MULTIDISZCIPLINÁRIS KIHÍVÁSOK
SOKSZÍNŰ VÁLASZOK

GAZDÁLKODÁS- ÉS SZERVEZÉSTUDOMÁNYI FOLYÓIRAT

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AGGREGÁLT LEAN KPI-K EREDMÉNYEINEK MINŐSÍTÉSE FUZZY LOGIKA MENTÉN

QUALIFICATION OF THE RESULTS OF AGGREGATED LEAN KPIS ALONG FUZZY LOGIC

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Kulcsszavak: *controlling, lean controlling, lean menedzsment, lean index, fuzzy logika*

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ÖSSZEFOGLALÓ

A lean menedzsment alkalmazása a 21. században az ipari vállalkozások működésében alapvető versenykritérium lett. A különböző lean menedzsmenthez kötődő eszközök és módszerek alkalmazása a vállalati funkciók jelentős részében megjelenik. Fontos megemlíteni viszont azt is, hogy számos más, nem lean célokat támogató eszköz és módszer vegyes alkalmazása mellett vannak alkalmazva ezen lean eszközök és módszerek. Ezen probléma pedig a controlling számára is kihívást jelent. Mivel a lean accounting módszerek ilyen környezetben nem feltétlenül hatékonyan mérik a lean mértékét, ezért mind a tudományos, mind az üzleti gyakorlati életben számos egyéb módszereket alkalmaznak, a lean monitoringozására. Ezek közül kiemelendő a fuzzy logikán alapuló lean értékelő modellek. Ezen modellek segítségével elsősorban pénzügyi adatok mentén lehetséges meghatározni egy vállalkozás lean teljesítményét. A modell hátránya viszont, hogy a lean menedzsment számos olyan funkcionális területen is megjelenik, amelyet pénzügyi mutatószámok mentén nem lehet értékelni, viszont egyértelműen elősegíti a lean menedzsment működését.

Kutatásunkban egy instrumentális esettanulmányon keresztül szemléltetönk egy olyan komplex lean controlling módszer együttest, amely alkalmazásával a vállalkozások számára lehetővé válik a lean menedzsment teljesítményértékelése, illetve a különböző beavatkozási pontok feltárása. A kutatási eredményeink által lehetővé válik a lean fuzzy index kiszámítása nem csak pénzügyi adatok mentén, ezáltal pedig pontosítva az index információtartalmát. A vizsgálatainkban megfogalmazott módszerek és mutatószámok mentén elkülöníthetővé és mérhető válik a lean módszerek és eszközök, illetve a lean célokat támogató folyamatok és módszerek hatékonysága. Kutatási célunk egy általánosan alkalmazható lean controlling konceptuális modell megalkotása.

SUMMARY

The application of lean management has become a fundamental competitive criterion in the operation of industrial enterprises in the 21st century. The use of tools and methods related to different lean management appears in a significant part of corporate functions. However, it is also important to mention that these lean tools and methods are used in addition to the mixed use of many other tools and methods that support non-lean goals. This problem is also a challenge for controlling. Because lean accounting methods do not necessarily measure the extent of lean effectively in such an environment, a number of other methods are used to monitor lean in both academic and business practice. Of these, lean evaluation models based on fuzzy logic should be highlighted. With the help of these models, it is possible to determine the lean performance of a company primarily along financial data. The disadvantage of the model, however, is that lean

management also appears in a number of functional areas that cannot be assessed along financial ratios, but they clearly influence the operation of lean management.
In our research, we illustrated a complex set of lean controlling methods through an instrumental case study, which allows companies to evaluate the performance of lean management and to explore different points of intervention. Our research results make it possible to calculate the lean fuzzy index not only along financial data, and thus clarify the information content of the index. Along the methods and indicators formulated in our research, the effectiveness of lean methods and tools, as well as the processes and methods supporting lean goals, can be separated and measured. Our research goal is to create a generally applicable lean controlling conceptual model.

INTRODUCTION

In recent years, databases and information opportunities have been made available to organizations through the use of IT and business IT innovation, mainly Big Data and digitization, which are fundamentally changing the controlling systems used so far (Hazen et al., 2014). Data mining methods and various mathematical-statistical models for the analysis of huge and extensive data sets make it possible to transform these data into relevant information and to extract the relevant information (Tabesh et al., 2019). These IT and mathematical-statistical methods and algorithms are excellent for extracting efficient information for a given goal (Thalmeiner et al., 2019), but between the strategic and the resulting functional, operational goals and the mathematical-statistical, data mining methods, the management control systems should form a kind of bridge. This bridge implements the application and development of different controlling methods for modern information-based management systems (Otley, 1999).
The various reports can express the performance or results of an entire area or factory unit in a single indicator. To achieve this, a basic requirement is the appropriate and efficient infrastructure and the application of appropriate professional and mathematical methods. Different evaluation algorithms and standardization norms are needed for effective interpretation and decision-making of indicators.
Lean management as a philosophy and as a process optimization management method has now become a basic competition criterion for industrial enterprises. Organizations that will be able to effectively and specifically measure the implementation of lean tools and methods in their processes will be able to implement an organization-wide lean philosophy. By implementing this

philosophy, they become able to continuously improve, with the help of which organizations can achieve more accurate results and thus higher efficiency. Measurability also provides an opportunity to make effective and appropriate management decisions. Industrial companies also use a number of other methods to support non-lean goals in their processes, which poses a complex challenge to the controlling system. Traditional lean accounting methods are not able to map tools and methods that support lean goals (Bromwich, 1990).

There are several controlling methods that can be used to monitor lean management. The various methods, value stream and value flow analyses as well as the indicators and correlations of the balance scorecard and the individually, specially developed logistics and complex indicators and systems measure and include the status and information related to the lean management tools. Lean fuzzy indices basically evaluate and measure the performance of lean management along financial data, from a business economics aspect. As a significant part of these models is based on financial data, it is not an effective tool for controlling in this form (Hines et al., 2004). Effective lean controlling should be a unified methodology that evaluates the entire corporate operation and lean management along functional levels.

As such a specialized indicator and methodology does not exist, the relationship between lean and controlling needs to be formulated first. Based on the literature and corporate practice, the relationship between controlling and lean is mostly to be found in the system of Key Performance Indicators. Along this line, after describing the more basic elements of Lean management, we present a universal model that is primarily composed of metrics that affect direct lean goals and is designed to measure the effectiveness of Lean processes. The results of our research can be used as a kind of new and special methodology for aggregating KPIs, and they can also be an effective input expert function for lean fuzzy index models.

LITERATURE REVIEW

The lean approach can be used to determine what the value is. It is only the end user who can decide what counts as value, and it is only possible to talk about value on the merits if a given product meets the needs of the customer at a given price and time (Womack - Jones, 2003). And value is always created by the producer (Shiego, 1989). Lean manufacturing is not only a manufacturing system, but also a manufacturing philosophy, paradigm, and culture, that appears

holistically among organizational functions and in this philosophy, culture plays a more important role than technical background.
With the help of the lean approach, the operations and processes that create value can be optimally ordered, and they can be performed more and more efficiently at the right time, in the right place, in the right quantity, without interruption (Vörös, 2010). This approach should not stop at the boundaries of a company, but should extend to the entire supply chain and the entire vertical of a given business line industry (Womack - Jones, 2003). By introducing its approach, it plays a very prominent role in shaping organizational culture and employee thinking (Liker, 2004). (Womack - Jones, 2003). Five principles have been defined for the effective operation of lean management, which are: value definition, value process identification, flow creation along value creation steps, application of pull principle, improvement, continuous improvement.
In the 21st century, many organizations use lean management, and in many industries the application and implementation of lean management in the operation of management organizational processes also appears as a competitive criterion. In contrast, in very few cases is the philosophy implemented in product development processes. Only organizations that are able to apply lean philosophy to product development can become fully value-creating organizations (Marodin et al., 2018).
The effective implementation of lean management is not determined by the industry, but by the nature of the processes. Implementation can be successful in any industry, but tools need to be tailored to the specifics of the sector and organization, and the philosophy needs to become part of the organizational culture. In order for lean transformations to be effective, it is necessary to incorporate the new approach into an already ready organizational culture (Gyenge et al., 2015). The literature does not provide a clear answer as to what is considered an "ideal lean culture". To solve the problem, the solution can be found from the widely accepted recognition that the foundation of lean management and the best example to date is provided by the Toyota system. Based on this, Toyota's corporate culture can be called the "ideal lean culture" (Toarniczky et al., 2012).

ERP systems

Enterprise management information systems are referred to in the literature as ERP (Enterprise Resource Planning). An information system is a complex set of people, activities, and hardware and software tools that enable the controlled and continuous acquisition, processing, storage, and provision of information about the company's environment, internal operations, and corporate environment transactions (Grant, 2000). In the case of ERPs, the functional approach remained. The basic elements of the systems are the modules that theoretically and practically correspond to certain functional areas of the company, for example: logistics, production management, sales, accounting, controlling, asset management modules. The development of ERP systems is unbroken to this day. It plays an important role in both managing transactions and facilitating managerial decision-making (Jacobs - Weston, 2007) (Radó, 2019). The tracking of lean processes is greatly facilitated by different ERP systems. There are several custom-developed and standardized lean modules, all of which can be used to support the lean controlling system (Chiarini, 2013).

Business Intelligence systems

Business Intelligence (BI) is an application or technology designed to support companies make decisions by providing access to relevant data and storing it appropriately, as well as versatile analytics capabilities. Business Intelligence solutions include modern forms of data storage, real-time reporting, analytics, prediction, and data mining procedures (Negash - Gray, 2008).

There are many different versions of BI tools and they vary greatly, depending on the complexity of the area of use, development costs, and user needs. We cannot talk about a typical system and simple choice decisions (Hawking - Sellitto, 2010). In many cases, we can talk about the combined use of BI tools, and what we call BI also depends on the decision-maker's attitude and interpretation, that is, on the level at which he interprets the information. For example, a structure or system application where the selected device has BI capabilities but is not exploited by user management cannot be considered real BI. Conversely, if the organization does not use costly specialized tools and systems, we can still talk about a business intelligence application. A common feature, therefore, is to define the use of a large number of complex data or machine support for the exploration of ambiguous relationships (Richards et al., 2017).

Thus, it can be stated that business intelligence systems do not have a specific field or form, or even widely accepted software (Hawking - Sellitto, 2010). It is important to emphasize that the definition of goals, including controlling and functional support goals, is at least as important a task as the design of the system itself or its implementation in a given corporate environment. In the practical application of business intelligence systems, visuality is extremely important because the complexity of data and information in interpreting complex analytics would take a lot of time for both controllers and managers. Automating certain management tasks and resource commitments (administrations) is also very important, and is actually the essential purpose of BI, as well as a better and more complete understanding of customer needs (Richards et al., 2017).

One of the essential elements of lean controlling is continuous monitoring and dynamic result feedback. Business intelligence systems can facilitate these in a number of ways. The basis of Andon systems is provided by business intelligence-based systems in production systems, and they can also play a significant role in the assessment of intervention points related to different value streams (Singh et al., 2011).

Value stream costing

According to the lean philosophy, costs and the incurrence of costs are caused by processes. The goal of lean management is to identify and reduce the costs associated with these processes. Because of their complexity, basic costing, such as process-based costing, has generated the development of additional alternative costing methods that provide relevant information content. The term "lean accounting" first appears in Maskell's (2000) writing, which defines lean accounting as the purpose of providing useful information to the people who implement and maintain lean manufacturing (Ruiz - de - Arbulo - Lopez et al., 2013).

The VSC determines the optimal costs for the activities of value-creating processes. To determine costs, the processes of value-creating activities must be mapped in advance, which is most often mapped using the VSM (Value Stream Mapping) method. A special feature of VSC costing is that it is not necessary to determine product costs because costs are assigned directly to the value stream. An accounting system needs to be developed that focuses specifically on value flows, provides performance measurement and reveals the shortcomings of traditional costing (Stake, 1994).

The concept of VSC can be traced back to Womack and Jones (2003), who, instead of classifying costs, suggest cost collection based on value streams, without distinguishing between direct and indirect costs. Even employees, products and services should be connected to only one value stream. Ideally, resources can be assigned to a single value stream. If this useunsuccessfuls, resources need to be allocated to value streams in proportion to their use (Ward et al., 2003).

Key Performance Indicator

A KPI (Key Performance Indicator) is a complex indicator that shows the effectiveness of various functional and strategic goals of a given organization (Thalmeiner, 2021). There are KPIs defined at hierarchically lower levels or formulated at higher levels. KPI aggregation can be used to explore and evaluate the logical relationships between these hierarchical and vertical levels (Anthony – Vijay, 2006). KPI aggregation is a set of methodologies based on mathematical-statistical and logical correlations (Duru et al., 2013), which use KPI indicators of different functional areas along a target value formulated at a given organizational level can be expressed in a defined indicator (Fanning, 2016).

KPI aggregation

KPI aggregation can be an effective methodology for processing indicators and statements with different functional and big data sets (Schnellbach - Reinhart, 2015).

KPI aggregation methods allow organizations to report accurately and comprehensively and to process data generated by digitization and industry 4.0 from the perspective of strategic objectives, as illustrated by a small number of predefined indicators. The proper definition, structuring and aggregation of KPIs can serve as a bridge between corporate information systems, data processing provided by Big Data and Industry 4.0, corporate strategic goals and more accurate management decision-making (Zéman, 2020) (Barta – Molnár, 2021).

KPI aggregation can also be a useful methodology for increasing the efficiency of financially and logistically deterministic, measurable indicators and statements (Schnellbach - Reinhart, 2015). Consequently, the aggregation of KPIs related to lean management also plays a very prominent role. Properly defining KPIs is a kind of bottleneck, as lean operations and lean processes appear separate in the management organizational processes of organizations. Because of these, it is a challenge to measure the effectiveness of organizations 'lean management tools (kaizen, JIT, KAN-BAN, VSM, etc.) using lean accounting methods. Proper definition of lean KPIs and the controlling models derived from them, on the other hand, make it possible to extract the effectiveness of separate lean processes and to effectively detect the "leanness index". This index can be created using fuzzy logic (Bayou – Korvin, 2008) and aggregation methods organized along other logical correlations and can be interpreted as an index suitable for characterizing organizational lean processes interpreted in a dynamic index (Duru et al., 2013).

Fuzzy logic

In the natural sciences and social sciences, however, in many cases there are phenomena that can be poorly or subjectively defined, it is not possible to model their operation with exact methods at all. To solve this problem, the method of fuzzy logic was developed by Zadeh in 1965 (Zadeh, 1965).

The meaning of fuzzy is vague, hence the classification into a given set in these systems is determined by membership functions. These functions illustrate the value of a particular linguistic terms, for example, the evaluation of a particular enterprise can be the values of a language variable: poorly performing, moderately performing, very well performing. Thus, based on the former example, belonging to a given set can be determined using a function. This operation is called fuzzification (Havasi – Benő, 2012). The next step is to create a system of rules that performs actions and inferences using each linguistic term. As a result of this process, an aggregate of member functions can be created, which is an essential element of defuzzification. During defuzzification, an actual value can be created and this can be considered the end result of the fuzzy analysis (Zadeh, 1965) (Havasi – Benő, 2012).

RESEARCH METHODOLOGY

In our research, we performed an extended case study and model development. We chose the extended case analysis method to discover the shortcomings of the existing theories and the methods used in practice, and to further develop the model used in practice along a model formulated in a given theoretical literature along various parameters (Babbie, 2013). We aimed at the sequential logical structure of different controlling models and mathematics in the controlling system of the examined industrial organization. Next, our goal is to build an evaluation complex controlling model based on general aggregated KPIs. To illustrate the operation of the model, we defined lean KPIs as aggregated KPIs. We chose this because both the managers of the company and the literature say it is a critical and well-defined KPI system. As the model is used to describe reality, the parameters of this area and enterprise as an aggregate target KPI can be exchanged in the model for other aggregate target KPIs, but this has no significant effect on the logical structure of the model.

Before applying the fuzzy-logic methodology for measuring lean, we provide the following brief overview of fuzzy-set concepts.

Fuzzy logic

The lean fuzzy methodology was first applied in 2008. The concept of lean fuzzy is based on the fact that the word lean as "slenderness" is an adjective that has no sharp boundaries that could be used as a general categorization. "The lean level of enterprise A is worst than the lean level of enterprise B" or "The lean level of enterprise C is appropriate" and "This enterprise is lean acceptable" (Bayou – Korvin, 2008).

In this paper, we define the classification of a lean index as a fuzzy subset. To formulate a fuzzy-logical model, it is mandatory to define the universe (*U*), the (*xi*) items *U*, where *U*={*x*1+*x*2+...*xn*}, and a subset of fuzzy *A* included *U*, where

$$A=\left\{\frac{x}{\mu_A(x)\,|\,x\in U}\right\}$$

The membership fuzzy function of subset "A" is in most cases expressed as:

μA: U → [0,1], amely az x ∈ U assigns to each element of x μx degree of membership in A: μA (x) = μx.

The most commonly used fuzzy-logic operations are intersection, merging, and complementary:

- Intersection of two fuzzy subsets A and B: μA∩μB = minimum {μA (x), μB (x)}
- Merging of two fuzzy subsets A and B: μA∪μB = maximum {μA (x), μB (x)}
- Complementary: μ_A '(x) = 1 - μ_A (x) (Zadeh, 1965)

The methodological framework of the model is provided by the following steps:

Step 1: To assess the lean level of the surveyed enterprise, benchmarks need to be established. These benchmarks should be set for KPIs.

Step 2: The applicable standardized standard to be used as a basis for evaluation should be selected.

Step 3: Select the metrics and KPIs associated with measuring the various processes that affect the lean performance and lean index involved in the analysis. It is advisable to group and aggregate these along some predefined aggregation or logical context. By aggregating the information content, managerial decision support is available.

Step 4: Apply the developed model, wich can be found in the result. Normalization of the outputs of the presented computational models. Lean index categorization into predefined quality categories.
In applying these steps, the methodology provides a general framework that can be universally applied to measure and assess the lean level of any organization. The general steps can be supplemented, as illustrated in the result section.

RESULTS

In the case study, we examined the aggregation possibilities of a lean KPI of a vehicle manufacturing organization and created an aggregation map along a logical structure along the applied KPIs. This aggregation map contains the different aggregation options for KPIs. Two groups of aggregation are possible. One is the aggregate indicators of lean effectiveness from non-lean tools and methods. The other group is aggregate indicators of the effectiveness of lean management tools and methods. The ultimate goal is to calculate the lean index. In the model, the set of two aggregated KPIs may have different results for the lean index.

Monitoring lean processes

The operation and development of the organisation's controlling system is the responsibility of the controlling department. This controlling department has a number of tasks, the most important of which are periodic reporting, financial forecasting, plan-fact analyzes, cost calculation, process controlling analyzes, analysis of project financial decisions and monitoring of the goals formulated in the strategy. The organization has an extensive corporate governance system that structures the data along various parameters and the interim and other reporting tasks are performed using this database. This IT system includes an artificial intelligence module, the construction and application of which is under development.
The lean controlling system of the examined organization is based on the lean KPI (Key Performance Indicators). When defining lean KPIs, it is not necessary to assign a cost to the indicators, on the other hand, simplicity is mandatory as one of the most important principles of the lean philosophy. These KPIs are defined and interpreted at several levels.

The KPIs presented below are the indicators related to the most emphatic lean principles. In addition, the company uses a number of other indicators for accurate monitoring.

- Quality circles:

The organization defines four special basic indicators for monitoring these quality circles, and the quality circles also have four levels.

1. Regulatory KPIs:

Number of errors noticed by employees. As under Regulation 1, all operators and employees involved in the production process are 100% responsible for their own work, so self-monitoring is one of the very first steps in terms of efficiency. As there is no suitable feedback system for all employees, this indicator is calculated for value streams. The indicator measures on a scale of 0-1, and the closer it is to 1, the better the value, as this means that workers filter out a high proportion of defective products in the first quality round.

$$\frac{\text{Number of defective products noticed by workers per value stream}}{\text{Number of defective products per value stream}}$$

2. Regulatory KPIs:

Number of requests for help and support in case of quality problems. The second set of regulations is primarily a form of support and assistance to employees in the event of any quality issues that they are unable to address at the expected level. This task is performed by the plant quality assurance. This indicator can be measured at both value stream and factory unit levels. This indicator can also take values between 0-1 and the closer it is to 0, the better the result. This is because in such cases, the operators were able to filter or resolve the occurrence of errors.

$$\frac{\text{Request a factory quality assurance}}{\text{Number of defective products per factory unit or value stream}}$$

3. Regulatory KPIs:

Defective product detection rate by quality management checks. For the third quality group, control is a general activity. In this regulatory circle, quality management professionals who test different raw materials, semi-finished products, or parts according to different algorithms and methods at different times and by different means. The "rate of detection of defective products by quality management checks" is an excellent illustration of the proportion of total defects detected by quality management checks over a given period. This indicator can also be interpreted for value streams and at the factory unit level. The indicator measures on a scale of 0-1 and the closer it is to 0, the better the result, as it assumes that a larger proportion of defective products have already been discovered in previous quality circles.

$$\frac{\text{The number of errors detected by quality management checks over a given period}}{\text{Total number of errors for a given period}}$$

4. Regulatory KPIs:

Defective product detection rate by test track inspections. The fourth control circuit examines the evaluation from the customer's point of view, i.e. the finished product undergoes a quality control during a given test track test. The indicator measures on a scale of 0-1 and the less the better, because the smaller the more errors have been observed in the previous control circuits.

$$\frac{\text{Number of errors detected by test track inspections over a given period}}{\text{Total number of errors for a given period}}$$

- Just In Time

The average time spent in the storage process per part. This KPI is a very complex indicator that includes in-process inventory and longer raw material or finished product storage time. As a result, this can be taken into account in all value streams where it is possible to be in stock between production, as well as in the warehouse of incoming raw materials and in the warehouse of the finished product. When assessing the value of the indicator, the value streams form an individually defined benchmark in the case of inter-production stock, but in total this can be a maximum of 3.5 days, while in input or output warehouses a maximum storage period of 1.5 days is defined as a target.

$$\frac{\text{Time in storage}}{\text{Total number of parts}}$$

- 0 Error

0 km error: Parts or semi-finished products returned to the previous workstation or value stream in the production sequence due to complaints during a given period. The index is measured in number of parts in proportion to all parts produced. This indicator can be interpreted between factory units, value streams and even workstations.

$$\frac{\text{Parts returned}}{\text{All manufactured parts}}$$

Number of Q alerts per employee: This indicator shows how many q-alarms per employee in a given value stream, or even in the entire production unit. This indicator is considered appropriate if the value of the indicator converges to 0.

$$\frac{\text{Number of Q alarms}}{\text{Number of employees}}$$

In cases where a solution to the problem cannot be found within a specified time frame, the Q stop takes effect, which can mean a partial or even complete workstation, value streams, or production line shutdown.
Q-alarm - Q-stop ratio: The indicator illustrates what percentage of Q-alarms became Q-stops.

$$\frac{\text{Q-stop}}{\text{Q-alarm}} \text{X } 100$$

- Kanban

The personnel cost of the lack of raw material availability projected by one employee. The organization's Kanban processes can be fully modeled by the information system and manufacturing process design software it uses and develops. For this reason, the controlling system does not place much emphasis on monitoring Kanban or defining the corresponding KPIs, as this is the task of the process group and the technical planning and management. The most important indicator used for Kanban is the cost of lack of raw material availability. This indicator is a complex KPI that can be measured for both the factory unit and the value streams. It shows the inefficient operation of the kanban and the costs involved.

$$\frac{\text{Value stream waiting cost (Human and / or machine cost)}}{\text{Total waiting time}}$$

- 6S

In the case of 6S, the controlling system of the organization does not define KPIs, but the value streams managers and the engineering and process management and organization departments jointly define different measurement points. These measuring points are not integrated into the controlling system.

- Full operation

This indicator illustrates how much of the total available time (human and machine) is actually spent on the production of a value-creating product that is of good quality. This indicator can also be interpreted in terms of value streams and total production unit.

$$\frac{\text{Number of products that meet the quality parameters X (Cycle time and machine changeover time))}}{\text{Predefined production time}}$$

Lean KPIs for non-lean principles

KPIs related to non-lean principles can appear at two levels. These indicators can be interpreted either at the level of value streams and factory unit or only at the level of factory unit. These KPIs are too complex and multifaceted and too organization-specific to be defined for general lean principles indicators.

Product lead time: This indicator illustrates the average time taken to complete a given product type or all manufactured product types from the order. The indicator is not examined by the factory only at the level of the factory unit or product. It could also be interpreted at the value stream level. The unit of measure of the indicator can be measured in days or hours.

$$\frac{\text{Execution of an individual order for a given product type}}{\text{Validated order date}}$$

HPV (Hours/Vehicle): One of the most important indicators for the company and the examined subsidiary is HPV. This indicator differs from the lead time of the Product in that it takes into account only the actual working time, broken down into hours. Other non-value-creating time (such as warehousing) is not included in this indicator. The indicator is only measured at the factory unit level and is not calculated for individual product types, only the average time is calculated on the basis of all vehicles produced.

$$\frac{\text{Total working time (Human and / or machine working time)}}{\text{Number of vehicles produced}}$$

P-Factor (Performance Factor): This KPI is one of the company's most emphatic and accurate productivity metrics. This indicator can be calculated using the HPV already illustrated. This KPI illustrates human resource working time from HPV and compares constructive production time to it. The unit of measure in each case is hours.

$$\frac{\text{HPV X Number of vehicles produced-machine working time}}{\text{Constructive production time}}$$

Load index: The load shows the time that elapses from the time required to produce the product with value-creating work. (Production time is predefined by production engineers.) This indicator is critical to the operation of the plant unit, as this KPI is used to determine assembly lines and load distribution. The goal is to achieve the highest possible load. This indicator is very complex and has a number of influencing factors. For example: compliance with drift limits, availability of materials, design of processes, spatial and physical boundaries in time, necessary safety measures, etc.… Load index can be interpreted for value streams, workstations, production belts and complete production unit. The high KPI value of the load is associated with the low value of value creation then the organization defines it as muda.

$$\frac{\text{Load index } (\%) = \sum \text{TP}}{\text{Tact-time X 100}}$$

TP:Unit of time needed to manufacture a product)

In the controlling system of the examined organization, lean controlling appears from several aspects. It is important to highlight that this is a complex system in which there are a number of correlations with respect to lean KPIs. Because many metrics and lean KPIs are measured at the organization, for effective reporting, these metrics need to be aggregated in some form to ensure high effectiveness of decision-making and intervention at critical points. So one of the most important methods of these reports is aggregation. The model below illustrates what aggregates can be created in the controlling system developed by the organization. In Figure 1, the units marked in gray represent the possible aggregation possibilities. Quality Circles, JIT, 0-Error, KanBan and Total Operation as lean principles and the related aggregated KPIs are suitable for demonstrating the effectiveness of the organization's lean management and lean processes. The aggregation of lean KPIs according to value streams is also suitable for demonstrating the effectiveness of the organization's lean management and lean processes. In contrast, P-factor and Product lead time as key indicators in themselves can be good indicators to monitor the effectiveness of lean processes at the factory unit level. However, in addition to the aggregate factory unit level, the Occupancy Index is also suitable for the analysis of different value streams.

The value of the effectiveness of the 6S lean principle, the results from the evaluation of the organization's suppliers' lean processes, and the results of customer value creation monitoring are not included in the organization's lean controlling system. However, most of the values of these indicators are integrated into the entire organizational controlling system, and the indicators related to 6S are important applied indicators of engineering planning and management. (Engineering design is not part of the controlling system)

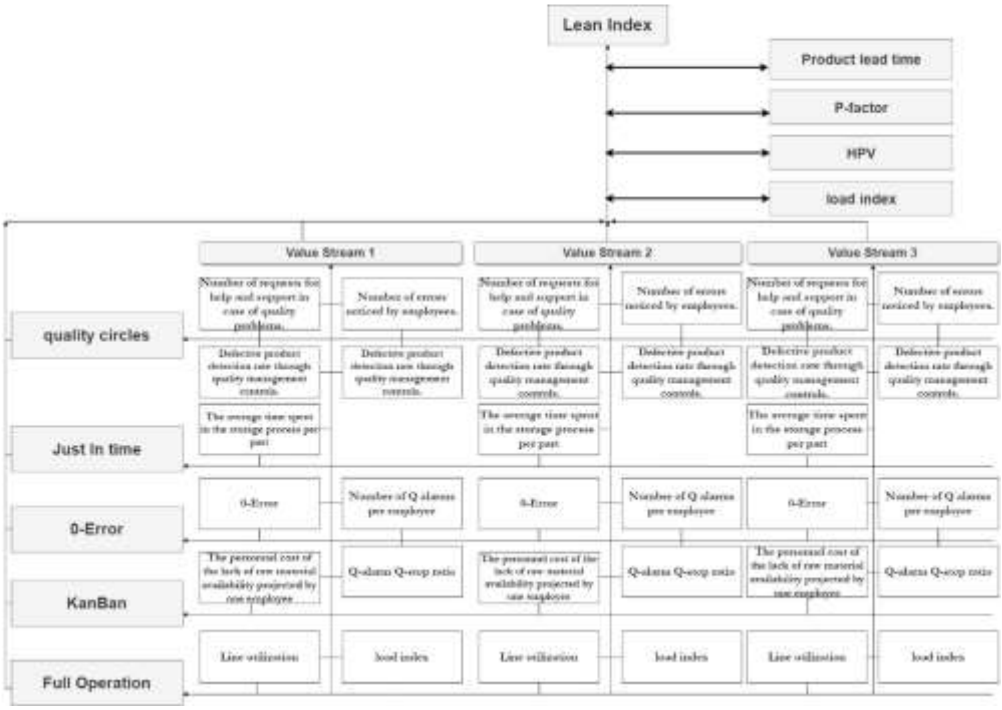


Figure 1: Lean aggregation map

Sources: Own edition based on (Womack – Jones, 2003), (Bayou – Korvin, 2008).

It can also be seen from the figure above that the causal relationship of the aggregation possibilities is determined by an expert opinion and not mathematical correlation relationships. Aggregation is based on a weighted average at each level. These subjectivities in the model raise the problem that the association of different indicators and the aggregation of information content are also subjective. In many cases, value streams define completely different metrics to measure their performance, and these KPIs do not necessarily help meet lean goals. These indicators should be disregarded when determining the lean index.

In our research, we included in the analysis only those indicators of the examined company, the effectiveness of the measured processes and operations influencing the achievement of the lean goals.

Lean controlling fuzzy index

It is not possible to establish a set of predefined KPIs on the basis of which the development of the lean index could be modeled with complete accuracy, so the model must take subjectivity into account. Expert opinions can serve as an input function in the lean index model. Input functions in lean fuzzy models usually use a result related to some financial or lean principle, but in this controlling aspect model this is not necessarily effective. This is because in addition to lean management tools and methods, the company uses a number of other methods that also contribute to lean goals. And financial data also do not in themselves provide enough information to determine lean effectiveness. The effectiveness of the whole process is what the company defines as a lean goal.

The model should consider the lean index of different value streams as aggregate indicators. This allows management to receive feedback on lean performance for each value stream. In this case, too, fuzzy membership functions are a set of different KPIs that must be evaluated along some expert subjective methods and aggregated along logical correlations.

One of the basic determinants of fuzzy functions is the standardization norm. This norm makes it possible to determine the evaluation of the space occupied on the lean index scale. Based on these, it can be stated that the selection of the standardized norm is an important task for the model. The different lean fuzzy methodologies select the result of the best competitor in the industry (Bayou – Korvin, 2008) or in some cases average industry performance as the standardized norm. This would not be expedient in our present controlling model, as the efficiency of the different value streams would be distorted, it could not be applied in practice due to the lack of information. In addition, if the value of the firm's lean index and the value of the standardized norm show a large difference on the scale, management would not receive an evaluable result.

In the case of the company we examined, the basis of the production and controlling system is the value stream-based structure. In this way, it can be useful for the company to get feedback on all value streams along the lean goals. In our model, we will use the average performance of value streams as the standardized norm. It is important to emphasize that this standardization norm is a normative choice, so there can be many other possibilities.

Lean controlling fuzzy model application steps:

Step 1:

The company whose lean effectiveness needs to be evaluated should be selected.

Step 2:
The reference value must be determined. For the presented model, the standardized norm will be the average result of the value streams.
Step 3:
KPIs related to the measurement of the various processes affecting lean performance and lean index involved in the analysis should be selected. These should be grouped along some predefined aggregation or logical context. In our model, we used the lean KPI indicator system of a Hungarian car manufacturing organization and the professional aggregation indicators derived from it.
Step 4:
Description of the computational application of the illustrated model.
Step 5:
Evaluation of the outputs of the presented calculation model along the standardization norm. The normalized output is followed by categorizing the lean index into predefined quality categories.

Evaluation system

During aggregation, we grouped KPIs along several options in our model.

- Create five aggregate indicators according to the lean management tools and methods
- This group is not closely tied to lean management, but clearly expresses lean goals. Creating four aggregation indicators based on a group that largely includes the different results of lean tools and methods.
- It is also possible to aggregate different indicators along the value streams, for which we did not determine the amount of the created indicators. This is due to the dynamically changing and high number of value streams. (Nearly one hundred units are in operation at the time of the research.)

Our goal was not to evaluate the overall lean efficiency of the company, but also the lean efficiency of the value streams and applied lean management tools and methods. Thus, in our present research, we decided to include five aggregates in the model for illustration. These are defined as the aggregate results of the value streams, from which the lean index can be calculated for the value stream of the given factory unit. (The lean result of all value streams as a set of aggregates can also be included in the analysis if the calculation is supported by an appropriate IT system.)

1. Value stream (A)

a. (A)- KPI reasults.

2. Value stream (B)
b. (B)- KPI reasults.
3. Value stream (C)
c. (C)- KPI reasults.
4. Value stream (D)
d. (D) KPI reasults.
5. Value stream (E)
e. (E) KPI reasults.

The method of grouping according to the above-mentioned letters is presented below.

$$A_i = \sum_{1}^{n} a_i^1, a_i^2 \ldots, a_i^n$$

$$B_i = \sum_{1}^{n} b_i^1, b_i^2 \ldots, b_i^n$$

$$C_i = \sum_{1}^{n} c_i^1, c_i^2 \ldots, c_i^n$$

$$D_i = \sum_{1}^{n} d_i^1, d_i^2 \ldots, d_i^n$$

$$E_i = \sum_{1}^{n} e_i^1, e_i^2 \ldots, e_i^n$$

An average should be calculated from the grouped values of the lean index results of the examined value streams, thus it will be compared not with a standard value, but with the relative position of the examined periods. The average of the elements of the sets can be calculated as follows.

$$\frac{A_1,\ A_2, \ldots A_n}{n} \in A'$$

$$\frac{B_1,\ B_2, \ldots B_n}{n} \in B'$$

$$\frac{C_1,\ C_2, \ldots C_n}{n} \in C'$$

$$\frac{D_1,\ D_2, \ldots D_n}{n} \in D'$$

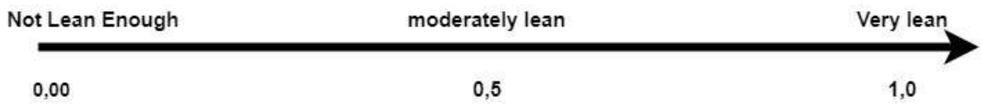
$$\frac{E_1,\ E_2, \ldots\ E_n}{n} \in E'$$

The value streams are examined as a function of the values of all the examined colonies. The relative eigenvalues of value streams can be determined as follows. This value also determines the position on the scale.

$$\frac{A_i}{\text{Max } A'} + \frac{B_i}{\text{Max } B'} + \frac{C_i}{\text{Max } C'} + \frac{D_i}{\text{Max } D'} + \frac{E_i}{\text{Max } E'} = X_i \text{ I } X \in [0,5]$$

Depending on this, the eigenvalue may be different for the different sets examined. The maximum value of the eigenvalue is 5. Thus, the relative position of the value streams can be determined. If the value streams are placed on a linear scale, it can become visible how they are positioned relative to the maximum value of the group and to each other.

Based on fuzzy logic theory, the eigenvalues obtained by the method can be determined by qualitative concepts rather than specific numbers. This creates a fuzzy logical membership function. Thus, the quality categories, in each case, refer to the situation relative to the group average. Below, we also defined three fuzzy categories.



Visually illustrated, it is possible to evaluate the lean effectiveness of each value stream based on its eigenvalue. The model in this case illustrates the exact deviation from the average efficiency. Numeric values cannot be interpreted in this case either, so we use the method of fuzzy logic.

CONCLUSIONS AND SUGGESTIONS

In our research, using a case study, we created a model to illustrate the lean effectiveness of value streams. Based on the fuzzy logic, we selected an expert input function that was one of the domestic subsidiaries of an international automotive manufacturing organization. Aggregate indicators were compared to the average result of all value streams along a standardized norm. Determining weights in the model is both possible and recommended, but the definition of weights is not exact either, as different experts and decision-makers have different preferences for indicators that affect lean performance. Thus, the creation of

weights can also be considered subjective, so fuzzy logic can be applied effectively in this case as well. There is no defuzzification at the end of the model, as it is not necessary to define an exact value for managerial decision-making, but to use intervals judged by language variables closer to human thinking. With the help of the model we have outlined, it is possible for lean fuzzy models to determine the extent of lean not only based on the lean index and financial data of enterprises.
From the controlling aspect, the model can also provide feedback on the efficiency of value streams and lean tools and methods. By applying the model, it is possible to achieve lean goals more effectively and to define intervention points more precisely. The logic of the model can also be applied to the evaluation of aggregate indicators of the area measured by any controlling system. The conceptual model we have outlined is an illustrative example.
It is extremely important for businesses to create a detailed controlling system that covers all hierarchical levels. This may make it possible to explore intervention points. Our model can be excellent for evaluating and monitoring other processes related to other specific goals (eg crisis resilience). In our research, we have clearly shown that the application and selection of standardized norms are key to the process of effective performance appraisal. The standardized norm we use has been determined based on the experiences and judgments of the participants in the research and business practice. It is a model with complex information content. Complex information content can be more conducive to managerial decision making. It should be emphasized, however, that in some cases, such as portfolio analysis and company evaluation, models with simpler standard norms may prove more effective. This raises the extension of the research to compare the effectiveness of the complex standard norm we have created and the models with simpler standard norms in supporting managerial decision making.
The steps of the model we present form a general methodological framework that allows its application regardless of organizational profile and sector.
As a further research opportunity, we recommend the calculation of the model we have outlined with data, and the development of a model for the management of extremes according to different standardization norms.

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