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LEAN PRODUCTION SYSTEMS

Рекомендовано редакционно-издательским советом федерального государственного автономного образовательного учреждения высшего образования «Самарский национальный исследовательский университет имени академика С. П. Королева» в качестве учебного пособия для обучающихся по основной образовательной программе высшего образования по направлению подготовки 38.04.02 Менеджмент

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The basic lean principles are revealed, the lean tools and elements are described. Lean system deployment tools are given, focusing on specific problems of the process and terms of addressing them.

The study guide is for master's students (Master's degree students) of Economics and Management Institute.

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Preface

The course aims to form common cultural and professional and general professional skills in order to have ability to manage organizations, divisions, teams, projects and networks

Learning Outcomes

To know principles of organization of the production systems of lean manufacturing and implementing lean events.

To be able to organize research of production processes, discussion of probable causes of marriage and their consequences.

To possess skills of introduction of the lean tool in production.

The course provides a complex of knowledge, skills and abilities.

Introduction

The main idea of lean production lies in consistent work on improving the working process through eliminating wastes.

There are 3 types of definitions of waste: describing action, situation and material things. According to the first type, waste is an activity that does not add any value. From the situation view, waste is a situation in which valuables are idle or not effectively used. According to the third type, it is a loss of resources that occurs due to their inappropriate use.

To eliminate the waste different methods are used such as Total Quality Management, Balanced Scorecards, international standards ISO 9000, Six Sigma, 5S, Kaizen, Kanban, Theory of Constrains and many others. Lean production implies introduction of these methods into the production process.

As the successful example of Toyota shows, the lean principles implementation and support can give great results and make a company effective and competitive. Toyota's lean implementation was followed by many Japanese and American companies, later – by European enterprises and Russian companies.

To spread the lean production concept among firms, there are some steps to be done, which include reviewing of the methods, acquaintance with positive consequences of their implementation, continuous support of lean projects and adjustment of methods to diverse macroeconomic conditions.

The aim of this guide is to show the lean methods, give examples of their implementation and show the positive effect of lean production. To cope with this objectives the following structure of the guide is promoted: the first unit deals with lean history, terms and principles of lean production. Unit 2 describes elements of the concept and lean production tools. The following unit is devoted to Hoshin kanri deployment tools. The last unit reveals and addresses the deployment problems of lean production.

Type codes

TPS-	Toyota Production System,
JIT -	Just in Time,
TQM -	Total Quality Management,
QMS -	Quality Management System,
TOC -	Theory of Constraints,
SOP -	Standard Operating Procedures,
BSC -	Balanced Scorecard,
TPM -	Total Production Maintenance,
SMED -	Single Minute Exchange of Die,
VSM -	Value Stream Map,
KPI -	Key Performance Indicator,
LPMS -	Lean Production Management System,
PDCA -	Plan-Do-Check-Act,
SDLC -	System Development Lifecycle,
OEE -	Overall Equipment Effectiveness,
MRP -	Material Requirements Planning,
IC/IM -	Inventory Control/Management,
MRP 2 -	Manufacturing Resources Planning,
ERP -	Enterprise Resources Planning,
CRM -	Customer Relationship Management,
SCM -	Supply Chain Management,
CSRP -	Customer-Synchronized Resources Planning,
MES -	Management Execution System,
CALS -	Computer-Aided Logistic Support,
CAD -	Computer-Aided Design,
CAM -	Computer-Aided Manufacturing,
CAE -	Computer-Aided Engineering,
PDM -	Product Data Management,
PLM -	Product Lifecycle Management,
CALS 2 -	Continuous Acquisition and Lifecycle Support,
BPMS -	Business-Process Management System,
SCADA -	Supervisory Control And Data Acquisition System

UNIT 1. Lean-system evolution, organizing and operating principles and issues

1.1. Background of Lean systems

Lean Manufacturing idea

The author of the *Lean Manufacturing idea* is considered to be Henry Ford, for he has successfully applied a number of innovative methods in production at his plants in the 1920s. He proposed to divide a cars conveyor assembly process into individual operations: each worker on the assembly line performed only one operation, the necessary details were delivered to his workplace.

Terms of line production formulated by H. Ford [1]:

- Division of labor and specialization of jobs;
- The use of high-performance special equipment, tools and accessories;
- Placement of equipment in the course of manufacturing process;
- Regulated rhythm of production;
- Mechanization of transport operations.

These ideas were far ahead of their time, the world economy was dominated by the manufacturer market and the struggle for the consumer had not yet developed, so at the moment they were not popular in the world.

The economy of 1930-1950s was determined by many factors: the gradual saturation of the markets, performance criteria of the company are sales and product quality. The manufacturing and marketing concepts of competitiveness became dominating. In the period of 1960-1970s there was a saturation of markets and the final transition to the consumer market with significant resource constraints of production development. Thus, the task of reducing costs became pivotal.

Lean Production concept	Lean Production concept occurred in the middle 1950s to the Toyota Corporation due to one of its managers Taiichi Ohno, who united all the advanced techniques to improve production efficiency in the Toyota factory.
Toyota Production System	Based on the development of existing scientific schools, Taiichi Ohno built his own unique system. The amazing success of the company enabled this concept to become popular, and the system of production organization became known as the *Toyota Production System* (TPS).

American experts have studied the system and proposed the concept of lean production (lean manufacturing). A significant contribution to the development of the theory of Lean Production was made by Dr. Edwards Deming, who worked in Japan after the World War II. The principle of continuous quality improvement and quality management program, formulated by him, became the basis of the theory of the TPS.

A significant contribution to the development of Lean Production theory was made by:

• Philip Crosby (proposed program "0 defects").

• Armand Feigenbaum (developed the principles of total quality control).

• Kaoru Ishikawa (one of the new concept of organizing production developers, the author of "cause - effect" diagram).

• Joseph Juran and others.

In the postwar period through the works of Edward Deming, Taiichi Ohno, Seich Nakayama, Shigeo Shingo the following concepts appeared: JIT (Just in Time), 5S, the study of continuous improvement, ZD and quality circles, TQM, SMED, TPM. All of these have been integrated into one of the most effective models of the Lean Production concept - Kaizen system, which is considered to be M. Imai’s ideology.

Kaizen in translation means continuous improvement. From the standpoint of the methodology the working efficiency is determined primarily by the creative work aimed at innovation, continuous improvement of working methods and personal effectiveness of employees. The second important area is the traditional reduction and regulation of all types of expenses.

It is important to mention E. Deming as a developer of a common concept of Total Quality Management TQM.

Total Quality Management	Formulated in 1970, the principles formed the basis of international quality standards ISO 9000. Quality Management System developed in parallel with Lean Production in Western Europe and the United States respectively.

Since market participants said that certification greatly reduced the risk of low-quality goods and services, ISO 9000 implementation became almost mandatory and the competitiveness of the companies turned to be influenced by certification for this standard. Business processes became the main objects of control as a high quality process guarantees high-quality products and services.

In a changing business environment desire for the originally perfect business is associated with the problem of immediate management adoption to external economic factors, as even the most perfect business requires improvements under the influence of changing reality.

Figures 1.1 and 1.2 represent a retrospective of the quality management system (QMS) and Lean Production development respectively which clearly reflect the characteristics of the two most popular management concepts and manufacturing technologies. [2].

The continuous improvement mechanism of the Kaizen system involves all employees of the company in the process of improving the business, transforming work of each employee.

Gradually the TPS concept has been applied at the industrial enterprises, then was adapted to the service sector (trade, health, etc.), has been successfully applied in the public, medical and military institutions.

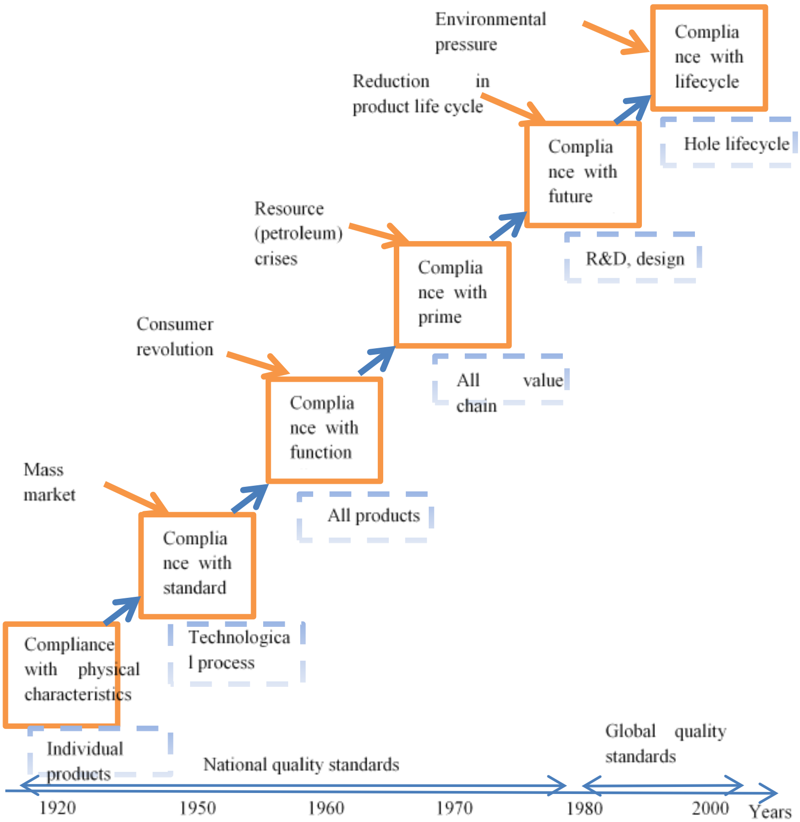


Figure 1.1 – Retrospective of the QMS development

Lean attraction secret lies in the high effectiveness of investment in the development of the production system. It is estimated that 80% of the costs occur to the organizational arrangements, and technology investment is accounted for 20%.

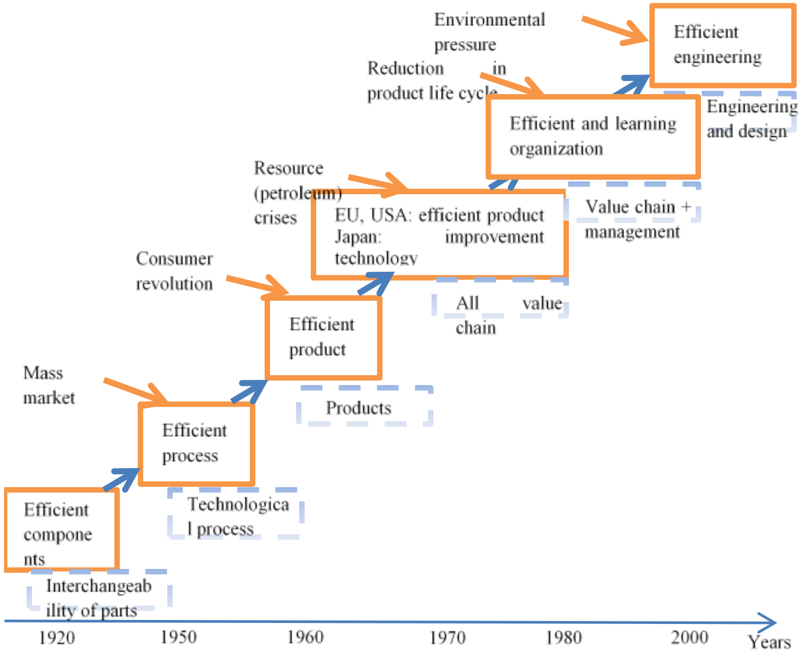


Figure 1.2 – Retrospective of Lean Production development

The concept of Lean Production has become the philosophy of management, based on the human factor, teamwork and a commitment to continuous perfection by gradual and continuous improvement (Kaizen method). Lean culture is creating a new type of relations not only within companies and organizations, but also beyond, extending to customers, suppliers and the society in general.

Lean has become one of the best management technologies in the XX and early XXI century, allowing businesses to compete successfully due to high quality, high cost-efficiency and maximum customer orientation.

Implementation and development of Lean Production concepts in different countries has its own characteristics. In Japan the Toyota Production System approach is based on the need for sustained, continuous improvement. In the understanding of American managers, a Lean Production approach is associated with economical, rational, well-organized production. In Russia there is a widely spread concept of Lean Production, which focuses on the tools and methods of TPS.

Summarizing a variety of approaches to the concept of Lean Production Systems, it can be concluded [3]:

Lean Production System	Lean Production System is a management system that includes the following:

- strategic management. Main tasks: concentration on the needs of the customer, the management of key performance indicators, the deployment of strategic goals.

– process management. Objectives: identifying and reducing losses, organizing a continuous flow of products, structured problem-solving;

- continuous improvement of the staff. Tools: Kaizen and innovation, teamwork, open communication.

The purpose of the deployment of Lean Production Systems: to create innovative management environment to improve productivity and competitiveness.

TPS focuses on the complete elimination of losses and is based on two principles:

- the principle of "just in time", when the necessary parts for assembly at the production line are given strictly at the right time and in the strictly required amount using information communication "*kanban*";

- the principle of autonomy (automation with intellectual element). It involves automatic termination of the abnormal course of the manufacturing process to prevent the production of defective products, or overproduction.

Currently, thousands of enterprises in various industries around the world are deploying their Lean production system, based on the experience of Toyota Production System. Leadership in the Lean Production Systems development still belongs to the Toyota Group, (80-90% of companies have implemented Lean Production), US corporations reached significant progress (General Motors, Ford, Chrysler, Boing, United Technologies, and others, in general, more than 75 %), South Korean manufacturers of cars and components, Japanese electrical and automobile companies, German companies such as Siemens, Volkswagen, Bosch, BASF, European Aeronautic Defence and Space group (EADS) and others. In total, the EU share of lean enterprise is more than 50%.

Significant progress has marked many of China's industrial enterprises. In Russia, only 5-10% of companies implemented the Lean Production.

The popularisation of lean production in Russia is connected with the works of the famous American specialist Michael Veeydera. In 2003 he started his activity in our country. Several projects for attracting and educating stakeholders were launched in the application of Lean principles at their enterprises. To date, hundreds of Russian companies successfully implement Lean Production, achieving high results in various fields of business, especially in mechanical engineering, metalworking, railway transport and others. Among the most prominent participants are JSC "Russian Railways″, ″Sberbank of Russia", PJSC "Company″ Sukhoi ″, NGO" World ", "Alfa-Bank", "Mail of Russia", "Russian Technologies", "Tatneft", "Irkut", "The Boeing Russia", "Yandex", ″Russian paints″ and others.

1.2. Lean systems development

The concept of Lean Production is the result of the integration of advanced management practices. A set of tools for better business is constantly enriched with new approaches: 6-Sigma, ISO 9000, Balanced Scorecard, E. Goldratt theory of Constraints, Kalita Function Deployment, Faylure Mode and Effect Analysis, self-organization model of T. Konti, J. Dalgaarda, D. Clemmer, benchmarking and others.

Figure 1.3 shows an embodiment of the composition of the modern Lean Production Systems tools and techniques [4].

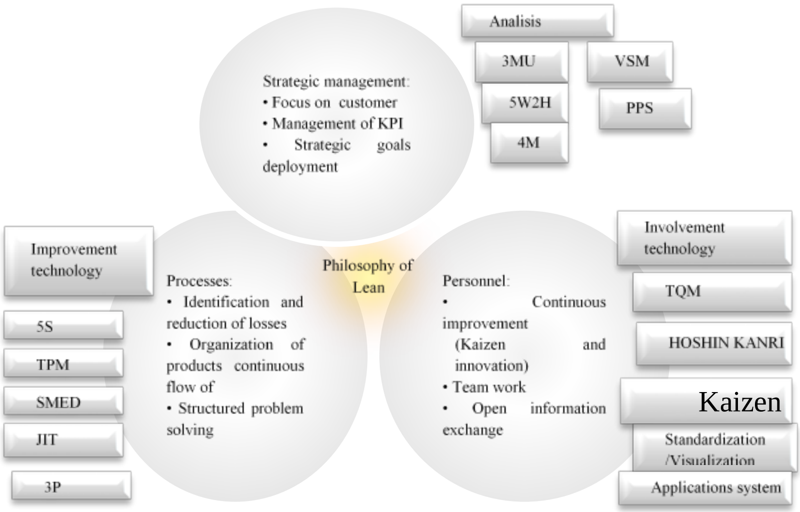


Figure 1.3 – The concept of lean production in OJSC "KAMAZ»

Lean Production concept adapts to environmental changes by new business tools integrating. In the evolution process the tools developed into the new improvement systems. Currently the most effective systems are Lean Production, Six Sigma and Goldratt's Theory of Constraints (TOC).

As a result of combining two complementary approaches, Lean Production and Six Sigma, a new widely used concept occurred - Lean Six Sigma.

Six Sigma is a production management concept, developed by Motorola Corporation in 1986, which was later successfully implemented in the company General Electric.

Lean Six Sigma

The essence of the concept is the need to improve the quality of each process output, minimizing defects and statistical variations in operating performance.

Six Sigma instruments include quality management methods, including statistical methods, imply the measurability of objectives and results, as well as provide the creation of special working groups, performing projects for troubleshooting and improvements.

Six Sigma is a high-tech method of business process configuration, providing reduction of probable defects occurrence in the operating performance.

The Lean Six Sigma concept managed to combine several approaches to solving problems: the elimination of waste and non-manufacturing cost**,** reducing process variability and stabilizing the product characteristics. This integration has provided a comprehensive solution for reducing defects in the production and minimization of not profitable activities.

The following table presents the results of the comparative assessment of the integrated Lean Six Sigma systems effectiveness [5].

Table 1.1 – Scores of improvement systems efficiency

Improvement systems efficiency	Scores (1-100)
ISO-9000	5
QS-9000	10
Requirements Malcolm Baldrige Award	25
TQM	35
Six Sigma	50
Lean Six Sigma	90

Theory of constraints

Theory of constraints (TOC) was developed in 1980s by Eliyahu Goldratt.

The main methodological sense is finding and managing the key constrainer of a system. The approach is based on identifying the restriction and controlling it to increase the rate of profit. Goldratt suggested a methodology and a number of logical tools to find the limit, to identify an administrative contradiction, find a solution and implement it, taking into account the interests of all stakeholders.

The theory is applied in production management, project management (development of new products, construction), managing the procurement and distribution of goods.

Types of constraints: power; market size; time.

Basic steps for system management through the constraints:

1. Search for system limitations.
2. Making decisions about how to maximize the use of system limitations.
3. Submission of "unlimited" elements of decision-making system.
4. Expansion of the constraints.
5. When constraints are removed it is necessary to return to step 1 and continue to seek restrictions.

Lean Production and Theory of Constraints are very popular and oriented on improving the efficiency of production.

Theory of Constraints is aimed at identifying and addressing capacity constraints to increase production capacity. Lean Production is focused on eliminating the production losses and, as a result, the production costs reduction. Thus, the combination of Lean Production and Theory of Constraints is seen as a way to get an extra effect.

In some cases, Theory of Constraints can provide a variety of improvement projects, Lean Production in turn can provide improving methods tools. As a result, the effectiveness of revealed solutions increases and reduction of losses in the limiting elements of the system is provided.

Figure 1.4 presents the concept of Lean Production tools interaction in the analysis of constraints [6].

Identifying the constraint is implemented through VSM and Gemba (going out of office to see the real plant work.)

Exploiting the constraint means applying 5S, Kaizen, standards of work and visual factory (a strategy of using special displays in manufacturing process) with andons (visual displays that show the production status).

To subordinate to the constraint the Kanban and line control are used.

The tools to elevate the constraint are as follows: TPM, SMED, Poka-Yoke, Jidoka (“automation with a human touch”, i.e. control and braking constraints without great investments but with less costs due to partial automation.)

The successful practice of the concepts of Lean Production, Six Sigma, Theory of Constraints and others in a number of cases confirms the presence of additional effects from the joint implementation of these tools to the problems of finding effective solutions [16].

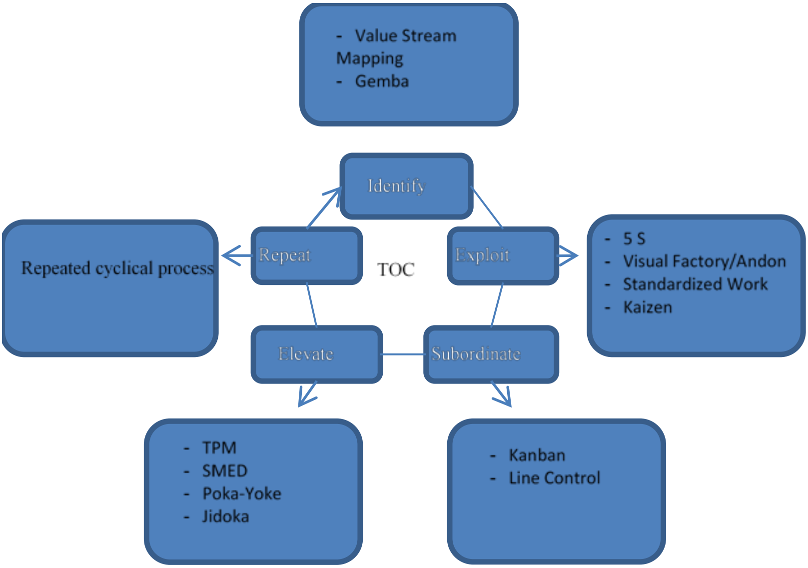


Figure 1.4 – The concept of Lean Production tools interaction in the analysis of constraints

The process of deploying Lean Production Systems in the enterprise is accompanied by a rather arbitrary choice of methods and tools, depending on specifics of the activities and experiences of the organizers, however it is based on the basic principles and experience of TPS.

Questions:

1. The line production as a base for lean management.
2. Lean Production concept occurrence.
3. Toyota Production System concept and principles.
4. Developers of Lean Production theory and their contributions.

5. Terms and definitions of Kaizen.
6. Total Quality Management TQM principles.
7. Give a retrospective of Lean Production development.
8. Give a retrospective of the QMS development.
9. Lean Production System definition and main terms.
10. Countries' statistics on lean-production implementation.
11. Lean Six Sigma concept.
12. Theory of constraints (TOC) – aims and development features.
13. Types of constraints and steps to their elimination.
14. Lean Production tools interaction in the analysis of constraints.
15. The tools to elevate the constraint.

UNIT 2. Elements of the concept and Lean Production tools

Lean Production Systems consist of diverse elements and are constantly updated. In numerous publications dedicated to the lean tools a description of the methods and practice of use are given, but the scope and range of tasks are not enough systematized.

Evolution of Lean Production concept consists of continuous adaptation to the problems of growth in real business efficiency. Like any evolving system, Lean Production has integrated in itself only the most effective methods and tools.

Each specific Lean Production System has its features. For example, the three major subsystems are allocated to the MS KAMAZ [4]:

- strategic management;
- processes;
- employees.

Thus, a plurality of methodologies and tools as part of Lean Production are grouped in technique complexes:

- improvements;
- analysis;
- involvement.

Figure 1.3 represents technology tools of each subsystem, but the represented composition is far from complete.

Each tool is designed to solve a local problem, and when used in conjunction with other techniques it allows to find a complex solution to the problem.

2.1. Engagement and stuff development tools

Tools of management and involvement allow to solve a wide range of personnel development tasks. With some degree of conditionality involvement tools include: the philosophy of kaizen, the quality management system of TQM, strategic changes planning system Hoshin Kanri, standard operations, system for submission of proposals and other tools and instruments. Different sources offer their combinations.

In particular, the improvement and development of production relations is achieved by using kaizen principles, organization of innovation, teamwork, open communication.

Kaizen	The term as a philosophical concept is the Japanese philosophy and practice of continuous improvement of production processes, development of supporting business processes and management, as well as all other aspects of life.

"Kaizen" in business is the pursuit of continuous improvement of all elements of the production system, the goal is the establishment of production without any loss.

The basis of kaizen management philosophy consists of a few fundamental principles [7]:

• Kaizen and management.
• The process, not the result.
• Follow the cycles PDCA/SDCA.
• Quality is pivotal.
• Say basing on data.
• The following process is the consumer [8].

Kaizen philosophy permeates all levels of company management. It implements a general involvement of personnel in the process of continuous improvement. The strategy, corporate standards and policies of the company are formed according to its principles, providing the maintenance and improvement of standard operating procedures (SOP).

Kaizen methods are focused on communication, training, teamwork, involvement and self-discipline.

The process, not the result. Kaizen process orientation allows to achieve continuous results improvement by improving processes, detection and correction of process errors.

Focus on the human factor is a notable difference of kaizen from the western approach in management. The most important condition for success is the universal involvement and commitment, including senior management of the company.

A principle of «Follow the PDCA/SDCA cycles» provides continuous improvement. During the planning stage, goals of actions and change are set. At the «do» stage the implementation of planned actions is performed. The following is the stage of the results "check" evaluation. At the «act» stage basing on current management cycle analysis the new procedures are made and standardized, to fix improvements and set new goals. Any changes in the process make it unstable, with the help of cycle standardization SDCA this risk is greatly reduced. Stabilization of the current process allows to re-start its perfection.

Quality is pivotal. This principle sets the highest priority to the quality of a number of other important goals of kaizen, such as costs, delivery and others. This principle rejects any compromise solution of the issues that reduce the quality.

Say basing on data – principle obliging to correctly display situation. Parametric description of the object allows to widely use the study of modeling techniques, statistical methods and other tools to make informed decisions.

The following process is the consumer. Process errors can be transferred to other processes, so it is important to ensure the high quality of the product or process services and stop the spread of poor quality results.

2.2. Improvement tools of Lean-systems

Kaizen implements its objectives by involving all staff and by improving production systems technologies.

Technology improvements are aimed primarily at improving the processes at the expense of identifying and reducing losses, organizing a continuous flow of products and structuring solutions to problems. For this purpose the following lean tools are applied:

- System 5S of production process improvement includes: Sort (Seiri), Compliance with order (Seiton), Contents clean (Seiso), Standardization (Seiketsu) and Perfection (Shitsuke);
- Just in Time (JIT) – the concept (the system), of production management aimed at reducing the level of reserves and losses;
- TPM (total production maintenance);

- SMED (single minute exchange of die);
- 3P (production, preparation, process);
- Kanban – pull production and others.

Implementation of 5S system is the first step to the deployment of Lean Production System and the development of the staff ability to continuously improve the working environment, reducing the possible risk factors. The psychological effect appears in increase of efficiency and strengthening of production discipline. Economic effect – in reducing costs, growing quality of work, reducing reserves of unfinished production.

Methodology of 5S implementation consists of several stages.

Seiri of 5S	In the first stage, there is the removal of all unnecessary items and tools in the workplace. They are sorted (Seiri) into the following groups: necessary, unnecessary and not needed immediately.

The necessary objects are stored in the workplace, the unnecessary are removed and not needed immediately are stored in the designated areas. Areas of responsibility are defined for the workspace for each employee. Thus it is possible to reduce the unnecessary reserves and storage space, reduce injuries and the loss of raw materials.

Seiton of 5S	In the second stage the retention and disposition rules in the workplace are defined for the necessary items (Seiton) to ensure the availability and security of their use, ease of control due to the storage space visualization and a number of other requirements, enhancing aesthetics and order.

Due to these measures the working conditions are improved, time loss, injuries and the number of defects are reduced.

Sekisui of 5S	In the third stage the sources of workspace contamination (Sekisui) are identified and eliminated.

This ensures equipment breakdowns and accidents downtime reduction, health conditions and fire safety improvement and injuries decrease.

Senketsu of 5S	The fourth stage is the rules development for bringing order and cleanliness (Senketsu), for example, the rules of storage and usage of tools and documentation.

Persons who have the right to use items in the workplace are defined. Due to the control visualization and management the losses are reduced. Standard control procedures become habitual and daily.

Sitsuke of 5S	At the last stage the steady habit for order and cleanliness in the workplace is formed (Sitsuke). New experienced procedures are being set up, instructions are being spread and a responsible person for compliance with the new rules is being established.

If necessary, the system of administrative penalties can be entered. The result is a strengthening of motivation on productivity and compliance with industrial culture, declining defects rate caused by misconduct or error.

The successful implementation of 5S system is often ensured by the presence of "change agents" i.e. employees, promoting the ideas of bringing order and cleanliness, uniting groups of enthusiasts, who control the course of change. The most important condition for success is the implementation of the universal principle of involvement of staff in the process of 5S system implementation.

Just in Time	The concept of Just in Time. JIT system is a system of continuous-line production with minimal reserves. The basis of the organization is flexible management of resources supply in exactly the right quantities, in synchronization with the needs of production.

To do this, the supply systems of pulling type are used, such as Kanban.

Kanban cards allow to efficiently manage replenishment of components needed in a particular area of production, due to placing an order for manufacturing on the previous stages of production. Thus, the resources pull principle is implemented in a particular production stage, throughout the entire production system.

Unlike traditional systems, where the risk of violation of the production rhythm is reduced by the creation of insurance reserves, JIT system provides a reduction in inventory levels and a general high efficiency by eliminating the causes of any risks. The successful implementation of JIT principles is based on elimination of the causes of any failures, harmonious interaction of all elements of the production system, beginning with suppliers.

Total Productive Maintenance

TPM method is focused on the systematic elimination of any loss sources by improving maintenance processes and preventative maintenance.

As a result of the TPM system implementation the losses associated with the failure of the equipment, long changeover times, reduced equipment productivity, etc. are eliminated.

Single Minute Exchange of Die

SMED method of reducing the changeover time allows, due to release of time, to raise the level of equipment maintenance, to increase overall productivity and production flexibility because of constant availability of equipment for processing of the next order.

The basic idea of SMED is to perform the greatest possible amount of work on the readjustment without stopping the equipment in the course of its operation.

2.3. Research tools of Lean-systems

The effectiveness of the lean methods implementation is based on the systematic detection and elimination of all types of losses in all areas of the company. Therefore Lean production methodology includes a variety of systems and methods for reducing losses, for example, Value Stream Map.

Value Stream Map

VSM is an information and material flow analysis tool during the execution of the order. VSM allows to identify the problematic stages, as well as all overheads and processes that do not create value for the customer.

For identifying, a detailed survey and the timing of the process are made, the VSM «as-is» is developed. On the basis of this model's parameters the measures to eliminate losses are offered, the future VSM «as-to-be» is constructed, state and process improvement plan is drawn up. The map shows the options to improve processes and key performance indicators characterizing the future state of the value stream.

VSM can firstly be drawn on paper with pencil and stickers, and after that, transferred, for example, in MS Excel.

3-MU	3-MU procedure (Muda; Muri; Mura) orients researchers to search for reserves of efficiency growth in three directions:

- losses (Muda) as a result of not creating value for the customer production, but that consumes resources;
- overload (Muri), or intense operating regimes of the equipment and personnel that lead to lower quality and higher injury;
- inconsistency (Mura), associated with deviations from the standard progress of work.

In all of these 3-MU areas the reserves are identified in the following categories: human losses, technology, method, time, equipment, appliances and tools, materials, production volume, reserves, place, way of thinking.

For example, losses classification includes:

- losses from overproduction;
- losses from unnecessary movement;
- losses from the excess inventory;
- losses from defects;
- losses from idle;
- losses from transportation;
- losses from excessive processing;
- losses from the production of the product that does not meet the requirements of the customer;
- loss of skills and labor when used in not full force.

5 Why's	5W method belongs to the simplest lean instruments of search for the root causes of failure, scraps and other negative phenomena. This method allows to find out the cause-and-effect relationships.

For these purposes there is a widely used cause-and-effect diagram of Ishikawa (Fishbone Diagram). It is a part of the so-called “seven simple instruments of Lean production” [9]:

• Control chart;
• Pareto chart;
• Bar chart;
• Checklist;
• Ishikawa diagram;
• Stratification;
• Scatterplot

Considered systems and methods are only a part of extensive Lean Production tools, its application in practice is constantly enriched and updated.

2.4. Types of losses (muda, mura, muri). Loss Estimation Methodology

Production losses (wastes) reduce the efficiency of the company, so their removal is converted into a continuous process. Among the most effective methodologies to reduce losses and increase efficiency is Lean production.

Lean production tools allow to identify and eliminate waste, and the Kaizen philosophy ensures the continuity and stability of process improvement.

Lean Production consists of three types of losses:

Muda	Wastes. Any actions that do not add any value.
Mura	Uneven loading.
Muri	Overloading of people or equipment.

Wastes (Muda) are as follows:

- waste due to overproduction;

- waste of time due to waiting;
- waste during unnecessary transportation;
- waste because of the extra processing steps;
- waste because of excess reserves;
- waste because of unnecessary movements;
- waste because of defective products production.
- missed creative potential of employees.

General principle of loss calculation:

$$L = \sum C_r = \sum_i R_i \times c_i \ ,$$

where C_r is the cost of resources spent not on value creating;

R_i are kinds of wasted resources (material, energy, labor, and others);

c_i is the unit value of the *i*-th resource.

The economic effect *E* of the lean events implementation is the difference between the value of the costs reduction associated with the event and the cost of its implementation.

$$E = \begin{bmatrix} \begin{matrix} Current \\ costs \end{matrix} & - & \begin{matrix} Costs \\ due\ to \\ implementation \end{matrix} \end{bmatrix} - \begin{matrix} Implemen \\ tation \\ costs \end{matrix}$$

Implementation costs - it is a one-time cost of implementing the event (costs of materials, energy, labor and other payments)

$$\begin{matrix} Implemen \\ tation \\ costs \end{matrix} = \begin{matrix} Quantity \\ of\ resources \end{matrix} \times \begin{matrix} Costs \\ of\ resources \end{matrix}$$

Costs before implementation - are estimated based on mapping of the current state of the process or on the basis of accounting, management accounting data.

$$\begin{matrix} Current \\ costs \end{matrix} = \begin{matrix} Current\ quantity \\ of\ resources \end{matrix} \times \begin{matrix} Costs \\ of\ resources \end{matrix}$$

The costs due to implementation are calculated as either a planned (in the preliminary assessment phase) or as an actual (in step of confirming the effect) resource consumption in monetary terms.

$$\begin{matrix} Costs \\ due\ to \\ implementation \end{matrix} = \begin{matrix} Quantity \\ of\ resources \\ due\ to \\ implementation \end{matrix} \times \begin{matrix} Costs \\ of\ resources \end{matrix}$$

Calculation of efficiency of «Implementation of standard-packaging» can be done by formula:

$$E = \frac{Т_1 - Т_2}{3\ 600} \times С_{lh} \times К_{add} \times С_{sn} \times А,$$

where T_1 and T_2 is standard time for processing a unit of production before and after the use of the event, in seconds.

C_{lh} is the cost of labour hour of a worker, rubles.

K_{add} is additional wage rate,

K_{sn} is deduction for social needs,

A is production volume for the reporting period in natural units.

From the experience of Russian consulting companies [3] follows that in the implementation of Lean production a large proportion of the loss falls on the movement and control of the technological process.

Methods for determining the economic impact of a particular event may be different, each company develops its methodology [2, 7, 8].

As an example, calculations for some types of effects are given. [4]

The economic effect from the reduction of working time losses:

$$E_{tl} = \Delta Т_l \times L_{aao} \times R_{pl},$$

where ΔT_l is loss of working time, to be reduced (within the shifts and hole shifts downtime, truancy, absenteeism with a permission of the administration), days;

L_{aao} is the average annual output per worker, calculated from prime costs, rubles;

R_{pl} is planned level of profitability, %.

The economic effect from the reduction of the duration of the production cycle:

$$E_{\text{ТЦ}} = (Т_c^1 - Т_c^2) \times С \times n \times К_{kg},$$

where $Т_c^1$ и $Т_c^2$ – the duration of the production cycle of manufacturing parts and products before and after the event to reduce it, days;

C is the cost of one piece or product manufacturing, rub.;

n is lot size of parts or products, items;

K_{cg} is cost growth coefficient.

The economic effect of a full load of equipment:

$$E_{el} = \left(F_{ф} \times N_{ф} - F_{пл} \times N_{пл}\right) \times v_{час} \times R_{пл},$$

where F_{pl} and F_{fact} are the planned and the actual fund operating time of a piece of equipment, h;

N_{pl} and N_{fact} are the number of pieces of equipment, operating and actually intended to be loaded on the plan;

V_{hour} is output for 1 hours work of a piece of equipment, rubles.

$R_{пл}$ is planned level of profitability, %.

The economic effect in reducing losses from manufacturing flaws E_{fl} and defects E_d:

$$E_{fl} = \left(К_{fl}^{1} - К_{fl}^{2}\right) \times С_{fl}\ ,$$

$$E_{d} = \left(К_{d}^{1} - К_{d}^{2}\right) \times С_{d}\ ,$$

where $К_{fl}^{1}$ – the number of defective items in the base period;

$К_{fl}^{2}$ is the number of defective products after the arrangements;

C_{fl} is the cost of defective parts.

$К_{d}^{1}$ is the number of defective products in the base period;

$К_{d}^{2}$ is the number of defective items in the billing period following the organizational activities;

C_d is the cost of basic materials and wages with charges of production workers involved for correcting defective product, rub.

The economic effect of reducing the time to set-up and changeovers:

$$E_{НО} = \left(Т_{adj}^{1} - Т_{adj}^{2}\right) \times Тh_{adj} \times v_{hou} \times R_{пл}\ ,$$

where $Т_{adj}^{1}$и $Т_{adj}^{2}$ is the time required for adjustment or readjustment of the equipment for a certain period of time before and after implementation of organizational improvements, h;

$Тh_{adj}$ is hour tariff rate of an adjuster, rub.

V_{hour} is output for 1 hours work of equipment, rubles.

R_{pl} is planned level of profitability, %.

Questions:

1. Evolution of Lean Production concept.
2. Lean Production System structure of KAMAZ.
3. Basis of kaizen management philosophy.
4. Follow the PDCA/SDCA cycles contents.
5. 5S system definition and stages.

6. Just in Time concept.
7. Kanban appliance.
8. Total Productive Maintenance method main features.
9. Single minute exchange of die method main features.
10. Value Stream Mapping procedure.
11. 3-MU procedure description.
12. 5W method insights.

UNIT 3. Lean-system management

The deployment and continuous improvement of production Lean-Systems is one of the complex and informal transformations that causes changes in the order of organization of all processes and relationships within the enterprise, aimed at creating value for the customer.

Coordinated development of business processes and staff development is an essential condition to achieve practical results. One of the common mistakes deploying Lean-systems is the weak link of current changes with the strategic objectives of the company, for example, the introduction of a specific lean tools without a radical change in thinking and personnel transformation of work culture. Implementation of Lean production individual instruments often becomes a goal in itself, following the next fashion trend. At the heart of transformations should be lean principles and philosophy of kaizen.

Traditionally, management monitors the performance indicators such as: the volume of production, quality**, cost,** productivity. The staff stimulation system is also usually focused on these parameters. In Lean production a great attention is paid to actions in the process, with such features as a way of thinking, ways and methods of behavior motivation.

Thus, in the Lean production systems management the focus has shifted from performance management to personnel management.

3.1. Hoshin kanri

The value orientation of enterprises creates specific requirements for management and planning of the Lean production systems development. One of the most effective methods of strategic management in Lean production is Hoshin kanri planning method.

Hoshin kanri	The concept of *Hoshin kanri* (policy management or policy deployment) appeared in 1960 in Japan and gained popularity due to its successful application in Toyota and Komatsu to address strategic planning tasks.

The method Hoshin kanri actualizes a systematic approach, involving close connection of macro and micro levels of the organization, through a decomposition of business-processes from the top-level goals to scheduling problems on the lower level of management.

Problems to be solved by Hoshin kanri:

- the union of all creating a value stream activities of the organization;
- uniting efforts of supplier companies into a single system of value creation;
- planning of new products and services production;
- coordination of multiple projects management concerning strategic changes;
- management of the process of lean manufacturing systems deploying.

Hoshin kanri provides the company with the systematic movement towards strategic goals. The effectiveness of this approach is provided by the constant coordination of real-time control system based on the principles of Kaizen continuous improvement, with the strategic objectives of the company. Deployment logic is based on the PDCA (plan-do-check-act) cycle.

After determining the strategic objectives and targets at the level of a corporation, they are decomposed (deployed) down the management hierarchy. At each level, they are specified to the level of concrete measures and actions.

Schematically decomposing a strategy is shown in Figure 3.1. As a result of this gradual work, the so-called X-matrix is filled with the main directions of company development [10].

X-matrix is made on A3 size paper in the form of a visual and concise document (see. Figure 3.2)

Each level of the X-matrix consists of four blocks: the global objectives, strategy, tactics and quantitative goals. The strategy and the global goals are hierarchically linked to the objectives and indicators of lower levels [11].

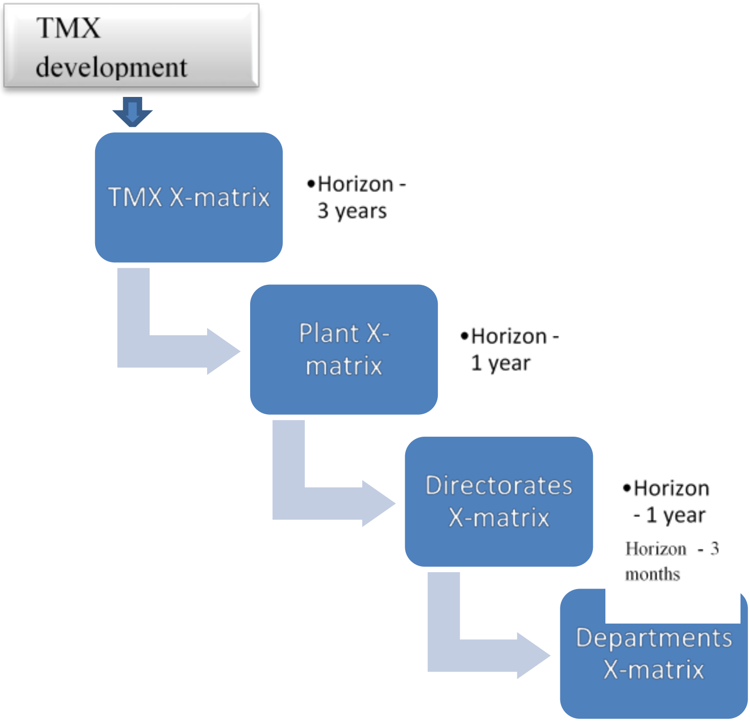


Figure 3.1 – Scheme of strategy decomposing

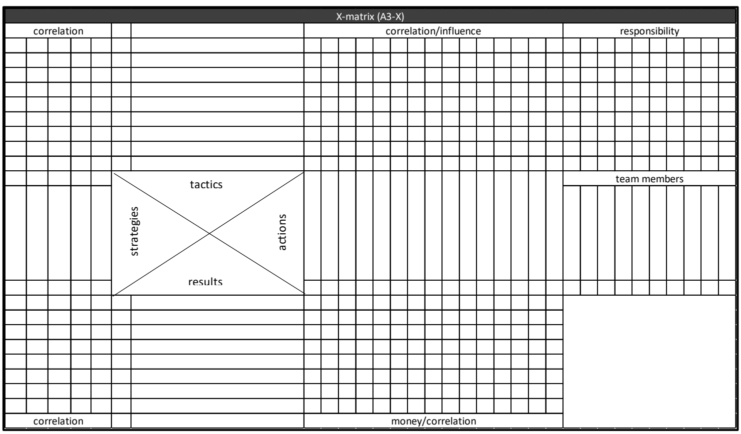


Figure 3.2 – Template of Hoshin kanri X-matrix

The "strategy" is filled with the results of the strategic analysis of the enterprise, goals in term of 2-3 years are written in it. The "tactics" field specifies the path to the strategy realization of the next 0.5 - 1.5 years. In the "objectives" there are the processes and events that determine the solution of tactical problems. In the "goals" field there are specific indicators of strategic plans. In the "responsibility" there are performers.

There are additional matrix between these fields allowing to identify expert estimates for the correlation levels (strong, medium and weak) between the respective fields.

The deployment of higher-level strategic goals for all management levels is carried out through the organization of an iterative matching of the X matrix content downwards and upwards using the methodology of "catch-ball" (see. Figure 3.3).

The point of the method is that the proposals on strategy formulation and planning of activities are iteratively agreed between the various levels before the final decision. With the catch-ball method the senior management goals are converted into goals of all employees.

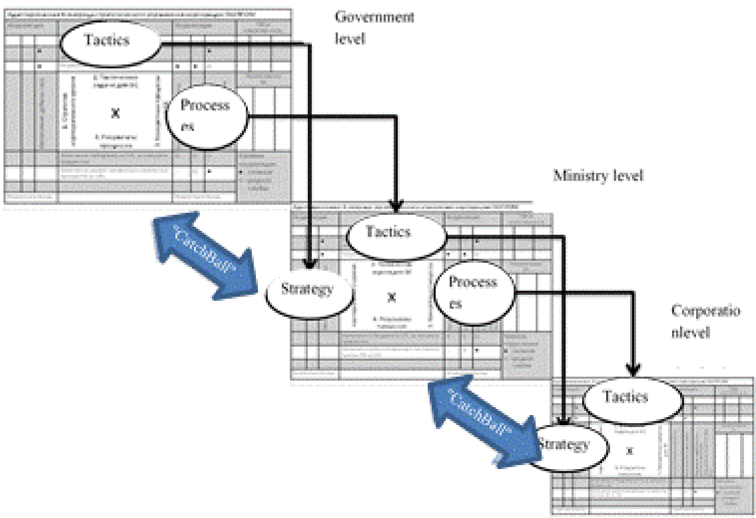


Figure 3.3 – Organization of X-matrix matching by the method of catch-ball

Besides Hoshin kanri method for the purposes of deploying the strategy, there is a widely applied method of Balanced Scorecards (BSC). Authors: Robert Kaplan and David Norton.

Balanced Scorecard	The BSC is a management system that maps an organization's strategic objectives into performance metrics in four perspectives: financial, internal processes, customers, and learning and growth, providing a systematic development of a company's campaign.

The financial perspective focuses on financial performance of an organisation. It normally covers the revenue and profit targets of commercial companies as well as the budget and cost-saving targets of not-profitable organisations. The financial health of an organisation is a critical perspective for managers to track. It is important to note that financial performance is usually the result of good performance in the other three scorecard perspectives.

The customer perspective focuses on performance targets as they relate to customers and the market. It usually covers customer growth and service targets as well as market share and branding objectives. Typical measures and KPIs (key performance indicator) in this perspective include customer satisfaction, service levels, net promoter scores, market share and brand awareness.

The internal process perspective focuses on internal operational goals and covers objectives as they relate to the key processes necessary to deliver the customer objectives. Here, companies outline the internal business processes goals and the things the organisation has to do really well internally in order to push performance. Typical example measures and KPIs include process improvements, quality optimisation and capacity utilisation.

The learning and growth perspective focuses on the intangible drivers of future and is often broken down into the following components:

- Human Capital (skills, talent, and knowledge).
- Informational Capital (databases, information systems, networks, and technology infrastructure).
- Organisational Capital (culture, leadership, employee alignment, teamwork and knowledge management).

Typical example measures and KPIs include staff engagement, skills assessment, performance management scores and corporate culture audits.

Outcome of the BSC development is a strategic map, on which the goals accepted to achieve are noted, as well as initiatives and indicators characterizing the level of its achievements.

The most important condition for the successful application of the Hoshin kanri and the BSC strategies is the continuous monitoring of indicators, changes in key external factors and strategy correction. The ability of the organization to quickly adapt to the economic factors of the environment has become an important competitive advantage.

So, Hoshin kanri provides coordinated interaction of officers and organizational units from corporate strategy development to implementation of tactical plans of its functional units.

Visual display form of goals, objectives and the results is achieved with the help of X-matrix Hoshin kanri shown in Figure 3.4.

Through x-matrix the links between different levels of administration are determined. Particular executors listed in the matrix of responsibility, ensure compliance with the planned values on their levels of management hierarchy.

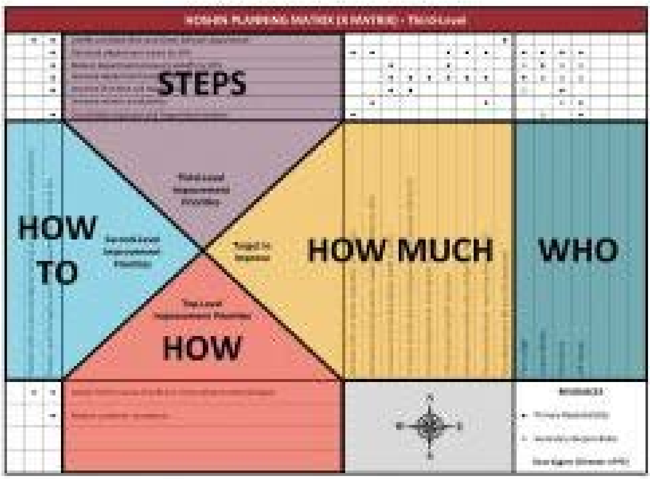


Figure 3.4 – Purpose of Hoshin kanri X-matrix fields

EXAMPLE 1

As the strategic objective the corporation is considering an increase in production volumes.

This can be achieved by increasing productivity and reducing losses in existing plants, as well as through the introduction of new capacities.

Decomposition of these tasks to the levels of business units means:

- Increased sales by 5%.
- Increased share in regional markets to 10%.

As a factor that ensures the solution of tasks, an implementation of projects is considered:

- Development of infrastructure in regions.
- Creating and commissioning of new capacities.
- Implementation of the Lean production principles at existing platforms. In particular, the increase in productivity is planned to be provided through the introduction of SMED and TPM methods.

The expected result of the project is to ensure the implementation of the stated strategic objectives. The corporation consists of several business units, and the orientation on production have three of them: BU1, BU2, BU3.

It is necessary to introduce an adapted strategy using hoshin kanri matrix.

Solvation.

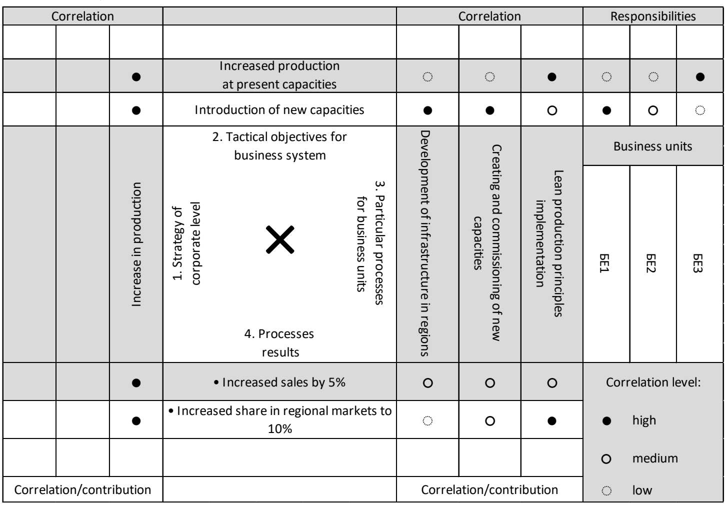


Figure 3.5 – Filled X matrix

Filling in the matrix is necessary to begin with the field of strategic objectives. In this example it is the left part of the table. The finished view of hoshin kanri matrix is obtained after filling correlation and specific implementing projects matrices. Figure 3.5 shows a filled X matrix.

3.2. Designing features of lean- systems. Lean production management system

Producers operate a variety of options how to implement the Lean Systems now [12]. They imply the algorithms of James P. Womack, Dennis Hobbs, Lonnie Wilson and others. A lot of consulting companies offer their own techniques in the design of Lean Systems.

Timing of implementation and positive results depend on the willingness of enterprises to reforms, the level of involvement of staff in the implementation of the project, the scales of production, the composition of the equipment and product mix parameters. In the case of external consultants, time and results will depend more on the accuracy of obeying their recommendations.

There is no unified standard procedure of implementation, any Lean system is unique. The general sequence of project parts of creating Lean-system can be represented by the following steps.

A typical example of implementation schedule from the company "Inter Consult" is shown in Figure 3.6. It includes: [13]

- analysis of the current condition of the company and the preparation of project implementation;
- the company's management training;
- lean-management system design;
- implementation of lean management system, which includes staff training;
- lean management system audit;
- support for certification;
- post-project support.

Theory and practice of Lean systems are constantly enriched with new tools and best practices for their application. The dynamics of the number of publications in the field of Lean production from 1998 to 2013 is gradually upcoming.

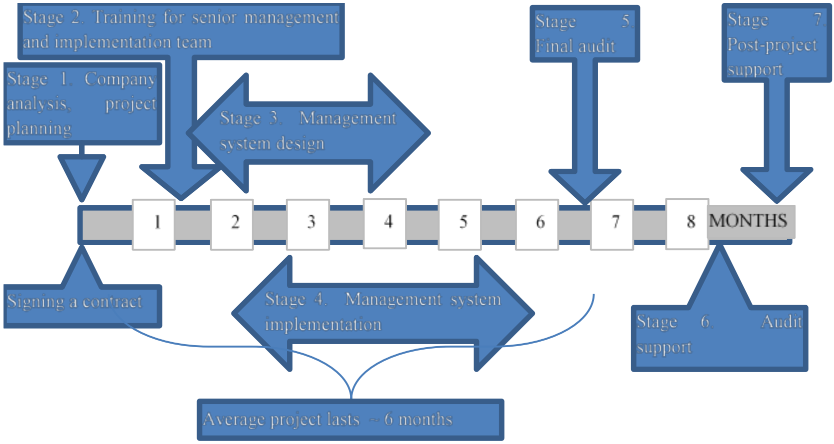


Figure 3.6 – Lean- system implementation schedule

It has become clear to many researchers that the accumulation of knowledge raised a need of its generalization, which is reflected in the appearance of international standards. To summarize the established approaches to Lean systems creation, secure the major achievements and evaluate the implementation results the systems of international standards are designed and being developed:

- SAE J 4000-1999 «Identification and Measurement of Best Practice in Implementation of Lean Operation». SAE is a professional organization for mobility engineering professionals in the aerospace, automotive and commercial vehicle industries of USA;
- Indian standard IS 15171:2002 «Guidelines for Establishing and Implementing 5-S Concept»;
- ANSI B11.TR7-2007 «Designing for Safety and Lean Manufacturing». A guide on integrating the safety and lean manufacturing principles in the use of machinery by the Americal National Institute of Standards;
- standards VDI 2870 Part 1 "Lean production systems. Basic principles, introduction and review", VDI 2870 Part 2 "Lean production systems – List of methods" by the German Union of Engineers and other standards.

Standard SAE J4000 was one of the first to be developed; it identifies six basic elements and 52 requirements of Lean production, as well as criteria for evaluating the implementation requirements and elements of the Lean production methods.

The results of the components implementation are measured at the level of achievement on a scale from 0 to 3. The absence of a component, or significant violations of requirements of the standard correspond to the zero level implementation. Minor deviations compliant with the level 1. Level 2 corresponds to the fact of the successful implementation of the component. Level 3 corresponds to the effective implementation of the component as well as to the entire improvement over the last 12 years. In this case, the result achieved is considered the best practice for companies implementing the Lean [14].

In Russia has now been accumulated an experience of creation and development of production systems based on Lean principles. Particularly significant results were achieved by such companies as OJSC "KAMAZ", State Corporation "Rosatom", *JSC "*GAZ", etc. At the same time many enterprises, when creating production systems, use primarily international experience, presented in numerous publications. Russian consulting organizations also offer original methods that are not always proven in practice. Thus the need to systematize a profound domestic and foreign experience in developing of Lean production systems in terms of terminology, methods, and certification requirements emerged.

In 2014, the Ministry of Industry and Trade of the Russian Federation decided to establish a certification system in the field of Lean production and developed the series of state standards for regulatory and methodological support of the modernization of the organizational and managerial bases of Russian industry in accordance with modern approaches and models.

The structure of the national standards system of "Lean manufacturing" series is shown in Figure 3.7.

The system of national standards of "Lean Production" series includes the following documents [15]:

- GOST R 56020–2014 «Lean Production. Fundamentals and vocabulary» (enacted on March 1, 2015);

- GOST R 56404–2015 «Lean Production. Requirements for management systems» (enacted on June 2, 2015);
- GOST R 56405–2015 «Lean Production. Certification process of management. systems. Assessment procedure» (enacted on June 2, 2015);
- GOST R 56406–2015 «Lean Production. Audit. Questions for assessment management system» (enacted on June 2, 2015);
- GOST R 56407–2015 «Lean Production. Basic methods and tools» (enacted on June 2, 2015).

industry-wide level	GOST ISO 9000Quality management systems. Fundamentals and vocabulary	GOST R56020 Lean production. Fundamentals and vocabulary		2013
	GOST R 56404-2015 Lean manufacturing. Requirements for management systems	GOST R 56406-2015 Lean manufacturing. Audit. Issues for the assessment of management system		2014
	GOST R 56405-2015 Lean manufacturing. Process of certification of management systems. Assessment procedure	GOST R 56407-2015 Lean manufacturing. Basic methods and tools		
	GOST R Lean manufacturing. Integrated Quality Management System	Guidelines on the application	Future standards. The list and contents are specified after the research	2015
specific requirements of industry	GOST R. Lean production.The application features in the automobile industry	GOST R. Lean production.The application features in the aircraft industry		2015 - subsequent years
	GOST R. Lean production.The application features in the defense-industrial sector	GOST R. Lean production.The application features in the shipbiulding industry		

Figure 3.7 – The system of national standards of "Lean Manufacturing» series

Thus, according to GOST R 56020, Lean manufacturing is a concept of business organization focused on creating the appropriate value for the customer by generating a continuous stream of value creation, involving all the organization's processes and their continuous improvement through the involvement of staff and the elimination of all kinds of losses.

The basis of this concept is the principle of focus on customer and formation of value stream covering all processes of the organization [17].

Lean Production Management System (LPMS) model is presented in Figure 3.8 [18, 19].

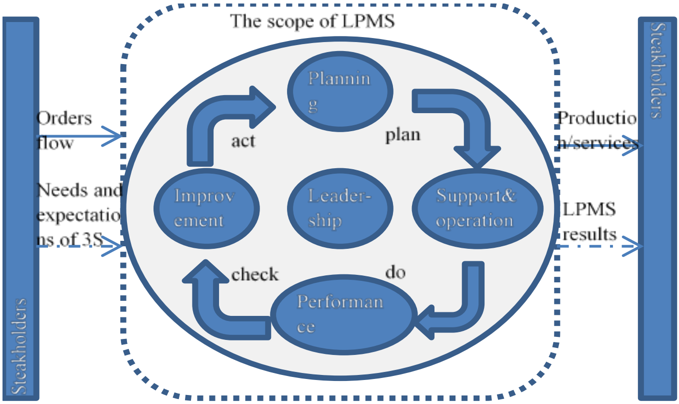


Figure 3.8 – LPMS model

The figure reflects a systematic approach to the implementation of the PDCA cycle management by development of the Lean production system.

Figure 3.9 presents the stages of development of the enterprise management system for the lean manufacturing on each maturity level.

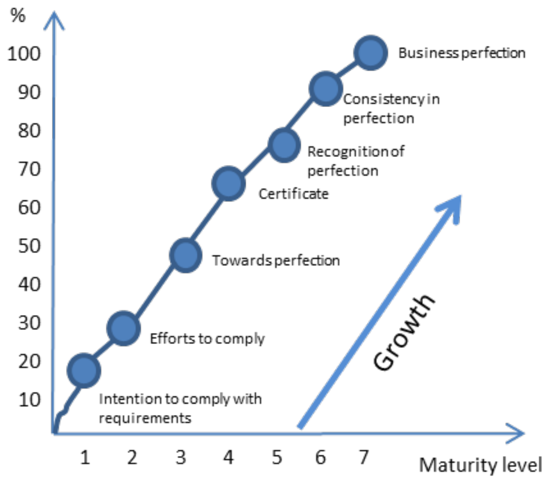


Figure 3.9 – Enterprise management system development stages

According to the chart, standards imply stages of the Lean production systems development, one of which involves the voluntary certification of the production system to meet the requirements of «Lean Production Management System».

Voluntary certification fixes the achieved results and directs the organization to further improving of its production system. The certificate confirms the high level of results on the use of the principles, methods**,** tools of Lean production, staff training and transformation throughout the management system.

Basing on results of Lean production system audit the conclusions are carried out. In order to assess the achievement of Lean production maturity levels there a rating scale from 0 to 4 is used.

Repeated audits to assess the current level of maturity of the system allow to measure the effectiveness of steps of further Lean production system improving.

Successful certification does not mean the achievement of the international level, but allows the company to target the search and development of its competitive advantages in view of foreign and domestic experience.

3.3. The Poka-yoke system, FMEA analysis

Poka-yoke	Protection against unintentional errors «poka-yoke» is a tool of Lean production, the method is aimed at the prevention of occurrence of unintentional errors and their prompt elimination.

Devices of protection from unintentional mistakes have three main functions [1]:

- Warning. In case of an error detection by a system «poka-yoke» the performance of the next operation is blocked;
- Control. If the operation is carried out with an error or not completely, the protection device «poka-yoke» does not allow the detail to leave the processing site;
- Stop. In case of detection by a system «poka-yoke» a defective details, its transfer to the next operation is blocked;

The effectiveness of the method in scores by the indicators system and implemented principles of Lean production are shown in Table 3.1 [2].

Table 3.1 – The degree of influence of the method «poka-yoke» on quality, cost, time

The impact of the method on the characteristics:			Ongoing principles of Lean production
quality	cost	time	
+ + +	+	+ +	Reduction of losses. Priority of security providing. Built-in quality

As follows from the above stated estimates, the method has the greatest impact on the quality growth, while ensuring the reduction of losses from possible errors and the reduction in injuries.

When designing the system poka-yoke different Lean production tools are applied, such as built-in quality Jidoka, Ishikawa diagram, the five "why" and other methods of research. Technical implementation of the system includes the elements of Andon information management and visualization.

The disadvantages of this method include delays during the implementation of production operations. The possible resistance of a current working system to a forced intervention of devices for protection against errors often ruins the efforts to improve the process.

Accidental or intentional human errors can lead to losses due to the need to rework and rejects.

The probable causes of human errors may include:

- obliviousness;
- deliberation;
- inattention;
- unexpected situation;
- lack of experience;
- lack of standards;

- opportunities revaluation;
- sabotage.

As a result of the listed reasons, different types of defects occur:

- missed operations;
- processing faults;
- disposition of workpiece;
- missed workpieces;
- wrong workpieces;
- processing of wrong workpieces;
- Incorrect operation on the correct workpieces;
- configuration errors;
- Incorrect installation of the equipment;
- using the wrong tool and equipment.

Figure 3.10 provides an example of «poka-yoke» in modern gadgets, the connectors of which are made so that it is impossible to connect them incorrectly.

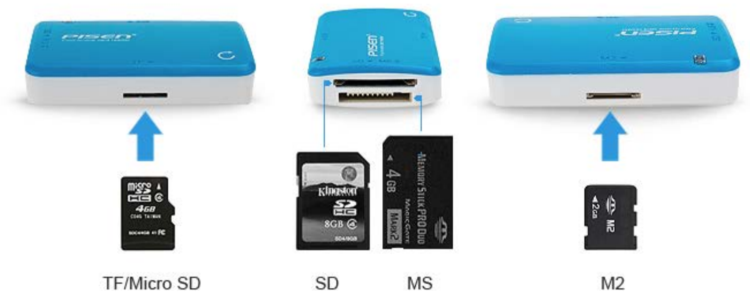


Figure 3.10 – Example of «poka-yoke» implementation in modern IT devices.

The industrial machinery with hazardous to human areas provide two "start" buttons. The process can be started only by the both buttons being simultaneously pressed (see Fig. 3.11). Thus, using both hands, the possibility that one arm may remain in the working zone is excluded.

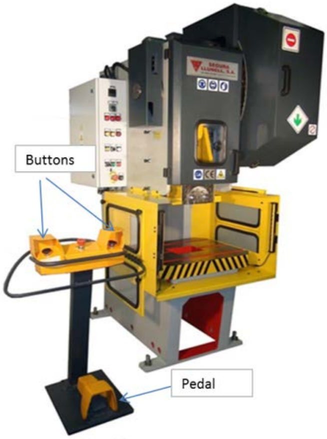


Figure 3.11 – The machine with two control buttons [3]

Any danger of injury in the manufacturing process must be eliminated or halted. In the simplest case, all access to the source of danger must be prevented. Widely used, automatic "photo barriers" (see. Fig. 3.12) are the devices that generate signals for the equipment moving parts blocking prior to elimination of the trouble in the work area in case the foreign objects get into the monitored zone.

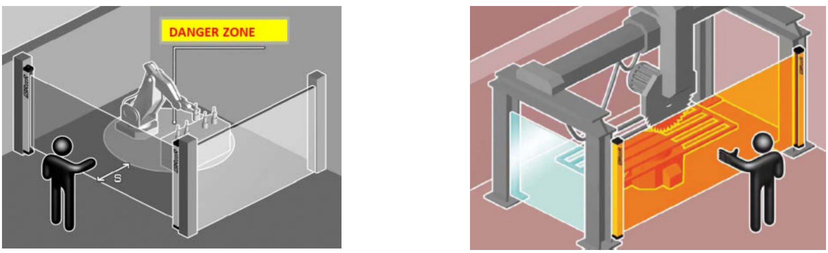


Figure 3.12 – The principle of the light barrier operation [4]

Figure 3.13 shows the push-button switches in structure of which «poka-yoke» function is enabled, random switching is difficult.

Mushroom pushbutton with fixation with foolproof

Illuminated power switch with unintentional power protection

Figure 3.13 – Pushbutton switches with the «poka-yoke» function

Application of the «poka-yoke» methodology is expedient at the design stage of production processes and products. During the deployment of Lean production the corrective actions for error protection may be required. To assess the potential risks FMEA analysis can be applied.

FMEA analysis	Analysis of the types and consequences of potential defects (Failure Mode and Effects Analysis) is used in the development of new products and business processes, as well as at the stages of Lean production improvement.

Based on the results of FMEA proposals to address the causes of defects are developed.

The method of analysis involves several tasks:

- identification of potential defects and variations of failures in the application of products or the operation of the process;
- identification of the main causes and possible consequences of the identified defects and failures;
- development of action to address the underlying causes or the prevention of the possible consequences.

The method has found widespread use in quality management systems and is regulated by GOST R 51901.12-2007. Risk management. The method of types and consequences of failures analysis.

The technology of FMEA-analysis include construction and investigation of component, structural, functional, streaming models of an object and Ishikawa diagram.

The process is analyzed and reverse brainstorming is carried out based on the models research. As a result, the list of the possible consequences (S) of each failure is built, each effect is estimated by experts, usually on a 10-point scale of severity.

Also by the 10-point scale the probability of each consequence (O) and the probability of detection of failure and its consequences (D) are assessed . Table 3.2 shows the scale of factors evaluation.

Table 3.2 – The S, O, D factors estimation scales

S factor effects of severity	O factor probability of occurence	D factor probability of detection
1 – very low (almost no problems)	1 – very low	1 – most probable detection
2 – low (problems are settled by stuff)	2 – low	2 – high detection
3 – not very severe	3 – not very low	3 – good
4 – ower then average	4 – lower then average	4 – moderately good
5 – average	5 – medium	5 – moderate
6 – higher than average	6 – higher then average	6 – weak
7 – pretty high	7 – close to high	7 – very weak
8 – high	8 – high	8 – bad
9 – very high	9 – very high	9 – very bad
10 – catastrophic (dangerous for human)	10 – 100%	10 – almost impossible to detect

For the obtained values of S, O, D for each effect the risk priority number – RPN is calculated.

$$RPN = S \times O \times D.$$

Multiple effects are ranked by the value of the PRN. The failures with high values are marked to be worked out firstly, the measures to eliminate or reduce failures are developed. The predictive value of RPN based on developed measures is calculate.

The method allows to detect and correct errors at the stage of products and processes designing, provides its exceptional efficiency. It is quite easy to learn and allows to involve the experts in different fields, ensuring the objectivity of the problems study.

3.4. Workplace arrangement 5S. Lean-systems investigation instruments

The system of workplace organization refers to the basic tools of Lean Production. 5S activities have a strong influence on the formation of such system of indicators, as quality, cost, time.

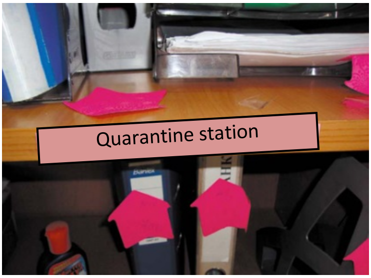
Mass application of tools is caused by a quick impact, clarity and apparent simplicity. Ongoing principles of Lean Production are as follows [1]:

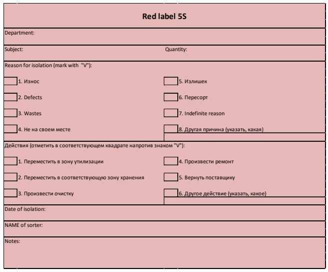
- continuous improvement;
- reduction of losses;
- visualization and transparency;
- priority security;
- construction of a corporate culture based on respect to the individual;
- built-in quality;
- obeying standards.

5S method is intended to create conditions for reducing the main types of loss, especially the loss of time, excess inventory, and others. Provides improved performance and safety at work; creation and maintenance of order and cleanliness in every workplace.

The most often used methods for workplace organization are:

- "Red label" method (Figure 3.14);
- contouring;
- cell placement of objects;
- analysis of changes before/after by photos;
- audits to evaluate the effectiveness of the 5S program implementation.





Red label 5S

Department:

Subject: Quantity:

Reason for isolation (mark with "V"):

1. Износ	5. Излишек
2. Defects	6. Пересорт
3. Wastes	7. Indefinite reason
4. Не на своем месте	8. Другая причина (указать, какая)

Действия (отметить в соответствующем квадрате напротив знаком "V"):

1. Переместить в зону утилизации	4. Произвести ремонт
2. Переместить в соответствующую зону хранения	5. Вернуть поставщику
3. Произвести очистку	6. Другое действие (указать, какое)

Date of isolation:

NAME of sorter:

Notes:

Figure 3.14 – Examples of drawing a "red label"

More information about the rules of 5S

Sorting. Equipment and tools are divided into groups of necessity.

Compliance with order. security; quality; work efficiency.

For this purpose a few simple rules for objects are used.

To place in a prominent position so as to be easy to take, easy to use and easy to return to the place (Figure 3.15).

Keeping clean. The work area must be kept perfectly clean.

Standardization. These are requirement to consolidate the content of the rules of the workplace, the technology work and other procedures developed and adopted during the transition to the 5S, in the form of detailed instructions, control rules and methods of encouraging.

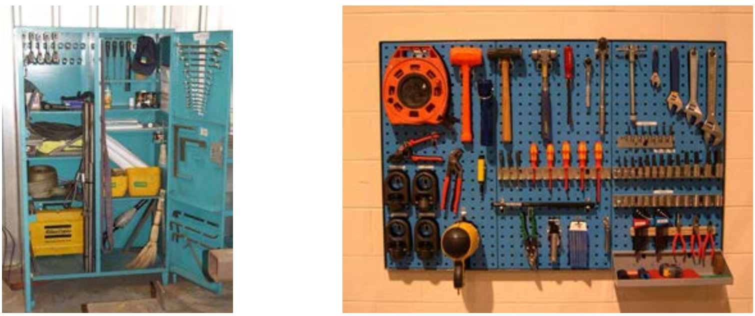


Figure 3.15 – «Easy to take, easy to use and easy to return to the place»

Improvement. According to the philosophy of Kaizen, the system must be constantly developed, so any achievements are not only fixed and becoming the norm, habit, but also analyzed in order to achieve perfection, which, as we know, is not achievable. One form of such an analysis is a program of periodic audit jobs.

Questions:

1. The concept and background of Hoshin kanri.
2. Problems to be solved by Hoshin kanri.
3. The scheme of strategy decomposing.
4. X-matrix as a result of strategy decomposing work.
5. "Catch-ball" methodology.
6. The Balanced Scorecard system.
7. Designers of Lean Systems implementation algorithms.
8. Systems of international standards.
9. The system of Russian standards of "Lean Manufacturing» series.
10. Lean Production Management System model.
11. Enterprise management system development stages.

UNIT 4. Lean-systems deployment problems

The first projects to create Lean production systems appeared in Russia in 2004. To date, this process has acquired a mass character, has intensified the consulting services market, also there are different schools and centers. The accumulated experience of the Lean production system projects implementing reveals the certain conditions of successful implementation, such as [20]:

- leading role of top management;
- training and development of staff at all levels of the management hierarchy;
- commitment to Kaizen ideology;
- the Lean tools mastering;
- benchmarking.

Lean systems deployment process is shown in Figure 4.1.

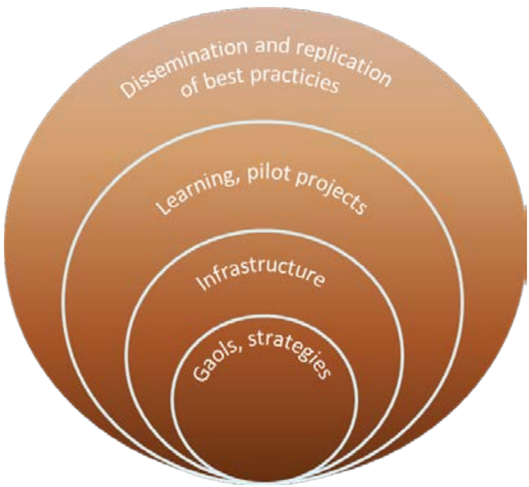


Figure 4.1 – Lean systems deployment process

Gorky Automobile Plant "GAZ Group" was one of the first in Russia to develop its own system of lean manufacturing based on

Toyota Production system principles. The results of the implementation were: the annual reduction of completions by 25%, work in process by 30%, the annual economic effect reached 500-700 mln. rubles. The successful implementation of production systems adopted and creatively applied by many domestic companies: Kamaz, SC "Rosatom", Rusal, Evraz, EuroChem, VSMPO-AVISMA Corporation, YaMZ and others.

Determinant of success in this case is the perception of the top management of necessity to develop the production system as means of achieving the company's strategic goals. Most Russian companies have their own peculiarities of Lean Production systems, but the results are not always equal to those expected due to various reasons.

4.1. Lean-systems life cycle. Problems of involvement and staff training

System development lifecycle	SDLC is a sequence of process steps, covering a variety of state of the system, starting from the outbreak of the need for such a system and ending with its complete decommissioning.

This definition of SDLC assumes that there should be a stage of upgrading the aging system. The obvious reason for this may be a change in the strategic goals of the production systems development**,** technologies change and others. At the same time the phase of the new (adapted) production system deployment is provided by all previous experience in the field of quality management and Lean production available to the businesses.

An analysis of numerous publications on the Lean subject has shown that many participants of Lean projects do not realize the necessity of lifecycle management of production systems development.

Comprehension of variety of approaches, requirements and successful practices has led to the creation of standards for the Lean management system (LMS). They fully represent the stages of Lean systems lifecycle, including the stages of the certification and further improving.

In practice, the successful development is evaluated by reduction in the level of inventories and work in progress, minimizing waste, increasing productivity (a measure of Lead Time), increasing overall equipment effectiveness (OEE index). Involvement of staff and understanding of the principles of Kaizen can be traced through the activity of employees, flow of suggestions for improvement and their implementation. The overall effect can be estimated using the financial indicators.

Not all the Lean production development projects are to be successful. Often, the implementation is reduced to the exploration of 5S methodology for the organization of workplaces, but the results are gradually lost in the daily routine and old habits. Lean- project implementation period to Russian enterprises usually takes 1 to 3 years or more.

First, with the assistance of consultants and in full enthusiasm of participants of the experimental group the changes significantly alter the usual processes and workplaces**.** At this stage, training and the approaches of Kaizen study are held.

Lean Production implementation programs are actively advertised and promise a quick return upon completion within 6-12 months.

After a phase of intensive work under the care of consultants comes the stage of independent development, and if the idea did not become popular among employees, the initiated transformation is continued only by leaders. This can be proceeded by negative perception of the new requirements, formal performing, reducing involvement, and the process of Lean production system development stops.

Upon successful completion of the basic development cycle, there may be differences in 3-4 years in the results and prospects of further development.

In case of the decrease of all active work on improving the lean system the company can again appeal to consultants and repeat the same scenario or take the decision on inappropriate use of Lean production concepts in the development of the company.

In some cases, individual lean system tools and techniques can be integrated into the existing system of process organization**,** shortly increasing its effectiveness.

The main reason for failure of Lean projects is considered to be a low level of staff involvement because of the significant innovations resistance, mistrust and poor level of education**.**

Blind faith in success, ignoring the principles of kaizen and the desire to create an ideal production system due to the ambitious innovations in a short time is a misconception. It leads to a significant loss and disappointment in Lean production concepts.

4.2. Lean-systems implementation terms. Lean-Process IT-support systems

Despite of multiple mistakes and examples of unsuccessful implementation of Lean production concepts, creation of an effective Lean production system, however, is real. This happens provided that the lean concept becomes an instrument of development strategy, along with the consistently and globally applicable principles of kaizen, senior management providing continuous management of the deployment process, changing system of employee stimulating and motivating.

The condition for the successful implementation of lean projects is the consistent implementation of the following stages:

- Involvement;
- Estimating the value;
- Identifying the value stream;
- Organization of the flow;
- Pulling the product;
- Perfection.

The fulfillment of these conditions is achieved by using the methods and tools of Lean production.

Comparative evaluation of the individual components development level of the KAMAZ production system with the average performance of Russian mechanical engineering industry (see. Figure 4.2) clearly demonstrates the superiority of the industry leader in terms of production system elements development [4].

Signs of a successful production system deployment:

- Changes in management structure and empowerment the leader of lean transformation.

- Creating a transformation command, the organization of training and explanatory work to involve everyone in the organization, training for implementation.
- Implementation of pilot projects to implement lean principles and tools, training in progress of the work.
- Standardization and consolidation of the results achieved, the assessment of the current state.

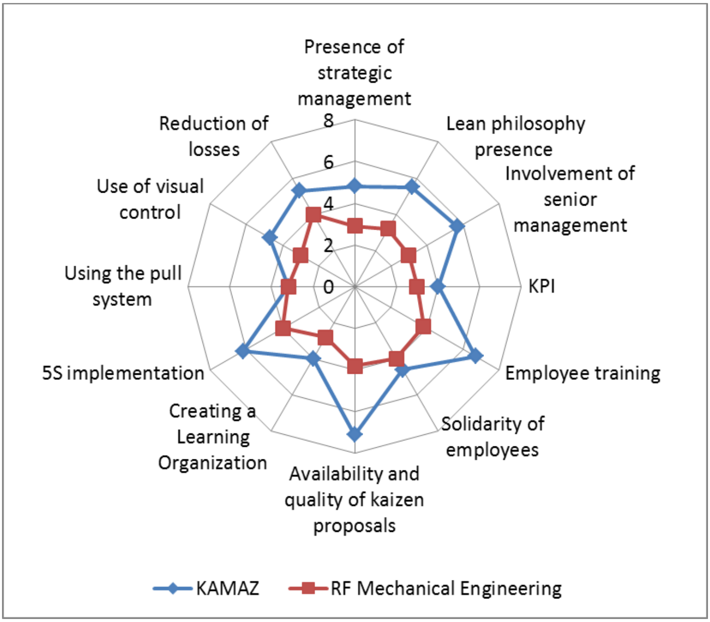


Figure 4.2 – OAO KAMAZ production system implementation management model

The presence of these features characterizes the project team ability to manage the development process, involved personnel, resources and processes of the enterprise.

In modern production systems, the information systems play a special role. They have penetrated into all levels of government, providing data collection and processing, resource planning, decision-making support. The following types of information systems have received widespread in the industry:

- MRP (Material Requirements Planning) – system of material requirements planning, including the optimization of inventory (Inventory Control/Management, IC/IM).
- MRP 2 (Manufacturing Resources Planning) – manufacturing resource planning system, including capacity utilization.
- ERP (Enterprise Resources Planning) – company resources planning system, including human and financial ones.
- CRM (Customer Relationship Management).
- SCM (Supply Chain Management).
- CSRP (Customer-Synchronized Resources Planning).
- MES (Management Execution System).
- CALS (Computer-Aided Logistic Support).
- CAD (Computer-Aided Design).
- CAM (Computer-Aided Manufacturing).
- CAE (Computer-Aided Engineering).
- PDM (Product Data Management).
- PLM (Product Lifecycle Management).
- CALS 2 (Continuous Acquisition and Lifecycle Support, CALS 2).
- BPMS (Business-Process Management System).
- SCADA (Supervisory Control And Data Acquisition System).

Figure 4.3 shows the area of responsibility of various corporate information systems [21].

Information technology in Lean production, as an integral part of modern control systems, provide process monitoring, management continuity, processes status visualization, management accounting and planning, performing other tasks.

Involvement of information resources in the field of lean transformation offers great opportunities. For example, using the BSC (balanced scorecard) system in the planning and monitoring of key performance indicators of IT allows to create a comfortable information environment to support management decisions. Implementing of pulling systems in many enterprises is realized through electronic Kanban cards.

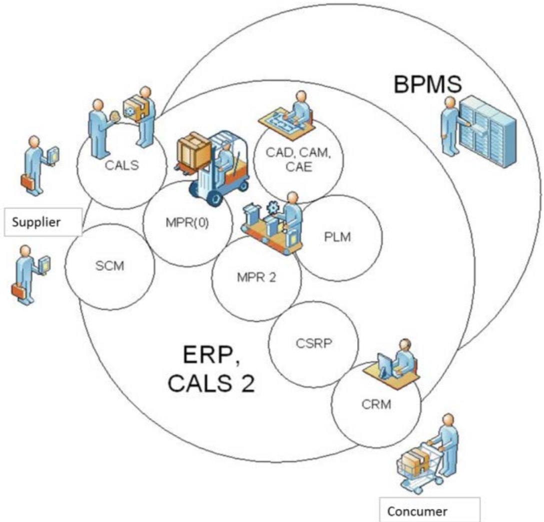


Figure 4.3 – Areas of responsibility of corporate information systems

Implementation of TOC methodology assumes decision making to a large volume of problems in operational planning of production orders and loading bottlenecks of work shifts**,** departments, workplaces. This becomes possible due to the MES system existence.

Availability of management information on the state of technological processes is provided by SCADA system.

Modern inventory management systems provide a minimum level of stocks at an acceptable risk level. For example, CRM systems allow to provide close cooperation with suppliers, and with the help of VMI systems (vendor managed inventory) suppliers become able to manage inventory in the warehouses of the consumer supply. These systems provide minimum levels of inventory and rapid response to changes in the external corporate environment**.**

The decision-making managers need information that allows to detect deviations and failures in the production process. Modern IT technology can solve this problem. Such problems are particularly relevant in the Lean Sigma systems. The accumulation of statistical data on the processes status and their processing can be performed using special applications.

High adaptability of the corporate management systems is achieved through the ability to make the necessary changes in the business process system quickly. The implementation of these requirements is possible through the use of BPMS systems.

Information technology should be used in the solution of other problems, significantly reducing the time and resources, for example:

- development and maintenance of reference databases;
- integration of design processes with CAD / CAM / CAE / PDM manufacture technology;
- maintaining the accompanying roadmaps;
- electronic registration and processing of applications;
- using the information centers in the manufacturing process and others [22].

The emergence of new technologies becomes useful in production processes fast enough. Thus the Volkswagen Group to improve the quality and reduce the build configuration errors began to use smart glasses in the assembly lines of the factories, [24].

The glasses allow to receive all the necessary information directly into the field of view. The touch and voice control are supported. The camera glasses works as a barcode scanner, which are highlighted in green in the case of a correct choice of components and the red on error. Thus, the staff of the assembly line can more effectively carry out their work without being distracted by browsing the documentation and work with a traditional computer.

The use of "smart" technology has, as a rule, **a** revolutionary impact on the development of Lean Systems.

By now, a significant trend in the field of mechanical engineering of the Russian Federation has become the mass introduction of flexible automated machining lines, realizing the concept of CAD / CAM / CAE / PDM integration of the design process with product manufacturing technology.

4.3. QFD analysis of processes and products

QFD-analysis (Quality Function Deployment) is a structured approach to defining customer needs or requirements and translating them into specific plans to produce products to meet those needs.

The QFD algorithm consists of the following steps [19]:

- Identification of customer requirements to the product.
- Interpretation of customer requirements in the technical specifications.
- Analysis of the current capabilities and production technologies.
- Analysis of competitors' achievements and the achievements of benchmarking in other sectors.
- Identifying gaps on the performance and requirements of world-class models.
- Determining how to reduce the gaps and achieve excellence.
- An analysis of compromise options in addressing conflicting demands.
- The selection of priority indicators of quality.
- Structuring the quality program.

For greater clarity, Figure 4.4 shows images of various types of matrix diagrams [20].

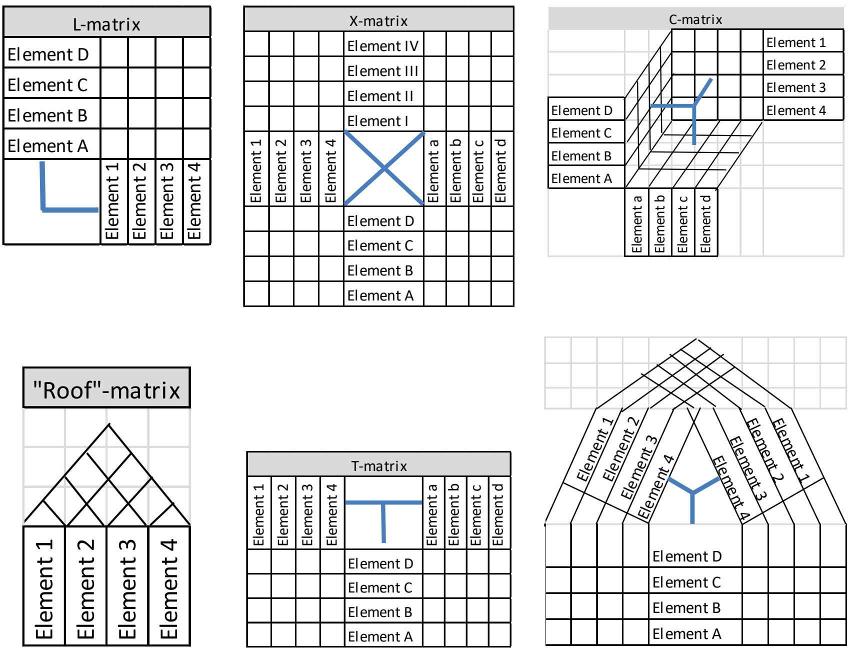


Figure 4.4 – Different types of matrix-charts

QFD analysis technique is based on the extensive use of several types of matrix diagrams, called on the Latin alphabet letters because of the resemblance of shapes. The most famous are:

- L – matrix;
- T – matrix;
- X – matrix;
- C – matrix;
- Y – matrix;
- matrix of the «roof» type.

Depending on the number of matched sets of parameters, among which it is necessary to identify the degree of relationship (correlation), one or the other type of matrix is selected.

The matrix chart provides a visual representation of the presence and strength of the relationships of the various elements of compared sets as multidimensional graphics images.

QFD-analysis is often referred to as the deployment process of "quality home" because of the similarity of applied matrix diagrams with a picture of a house (see Figure 4.5).

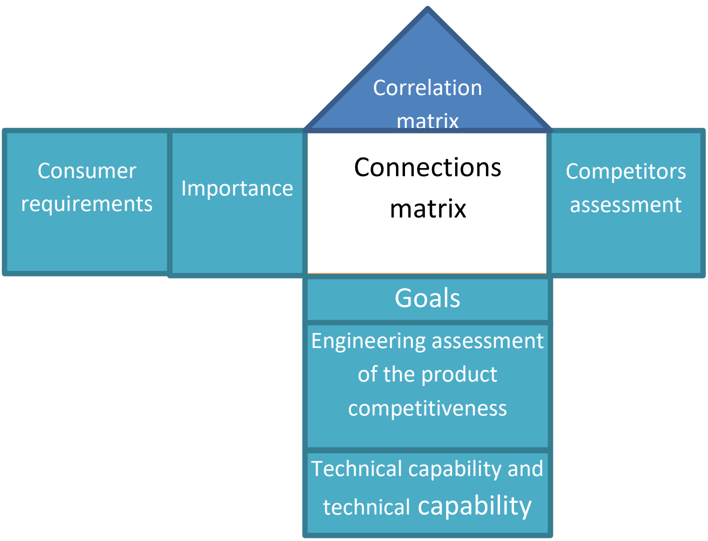


Figure 4.5 – Quality house of QFD-analysis [22]

The central part of the "house of quality" is the L matrix whose columns correspond to the technical characteristics of the product, and the rows correspond to consumer characteristics. The cells indicate level of dependence, if any. The roof of the house is information about the correlation between the technical characteristics.

The left wing of "quality home" - a column of user performance priorities. Right wing - table of consumer performance ratings (in terms of product buyers) to similar products on the market.

Basement of the house contains an analysis of the technical characteristics of competing products, the results of development of strategies to change specifications of the product (the planned figures for the initial development), estimates of the absolute and relative importance.

4.4. Targets results of the Lean- projects implementation. "The system of 20 keys"

To assess the effectiveness of Lean production projects the indexes of UNIDO are used:

- payback period (PBP),
- net profit value (NPV),
- profitability index (PI),
- internal rate of return (IRR).

Determination of the dynamics of costs due to Lean activities may have characteristics defined by the company's accounting policy.

For example, the basic wage of workers is determined by the hourly wage rate of j-skill category in the i-th operation ($Rhour_{ij}$, rub.) and standard time for implementation of the i-th operation ($S_{time\ i}$, hours)

$$So_{wage} = \sum_{i=1}^{m} Rhour_{ij} \cdot Stime_i,$$

where *m* is a number of process operations.

Standard time at each operation consists of the operational time, which in turn includes a main (machine) and the auxiliary time, organizational and technical time, preparatory and final time and time to rest:

$$Нвр_i = \left(t_{main(м)} + t_{aux}\right) + t_{org-tech} + t_{prep-fin} + t_{rest}.$$

If the results of Lean activities are aimed at reducing the organizational and technical time, then the basic salary of the worker, for this operation will be less than the value of R×Δt (hour), where Δt the value of saving the execution time.

$$So_{wage1} = R_{hour1} \cdot (S_{time1} - \Delta t).$$

Accordingly, article of production cost "basic wage of production workers" will be equal to:

$$So_{wage1} = So_{wage} - К_{hour1} \cdot \Delta t.$$

Thus, based on the information on the reduction of losses after Lean events, you can make a new costing and compare its content with similar items costs in the current conditions of the company.

Questions:

1. Present the conditions of successful lean implementation.
2. Lean systems deployment process.
3. System development lifecycle definition.
4. Overall equipment effectiveness index.
5. Lean- project implementation periods to different countries.
6. Give reasons for failure of Lean projects.
7. Stages of successful implementation of lean projects.
8. Structure of the KAMAZ production system implementation management model.
9. Signs of a successful production system deployment.
10. The types of information systems.
11. Areas of responsibility of corporate information systems.
12. Role of information technology in the lean implementation process.
13. "Smart" technologies used in lean production.

UNIT 5. Features of the lean manufacturing deployment at Russian enterprises

The practice of Lean implementation in Russia revealed the problems faced by domestic enterprises. The openness and accessibility of the concept, however, does not provide a stable fixing of its principles in the daily activities of personnel..

Project Management of Lean implementation must be carried out on targets.

The development of production systems is aimed at identifying and better utilizing of capacity and internal resources of the organization, the results are presented in the form of projects and individual proposals to reduce costs at all stages of production.

The results of the cost reduction can be structured as follows [23]:

- Reduction of material consumption:
- replacement of the material by a cheaper one;
- reduction of material consumption norms.
- Reduced cycle time:
- reduction of labor intensity;
- reduction of the main processing time;
- reduction of set-up times;
- elimination of "bottle necks" and the release of additional production volume.
- Resourcing:
- use of space;
- reduction of labor intensity of support workers, professionals, employees;
- economies of handed metal scrap and other materials of the project.
- Reduced overheads:
- energy savings;
- saving auxiliary materials;
- reducing the costs of providing services, including provided by third parties;
- reducing the transport cost.

The implementation of any proposal or project can give the effect on one or several directions, so it should be calculated as the sum of the effects of the directions. It also takes into account the costs for the implementation.

$$E = \sum E_i - \sum Z_i ,$$

where E – economic effect,

$\sum E_i$ – sum of economic effects,

$\sum Z_i$–sum of the cost of implementing the proposal or project.

CONCLUSION

The appliance of lean principles in production makes it possible to reduce waste and make the manufacturing process effective. It is a key for a company's successful work.

Lean production is a young concept, but has multiple methods and approaches. Getting acquainted with them and their impact on the production effectiveness is pivotal for every senior manager in order to start using lean methods. The course of lean production is complex, covering a wide variety of topics including lean history, terms and principles; elements of the concept and lean production tools; Hoshin kanri deployment tools; the deployment problems of lean production.

If a company possesses and implements the knowledge in this spheres, it is more likely to increase its production efficiency and competitiveness.

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LEAN PRODUCTION SYSTEMS

Study guide

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