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KPI tree - a hierarchical relationship structure of key performance indicators for value streams

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Abstract

Performance Measurement Systems (PMS) have been a potential answer to problems related to production systems monitoring, allowing the management and manipulation of data collected at various levels in organizations. PMS can be defined as a group of indicators in an information system. There are several types of PMS, however, the relationship between indicators in a PMS is still an issue that needs to be explored, as the KPIs in a production system are not independent and may have an intrinsic relationship. The purpose of this paper is to present a multilevel structure and its intrinsic structural relation for managing and analysing KPIs for a value stream production system. This hierarchical structure has different KPI levels such as Improvement KPIs, Monitoring KPIs, and Results KPIs or KPR (Key Performance Results), intrinsically related from the strategic levels to the operational levels. This provides a useful tool for the management of production systems, being used to analyse, and support the organization's continuous improvement processes.

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1. Introduction

With the increase in competitiveness and market demand, companies are obliged to adopt practices that aim at cost optimization, increase in quality, and renewal of products and their useful life, to survive the conjuncture (Suzaki, 2017). With the emergence of the Lean Production philosophy, based on the Toyota Production System (TPS), whose goal is to increase value for the client while simultaneously striving for the elimination of waste, companies have gained more concepts and tools to face new challenges (Womack, Jones, and Roos 1990). However, the survival of companies has been related to long-term competitiveness, i.e., companies must guarantee a production system characterized by high performance in terms of reliability, sustainability, flexibility, and productivity (Ante et al. 2018). According to Mejjaouli and Babiceanu (2014), manufacturing companies characterized by long-term competitiveness issues are subject to more complex problems, which in most situations have to do with compliance, low stocks, uncertainties in demand, standardization of processes, and product development complexity.

With the rise of industry 4.0, it became easy to collect data on machines, emphasizing quality, and avoiding flaws in the production process. However, this paradigm creates the opportunity for great flexibility and competitiveness in production systems, but at the same time requires a high level of system control, which depends on the ability to measure, monitor, and evaluate the system parameters (Lu, 2017).

According to Braz, Scavarda, and Martins (2011), one of the pillars that makes it possible to face the challenge of monitoring the performance of production systems, is the implementation of a robust system to control and monitor the entire production system.

Aikhuele, Ansah, and Sorooshian (2017) consider that performance measurement is an integral part of a planning and control system that cannot be treated in isolation, but rather as part of a strategy to evaluate actions taking into account efficiency and effectiveness. Therefore, a production manager can evaluate performance through the analysis of KPIs, which allows quantifying the efficiency and effectiveness of actions both in part and also in the entire production process without losing sight of general aspects such as strategic directives, customer satisfaction, and other intangible parameters (Ante et al., 2018a).

Therefore, manufacturing industries have incorporated several systems to evaluate the performance of the production processes, called Performance Measurement Systems (PMS). A PMS consists of a set of metrics capable of quantifying the efficiency and effectiveness of the production processes (Neely, Gregory, and Platts 1995). In a PMS, the strategic objective is defined according to the needs of the company, then, each objective is supported by a detailed set of indicators that contribute to achieving the strategic objectives. These indicators are called Key Performance Indicators (KPIs), which consist of a quantifiable set of measures in a PMS, which reflect the critical success factors of the company or a particular activity (Kang et al., 2016).

KPIs plays a crucial role in the study and improvement of the production system performance, according to International Standard ISO 22400-1 (2014) and International Standard ISO 22400-2 (2014) report, it presents a set of 34 KPIs along with their contexts and content. Some of these KPIs are not independent, with an intrinsic relationship between them. Therefore, for the effective use of KPIs for production control or continuous improvement, understanding the relationships between them is very important.

In a production system, once a set of KPIs is defined in a PMS, each parameter reflects a facet of the system's performance. Since different variables of performance are not independent and cannot be separated, KPIs also have mutual relationships. Some KPIs can be correlated positively or negatively. Some can be obtained and replaced by others. To effectively use KPIs for continuous improvement (CI) or production control, it is important to understand these relationships (Kang et al., 2016b).

Kang et al. (2016) stated that the investigation of KPI relationships relies mainly on statistical data-based approaches. This method identifies positive or negative correlations between KPIs. However, it may fail to find intrinsic connections and managerial insights. In addition, data collected from different companies can lead to substantially different results. Therefore, a new approach to discovering KPI relationships through intrinsic implications needs to be developed. To achieve this, KPIs need to be properly arranged at different levels, which means, a hierarchical structure must be developed.

There are several hierarchical structures developed, Cross and Lynch (1988) proposed the SMART (strategic management and reporting technique), a four-level performance pyramid that connects company strategy with operations through the hierarchy, transforming objectives from up to measures from bottom. Fitzgerald et al. (1991) developed the Result and Determinant Framework. The structure divides measures into two categories: results (measures that are actions result, for example, competitiveness, and financial performance) and determinants (measures that measure actions that lead to certain results, for example, quality, flexibility, use of resources and innovation). Kaplan and Norton (2005) developed the Balanced Scorecard, the well-known performance measurement system. It is a balanced performance measurement system; it contains both financial and non-financial measures. It sees the business comprehensively from four different point of views (customer, financial, innovation and learning, and internal processes). Ruano Pérez et al. (2018) and Perera and Perera (2019) identify the growing importance of hierarchical models that have been drawing the attention of practitioners and also researchers, given the growth of work done in this area.

Despite these efforts stated above, there is still space for improving the knowledge of the intrinsic relationships of KPIs in production systems (Ante et al., 2018a). Thus, this article aims to improve the knowledge of the intrinsic relationships of KPIs in production systems, presenting details of a value stream performance measurement system, based on a KPI tree, a hierarchical structure used to describe and relate KPIs from the strategic to the operational level.

The KPI tree for this company was presented by Ante et al. (2018) and the current submission increases the knowledge related to the specific utilization of such a tool for measuring the performance of a value stream. Thus, this tool is structured considering a lean production system, organized by value stream, to collect data at a very specific level. The system in this study belongs to the Bosch group, located in Braga-Portugal. The KPI tree is composed of several levels of indicators, and based on this, the relationship between levels and between indicators within the levels is explored. In addition, the usefulness of using the KPI tree in continuous improvement projects will be presented.

2. Literature review

Performance measurement systems are mainly based on financial measures, are strongly results-oriented and have a focus on past actions since they can describe actions or decisions only after they are applied (Hatzigeorgiou and Manoliadis, 2017; Staedele et al., 2019; Susilawati, 2021). This idea is reinforced by Peñaloza, Formoso, and Saurin (2017), in an analysis of PMS in the area of security, refer that the evaluation indicators use a retrospective or evaluation perspective of past conditions based on statistical data.

Roth, Deuse, and Biedermann (2020) call static PMS those that collect and evaluate indicator data, but their statistical instruments are not sufficient to consider the dynamic behaviour of the organization, and therefore cannot evaluate trends, and reflections of variability, waste, etc. Therefore, these authors advocate a framework that advocates a dynamic system of performance measurement structured from the vertical and horizontal integration (inter and intra linkage) of different dimensions composed of various quantitative and qualitative indicators.

Based on an extensive literature review investigation, Aikhuele, Ansah, and Sorooshian (2017) identified several PMS and concepts and, as a synthesis, the authors refer that most of these systems are limited to a certain delimited set of values focused on a few aspects of lean manufacturing principles. For example, a proposed PMS for British manufacturing companies, they are based on 5 lean enablers, namely supplier relationship, lean management, lean workforce, process excellence and customer relationship, and considers supplier delivery, management culture and process optimization as performance indicators.

Several authors hold the view that more effort needs to be put into developing a model that evaluates all lean principles (Carneiro et al., 2017; Khaba and Bhar, 2017), going beyond traditional indicators such as meeting delivery deadlines, financial indicators, and other specifications, and include factors such as value maximization, waste minimization, cycle time reduction, and production flow stability improvement, which causes the PMS to accommodate indicators that are characterized by a gradation between the quantitative and the qualitative.

Chiarini and Vagnoni (2015) stated that the TPS-lean PMS is usually based on funded limited set of measures that preys on the speed and frequency of the performance indicator measurement process. However, in a study conducted by the authors on the world-class manufacturing concept developed by Fiat, they identified that the company has developed its own PMS that integrates the strategic objectives, safety, quality, environment, and energy management aligned with other goals established in the strategic planning. Although the performance indicators are integrated into a single system, they are designed in such a way that safety and quality cannot have trade-offs with costs or other strategies. Therefore, it is an articulated model of performance indicators.

The increasing complexity of goods and services production systems, therefore, has provoked researchers and practitioners to seek an articulated solution for performance evaluation. Several authors (Hatzigeorgiou and Manoliadis, 2017; Staedele et al., 2019; Susilawati, 2021) consider that with the emergence of the Lean Production philosophy, performance evaluation has gained new challenges and greater complexity as objectives such as waste reduction, variability reduction, and simplification of operations have become pursued, and new forms of evaluation such as benchmarking have been adopted to address this need for more comprehensive evaluation.

A line of thought related to PMS approaches is rooted in the quality management area, being two examples of those the European Foundation for Quality Management (EFQM) Excellence Model and Balanced Scorecard (BSC) (Hatzigeorgiou and Manoliadis, 2017). The BSC proposes a balanced set of measures that provides top management with an overall understanding of the business (Olivella and Gregorio, 2015); however, the authors point out that this model presents a high-level view, not so easily applicable to the operational level. In general, these frameworks demonstrate that there is a need to combine groups of quantitative results and qualitative results. The need for diversification in the PMS approaches, is also highlighted by Nudurupati, Tebboune, and Hardman (2016), who suggest the incorporation of “behavioural as well as environmental and social measures”, enlarging the collection of data to collaborative networks and social media.

Beelaerts van Blokland et al. (2019) suggest what they call a third-generation business PMS or method that consists of evaluating intangible and non-financial dimensions, with indicators such as Conception, related to research and development, Configuration, related to Supply Chain, and Continuation, related to People Management, to thus obtain a "big picture" or "big story" about what happens within the organization and that helps to understand its complexity.

Some of the proposals to advance PMS are pyramid-based models, which consider a hierarchy of organizational objectives including operational performance, and prism models based on a prism of performance evaluation perspectives including stakeholder satisfaction, strategies, processes, capabilities, and others (Perera and Perera, 2019; Ruano Pérez et al., 2018).

For Ante et al. (2018), a structured framework of performance indicators is crucial for measuring the gap between the current state of operations and the desired state, and in many cases, it can be used to identify the path of progress in terms of overcoming productivity gaps. Therefore, they suggest a pyramid-based structure divided into three levels hierarchical levels: main system, sub-system and individual measures. The topmost level (main system) corresponds to the corporate vision, and financial and market objectives. At the intermediate level (sub-system), are the objectives regarding the maintenance of high productivity and quality, speed of response, flexibility, and lead times. And finally, the last level is related to the operations with indicators such as cycle time, loss of materials, number of failures, etc.

As implicitly shown, all PMS are based on performance indicators related to the objectives of the organization and the relationship between those indicators. A performance indicator quantifies systems’ dimensions and behaviours, measuring how well an activity is being performed (Eckerson, 2009), and can act as an early warning sign that an unfavourable condition exists. A Key Performance Indicator (KPI) reflects the performance of an organization considering its key success factors. KPIs carry information relevant to managing operations at various levels in the organization. Through the measurement and continuous monitoring of KPIs, aspects in the production process are quantified and identified that allow the continuous improvement of the system (Kang et al., 2016b). According to Stricker, Echsler, and Lanza (2017), understanding the connection that a KPI has regarding the quantities measured in the system is important, but it is also important to understand the relationship between KPIs and the interdependencies inherent to them. Jooste and Botha (2018) argue that there is a limited understanding of the impact of KPIs on the projects or organization results and the impact of one KPI on another.

KPIs have different directions, strengths, and polarities, i.e., the addition of some can cause the decrease of others, positive (the bigger the better), negative (the smaller the better). For Saiz, Bas, and Rodríguez (2007) when there is a deviation from a certain indicator, certain objectives are not achieved, making it hard for the manager to have early information on the causes of the problem, due to the lack of information associated with the deviations of the indicators, this is because a cause-and-effect relationship between the indicators is not established.

The relationships between KPIs are established in several ways and using various techniques. Rodriguez, Saiz, and Bas (2009) use a method based on statistical data that consists of quantifying the cause-and-effect relationship between KPIs. They apply the Principal Component Analysis (PCA) method to determine the correlation coefficients. Jooste and Botha (2018) applied the same method improving it with Parallel Analysis (PA) and Screen Plot, for better identification of the indicators. Zhu et al. (2018) propose a structure for organizing KPIs. The structure is divided into process KPIs and measurement elements. Since process KPIs are dependent on the measuring elements, the latter are measured directly on the shop floor. According to Kang et al. (2016), statistical methods have an advantage in identifying the sign (positive or negative) of the relationships. However, they may not find intrinsic connections between indicators and their management ideas, in addition, the data collected in different production systems can lead to substantially different results. The same author proposes a multilevel hierarchical structure, which consists of three categories: supporting elements, intermediate KPIs, and comprehensive KPIs.

Although the International Standard ISO 22400-1 (2014) and International Standard ISO 22400-2 (2014) report describes 34 KPIs, more stringent definitions are necessary to make clear the differences between them. It is necessary to redefine some KPIs and additional KPIs must be added. In addition, these KPIs must be classified logically, so that it is necessary to discover the intrinsic relationships between them. Therefore, it is necessary to group KPIs into various categories at various levels, which have explicit cross-links, and the KPI tree performs this function well.

A Key Performance Indicator Tree (KPI tree) is a PMS in the form of a tree diagram which combines performance indicators in a hierarchical structure from the strategic objective at the highest level of the organization to operate at the lowest level, providing a transparent view of the status of all divisions of the organization at the strategic, tactical and operational level (Ante et al., 2018a). According to these authors, the KPI tree appears to respond to difficulties with the design of the entire structure of the PMSs, requiring the identification of appropriate key performance indicators (KPIs), the implementation of monitoring systems, and the identification of the relationship between the performance indicators.

3. Experimental

This section presents the adopted research methodology and the initial characterization of the KPI structure in the studied company.

3.1. Methodology

Case studies are used to clarify why a decision or set of decisions was made, how they were implemented and with what results were achieved. Moreover, a case study presents an analysis of a real-life problem, using practical methods to solve it and analyse its results (Easterby-Smith et al., 2018; Saleheen et al., 2014).

As the main goal of this work was to improve the knowledge of the intrinsic relationships of KPIs in production systems, presenting details of a value stream PMS, based on a KPI tree, a case study approach was selected. Thus, a case study would allow to illustrate the application of the KPI tree in the industrial context, at the company where this concept of the KPI tree was also developed. Moreover, it would also allow studying the way a KPI tree would promote continuous improvement projects.

The first step toward this study was to know how the KPI tree is built in terms of structure, indicator categories, and calculations. The second step was to know how the KPIs are linked to each other on the trees. After that, it would be possible to present some proposals for improvement of the utilization of the KPI tree in value stream continuous improvement projects.

3.2. KPI tree levels

According to Ante et al. (2018), the KPI tree is a tool adapted to the current dynamics of organizations, it contemplates their critical success factors, and can be adapted and improved according to the needs of the organization. Such a tool may help in the implementation of continuous improvement projects, as it can indicate the focus of the actions. In addition, the levels of the KPI tree correspond to the levels of responsibility in the company, i.e., each entity in the company knows which part of the KPI tree to look to obtain the information they need. In this case study, the KPI tree is composed of five levels of indicators as presented by (Ante et al. 2018).

- Level 1: Value Contribution

It constitutes the existence of the business unit (factory target). Executive management is responsible for them. The value contribution KPI is the highest in the hierarchy, it gives a global view of what was delivered as value to the customer and what would come in a form of profit or contribution to the survival of the company when compared to the product selling price. In the context of value contribution are KPIs related to controlling, accounting and finance. For example, Planned Manufacturing costs are a controlling KPI which are divided into planned manufacturing variable costs and planned manufacturing fixed costs and so on.

- Level 2: Key Performance Result (KPR)

At the KPR level, there are performance indicators at a financial level, such as total cost, delivery services, and quality, which contribute to determining the overall value of a given value stream (product or area). Operation management is responsible for them. This level of KPI receives all the inputs from the level below and translates them into cost KPIs. This translation allows the controlling of consumption in terms of costs. For example, the number of end products in a warehouse, or the amount of work in progress can be translated into cost values on this level of KPIs.

- Level 3: Value Stream KPR

At the Value Stream level, non-financial performance indicators for a given value chain are found, such as number of defects, productivity, and delivery performance. They constitute inputs for KPR. Value stream management is responsible for them. The value streams KPR are effective for value stream management, this level groups all the KPIs related to topics that assess the performance of the value stream in terms of quantities and time. They are supported by Monitoring KPIs, presenting a global and combined view of every product variant KPI. For example, by monitoring the produced quantities, the number of operators and working time, the productivity of product variants and as well as the productivity of the value stream can be obtained.

- Level 4: Monitoring KPR

At the Monitoring level, are found the indicators to execute and monitor the production system such as OEE, stock level, and Line Takt. They are inputs for Value Stream KPRs. Shop floor leadership is responsible for them. Monitoring KPIs are obtained by some sort of calculation that can be performed using standard formulas in line with the system features. Most of the KPIs of these levels are dependent on others to have some value or result. Kang et al. (2016) call these sets of KPIs Basic KPIs, according to them, basic KPIs reveal some performance aspect of work system, obtained from monitored data of supporting elements. They categorized the basic KPIs into three groups: production, quality, and maintenance.

- Level 5: Improvement KPIs

In terms of Improvement, there are indicators directly measured in the process, such as cycle time, defects, stops, and lack of resources. Improvement KPIs indicate a potential for improvement and areas of activity and constitute inputs for Monitoring KPIs. Operators are responsible for the Improvement KPIs. If these are well-defined, then obtaining improvement KPIs become a simple direct process to be implemented by the organization, either by collecting automatically with sensors or measuring manually. Improvement KPIs are considered elementary, so that performance can be identified and measured, making it easy to define the right actions for performance increase. (Kang et al. 2016) defines these as support elements, being divided into categories of time and quantity used to support improvement or basic KPI.

4. Results and discussion

4.1. Intrinsic relationship between Indicators

The intrinsic relationship among indicators through the KPI tree follows a bottom-up approach, the improvements KPIs support the monitoring KPIs, and these are the KPRs. Improvements KPIs are used to collect data at the level of the production process on machines, operators, or even the combination of both in a single indicator. And it is from these data that the results of the above indicators are derived. These data indicators are essentially categorized as time or quantity (Kang et al., 2016b), which are subsequently worked with other factors to obtain the results of the elements above.

The following is a demonstration of how KPI tree indicators linked to productivity are intrinsically related. A tree that can be used to report the productivity of a value stream, and all the indicators underlying it. It is important to note that trees such as the one below can exist for several KPRs related to quality, delivery performance, and indirect productivity.

The demonstration is done from top to bottom, starting from KPR to the Improvements KPI that supports them. The indicators will be identified by (I) improvement, (M) Monitoring, and (R) KPR for better categorization according to the levels of location in the trees. Table 1 shows the units of the indicators represented in the KPI tree.

Table 1. KPI tree productivity indicator units

Unit	Description	Unit	Description
pcs/mhr	parts per hour man	min	minutes
Nr	labors, unity	event	events
h	hour	min/event	minutes per event
pcs	parts	pcs/event	part per event
sec	Seconds	pcs/sec	part per seconds

The formulas used to describe the relationships are based on the case study. At the top of the productivity KPI tree, **Fig. 1**, is the production line productivity (WPD):

$$WPD = \frac{Output}{N_{pcd} * Workinghours} [pcs/m\,hr] \text{ (R),}$$

- $Output[pcs]$ - quantity of produced parts (M),
- $N_{pcd}[Nr]$ - number of direct line employees (I),
- $Workinghours[h]$ - observed production period (M).

The number of employees is considered an Improvement KPI, and it can be measured directly through observation. As shown in Fig. 1, the productivity of the Value stream can be obtained through the relation of the productivity of the existing lines in it.

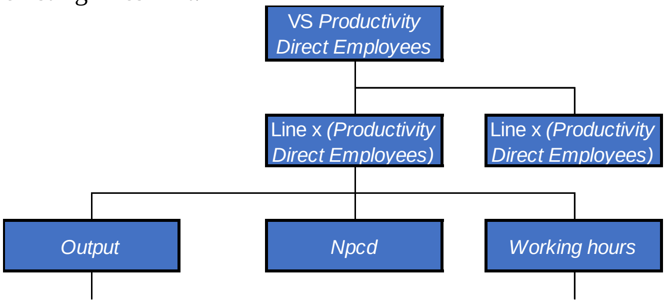

Fig. 1. KPI tree Productivity for a Value Stream (Production Line)

At the level of Monitoring KPI is the Output of the line, Fig. 2 shows its connection:

$$Output = \frac{POT}{} * OEE[pcs] \text{ (M),}$$

- $POT[min]$ - planned production time (M),
- $[psc/sec]$ - line cycle time (M) e
- $OEE[\%]$ - effectiveness indicator (M).

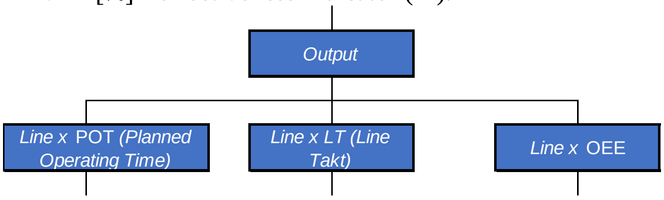

Fig. 2. Line Output

POT, Fig. 3, obtained by:

$$POT = Shifttime - Legalbreaks - Plannedstoppages[min],$$

- $Shifttime[min]$ - shift duration time (I),
- $Leagalbreaks[min]$ - time for legal breaks and the (I)
- $Plannedstoppages[min]$ - planned downtime (M).

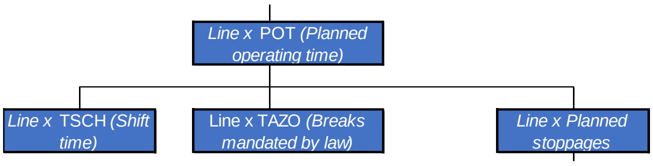

Fig. 3. Planned operating time structure.

$Shifttime$ and $Legalbreaks$ are predefined basic times. While the planned downtime, Fig. 5, is obtained by:

$$Plannedsoppages = TPM + Shiftchange + sampleproduction + Plannedmeetings + PlannedCIPactivities[min],$$

- $TPM[min]$ - duration of productive maintenance (M),
- $Shiftchange[min]$ - shifts change time (I),
- $Sampleproduction[min]$ - sample production time (I),
- $Plannedmeetings[min]$ - planned meeting time (I),
- $PlannedCIPactivities[min]$ - time for continuous improvement activities (I).

Among these KPIs, only the TPM, Fig. 5, is not an Improvement KPI, which is obtained by:

$$TPM = Autonomousmaintenance + Plannedmaintenance[min],$$

where the first part is autonomous maintenance time and the second is planned maintenance time, respectively. $Autonomousmaintenancetime$, is obtained by:

$$Autonomousmaintenance = \sum_{i=1}^{n} Durationofsingletask_i * Frequency_i\ [min]\ (M)$$

- $Durationofasingletask[min]$ – activity duration (I),
- $Frequency[Nr]$ – number of times the activity is performed (I) e
- $n[un]$ – Number of tasks to be performed (I).

The planned maintenance time is obtained by:

$$Plannedmaintenance = \sum_{i=1}^{n} Duration\ of\ singletask_i * Frequency_i\ [min].\ (M)$$

$Output$ it is also calculated with the cycle time, Fig. 4, and this one is obtained by:

$$= \sum_{i=1}^{n} CTOP_i + CTMAE_i[sec/pcs],$$

- $CTOP_i[sec/pcs]$ - cycle time of an operation performed by the operator (I) and
- $CTMAE_i[sec/pcs]$ - cycle time of an operation performed by a machine (I).

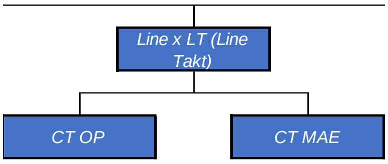

Fig. 4. Cycle time structure

Cycle time structure

$Output$ is also calculated by OEE, Fig. 6, and this one is obtained by:

$$OEE = (1 - Performancelosses * Qualitylosses * Availabilitylosses)[\%],$$

- $Performancelosses[\%]$ - line performance losses (M),
- $Qualitylosses[\%]$ - loss of quality on the line (M) and
- $Availabilitylosses[\%]$ - availability losses (M).

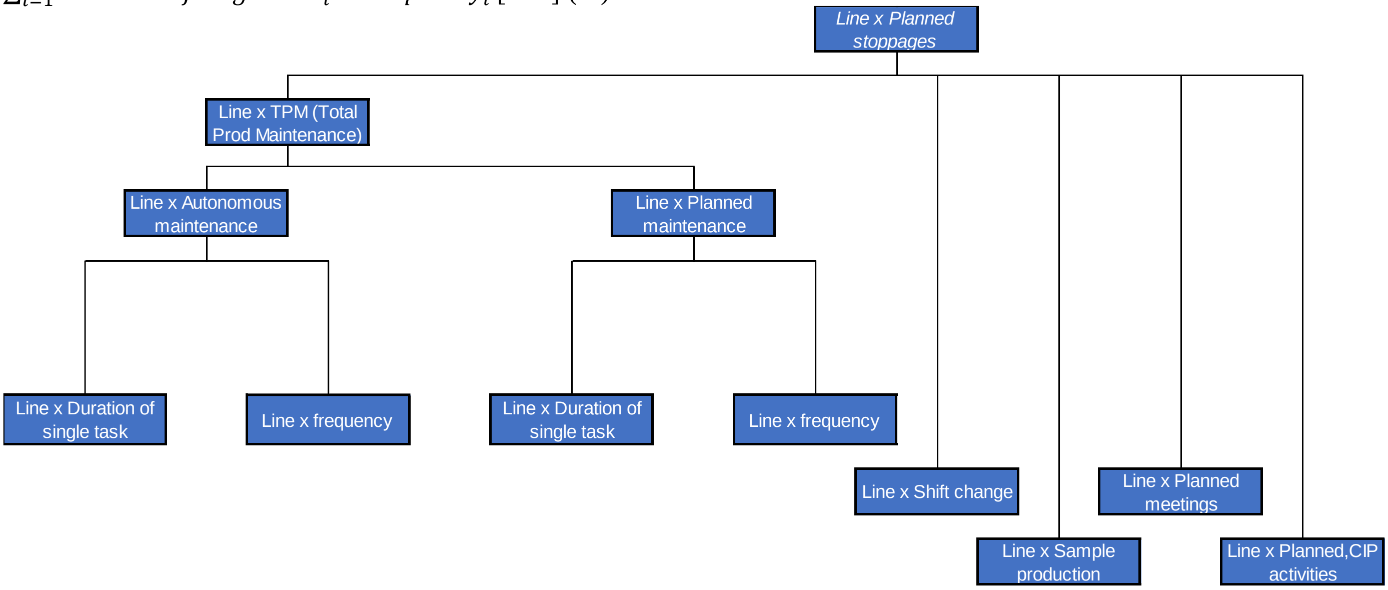

Fig. 5. Structure of planned stoppages

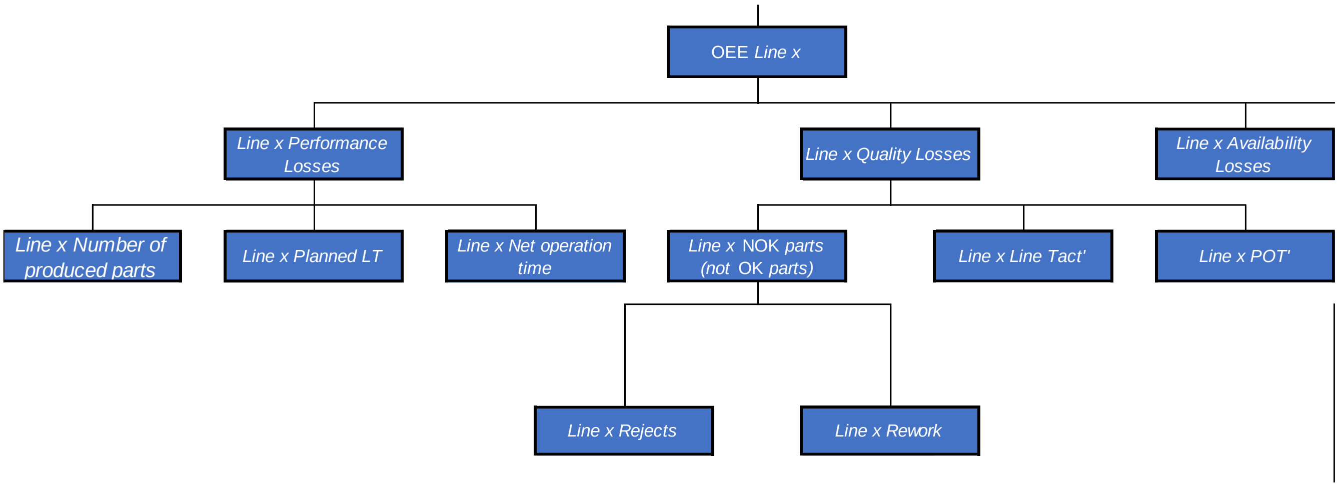

Fig. 6. OEE structure with loss of quality and availability

The performance losses are obtained by:

$$Performancelosses = 1 - \left(\frac{Numberofproducedparts*PlannLT}{Netoperationtime*3600}\right) * 100[\%],$$

- $Numberofproducedparts[Nr]$ - quantity produced including good, defective and reworked (M),
- $PlannLT[sec/pcs]$ - planned cycle time (M) and
- $Netoperationtime[min]$ - planned time of operation without losses due to availability (downtime, lack of material and employees) (I).

The quality losses, Fig. 6, are obtained by:

$$Qualitylosses = \left(\frac{NOK * Line\ Takt}{POT}\right) * 100[\%],$$

- NOK - number of defective parts (I),
- Line Takt - cycle time and (M) and POT - planned operating time (M).

Being that,

$$NOK = Reject + Rework[pcs],$$

- $Rejects[pcs]$ - quantity of rejected parts (I) and
- $Rework[pcs]$ - number of reworked parts (I).

The Availability Losses, Fig. **7**, are obtained by:

$$Availabilitylosses = \left(\frac{COlosses+Organizationallosses+Techinicallosses}{POT}\right) * 100[\%],$$

- $COlosses[min]$ - losses during changeover (M),
- $Organizationallosses[min]$ - organizational losses (M) and
- $Techinicallosses[min]$ - technical losses (M).

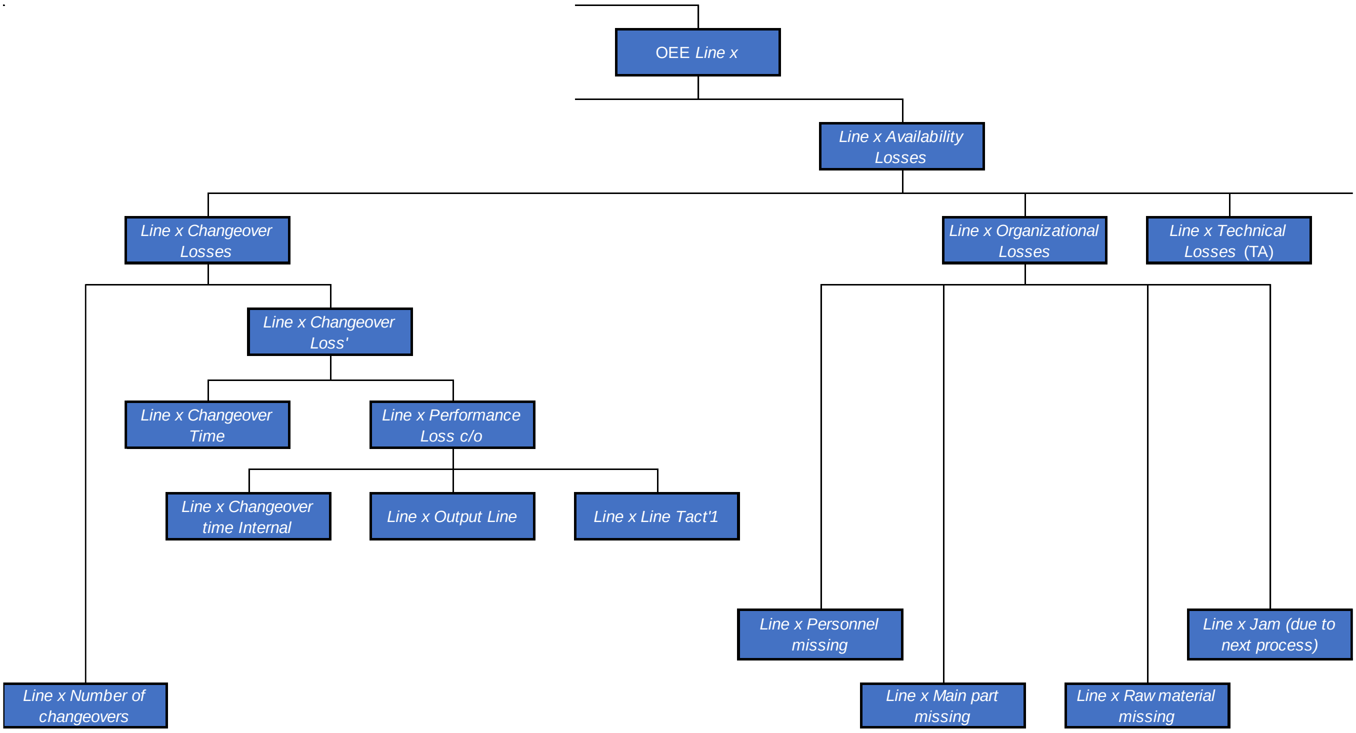

Fig. 7. OEE availability structure

Changeover losses, Fig. 7, are obtained by:

$$COlosses = Numberofchangeover * Changeoverlosses[min],$$

- $Numberofchangeover[Nr]$ - number of changeovers made (I) and
- $Changeoverlosses[min]$ - changeover losses (M).

The losses for each changeover, Fig. 7, are obtained by:

$$Changeoverlosses = (OutputCO *) + Changeovertimeinternal[min/event],$$

- $OutputCO[pcs/event]$ - quantity produced during changeover (I),
- $[pcs/sec]$ – cycle time (M) and
- $Changeovertimeinternal[min/event]$ - internal changeover time (I).

Organizational losses, Fig. 7, are obtained by:

$$Organizationallosses = Personelmissig + rawmaterialmissing + jam[min],$$

- $Personelmissig[min]$ - lack of collaborators (I),
- $rawmaterialmissing[min]$ - lack of raw materials (I) and
- $jam[min]$ – obstruction during production (I).

The technical losses, Fig. 8, are obtained by:

$$Techinicallosses = Durationoffailure * Numberoffailure[min],$$

- $Durationoffailure[min]$ - duration of the technical failure occurred (M) and
- $Numberoffailure[Nr]$ – number of Occurrences (I).

The duration of the failure, Fig. 8, is obtained by:

$$Durationoffailure = Reactiontimeofrepairservice + Reactiontimeofoperator + Timerepairthefailure[min]$$

- $Reactiontimeofrepairservice[min]$ - repair service reaction time (I),
- $Reactiontimeofoperator[min]$ - operator reaction time (I) and
- $Timerepairthefailure[min]$ - repair time of failure (I).

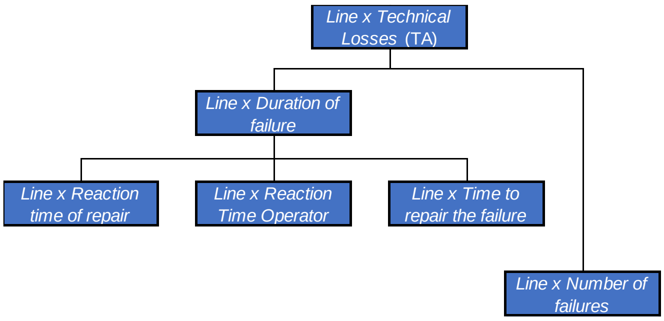

Fig. 8. Structure of technical losses in the OEE

The observation period is part of productivity calculation, Fig. 9, and this is obtained by:

$$Workinghours = Plannedstoppages + POT[h],$$

- $Plannedstoppages[min]$ - planned downtime (M),
- $POT[min]$ - planned production time (M).

The planned production time in this branch, Fig. 9, is broken down as follows:

$$POT = Ordertime + AgreedBreaktime + Scheduledmaintenancetime[min],$$

- $Agreedbreaktime[min]$ - break time (M),
- $Ordertime[min]$ - time to order (M) (batch),
- $Scheduledmaintenancetime[min]$ - Planned maintenance time (M).

The order time (batch), Fig. 9, is obtained by:

$$Ordertime = Executiontime + Setuptime[min],$$

- $Executiontime[sec]$ - execution time per unit (cycle time) (M),
- $Setuptime[min]$ -preparation time (M).

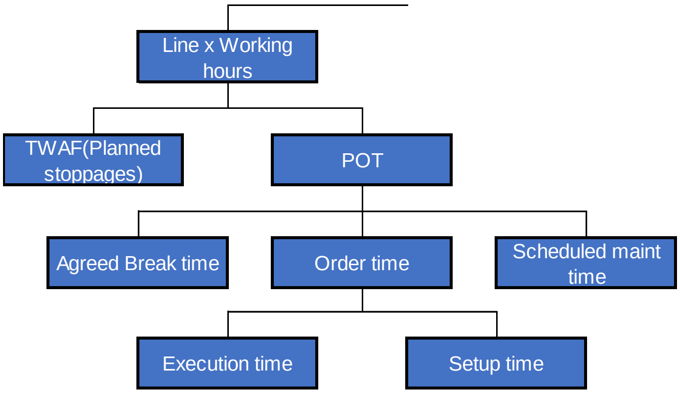

Fig. 9. Working hours KPI´s structure

The execution time (time to produce an order), Fig. 10, is obtained by:

$$Executiontime = Basictime + Allowancetime[sec],$$

- $Basictime[sec]$ - basic time of an operation is obtained by (I),
- $Allowancetime[sec]$ - time allowed for any interruptions (I).

The basic time for an operation, Fig. 10, is obtained by:

$$Basictime = Ativitytime + Waitingtime[sec],$$

- $Activitytime]$ – time to perform an operation (I),
- $Waitingtime]$ - waiting time between operations (I).

The activity time of an operation, Fig. 10, is obtained by:

$$Activitytime = influenciabletime + noninfluenciable],$$

- $influenciabletime[sec]$ - time which operator impact product (I),
- $noninfluenciabletime[sec]$ - time which operator does not impact the product (I).

The time allowed for any interruptions, Fig. 10, is obtained by:

$$Allowancetime = Thechinicaltime + Personal],$$

- $Thechinical[sec]$ - Interruptions due to technical situations (I),
- $Personal[sec]$ - Interruptions due to personal situations.

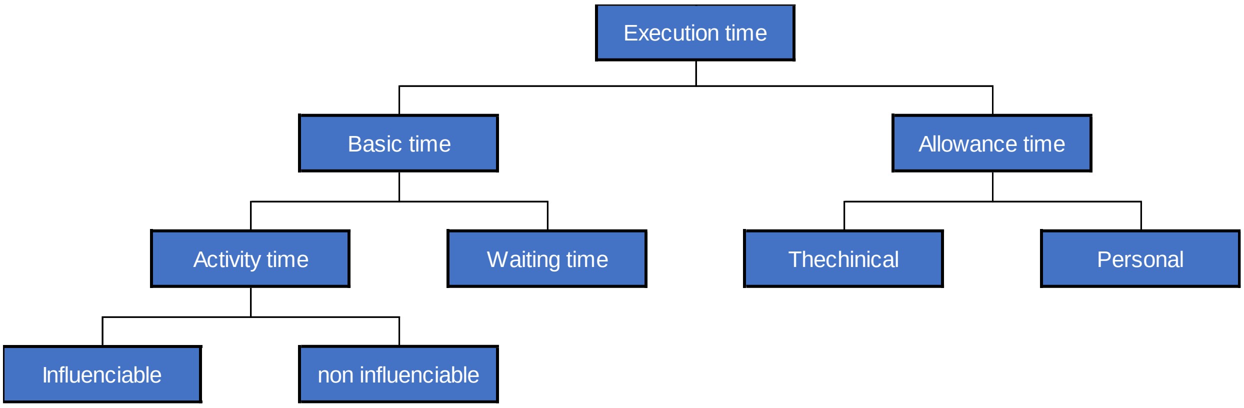

Fig. 10. Execution time, time to produce 10 units for example

The union of the branches represented above results in a larger tree that covers almost all measured indicators that contribute to the productivity of a line, and consequently the value stream. The collection and availability of data to feed each indicator of the structure make the tool more robust and useful for system monitoring. The intrinsic relationship between the indicators helps in calculating the results of the indicators at the highest levels, with the values of the indicators at the lowest levels being directly measured.

4.2. KPI tree as a tool to support improvement projects

Besides the use of the KPI tree to assess the performance of various indicators in the value stream, the company also uses it to define continuous improvement projects. However, this tool was not well used for this purpose, which led to a long time in the definition of projects, because there was no well-designed structure like the KPI tree that could explain the root causes of the project and its impact on indicators at higher levels of the value stream.

Thus, it was found that the definition time was 154 minutes per project, and often 10 to 30 projects are defined, which normally take a few days to define all. It was also found that only 38% of the projects had KPI trees, but these were not built according to the norms, which often made it difficult to discover the root causes of the projects, and consequently in the high execution time.

The problems mentioned above had the following root causes:

- No visual standard for KPI trees: There was no visual standard for the KPI trees used, which made it difficult to read and apply the created trees.
- Inexistence of a standard to create a KPI tree: There was no standard tool to create the KPI tree, which made it difficult to implement in a project.
- Difficulty in accessing the KPI tree documentation: Access to documents related to the KPI tree was difficult, leading people to a lack of knowledge about the KPI tree and consequently difficulty in using it.
- No databases to feed KPIs: KPI tree data was not obtained automatically, it was placed manually. In addition, intrinsic relationships between KPIs were not established.

The causes pointed out led to the lack of a structure of indicators that would allow a quick and relational analysis of them, to define projects in less time and, consequently, guarantee the presence of this tool during the definition, execution, and presentation of projects. To reduce the impact of these issues, the following proposals were developed:

- Creation of a new visual standard: this solution allowed for better visual management of the indicators, allowing them to be differentiated based on their status, and making it easier for users to read them.
- Development of a tool to create KPI trees: this solution allowed KPI trees to be created exclusively with a tool to ensure agility and maintenance of the visual standard created.
- Organization and centralization of documents about the indicators and the KPI tree: this measure allowed easy access to documents about the KPI tree and its indicators. Which contributed to the increase of the knowledge of the people involved in the process.
- Creation of a database and establishment of the intrinsic relations between the indicators: this measure allowed the obtainment of data and the calculation of the results of the indicators on the upper levels of the KPI tree in an automatic way. In this way, the tool to create a KPI tree has become more agile and effective for its proper use.

The results obtained with the implementation of the previous proposals led to an increase in the number of projects with a KPI tree. During the project definition workshops, the tool was applied with functions that facilitated obtaining the data and reading the results indicators automatically and fast. Therefore, the percentage of projects with a KPI tree increased from 38% to 77% as shown in Table 2.

Regarding to the time taken to define projects, it has also been reduced, since the phases of analysis of indicators that were previously carried out on sheets, and tables and took a long time, causing problems in reading the relationship between the indicators and updating their data. The problem was solved by automating the process of obtaining the data, creating the KPI tree, and establishing the intrinsic relationships between the indicators. Thus, the derivation time was reduced from 152 to 126 minutes.

Table 2. KPI tree implementation results

Period	nov/19		oct/20	
No Projects	39	100%	70	100%
No Projectcs without KPI Tree	24	62%	16	23%
No Projects without KPI Tree	15	32%	54	77%
Project definition time (min)	152		126	

5. Summary and conclusion

In this article, a hierarchical structure that intrinsically relates the performance indicators in a KPI tree is presented. The relationship of such a structure applied to a value stream allows the representation of the indicators' values measured and interrelated at different levels, to support the management decisions.

A KPI tree can be composed of several KPIs so that it covers all the monitorization points, but it is not easy to implement on a large scale because not every system has a very well-defined gathering data system. Moreover, the way the data is collected and managed is important to make it easy to treat and reported. Once a set of KPIs for a KPI tree is defined, a set of targets for these defined KPIs must be defined as well, so that each KPI can be compared to its target to evaluate improvement opportunities. Therefore, the KPI tree can be used to track the root causes of a deviation by the traceability that is enabled by intrinsic relations established in the hierarchy of KPIs.

The tool can indicate the root cause of the problem, but not the solution. This is possible because the representative structure allows an easy read of the KPI status and the relationship between indicators is crucial to this function. besides the graphical structure, mathematical and logical relations must be set so that the interdependence between indicators can be established. Therefore, companies must standardize their way to measure, calculate and analyse KPIs to facilitate the construction and maintenance of a KPI tree.

Setting up a management tool like a KPI tree requires a level of maturity that avoid the organization to miss any important indicator and, therefore, allows it to select and collect information on KPIs useful to manage the performance of the production system. An example of establishing the relationships between the indicators has been presented by using the productivity KPI tree of a production line, being possible to relate the dependent indicators to the independent ones, since these latter are measured directly in the process.

A case study of the application of the KPI tree is also presented, which allowed reducing the time of defining project indicators and later to monitor its performance. The tool in this case study showed itself very useful to the context, it was a matter of getting all the data automatically and analyse the KPIs out of target in order to determine the focus of action.

It is important to note that a KPI tree tool as the one described must be adapted to the reality of the production system in which it is applied, to be useful for defining projects and making decisions at various levels of the organization.

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KPI树--价值流的关键绩效指标的层次关系结构

關鍵詞

绩效测量系统

KPI - 关键绩效指标

价值流绩效

精益生产

持续改进

摘要

绩效测量系统（PMS）一直是解决与生产系统监控有关的问题的潜在答案，它允许管理和操作在组织的各个层面收集的数据。PMS可以被定义为信息系统中的一组指标。有几种类型的PMS，然而，PMS中的指标之间的关系仍然是一个需要探讨的问题，因为生产系统中的KPI指标不是独立的，可能有内在的关系。本文的目的是提出一个多层次结构及其内在的结构关系，用于管理和分析价值流生产系统的KPI。这个层次结构有不同的KPI级别，如改进型KPI、监控型KPI和结果型KPI或KPR（关键绩效结果），从战略层面到操作层面都有内在联系。这为生产系统的管理提供了一个有用的工具，被用来分析和支持组织的持续改进过程。