Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 54 (2021) 309–319

Transportation Research Procedia

www.elsevier.com/locate/procedia

TransSiberia 2020 Conference

The Emergence and Development of Lean Thinking in Transport Services

Valeriy Kurganov[a,*], Vasiliy Sai[b], Mikhail Gryaznov[c], Aleksey Dorofeev[d]

[a]*Tver State University, 33, Zhelyabova, 170100, Tver, Russia*
[b]*Ural State University of Railway Transport, 66, Kolmogorov str., 620034, Yekaterinburg, Russia*
[c]*Magnitogorsk State Technical University Named After G. I. Nosov, 38, Lenin Ave., 455000, Chelyabinsk region, Russia*
[d]*Financial University Under the Government of the Russian Federation, 49, Leningradsky Ave., 125993, Moscow, Russia*

Abstract

The purpose of this work is to study the evolution of lean thinking and optimize the value stream in the transport provision of enterprises. An overview of the creation and development of lean thinking is presented, a historical and genetic research method, methods of comparison, analysis and synthesis are implemented, and a mathematical model of the optimization criterion for implementing lean transportation is proposed. It is established that the creation of lean thinking should be associated with the development of scientific management methods, which were implemented in Ford Motor Company. Adapting the principles of the American automobile industry to the specifics of enterprises in Japan in the late 1940s allowed Toyota to create a production system. It was significantly different from the American experience, although it was based on it. The peculiarity of technological processes of Japanese enterprises provided high efficiency. When describing the Japanese experience, American researchers in the late 1980s used the term lean. Under this name, experts from the United States have studied and popularized the achievements of Japanese managers. Analysis of the value stream has shown the difference between this concept and the concepts of the value chain and use value. The analysis of the value stream has a separate specificity when considering the transport support of the company's activities. For these purposes, an optimization criterion is proposed that requires coordinated management of cargo flows and reserves.

Keywords: Lean Transportation; Road Transport; Value Stream.

* Corresponding author. Tel.: +7-909-271-8196.
E-mail address: glavreds@gmail.com

10.1016/j.trpro.2021.02.077

1. Introduction

The lean concept has now become one of the most popular, although its main principles were formulated in the early XX century by the pioneers of scientific management and successfully implemented by Henry Ford. After a significant update, the concept experienced its second birth at Toyota enterprises and from there began its victorious march around the World. At the same time, the term "lean" appeared much later when describing Japanese management methods by American researchers.

Thanks to the active popularization, the lean system is distributed in other countries of the World, not only in Japan and the United States. At the same time, there is no direct copying, but there is a certain originality, which is manifested, for example, in the national terminology when adapting this concept.

Experts on management improvement methods suggest combining lean with other methods of successful business management. From the automobile industry, lean principles have been adopted in other areas of activity, even such as education, medicine and banking, where the flow of material resources is either absent or insignificant. There are publications on the application of the lean concept in logistics and, in particular, methods of lean transportation are being developed.

However, existing publications about lean are often declarative and descriptive character, although it is known that process optimization is impossible without the use of quantitative methods, mathematical models and creating criteria.

In this regard, it is relevant to study the evolution of the lean concept and optimize the value stream in the transport provision of enterprises, which is the purpose of this paper. During the research, a number of tasks were solved. The review of publications reflects the chronological sequence of transformation of methods of scientific organization of production at Ford Motor Company enterprises into the Toyota production system. The appearance of the term "lean production" is considered. A conceptual scheme for creating and developing lean thinking is proposed. Terminological features of its distribution in Germany and Russia are considered. Attention is paid to the peculiarities of interpretation of the value stream. In relation to transport services, we recommend an optimization criterion based on the need for coordinated management of stream processes in the enterprise within the framework of lean transportation.

2. Research Methods

The study of the creation and evolution of the lean concept was conducted using the historical and genetic method, which requires consideration of the development in chronological order, including the origin and formation, as well as the establishment of links and causes of changes. The comparison method was used to assess the proximity of lean and the Toyota production system to previously used scientific management methods and technological principles of in-line production. The concepts of value stream, value added stream and use value were also compared to determine their content, similarities, and differences. Methods of analysis, synthesis and mathematical modeling were used to form and structure the lean transportation optimization criterion. Grouping elements of total costs is performed using the typology method. The axiological method is used to formulate the purpose of transport support for industrial production.

3. Results of Research on the Evolution of Lean Thinking and Its Implementation in Transport Activities

3.1. The Emergence of the Lean Concept

In production management, the phrase "lean production" has become one of the most popular terms. It has an author, John Krafcik, who now heads the company Waymo, created by Google for the development of self-driving car. In 1988, J. Krafcik, then a 27-year-old master's student at the Massachusetts Institute of Technology (MIT), wrote a paper (Krafcik, 1988). This paper placed the author's name next to such prominent industrial organizers as Edwards Deming, Joseph Juran and Ishikawa Kaoru and other. However, for J. Krafcik himself, working on a master's thesis under the supervision of James P. Womack was most likely only one of the stages of his successful career in the automobile industry.

The young master's student wrote the now famous paper based on his previous experience as a quality and manufacturing engineer in 1984-86 at the joint venture of GM and Toyota. He made an attempt to formulate the reasons for the success of Japanese methods of production management. J. Krafcik called the organization of production in the Toyota company "original Fordism with Japanese flavor" (Krafcik, 1988). The triumph of the concept described by him is proclaimed in the very title of the paper.

By coincidence, in the same year in 1988, when John Krafcik published his paper, an English-language edition of the book was published by Taiichi Ohno, who since the end of the 1940s led the creation of a special system of production organization of the Toyota company, aimed primarily at the maximum exclusion of losses (Ohno, 1988). One of the reasons for the emergence of this system in Japan is often considered a national desire for improvement and careful attention to all details and elements of the production process. An impressive effect was obtained by consistently following the simple and understandable principles that were communicated to every employee of the company for a long time.

Currently, two terms are actively used: "lean production" and "Toyota Production System-TPS". Both of these terms, in general, have very similar content. Taiichi Ohno in his book also uses the world-famous term kanbanto indicate the method of organization of the system created by him (Ohno, 1988).

Krafcik's mention of Fordism in a paper about the Japanese organization of production is not accidental. Henry Ford achieved unprecedented success in the organization of the automobile industry in the first half of the XX century, and his memoirs (Ford, 1922, 1926) became textbooks on the organization of production and labor of workers in enterprises around the World, including in Japan. Visit to the Ford Motor Company factory by the Japanese delegation, which included T. Ohno, allowed better understanding the advantages and disadvantages of Ford's ideas. After a long and careful work, they were able to adapt to the specifics of the automobile industry in Japan, to use in-line production on assembly lines to produce products for individual orders, rather than for mass production of the same type of products (Liker, 2004).

Speaking of Fordism, it is impossible not to mention Frederick Winslow Taylor and Frank Bunker Gilbreth. Their theoretical works and practical recommendations, which appeared at the beginning of the XX century, have become classics of scientific management. In a certain sense, the methods implemented by Henry Ford - are the development of Taylor's principles in relation to mass production of goods for a high-capacity consumer market with significant growth potential.

Alexey Gastev, head of the Central Institute of Labor, established in 1921 in the Soviet Union, was in regular correspondence with Henry Ford. One of the slogans of A. Gastev was: "Let's take the storm of the revolution of the USSR, put the pulse of life in America, and do: work - verified as a chronometer". The peculiarity of A. Gastev's approach - is the concentration on the personal productivity of each employee and on the efficiency of using working time. Many quotes from his book "How to work. Practical introduction to the science of labor organization" modern and today. For example: "Don't think of yourself as an organizer before you clean up"- is one of the principles of organizing jobs at TPS. Under the wording of A. Gastev "Our task - is to rebuild production, so that in its very organizational technique there is always a call for continuous improvement", any supporter of lean production can subscribe. From the moment of acquaintance in Russia with the publications of Taylor, Gilbrett and Ford from the beginning of the XX century, the term "Scientific organization of labor (SOL)" appeared and was used. In 2010, in Russia, the Council of the interregional public movement "Lin-forum. Professionals of lean production" established the Gastev's Cup in the field of production efficiency.

Considering in his paper (Krafcik, 1988) the work of the GM-Toyota enterprise, J. Krafcik focused mainly on two aspects: reducing reserves by delivering components and materials Just in Time and on how to neutralize the risks that arise.

J. Krafchik noted that the lean production management policy presents higher risks, but the technological processes at the Toyota plant did have minimal reserves (truly were lean operations) (Krafcik, 1988).

The main idea of John Krafcik's paper- is to contrast two concepts of production. One of them, the traditional concept, assumes the presence of buffer stocks to mitigate possible deviations of the technological process (buffered production). According to another concept (lean production), reserves that increases the cost of production is not needed (or is needed in minimal quantities), if everything is delivered to the workplace strictly on demand at the appointed time. Protection from emerging risks is provided by the discipline of deliveries, compliance of the delivered products with quality standards, training and interest of the personnel (Krafcik, 1988).

Thus, the original essence of lean production is to deprive each workplace of excess reserves of materials and components (a kind of "fat" that requires funds to maintain itself). For each workplace, for each technological conversion, everything must be supplied strictly to the needs and in accordance with the capacity. This dramatically reduces work in progress and reduces production costs. The production cycle is shortened and the output of finished products is accelerated. An additional effect is obtained by reducing the direct loss of resources that inevitably occur during reserves storage, which also reduces costs.

Lean production is implemented under the "pull production", and the main tool is a kanban system using cards clearly shows what and how much you should to make, is in the works or already made. Since the focus is on working places, work is underway to implement the 5C system — a technology for creating an effective working place. System 5C-is the organization of elementary order in the working places: cleanliness, nothing superfluous, everything is laid out in the established standardized order, all movements are carried out along rational trajectories (even a special marking is made – "visualization").

The original lean system in John Krafcik's understanding can be represented as a building, the foundation of which is the idea of minimizing or, if possible, completely eliminating reserves, and the safety of the "foundation" and the "building" itself is provided by the "roof with supports" — delivery of everything necessary exactly on time. Over time, this "building" between the "supports" appeared "walls", they put "wallpaper" on them, and then hung "pictures". The process of building and decorating the lean production building is still ongoing.

As far as we can tell, John Krafcik might have settled on another term. In his paper (Krafcik, 1988), he compared the typology of options for organizing production that he formulated with the one that was proposed earlier by other researchers. A technological system with reserves was considered more stable and more reliable in operation. Therefore, the analogue of "buffered production" was designated by the concept of "robust" (strong, reliable), and the production system that does not have reserves – "fragile", i.e. "delicate", "shaky", "unstable", "vulnerable". Apparently, the term "lean" seemed to Krafcik more neutral in comparison with "fragile". Here is an excerpt from Krafcik's paper (Krafcik, 1988): "The buffered / lean typology builds on the work of International Motor Vehicle Program researchers YaruoSimada and Jon Paul MacDuffie, we use the terms "robust" and "fragile" to denote similar concepts".

John Krafcik's supervisor when he wrote his master's thesis was a Professor at the Massachusetts Institute of Technology, James P. Womack. He began to study lean production, participating in large-scale research of the automobile industry. Two years after the publication of Krafchik'spaper, in collaboration with his colleagues, James P. Womack published a fundamental book on the production system of a Japanese company (Womack et al., 1990). It was after the publication of this book that the term "lean production" became known and widely spread, and soon expanded its meaning and evolved into the concept of "lean thinking". The first edition of the book outlining this concept took place in 1996, and the second - in 2003 (Womack and Jones, 2003).

In 1997, James P. Womack left the Massachusetts Institute of Technology and founded the Boston-based Lean Enterprise Institute (LEI). The President of the Institute is John Shook, a theorist and practitioner in the field of Lean management, author of a number of books (Rother and Shook, 1998). The Institute has branches in a number of countries, including in Russia-Lean Enterprise Institute Russia. The non — profit organization created on the initiative of LEI and Lean Enterprise Academy (Great Britain) - Lean Global Network-LGN unites specialists from different countries. There are a large number of internet platforms for communication of specialists and publication of various materials in this field.

3.2. Evolution of the Lean Concept

A number of researchers have proposed to distinguish two periods in the development of the "lean enterprise" concept and, accordingly, two lean concepts. The stage from the late 1940s till the mid-1990s is called the time of creation of the "basic lean enterprise system" (BLES). The period that followed was the development of the "contemporary lean enterprise system" (CLES) (Bozdogan, 2010). Apparently, this periodization suggests that the basic version of the concept was created as the Toyota Production System (TPS) and was supplemented by American researchers and consultants, thanks to which it became known in the World as "lean production" or "lean enterprise". As can be assumed, the interpretation by American experts of the Japanese system of industrial

production organization and the new name, according to the authors of this periodization, simultaneously became the beginning of the modern stage of its development.

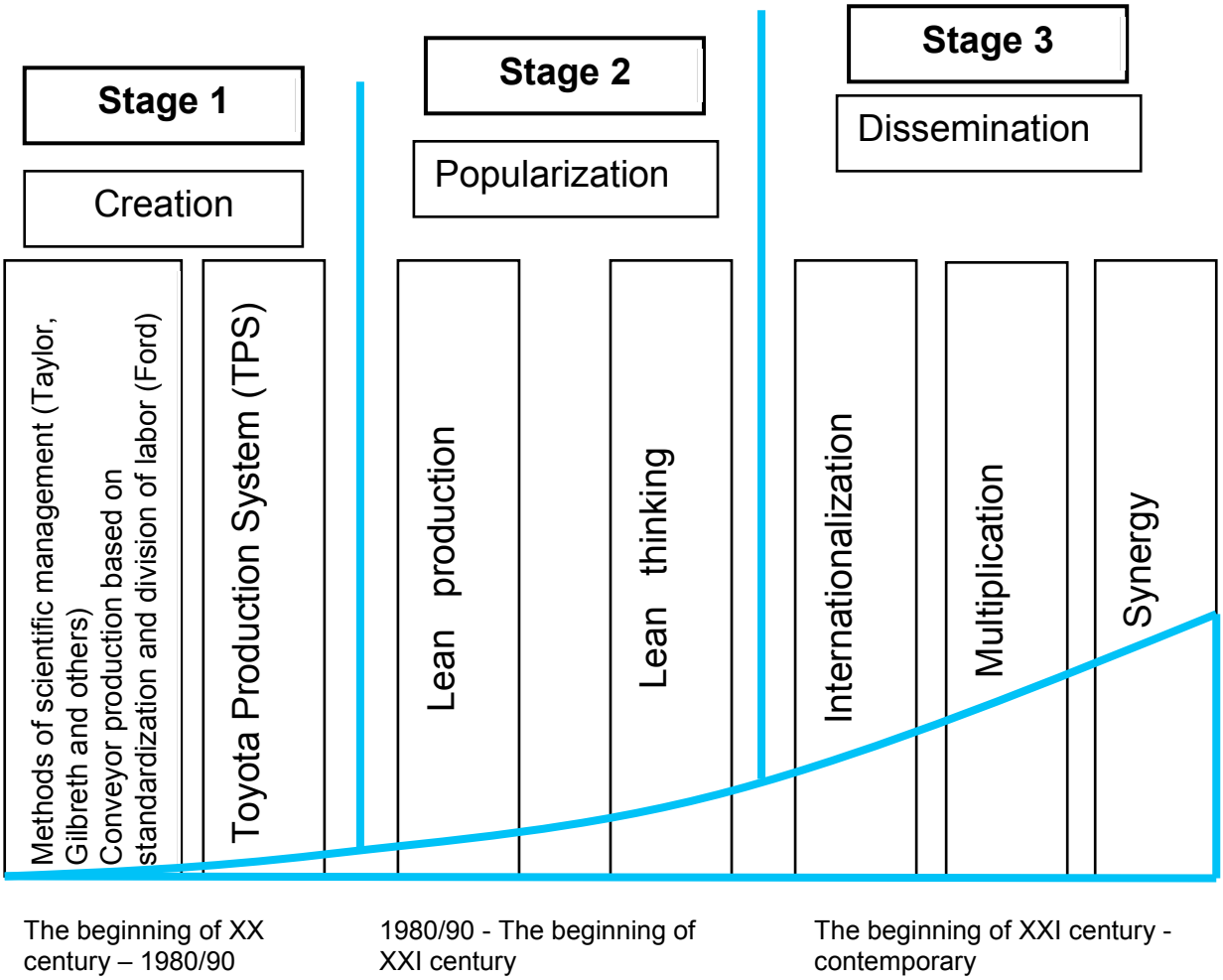

Fig. 1. Conceptual scheme of evolution lean thinking.

We have to admit that this approach oversimplifies the actual evolution of the lean concept (figure 1).

Its emergence is more justified to refer to the achievements of Henry Ford, which, in turn, are associated with the development and practical use of the principles of scientific production management in the early XX century in the United States and other countries. It was on this basis that the Toyota production system was created, which was later recognized throughout the World. This system was fully described in Taiichi Ohno's memoirs in the late 1980s (Ohno, 1988).

The second stage - is the popularization of Toyota's production system. The most significant contribution here belongs to James P. Womack, who most fully described his interpretation of the Japanese experience in a book published in 1990 (Womack et al., 1990). Thanks to James P. Womack, the term "lean production" became widely known. James P. Womack was able to show the universality of the approach and transformed an effective method of organizing production into a philosophy of achieving excellence in almost any field of activity — lean thinking (Womack et al., 1990; Womack and Jones, 2003).

The third stage is observed in the modern World, where the dissemination of lean ideas takes place in different countries with different cultures. Lean thinking ideas are specified in various fields, from education and banking to

army logistics, as well as in transportation and logistics. There is a combination of lean ideas with otherconcepts to improve efficiency. The useful result is significantly increased, since the integration process creates a synergistic effect. This is a stage of internationalization, multiplication and synergy.

3.3. Terminology of Lean Thinking in Countries around the World

Short and clear in its meaning, the term “lean” has, to some extent, an emotional connotation that is not entirely positive, which has caused difficulties in translating it into other languages. Countries such as Germany and Russia are interesting in this regard. Germany - is a recognized technology leader of the European Union, and the initiator of the Industrie 4.0 program, considered as the implementation of The Fourth Industrial Revolution. Russia has repeatedly demonstrated its ability to accelerate development and achieve leadership in high-tech industries, such as space exploration and nuclear power.

In Germany, the term “schlanke” is used, which is not a literal translation of the English word “lean” into German. Literally “schlanke” means “slender”. The English equivalents of this German word are “slim” and “slender”. The German phrase “Schlanke produktion” "in Germany is also understood as the concept of “lean production” in English-speaking countries. In the German-speaking space, the term “ganzheitliche Produktionssysteme” is also used, providing economical and time-efficient use of production factors (Unter Lean Production versteht man den sowohl sparsamen als auch zeiteffizienten Einsatz der Produktionsfaktoren). It is interesting to note that the German word “sparsam”, which, depending on the context, conveys the concept of“economical, thrifty, stingy, calculating”, has not been widely used to refer to the concept of lean, although it very closely conveys its essence.

In Russia, the term “lean” has undergone several transformations. In the late 1990s and early 2000s, a literal translation of the English word “lean” was used in Russian. The term “lean production” could be found in Russian-language scientific and educational literature.

After some time, the Russian information field began to appear variants with a more positive connotation, borrowed, apparently, from the German-language literature: “slender production” or “flat production”.

In 2004, the phrase “lean production” (English equivalents of “thrifty production” or “frugal production”) was first chosen to convey the meaning of the concept of “lean production” in Russian. It was suggested by Sergey Turko, editor-in-chief and translator of “Alpina publisher”, when the book by James P. Womack and Daniel Jones was being prepared for publication in Russian, published a year earlier by Free Press. (Womack and Jones, 2003). By 2018, the 12th Russian-language edition of this book was published. It played a significant role in spreading the ideas of “lean production” in Russia under the name “lean production”.

At present, when this concept of production organization is widely implemented in Russian enterprises, the term “lean production” proposed by S. Turko has become widespread and is present not only in the public literature, but also in corporate standards, manuals and production instructions. This is how the English term “lean production” and the German term “schlanke production”are translated into Russian, despite the dictionaries of foreign words of the general vocabulary. Sometimes, however, there is the phrase “economical production”, but it is not very common, because of the very broad semantic content of this expression is difficult to associate with the lean concept.

It is easy to see that the meaning of the word “lean production” (English equivalents of “thrifty production” or “frugal production”) it does not exactly match the meaning of the word “lean”, chosen by J. Krafcik in 1988 and used in many countries of the World. “Lean” means “skinny, thin, meatless, meager”, i.e. without excess fat, without reserves. “Thrifty” means “caring for the property”, which, in principle, does not exclude the availability of reserves. However, in Russian, works within the “lean” concept are usually translated using the word “thrifty”.

However, in Russian-language literature, authors sometimes avoid using the term “thrifty production" and give the name of this concept in its original English form: “lean production (LP)”.

Along with the English — language form of the term or its translation into Russian by the phrase “thrifty production”, there is also a Cyrillictransliteration of this term – “Lean”. Regularly held in Russia since 2013 The international summit “Smart production systems “is commonly referred to as the “Lean Summit”, and the program of the VII summit (Sochi, 4-5.04.2019) uses, along with other variants, Cyrillic transliteration, for example, in the title of the report “How to create and maintain a lean management system: the case of Finland”.

Options for the development of English-language terminology related to the concept of "lean production" are not exhausted. Contrasted with "anorexic lean" and "robust lean", which implies that it is undesirable to focus solely on reducing losses and minimizing reserves to a dangerous level (Murman et al., 2002).

The terms "lean production", "lean manufacturing", "lean enterprise", "lean thinking", "lean leadership", "lean management" or simply "lean" have become popular in various fields of activity: in industry, in services, in software development, in metallurgy, aircraft engineering, education, banking, etc. The concept is further developed and supplemented by combining it with the "Six Sigma" method, the Theory of constraints, Value Stream Mapping (VSM), the synergetic approach and so on (George, 2003, Goldsby and Martichenko, 2005, Poppendieck, Mary and Tom, 2007, Wader, 2002, Levinson and Rerick, 2002, Balzer, 2010). This is because the lean concept has the same basic principles, regardless of where exactly it is implemented. It is significant, for example, that it is studied at the U.S. Army Logistics University (ALU), opened in 2009 in Fort Lee, Virginia.

3.4. The Value Stream in the Lean Thinking Concept

Lean production quickly became understood as a system of functioning of the company as a whole and transformed into the concept of lean enterprise. Over time, a whole philosophy of "lean thinking" appeared. Its essence is in such an organization of thinking as to find and eliminate losses in the stream of value creation of a product or service (Womack and Jones, 2003). It is important to keep in mind that seeing the Whole Value Stream consists of two parts: information and materials.

The value stream analysis is based on a set of five principles (Womack and Jones, 2003).

First, we need to determine what is the value of the product or service to the consumer, what the consumer really needs. The consumer is usually understood as the buyer of the finished product, but in some cases the consumer may also be a subsequent link in the process chain.

Second, we need to understand how the value stream is implemented for the consumer.

Third, the value stream should be continuous.

Fourth, it is important to understand that the stream is initiated by the consumer, i.e. the consumer "pulls" the product. This principle helps to avoid overproduction.

Fifth, continuous efforts are required to improve production processes.

Value is understood as potential utility for the consumer, which differs from the concept of "use value", which goes back to the works of the classics of political economy. According to K. Marx, use value (der Gebrauchswert) exists in unity with exchange value (der Tauschwert) and thus characterizes the dual nature of any commodity (die Ware). Moreover, use value is realized only in the process of direct consumption, that is, when the product has already passed into the possession of the consumer (Der Gebrauchswert verwirklicht sich nur im Gebrauch oder der Konsumtion) (Marx, 1867).

As in the classical understanding of use value, the consumer - is, most often, the final buyer of the product. However, it is not always necessary to determine the monetary equivalent of the value of the manufactured product for the consumer. In many cases, a meaningful analysis of how useful and necessary certain properties of the product obtained at certain stages of the production process are to the consumer is sufficient, in other words, the concept of value is rather a subjective point of view of the consumer. The main purpose of using the concept of value stream in lean production - is to improve the production process as a whole, from design to product implementation, based on the consumer's opinion about the utility of the product they purchase (Womack and Jones, 2003).

The concept of value stream also differs from the value chain used in strategic planning. Strategic planning has the task to identify individual links in the process of production and sale of the product (purchasing, production, distribution, marketing, sales, service) in order to determine which areas of activity should focus on the company itself, and which should be outsourced to maximize its share of profits: "the value chain disaggregates the firm into its strategically relevant activities in order to understand the costs and existing potential sources of differentiation" (Porter, 1985).

The value stream - is not what is meant by the concept of use value (der Gebrauchswert), nor is it what the value chain is.

The value stream - is the output of products and services that best meet the needs of the consumer, which, in fact, is the purpose of functioning of an industrial enterprise.

Research of the goal (axiological analysis) allows to enter a single characteristic of the functioning of the enterprise, which does not depend on the level of its development and the state of the environment. The enterprise is a purposeful system, and its goal is formed in the process of interaction with the consumer market and performs a system-forming role. The company as a whole is aimed at achieving its goal — meeting the needs of the consumer market or, in other words, the requirements of buyers of its products.

This approach is also valid when considering individual technological divisions within the enterprise. Each of them has incoming and outgoing material streams, the parameters of which must meet the corresponding requirements. The consumer of the output stream is the next link in the process chain, and it has its own consumers. The production process can be represented as a consistent consumption of material resources in the working places.

Transportation has a special place in the value stream. Its task - is to ensure consumption. This requires improving not only the actual movement, but also optimizing the entire process of consumption, which allows to take into account the effect of speeding up turnover, reducing reserves, increasing the urgency and completeness of transportation. The decision on the method of transportation must take into account the cost of creating a reserve, ensuring storage, etc. It is necessary to optimize the performance of technological functions of the entire system as a whole.

3.5. Lean Thinking in Transport Activities to Optimize the Value Stream

The adaptation of lean thinking to transport activities is considered in a number of publications, the review of which shows a wide interest in this topic (Villarreal et al., 2017, Kurganov et al., 2019). However, the available approaches are mostly descriptive and do not contain mathematical models that could be used to optimize the value stream at the stage of transportation for the needs of the enterprise. Meanwhile, the value stream can be implemented with different transport options. These options differ in the amount of costs for their implementation. Accordingly, the resulting output costs of the finished product will differ, based on which the preferred lean transportation option should be selected.

As an example, we will show how important it is to choose the type of vehicle (figure 2). If we compare it with a single basic truck, the cost of repair and maintenance of tractor with semi-trailer is 1.49 times higher, and the cost of truck with full trailer is 1.31 times higher. This means that the difference in the content of the two types of trucks on average reaches 20% and is preferable to truck with full trailer. It is important that the full trailer is much cheaper than a semi-trailer.

There are other factors that provide the advantage of this type of vehicle. In particular, if the amount of cargo being transported decreases, the trailer may be parked, while the truck will carry the cargo.

From the very beginning, the creators of the Toyota Production System (TPS) among all types of costs identified those that are associated with the transport of the production process and storage of reserves. Therefore, lean thinking requires a thorough and consistent analysis of all elements of costs associated with transportation and reserves of material resources, work-in-process and finished goods. As a result, the resulting total output costs should be minimal.

Transport support of value streams for consumers differ not only by the type of vehicles used (figure 2). The option should be considered, required or no intermediate storage, what will be the size of the reserves of material resources, what will be the reliability of transportation (the safety of the cargo and the accuracy of meeting delivery deadlines) etc.

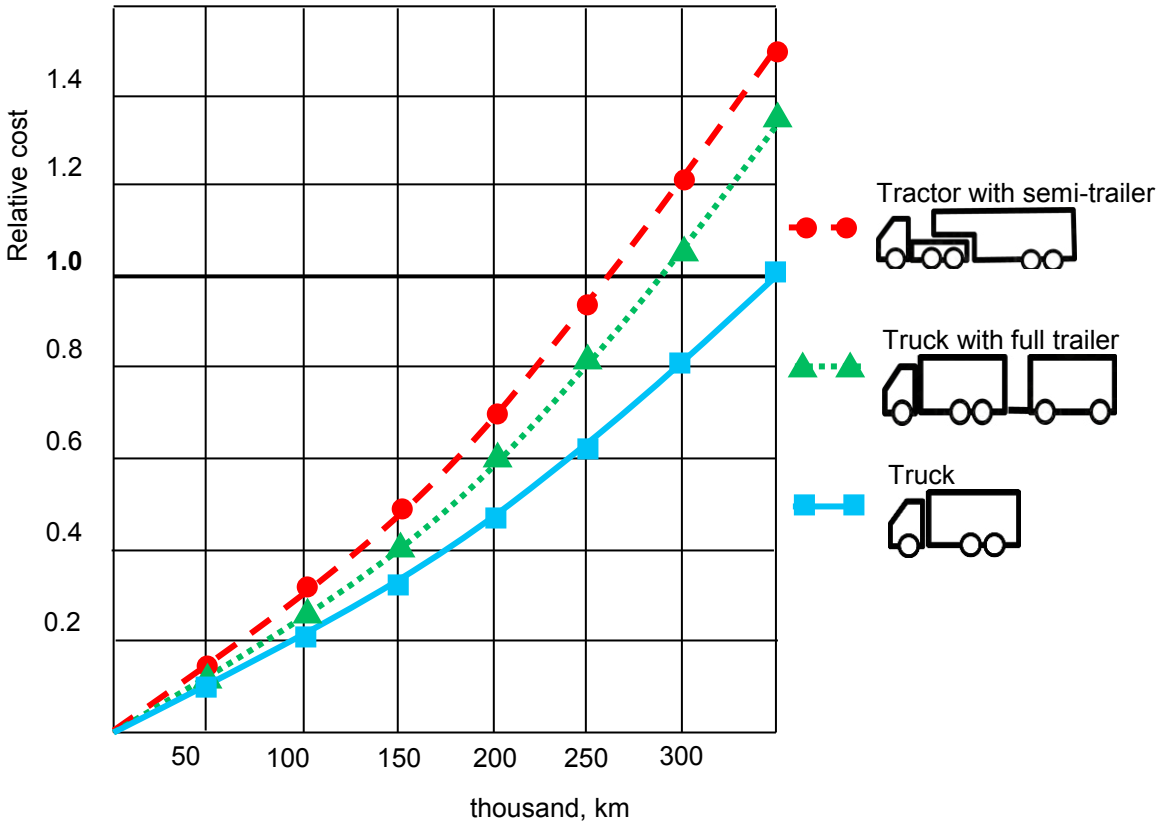

Fig. 2. The nature of the comparative dynamics of costs for maintenance and repair of vehicles of different configuration.

The total cost associated with transportation and reserves at an industrial facility can be structured as follows:

- costs directly related to traffic (all direct and indirect costs of using vehicles are taken into account);
- costs of loading and unloading the vehicles;
- expenses when performing warehouse operations (acceptance for storage, configuration, packaging, preparation for transfer to the consumer, reserves, accounting, damage or damage in the warehouse, theft, etc.)
- costs due to the occurrence of reserves in warehouses and working places;
- reserves costs in transit while vehicles are moving;
- costs due to the lack of necessary material resources in the working places;
- additional costs due to reduced safety, environmental damage, etc.

The first three types of costs can be combined into a group of operating costs, since they occur during the physical movement of material resources. The next two types of costs - are costs associated with the inability to use material resources while they are in reserves. In addition to them, it is recommended to allocate costs to a separate group when performing technological processes in the event of a shortage of material resources. Separate accounting is required for "external" costs that are additional to those mentioned and do not relate to the implementation of logistics operations and technological processes at an industrial enterprise. The proposed approach allows to use the formula for calculating total costs:

$$C_t = C_o + C_f + C_d + C_e, \quad (1)$$

where:

C_t - total cost associated with transportation and reserves of material resources at an industrial enterprise;

C_o - operating cost arising from the movement and storage of material resources;

C_f – costs due to frozen costs in reserves in warehouses and working places and also on the way;

C_d - costs due to downtime of workers, equipment, non-fulfillment of contracts, etc. in case of late receipt or deficit of material resources;

C_e - additional costs of "external" character;

To calculate costs due to the inability to use material resources while they are in reserves, the following formulas are proposed:

$$C_{fw} = C_r \cdot D_w \cdot P_k \tag{2}$$

$$C_{ft} = C_r \cdot D_t \cdot P_k \tag{3}$$

where:

C_{fw} - costs due to the inability to use material resources while they are in warehouses or at working places of the enterprise;

C_{ft} - costs due to the inability to use material resources while they are in transit;

C_r - cost of material resources;

D_w - time of storage of material resources in warehouses and working places, days;

D_t - time of movement of material resources from the place of departure to the destination, days;

P_k - the interest rate on capital assigned to 100%.

The proposed mathematical models of cost structuring require a transition from separate management of transport and warehouse operations and other divisions of the company to coordinated management of cargo flows and reserves. This will ensure that the interests of the supply chain participants are aligned and compromises are reached between them in order to optimize overall costs and form a lean transportation workflow. Some aspects of solving this problem are considered for the case of multimodal transport, as well as using the ontological model (Kurganov et al., 2018; Kurganov et al., 2020; Sai et al., 2020).

4. Results and Discussion

The research carried out on the evolution of the lean concept allowed to obtain a number of new results that are absent from previously published works or significantly supplement them. These new results are of theoretical and practical significance.

In publications on the subject of lean, there is a clear specificity to present this concept as a new method of management, which does not fully reflect the reality. In fact, the term lean first appeared in the description of the Toyota Production System (TPS) to emphasize the desire of managers of this company to eliminate reserves (to deprive the technological process in the company of excess "fat" in the form of reserves). In the future, the term lean was used in publications of American researchers who reveal and popularize the experience of Toyota.

When creating its system, Toyota relied on the experience of organizing the production line of Ford Motor Company, which embodied the results of work in the field of scientific management of production of both Henry Ford himself and other specialists who published their results at this time. Japanese managers refused to copy the technological process of the American automobile industry and made significant changes to it. The specifics of production activities and the specifics of the consumer market in Japan were fully taken into account. Nevertheless, the continuity of the Toyota production system with the achievements in scientific management in the United States is not in doubt. Thus, we can conclude that the emergence of the concept of lean should not be associated with the appearance of this term itself, or even with the creation of the Toyota Production System, but with work in the field of scientific management in the United States.

Since about the beginning of the XXI century, Toyota's experience in other countries has been adapted to other activities not related to the automobile industry. Internationalization and dissemination takes place within the framework of the lean thinking philosophy. In this sense, the term lean was very successful and acquired, to some

extent, an independent meaning in relation to the Toyota Production System. However, a number of countries, such as Germany and Russia, have abandoned the use of English-language terminology and its direct translation into national languages, introducing other terminology. This is the peculiarity of applying the lean principles.

Lean thinking is easily combined with other methods of increasing efficiency, which results in a synergistic effect when they are implemented. The identified stages are reflected in the proposed scheme of lean thinking evolution.

One of the central concepts of lean thinking is the value stream. Research on the content of this concept has shown that it differs from the concepts of use value and the value chain. This leads to the conclusion that value stream analysis should be performed using other methods.

Optimization of the value stream is achieved by choosing an option in which the consumer's requests are provided with minimal overall costs for the manufacturer. This conclusion applies not only to production activities, but also to the provision of services, including transport services. Lean transportation requires coordinated management of the movement of material resources and their reserves to minimize overall costs. The paper offers a formalized description of the criterion and provides a mathematical model that can be used to solve specific problems.

References

Balzer, W.K., 2010. Lean higher education: increasing the value and performance of university processes. Productivity Press, New York.

Bozdogan, K., 2010. Evolution of the lean enterprise system: a critical synthesis and agenda for the future. Encyclopedia of Aerospace Engineering, Section 5 - Manufacturing and Lean Technologies. https://dspace.mit.edu/bitstream/handle/1721.1/82085/100731_Bozdogan_EvolutionofLeanEntSys.pdf?sequence=1 (accessed 28 March 2020).

Ford, H., Crowther, S., 1922. My Life and Work. William Heinemann & Co, London.

Ford, H., Crowther, S., 1926. Today and Tomorrow. Doublday, New York.

George, M.L., 2003. Lean six sigma for service. Quality to Improve Services and Transactions. McGraw-Hill, New York.

Goldsby, T., Martichenko, R., 2005. Lean Six Sigma Logistics: Strategic Development to Operational Success. J. Ross Publishing, Boca Raton.

Krafcik, J., 1988. Triumph of the Lean Production System. MIT Sloan Management Review (SMR). Fall. Number 1. Reprint 3014. Pp. 40-52. https://www.lean.org/downloads/MITSloan.pdf (accessed 28 March 2020).

Kurganov, V., Gryaznov, M., Dorofeev, A., 2018. Management of transportation process reliability based on an ontological model of an information system. Transportation Research Procedia 36, 392-397. DOI: 10.1016/j.trpro.2018.12.113.

Kurganov, V., Gryaznov, M., Dorofeev, A., Nastasyak, O., Pervukhin, D., 2020. Using ontological and architectural approaches for the vehicle fleet management in the enterprise engineering context. IOP Conference Series: Materials Science and Engineering 760, 012016, 1-6. DOI: 10.1088/1757-899X/760/1/012016.

Kurganov, V., Sai, V., Dorofeev, A., Mukaev, V., 2019. Lean Transportation in Science is no Longer "Terra Incognita". Advances in Intelligent Systems and Computing 1116. Springer, Cham, 707-719. DOI: 10.1007/978-3-030-37919-3_70.

Levinson, W., Rerick, K., 2002. Lean Enterprise. A Synergistic Approach to Minimizing Waste. ASQ Quality Press, Milwaukee.

Liker, J., 2004. The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill, New York.

Marx, K., 1867. Das Kapital. Zur Kritik der politischen Ökonomie. Erster Band. Der Produktionsprozeß des Kapitals. Erster Abschnitt. Ware und Geld. Erstes Kapitel. Die Ware. https://www.textlog.de/kapital-gebrauchswert-wert.html (accessed 28 March 2020).

Murman, E., Allen, T., Bozdogan, K., Cutcher-Gershenfeld, J., McManus, H., Nightingale, D., Rebentisch, E., Shields, T., Stahl, F., Walton, M., Warmkessel, J., Weiss S. and Widnal S., 2002. Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative. Palgrave, Hampshire.

Ohno, T., 1988. Toyota Production System. Beyond Large-Scale Production. Productivity Press, Portland, Oregon.

Poppendieck, M., Poppendieck, T., 2007. Implementing Lean Software Development. From Concept to Cash. Pearson Education, Inc., London, New York.

Porter, M., 1985. Competitive Advantage: Creating and Sustaining Superior Performance. The Free Press, New York

Rother, M., Shook, J., 1998. Value stream mapping to create value and eliminate muda. Lean Enterprise Institute, Inc, Michigan.

Sai, V., Kurganov, V., Gryaznov, M., Dorofeev, A., 2020. Reliability of Multimodal Export Transportation of Metallurgical Products. Advances in Intelligent Systems and Computing 1116, 1023-1034. DOI: 10.1007/978-3-030-37919-3_100.

Villarreal, B., Garza-Reyes, J.A., Kumar, V., Lim, M.K., 2017. Improving road transport operations through lean thinking: a case study. Int J Logist 20.2, 163-180. DOI: 10.1080/13675567.2016.1170773.

Wader, M., 2002. Lean tools: A Pocket guide to implementing Lean Practices. Leadership Excellence International, LLC. New York.

Womack, J., Jones, D., 2003. Lean Thinking. Banish Waste and Create Wealth in Your Corporation. Free Press, New York.

Womack, J., Jones, D., Roos, D., 1990. The Machine That Changed the World. The Story of Lean Production. How Japan's Secret Weapon in the Global Auto Wars will Revolutionize Western Industry. Rawson Associates, New York.