster moves and the time spent on moving.

Table 10. Moving the caster

№	The name of the operation	Movement, m	Time, sec
1	Entering the working area	0,5	1
2	Lubrication chamber	0,5	1
3	Metal fence	0,5	2
4	Pouring metal into the pressing chamber	0,5	5
5	Control castings, remove gates	0,5	25
6	Waiting for the end of the machine's operating cycle	0	5
7	Extracting press mold	0,5	1
8	Putting press mold on the table	0,5	0,5
9	Set of molding paste	0,5	3
10	Lubrication of the mold with paste (grease occurs every 5 cycles, lubrication time is 15 seconds)	0	3
11	Taking the pistol	0,5	2
12	Lubrication of the mold	0,5	8
13	Return to original position	0,5	0,5
14	In total	5,5	57

With such a layout of the workplace, the caster passes the path equal to 5.5 m and spends a time equal to 57 seconds. As a result, the movement time was reduced by 37 seconds. And, consequently, losses were reduced and time was not added to adding value.

We depict in Figure 13 the ratio of the time to move "before the transformation" (red color) and the movement under the system 5S (green). Due to introduction of lean manufacturing procedure, the time of manufacturing process of KVN 21073-1307015 was reduced by 40%.
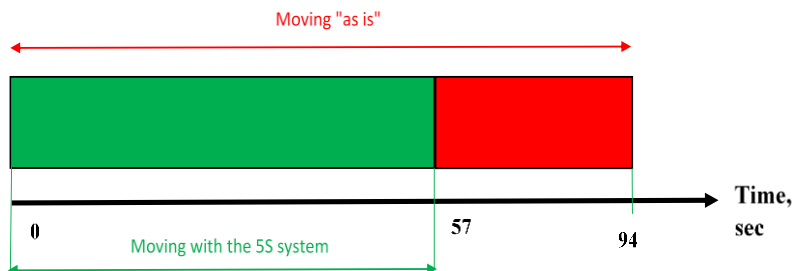

Figure 13. The ratio of time to move "before the transformation" (red color) and movement at the system 5S (green).

Assessment of the indicators of the technological process "after the transformation"

It will be more profitable to produce a water pump housing than in "before the transformations" by reducing the time resources, which provides an improvement in the quality of the water pump housing, since the resource costs are related to the product cost indexes. In Table 12, we present performance indicators of the process.

Table 12. Productivity Indicators

Indicators	Unit of measurement	Before implementation			After implementation	
Productivity	pcs/person	363			363	
Number of casters	person	1			1	
Production area	m^2	42			38,5	
Cycle time	sec	94			57	
Time of change	hour	Adjustment	0,5	12	0,5	8,5
		Rest	1		1	
		Lunch	1		1	
		Work	9,5		6	

4. Business case for proposed changes

Basic and proposed technological processes

As the object, the technological process of casting the body of the water pump 21073-1307015 was chosen. Daily output according to the data of the department of labor and wages is 340 items per shift. According to the annual program we calculate the time of the cycle according to the formula

$$T\_tact = F / N\_year, \qquad (4)$$
where
N year is the annual program: N_year = 160000 pcs.
F is a real time fund:
$$F = n \cdot f \cdot (t\_change-t\_break) \cdot 3600; \qquad (5)$$

Where
n = 249days-number of working days per year;

f = 2-number of shifts;

t _shifts = 12h-duration of the shift;

t _break = 1h-time for lunch break.

t _ (tech. break) = 1h-time for a technical break.

Then
F= 249 · 2 · (12-2) · 3600 = 17928000 s.

Thus, the clock time will be equal to

T _tact = 17,928,000 / 160000 = 112 s.

With a clock time of T_tact = 112 seconds, the change in output is:

N_shifts (as it should be) = (t_shift -t_break) / T_tact · 3600 = (12-2) / 112 · 3600 = 321 items.

Thus, in the shift is produced at 340 - 321 = 19 products more than the consumer demands.

It is proposed to reduce the time of manufacturing of one casting as follows:

To carry out operations (control of the finished casting, removal of rejects and sprues, laying of the finished castings in containers) during the next cycle of operation of the injection molding machine. As a result, the casting cycle time was shortened, and, consequently, productivity increased.

- Develop a value stream map.
- Make a redevelopment of the workplace of the caster.
- Develop a diagram of the operator's spaghetti.
- Develop a diagram of the spaghetti product.

Analysis of savings

We calculate the annual savings from the implementation of the proposed changes. The annual savings will be made up of savings on the wages of casters. The annual savings on wages will be 21300 $.

Y.Klochkov, A.Gazizulina, K. Muralidharan

5. Conclusion and Discussion

Lean Six Sigma - management tool that includes successful practices focused on improving product quality, reducing costs, reducing time spending. The study transmitted the experience of using the tool Lean Six Sigma in production.

The goal of increasing the efficiency of the production process of the body of the water pump 21073-1307015, due to the application of the lean manufacturing concept, was achieved by solving the set tasks.

Currently, the company has ISO 9001 KEMA and IQNet certificates with registration number 2022720. In accordance with the principle of ISO 9000 – continuous improvement – It was proposed to implement lean manufacturing. Introduction of the concept was decided to begin with the production process of the body of the water pump 21073-1307015.

Analysis of the process of casting the body of the water pump 21073-1307015 showed the presence of a large number of losses during casting of the product. With the help of lean manufacturing tools, a pulling production system was built. The time of the tact was T_tact = 68 seconds. Time shift changed from 12 to 8.5 hours. A continuous casting process will be provided by the proposed KANBAN system. To determine the value from the consumer's point of view, a matrix was developed from the point of view of the consumer, as well as a value stream map.

As a result, the area of the working section of the caster was reduced from 42 to 38.5, ordering of all items used by the caster was made. A diagram of the operator's spaghetti and a diagram of the product spaghetti are developed. These measures made it possible to shorten the time for moving twice.

The Lean Six Sigma methodology focuses on efficiency and error recovery. Practice has shown that this management methodology can be compared with the most modern technologies in production. It is a powerful tool that allows you to significantly improve the organization. The methodology is based on a strictly structured approach and involves a step by step solution to the problem. The steps to solve the problem are indicated: definition, analysis, improvement and control. Lean Six Sigma helps to succeed, and can be used in manufacturing or in the service sector, without requiring large expenditures. This work can help senior management and staff to better understand the results of applying Lean Six Sigma.

It should be noted that the goal of implementing Lean Six Sigma can be diverse: from the organization of control and testing to the optimization of logistic schemes. Lean Six Sigma is an effective tool for solving such tasks in an enterprise as reducing production costs, improving process reliability, reducing the production cycle, and ensuring guaranteed quality. These tasks have established goals, deadlines, allocation of responsibility and authority, requirements for determining risks, and maintaining records.

Another important result is that with the help of improvement tools it turns out to find ways to solve problems without substantial financial investments. Further, the economic effect amounted to 5612,90 $. The payback period for the implementation of changes is 2 months. The introduction of elements of lean production was successful. To date, a plan is being developed for the further introduction of lean manufacturing elements.

References:

Andreeva, N. V., Tyunina, M., Filimonov, A. V., Rudskoy, A. I., Pertsev, N. A., & Vakhrushev, S. B. (2014). Low-temperature evolution of local polarization properties of PbZr 0.65Ti0.35O3 thin films probed by piezoresponse force microscopy. *Applied Physics Letters*, *104*(11). doi:10.1063/1.4869147

Antony, J., Krishan, N., Cullen, D., & Kumar, M. (2012a). Lean six sigma for higher education institutions (HEIs): Challenges, barriers, success factors, tools/techniques. *International Journal of Productivity and Performance Management*, *6* (8), 940-948. doi:10.1108/17410401211277165

Antony, J., Manville, G., Greatbanks, R., Krishnasamy, R., & Parker, D. W. (2012b). Critical success factors for lean six sigma programmes: A view from middle management. *International Journal of Quality & Reliability Management*, *29*(1), 7-20. doi:10.1108/02656711211190846

Balashova, E. S. & Gromova, E. A. (2017a) Economic effect in the framework of lean production. *Journal of Applied Economic Sciences*, *12*(4), 1188-1193.

Balashova, E. S. & Gromova, E. A. (2017b) Russian experience of integrating modern management models. *Espacios*, *38*(53), 31.

Balashova, E. S. & Gromova, E. A. (2017c) TQM as one of the drivers of Russian industrial sector. *Quality - Access to Success*, *18*(159), 50-53.

Borovkov, A. I., Klyavin, O. I., Rozhdestvenskiy, O. I., Aleshin, M. V., Leontev, A. N., Nikulina, S. P., & Okunev, A. P. (2017). Validation of the mathematical model of isotropic material using parametric optimization of its physical and mechanical characteristics. *Materials Physics and Mechanics*, *32*(3), 312-320.

Burkovsky, R. G., Filimonov, A. V., Rudskoy, A. I., Hirota, K., Matsuura, M., & Vakhrushev, S. B. (2012). Diffuse scattering anisotropy and inhomogeneous lattice deformations in the lead magnoniobate relaxor PMN above the burns temperature. *Physical Review B - Condensed Matter and Materials Physics*, *85*(9). doi:10.1103/PhysRevB.85.094108

Chiarini, A. (2011). Japanese total quality control, TQM, deming's system of profound knowledge, BPR, lean and six sigma: Comparison and discussion. *International Journal of Lean Six Sigma*, *2*(4), 332-355. doi:10.1108/20401461111189425

Chiarini, A. (2012). Risk management and cost reduction of cancer drugs using lean six sigma tools. *Leadership in Health Services*, *25*(4), 318-330. doi:10.1108/17511871211268982

Corbett, L. M. (2011). Lean six sigma: The contribution to business excellence. *International Journal of Lean Six Sigma*, *2*(2), 118-131. doi:10.1108/20401461111135019

Delgado, C., Ferreira, M., & Branco, M. C. (2010). The implementation of lean six sigma in financial services organizations. *Journal of Manufacturing Technology Management*, *21*(4), 512-523. doi:10.1108/17410381011046616

Demidenko, D. S., Malinin, A. M., & Litvinenko, A. N. (2017). A new classification of the risks of the quality processes. Proceedings of the 30th International Business Information Management Association Conference, IBIMA 2017 - Vision 2020: *Sustainable Economic development, Innovation Management, and Global Growth*, 2017-January, pp. 2892-2897

Ganguly, K. (2012) Improvement process for rolling mill through the dmaic six sigma approach. *International Journal for Quality Research*, *6*(3), 221-231.

Glouschenkov, V. A., Grechnikov, F. V., & Malyshev, B. S. (1997). Pulse-magnetic processing technology when making parts and units of aerospace engineering. *Journal De Physique. IV: JP*, *7*(3), C3-45-C3-48.

Golenko-Ginzburg, D., Gonik, A., & Papic, L. (1999). Developing cost-optimization production control model via simulation. *Mathematics and Computers in Simulation*, *49*(6), 335-351.

Golod, V. M. & Dobosh, L. Y. (2017). Computation material science of structural-phase transformation in casting aluminium alloys. *IOP Conference Series: Materials Science and Engineering*, *192*(1), Article number 012027. DOI: 10.1088/1757-899X/192/1/012027

Grechnikov, F. V., Kozij, S. I., & Popov, I. P. (1999). Foundation and development of the metal forming department of the academician S.P. Korolev Samara State Airspace University. *Litejnoe Proizvodstvo*, (6), 3-9.

Hilton, R. J., & Sohal, A. (2012). A conceptual model for the successful deployment of lean six sigma. *International Journal of Quality and Reliability Management*, *29*(1), 54-70. doi:10.1108/02656711211190873

Hoerl, R. W., & Gardner, M. M. (2010). Lean six sigma, creativity, and innovation. *International Journal of Lean Six Sigma*, *1*(1), 30-38. doi:10.1108/20401461011033149

Hoerl, R. W., & Snee, R. (2010). Statistical thinking and methods in quality improvement: A look to the future. *Quality Engineering*, *22*(3), 119-129. doi:10.1080/08982112.2010.481485

Jeyaraman, K., & Teo, L. K. (2010). A conceptual framework for critical success factors of lean six sigma: Implementation on the performance of electronic manufacturing service industry. *International Journal of Lean Six Sigma*, *1*(3), 191-215. doi:10.1108/20401461011075008

Kansal, J., & Singhal, S. (2017). Application and validation of DMAIC six sigma tool for enhancing customer satisfaction in a government R & D organization. *International Journal for Quality Research*, *11*(4), 931-944. doi:10.18421/IJQR11.04-13

Kartashevskiy, V., Kireeva, N., Buranova, M. & Chupakhina, L. (2015) Study of queuing system G/G/1 with an arbitrary distribution of time parameter system. *2nd International Scientific-Practical Conference Problems of Infocommunications Science and Technology, PIC S and T 2015 - Conference Proceedings*, 7357297, pp. 145-148

Karthi, S., Devadasan, S. R., & Murugesh, R. (2011). Lean six sigma through ISO 9001 standard-based quality management system: An investigation for research. *International Journal of Productivity and Quality Management*, *8*(2), 180-204. doi:10.1504/IJPQM.2011.041845

Kodzhaspirov, G., & Rudskoi, A. (2017) Simulation of dynamic recrystallization of steels and alloys during rolling and forging through the use of FEM and experimental planning methods. *METAL 2017 - 26th International Conference on Metallurgy and Materials, Conference Proceedings*, 2017-January, 320-325

Kovalenko, I. I., Sokolitsyn, A. S., & Sokolitsyna, N. A. (2018) The Enterprise's Automated Management Stability System Taking into Account its Life Cycle Stage. *Proceedings of the 2018 International Conference "Quality Management, Transport and Information Security, Information Technologies", IT and QM and IS 2018*, 8524966, pp. 357-360

Kozlovskiy, V., & Aydarov, D. (2017). Analytical models of mass media as a method of quality management in the automotive industry. *Quality - Access to Success*, *18*(160), 83-87.

Laureani, A., Antony, J., & Douglas, A. (2010). Lean six sigma in a call centre: A case study. *International Journal of Productivity and Performance Management*, *59*(8), 757-768.

Melović, B., Mitrović, S., Zhuravlev, A., & Braila, N. (2016). The role of the concept of LEAN management in modern business. *MATEC Web of Conferences*, *86*, 05029. DOI: 10.1051/matecconf/20168605029

Muralidharan, K. (2015). *Six sigma for organizational excellence: A statistical approach*. doi:10.1007/978-81-322-2325-2

Naidu N. V. R. (2011). Development of mathematical models for optimal preventive maintenance policy in a steel industry: six sigma approach. *International Journal for Quality Research*, *5*(3), 179-185

Nemavhola, F., & Ramdass, K. (2017). Using statistical process control and six sigma to critically analyse safety of helical springs: A railway case study. *International Journal for Quality Research*, *11*(3), 627-642. doi:10.18421/IJQR11.03-09

Niemeijer, G. C., Trip, A., Ahaus, K. T., Does, R. J., & Wendt, K. W. (2010). Quality in trauma care: Improving the discharge procedure of patients by means of lean six sigma. *The Journal of Trauma*, *69*(3), 614-618; discussion 618-619.

Panyukov, D. I., & Kozlovskiy, V.N. (2014). Highlights of Russian experience in implementing ISO/TS 16949. *Life Science Journal*, *11*(8s), 439-444.

Papic, L. (2007). Deploying customer requirements via four-stage team approach in business planning. *International Journal of Reliability, Quality and Safety Engineering*, *14*(3), 263-274. doi:10.1142/S0218539307002635

Pepper, M. P. J., & Spedding, T. A. (2010). The evolution of lean six sigma. International *Journal of Quality and Reliability Management*, *27*(2), 138-155. doi:10.1108/02656711011014276

Radchenko, A. E., & Petrochenko, M. V. (2017). Implementation of risk management theory for the development of lean thinking in a construction company. Advances and Trends in Engineering Sciences and Technologies II. *Proceedings of the 2nd International Conference on Engineering Sciences and Technologies*, 2016, pp. 617-622

Rudskoy, A. I., Bogatov, A. A., Nukhov, D. S., & Tolkushkin, A. O. (2018). New Method of Severe Plastic Deformation of Metals. *Metal Science and Heat Treatment*, *60*(1-2), 3-6. DOI: 10.1007/s11041-018-0231-4

Ryan, T. P. (2011). *Statistical methods for quality improvement: Third edition*. John Wiley & Sons, Inc. doi:10.1002/9781118058114

Rybin, V. V., Zolotorevsky, N. Yu., Ushanova, E. A., Sergeev, S. N., Matvienko, A. N., Khomskaya, I. V. & Abdullina, D. N. (2017). Main patterns of lattice fragmentation in copper processed by dynamic equal-channel angular pressing. *Reviews on Advanced Materials Science*, *52*(1-2), 54-60.

Salah, S., Rahim, A., & Carretero, J. A. (2010). The integration of six sigma and lean management. *International Journal of Lean Six Sigma*, *1*(3), 249-274. doi:10.1108/20401461011075035

Setijono, D., Laureani, A., & Antony, J. (2012). Critical success factors for the effective implementation of lean sigma: Results from an empirical study and agenda for future research. *International Journal of Lean Six Sigma*, *3*(4), 274-283. doi:10.1108/20401461211284743

Shymchenko, A. V., Tereshchenko, V. V., Ryabov, Y. A., Salkutsan, S. V., & Borovkov, A. I. (2017). Review of the computational approaches to advanced materials simulation in accordance with modern advanced manufacturing trends. *Materials Physics and Mechanics*, *32*(3), 328-352.

Snee, R. D. (2010). Lean six sigma – getting better all the time. *International Journal of Lean Six Sigma*, *1*(1), 9-29. doi:10.1108/20401461011033130

Sokolitsyn, A. S., Ivanov, M. V., & Sokolitsyna, N. A. (2017). Statistic modeling industrial enterprises production process parameters. *Proceedings of the 30th International Business Information Management Association Conference, IBIMA 2017 - Vision 2020: Sustainable Economic development, Innovation Management, and Global Growth*, pp. 1041-1052.

Sokolitsyn, A. S., Kovalenko, I. I. & Zvontsov, A. V. (2017) Production risk economic assessment based on the fuzzy logic approaches. Proceedings of 2017 20th IEEE International Conference on Soft Computing and Measurements, SCM 2017, 7970738, pp. 834-836.

Timans, W., Antony, J., Ahaus, K., & Van Solingen, R. (2012). Implementation of lean six sigma in small- and medium-sized manufacturing enterprises in the Netherlands. *Journal of the Operational Research Society*, *63*(3), 339-353. doi:10.1057/jors.2011.47

Vasilyev, A., Sokolov, D., Sokolov, S., Glukhov, P., & Rudskoy, A. (2018). Mathematical model for evaluating lankford coefficient in automotive sheet steels. *METAL 2018 - 27th International Conference on Metallurgy and Materials, Conference Proceedings*, pp. 903-909.

Vinodh, S., Gautham, S. G., & Ramiya, R. A. (2011). Implementing lean sigma framework in an Indian automotive valves manufacturing organisation: A case study. *Production Planning and Control*, *22*(7), 708-722. doi:10.1080/09537287.2010.546980

Zhgulev, E., Bozhuk, S., Evdokimov, K., & Pletneva, N. (2018). Analysis of barriers to promotion of electric cars on Russian market. *Engineering for Rural Development*, *17*, 2110-2117.

Yury Klochkov
Peter the Great St. Petersburg Polytechnic University
St. Petersburg
Russian Federation
y.kloch@gmail.com

Albina Gazizulina
Peter the Great St. Petersburg Polytechnic University
St. Petersburg
Russian Federation
albinagazizulina@gmail.com

Kunnummal Muralidharan
The Maharaja Sayajirao University of Baroda, Department of Statistics
Vadodara
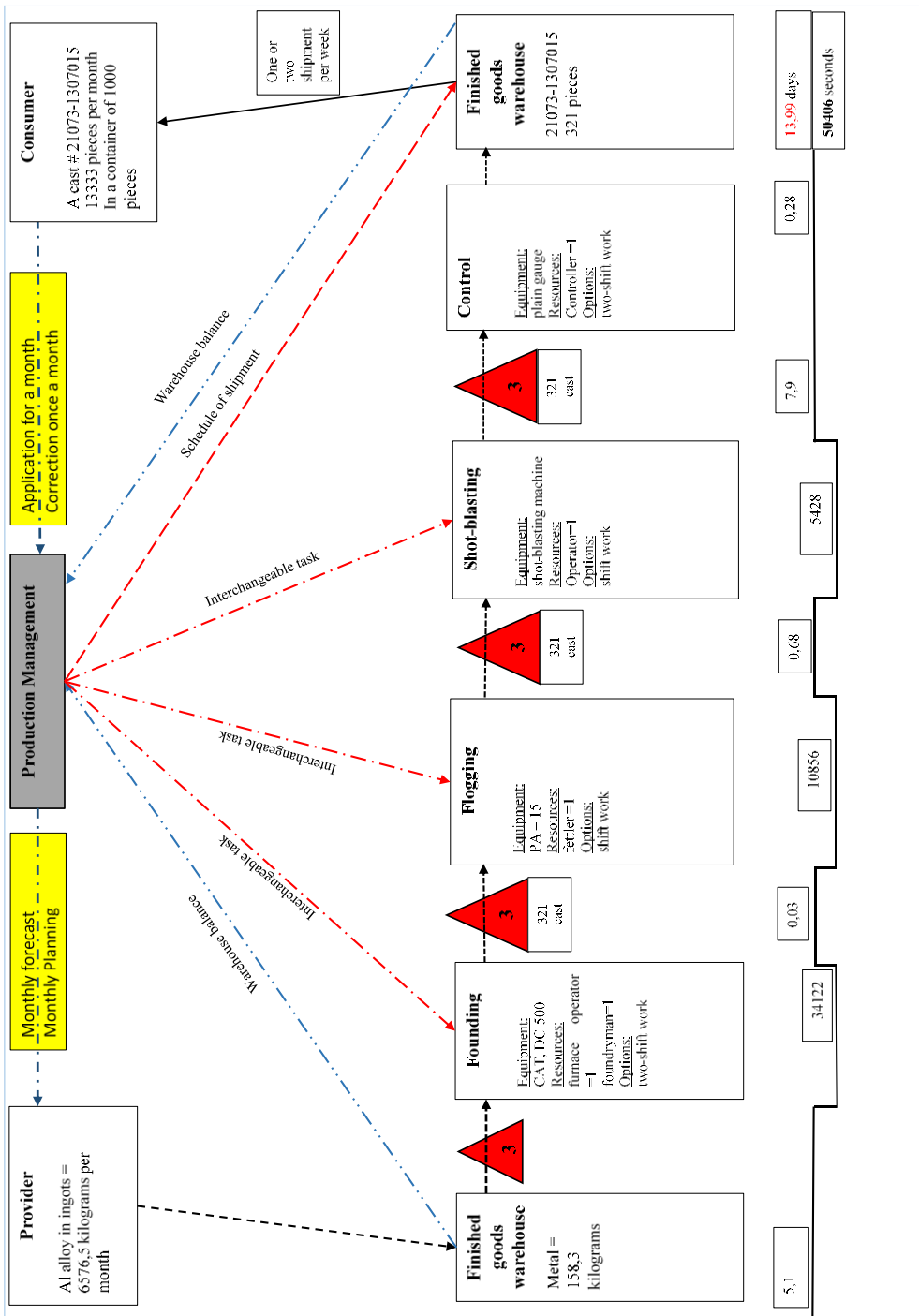India
lmv_murali@yahoo.com

Appendix:

Figure 10. Flow map of value creation