EVALUATION OF LEAN CONCEPTS AND PRINCIPLES IN PERFORMANCE MEASUREMENT SYSTEMS: SUBWAY OPERATION CASE STUDY

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ABSTRACT

The increasing appearance of performance measurement systems reveals the companies’ efficiency pursuit in their key activities. However, most of the measured indicators focus on cost and productivity aspects, without prioritizing the customers’ needs fulfillment, which makes difficult to follow continuous improvement processes based on lean production philosophy. This study’s objective is to evaluate the application of lean concepts and principles within a performance measurement system. The research method involved the definition of practices that are associated with concepts and principles in three implementation degrees, in addition of a case study to evaluate these practices in a subway operation system. The obtained results demonstrate that the analyzed performance measurement system adopted lean philosophy, partially. Furthermore, highlighting several fields for achievement improvement and recommendations proposed to the system.

Keywords: Lean Production, Performance Measurement, Continuous Improvement, Subway System.

1. Introduction

The constant search for more efficient and lean production systems is one of the key strategies of major global companies (SANTOS; POWELL; FORMOSO, 1998). While the traditional system perceives production as a conversion process, new lean production philosophy outlooks the flows as well, which do not add value to the final product (KOSKELA, 1992). Therefore, an essential perspective to allow efficiency increase and process improvement.

Measurement indicators that reflect the performance level of production activities support problem and critical situation detection previously, as well as an improvement of process transparency: it is crucial to enable continuous improvement system (SANTOS; POWELL; FORMOSO, 1998). Several traditional systems for performance measurement have been criticized for not allowing decision-making changes during processes, in a timely manner. Distinctively of lean indicators, that have an operational focus, reducing waste and adding value, while the processes are still occurring (KOSKELA, 1992).

The study’s objective is to evaluate the application of lean concepts and principles within performance measurement systems. Consequently, an evaluation method of the lean application in adoption degrees was developed and a case study was conducted to evaluate the subway operation between the cities of Salvador and Lauro de Freitas (Bahia State, Brazil) utilizing the performance measurement system.
2. Literature Review

2.1. Lean Production

One of the lean philosophy fundamentals is the comprehension of production systems as a network of process flows (materials) intercepted by operations flows (people, equipment and methods) based in waiting, processing, transportation and inspection-control activities. Lean production aims to increase efficiency and value produced during the production process through the elimination of residual activities that do not add value (SANTOS; POWELL; FORMOSO, 1998).

Ohno and Shingo of the Toyota automobile company triggered the starting point of this new production philosophy during the 1950s. This philosophy was based from the reduction approach or stocking elimination (work in progress), lot size reduction, layout reconfiguration, suppliers’ cooperation and production drawn by demand (KOSKELA, 1992). Based on Womack and Jones (2003), lean thinking provides the ability to design, program and implement precisely what the customer wants, in the right place with the required quantity and only when the customer desires it (just in time principle). In other words, the customer can establish a product-pull-production, instead of a pushed production, stabilizing the demand.

According to Koskela (1992), the concept of value refers to the satisfaction of all requirements demanded by the customer. The management or strategy based on value has as essential characteristic of continuous improvement (kaizen), in order to increase value to the customer. Companies that follow this principle are entitled as customer-oriented, in contrast the companies that are oriented towards competition. The effort to reduce waste and increase value is an internal, incremental and iterative activity that needs to be carried out constantly. Womack et al. (1992) conceptualize kaizen as a process of continuous and gradual improvement. The perfection principle is more subjective and difficult to understand, however, is kaizen that shows a path of increasing improvement in order to achieve perfection (HEINECK et al., 2009), which is complete waste removal.

According to Womack et al. (1992), the Toyota System, lean production precursor, was known to have a flexible production able to reduce costs and, primarily, supply the product diversity asked by the customers. Moreover, the relationship with the customer was different, since the customer was incorporated into the product development process directly, aiming to deliver loyalty and satisfaction.

Regarding the production flow within lean philosophy, it characterizes by time cycling, being calculated as the result of adding the time span of waiting, processing, transportation and inspection-control activities. The new production philosophy has as an objective to compress the time cycle, resulting in activity reductions that do not add value to the product or service. Productive processes are naturally variable; however, reducing variability is well seen from the attendance point of view towards the customer’s requirements. In addition, reducing the amount of non-added value activities and time cycle. The activities standardization through the adoption of arranged procedures is a way to reduce uncertainty and increase predictability of flow and conversion processes (KOSKELA, 1992).

Transparency is the basis of the visual management that can be found on various theories and tools, like: just-in-time, kanban, SS programs, andon, poka yoke and can be defined as the ability that a production process has in order to communicate useful information to humans (SANTOS; POWELL; FORMOSO, 1998). Many of the lean production tools are perceived, incorrectly, just as the methods for process development. In most cases, these tools are created to show the standards visually and, then, make any deviation visible for everyone (LIKER; CONVIS, 2011).

Visual management, as a start-point, allows performing benchmarking, which is a systematic process of measurement and comparing organizational performance with other similar businesses’ key activities, identifying and implementing best practices (KOSKELA, 1992). According to Costa (2008), industry groups in different countries, began benchmarking programs for process improvement through the performance measurement, revealing the growing concern of companies towards greater efficiency.

The reliability of complex systems tend to be lower than simple systems. Furthermore, the human ability to deal with complexity is limited, which encourages the simplification by reducing the number of components of a product or the number of steps for a material-information flow (KOSKELA, 1992). One of the Toyota Production System characteristics is the possibility of workers, at each workstation, to immediately stop the entire assembly line if a problem arises that cannot be resolved individually, mobilizing the entire team for its resolution, demonstrating team involvement (WOMACK et al., 1992).
Lean thinking, instead of treating problems such as random events, seeks to establish a problem resolution system based, for example, in the "five whys", in which workers restate, systematically, each error to identify its root cause and solution to avoid reoccurrence (WOMACK et al., 1992).

2.2. Lean Concepts and Principles Implementation

In control, effort reduction to convey information, re-work reduction, technological solution implementation, content value and optimization. The principles were adopted partially due to informal communication, lack of integration and criteria of model analysis, uncertainty within users’ requirements, among other reasons, which caused negative effects on results.

Mohan and Iyer (2005) analyzed the experiences of 16 companies that used many lean principles and achieved benefits involving cost, time, buffer stocks and re-work reduction. Among the most efficient principles, it outstands the Percent Plan Complete (PPC) and All parties Involved in design.

Much of the work evaluates the implementation of lean principles a case study. Tzortzopoulos and Kagioglou (2003) analyzed the application of lean principles in modeling processes, such as: activity during design and construction phases. For instance, the protocol developed by Etges et al. (2013) to evaluate lean practices use, included as sources of evidence: observation, document review and interviews with those responsible for framing practices in one of three possible degrees (not applied, partially applied, applied).

2.3. Performance Measurement Systems

The traditional measurement systems usually focus on cost and productivity aspects, which have resulted in critics that do not subsidize continuous improvement and perform measurements after the occurring events. In lean production, measurements should support the application of lean concepts and principles, from indicators related to waste reduction, adding value, variability reduction, cycle time, simplification, transparency, focus on the complete process, and continuous improvement (KOSKELA, 1992). According to Bassioni et al. (2004), the construction industry needs integrated performance measurement structures and there are gaps that need to be further investigated as specific indicators of areas such as leadership, people, innovation and learning.

Lantelme and Formoso (2001) proposed the following guidelines to be considered in measuring systems: transparency; information sharing, communicated and presented in an understandable format; moments for reflection, that should be formalized and conducted in an open and participatory environment; systemic thinking, understanding variable dynamics that influence results; cycle time reduction, with computerized data collection and processing; simplification, by reducing the number measures and usage of existing control systems and procedures; and benchmarking, comparative evaluation against competitors for continuous improvement.

According to Barth and Formoso (2008), dashboards implementation have an important role when inducing improvements to measurement systems. Therefore, they suggest as guidelines the following: involve a multidisciplinary team; get support from middle and senior management levels; prepare users for proper handling; set a coordinator for the collection, information processing and analysis; formalize analysis overview; mapping and systematization of the process that involve data collecting and analysis.

In a study made by Costa and Formoso (2011), an indicators system for collaborative benchmarking has been implemented within a web platform that allowed performance comparison between construction companies, good practices exchange and improvements development to their systems. The authors noted that companies should link the development state of its management processes in relation to their goals and the people’s needs with technical skills aligned to the desired level.

Lantelme and Formoso (2001) considered the simplification as a good practice for performance measurement systems, since complexity is not desirable, increasing costs and decreasing reliability. The selection of indicators and data collection planning should consider the procedures that need to be developed or modified, as well as the necessary staff training. The reduction of measurement cycle time is also important to increase reliability and motivation. The time between data collection and results dissemination that will support decision-making should be as short as possible, and through automation with computerized systems as an important strategy.
Halman and Voordijk (2012) developed a performance measurement system to monitor supply chains based on financial, customers, innovation, internal and external business indicators, being evaluated by managers of the Dutch sector about clarity, measurability and importance levels.

2.4. Subway Performance Indicators

Cronin et al. (2000) analyzed the quality, satisfaction and value effects in customer’s behavioral intentions. The study results indicate that quality and service value lead to satisfaction and suggest that customers, generally, seem to value service quality in relation to cost, which emphasizes the importance of a holistic vision and combined approach these factors by organizations.

Pezerico (2002) proposed a subway performance evaluation system for governmental organizations to apply. It focused on several aspects, not only on the financial and service areas. The structured model was applied within the transportation system in Porto Alegre - Brazil, aiming to become an instrument for strategic goal establishment, as well as management decision-making. An additional research, focused on subway maintenance by Cysneiros (2004), it was proposed indicators set to provide information seeking to improve existing processes and facilitating benchmarking processes with other transportation systems.

Lima et al. (2015) conducted a survey among subway users relating 54 items to 12 attributes; such as: speed, price, safety, punctuality, service, comfort, among others. Regarding the overall assessment for service quality, results showed a positive perception overall. However, while five of the highest average items are linked to system benefits (lower cost, speed) and facilities physical structure, the five lowest average items are attributes associated with comfort (seats number, insufficient train, trains with air conditioners) and social projects developed by Belo Horizonte subway system in Brazil, indicating a vast field for improvements towards customer perception. Cardoso and Portugal (2007) also assessed the subway user perception in Rio de Janeiro- Brazil, concerning service quality leading to safety and speed as the most important attributes considered.

Costa et al. (2008) evaluated the applicability of the American Customer Satisfaction Index (ACSI) methodology for Brazilian context by doing a research amongst subway users and their satisfaction level in Sao Paulo - Brazil. The results indicated that the perceived quality was the variable that most influenced in customer satisfaction, while the expectation had no effect, suggesting that the methodology is not applicable, in a satisfactory way, within Brazilian public services. The authors considered that satisfaction is much more oriented to quality and value than to expectation, validating previous researches.

3. Research Method

The scope of this study involved the following steps: a literature review about Lean Production concepts and principles associated with performance measurement systems; defining the evaluation method of the concepts and principles application within performance measurement systems based on the literature; and a case study applied to the measurement system for operation and maintenance performance of the Salvador and Lauro de Freitas subway system in Brazil.

Table 1 presents lean concepts and principles that were considered for evaluation, as well as the description of practices of the measurement systems design and/or implementation that the authors associated to each of them, in three adoption degrees (integral, partial or null), based on systematic literature review and in the perception of researchers, as evidence source.

<table>
<thead>
<tr>
<th>Lean Concepts and Principles</th>
<th>Practices description associated with design and/or implementation phase of the performance measurement system</th>
<th>Adoption Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Improvement (Kaizen)</td>
<td>Goals setting, use of good practices, standardized procedures and formalized process of actions for continuous improvement</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>It presents at least one of the practices described to the principle</td>
<td>Partial</td>
</tr>
<tr>
<td></td>
<td>Not include any of the practices described to the principle</td>
<td>Null</td>
</tr>
</tbody>
</table>

Table 1. Evaluation method of the lean concepts and principles adoption degree
<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual Management</strong> (Transparency)**</td>
<td>Dashboard existence with appropriate signaling and layout, information inclusion on work areas, use of visual tools for discrepancies identification, and information sharing in understanding easy format</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It presents at least one of the practices described to the principle</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Not include any of the practices described to the principle</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Variability Reduction</strong> (Standardization)**</td>
<td>Variability measurement to identify and eliminate the root causes, standardized procedures use and existence of anti-failure devices and/or procedures (poka-yoke) in the data collection and/or processing</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It presents at least one of the practices described to the principle</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Not include any of the practices described to the principle</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Attendance to Customer Requirements (Value)</strong></td>
<td>Customers internal and external needs identification and their incorporation to development processes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Customers internal or external needs identification and their incorporation in development processes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Failure to customer needs identification and not incorporation to development processes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Management based on Value</strong></td>
<td>There is a predominance of non-financial, operational and/or processes indicators and management oriented to customers</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>There is a predominance of non-financial, operational and/or processes indicators or management oriented to customers</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>There is a predominance of financial and/or results indicators and/or management oriented to competitors</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Benchmarking</strong></td>
<td>Establishing of strategic objectives, external good practices identification, processes performance understanding and comparing with competitors for implementation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Establishing of strategic objectives and identification of competitors external good practices</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not include any of the practices described to the principle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Cycle Time Reduction</strong></td>
<td>Predominance of automated data collection and processing and the results available in real time</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predominance of automated data collection and/or processing, but without the results available in real time</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predominance of manual data collection and/or processing</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Workers Involvement</strong></td>
<td>Workers empowerment (automation) involved in the data collection, processing, analysis and/or dissemination, and existence of participatory environment with formalized moments for questioning, reflection and creativity</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It presents at least one of the practices described to the principle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not include any of the practices described to the principle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Simplification</strong></td>
<td>Use indicators easily accessible and understanding and/or maintenance of existing control systems and procedures</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use indicators that require development and/or modification of existing control systems and procedures</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use indicators that require implementation of new control systems and more complex procedures</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Systemic Thinking</strong></td>
<td>Adoption of key activities representative indicators, use of tools for general background understanding and problems root causes identification that influence the results</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It presents at least one of the practices described to the principle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not include any of the practices described to the principle</td>
<td>X</td>
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</table>

The case study was conducted in the Subway System of Salvador and Lauro de Freitas, which is subject of an implementation and operation Public-Private Partnership (PPP). The concession contract designs in one of the annexes,
the Performance Evaluation System, that is formed by nine indicators set of operation, security, user satisfaction and maintenance groups, and their calculation results in Performance Score that focuses on part of the monthly remuneration to be paid by the public partner to operator concessionaire.

In addition, the contract specifies that the grantor hire a company called Independent Verifier (VI) to audit determined information in the performance measurement system. This hiring process is underway and uses as reference the Guide for Independent Verifiers Structuring prepared by the State of Minas Gerais, which has pioneering experience in Brazil in this area.

The application evaluation of these lean concepts and principles in subway performance measurement system was based on the documents analysis as Annex C of the Addendum n. 2 to the Concession contract n. 01/2013 - Performance Evaluation System, that presents the system design, the performing of technical visits and remote access to SIAD - Performance Verification Computerized System, implemented by the Concessionaire, as well as the researchers direct observation to obtain the necessary evidence.

4. Results Presentation

The nine indicators of the analyzed subway operation performance measurement system are divided into four groups:

- Group I - Operation: Regularity in Train Headway Indicator (IRIT), and the Fulfillment of Train Service Offers Indicator (ICOT);
- Group II - Safety: Accident Indicator with Users in the Subway System (IAUM), and Offences and Penal Contraventions Indicator with Users and Employees in Subway System (ICUM);
- Group III - User Satisfaction: Time Spent Indicator in the Paying-Access Area (ITAP), the General Complaints Indicator (IRGE), User General Satisfaction Indicator (IGSU); and
- Group IV - Maintenance: Train Service Availability Indicator (IDMR), and the Stations and Surroundings Availability Indicator (IDEE).

The next items will describe the application evaluation results of the ten lean concepts and principles in the analyzed subway performance measurement system, based on the practices identification during the case study associated with one of the three adoption degrees provided in Table 01.

4.1. Continuous Improvement (kaizen)

This principle was evidenced in the measurement system by goals setting for each indicator, as Annex C - Performance Evaluation System. As examples, the Fulfillment Indicator of Trains Offer (ICOT) must present values equal or greater than 90% of the scheduled journeys number and the Accident Indicator with Users in the Subway System (IAUM) must be equal or less than three per million passengers transported in each month.

Regarding the continuous improvement process existence, one of the Independent Verifier (VI) activities that will be hired refers with the continuous improvement proposition, such as in: indicators measurement processes and procedures, automation solutions in the measurement and monitoring, benchmarking, proposing good practices standardized procedures, among others. With the identification of these practices, this principle was evaluated with the full degree of adoption.

4.2. Visual Management (Transparency)

The main identified practices associated with visual management were the following: the usage of visual control panel (virtual dashboard) and remote access through the Performance Verification Computerized System (SIAD), including visual control use, such as graphics to support the indicators results discrepancies identification, as seen in Figure 01.
The performance system information are presented to access on some computers of the parties involved by concessionaire and public entity, however, it was not observed the inclusion of these results in other platforms, workplaces nor to system users, like panels in subway stations. Thus, the transparency principle obtained a partial degree of adoption during the evaluation.

4.3. Variability Reduction (Standardization)

Regarding the variability reduction, its measurement to identify and eliminate root causes is performed by monitoring of the own system of indicators with the discrepancy cause analysis and the improvements proposition. The procedures standardization is underway for guide preparation to information collection, processing and dissemination, and it is designed between the Independent Verifier assignments, the creation of standard operating procedures. As it is not formalized and it was not found fail-safe (poka-yoke) devices or procedures, the variability reduction was considered as partially adopted in the analyzed performance measurement system.

4.4. Attendance to Customer Requirements (Value)

The analyzed system has a specific group for user satisfaction composed by three indicators: Time Spent Indicator in the Paying-Access Area (ITAP), the General Complaints Indicator (IRGE), User General Satisfaction Indicator (IGSU). The preceding evaluates the ultimate customer’s satisfaction with service quality through quantitative semi-annual survey, as well as a preliminary stage of the customer needs annual survey using qualitative attributes that support the quantitative research. However, as the approach of this principle in the measurement system is based only on final customers (subway users), without identify internal customer’s needs who can add value, this lean principle was considered with a partial adoption degree.

4.5. Management Based on Value

The system analysis shows that there is a sufficient predominance of operational, non-financial and process indicators, such as operation, user satisfaction and maintenance indicators, which are: regularity in train headway, fulfillment of train service offers, time spent in the paying-access area, general complaints, general user satisfaction, train service availability, as well as stations and surroundings availability. These types of indicators are common in lean systems because they support decision-making at operational levels and allow improvement implementation within management, oriented towards customers and adding value, which made this principle be considered with an integral adoption degree.
4.6. Benchmarking

The system design for performance measurement allows indicator review through the identification of good external practices and specifies that the Independent Verifier should conduct strategic indicators benchmarking with similar subway transport systems in other Brazilian regions and in the world, in order to propose improvements. Therefore, this lean concept was evaluated as integral adoption.

4.7. Cycle Time Reduction

Most of the indicators have data collected automatically, originated from subway platforms and operation and maintenance systems. A similar situation occurs in the data processing, still requiring some manual manipulation and migration to the performance evaluation computerized system. Indicators like time spent during the paying-access area and the user satisfaction survey still need of manual data collection, increasing the measurement cycle time. This principle was considered as partially adopted, because the results availability is not in real time, being monthly consolidated.

4.8. Workers Involvement

In relation to this principle, it weren’t found practices evidence directly related, such as: worker empowerment (autonomation) at the operational level for collection, processing, analysis and results dissemination to solve problems immediately. With the Independent Verifier exercising independent role between the parties, it is expected a more involving environment with formal moments for reflection, creativity and questioning is established. Therefore, the evaluation was established as a null adoption degree.

4.9. Simplification

The simplification principle was perceived in the system design of the performance measurement with a representative group of only nine indicators from four major groups of a subway system. Most indicators are easily accessible and understandable, with automated data collection and processing or facilitated by the use of control systems and procedures generally existing in subway operations, which reinforces the simplification considered as integral adoption.

4.10. Systemic Thinking

Likewise perceived during simplification, indicators measured in the system involved four key activities areas: operation, security, user satisfaction and maintenance, representing aspects of great relevance for global background understanding. Some of the tools designed for implementation by the Independent Verifier aiming systemic thinking are: presentation of indicator interrelations through a tree diagram and a benefit map creation for each indicator group. However, no tools were found to support the identification cause of root problems like the Ishikawa diagram and five whys method, which made this principle be evaluated as partial adoption.

During the progress of this case study, only Line 1 of the subway system was starting its operation and performance measurement. Table 02 shows the adoption evaluation results of ten lean concepts and principles in the measurement system of subway performance in Salvador and Lauro de Freitas. Half of them are partially used, while four are adopted integrally and the worker’s involvement principle was observed with null adoption degree. The results show favorable areas for recommendations proposition and improvements implementation, aimed at obtaining of integral adoption degree related to the lean principles in full operation of the Lines 1 and 2.

<table>
<thead>
<tr>
<th>Lean Concepts and Principles</th>
<th>Adoption Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Integral</td>
</tr>
<tr>
<td>Continuous Improvement (<em>Kaizen</em>)</td>
<td>X</td>
</tr>
<tr>
<td>Visual Management (Transparency)</td>
<td></td>
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<tr>
<td>Variability Reduction (Standardization)</td>
<td></td>
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<tr>
<td>Attendance to Customer Requirements (Value)</td>
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</tbody>
</table>

Table 2. Adoption Evaluation of lean concepts and principles in subway measuring system

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5. Final Considerations

The results indicated that almost half of the lean concepts and principles evaluated were integrally adopted by the analyzed performance measurement system. However, only one principle was not identified with some practice associated to lean philosophy. One of the factors that explain this lean adoption is the project’s contractual mode, being a public-private partnership (PPP) concession that involves a subway system implementation and operation for thirty years. Therefore, investment and operation remuneration is based on the service quality and the performance indicators design prioritized operational, not financial and user satisfaction aspects, aligned with lean philosophy fundamentals.

Based on the results, the following recommendations are given in order to improve the system: a) strongly involve workers within the measured processes by empowering them with responsibilities, autonomation and contribution encouragement; b) present the performance results to customers by visual tools in subway stations and workstations; c) implement indicator measurement related to internal customer requirements; d) disclose the indicator’s results immediately for those involved to reduce this process cycle time, enabling decision-making faster; e) use tools to identify root cause for detected failures, for instance, the Ishikawa diagram.

The survey results provide a lean principles adoption diagnosis in the subway performance system, allowing achievement changes, still in early stages of implementation. Furthermore, contribute to the development of lean evaluation methodology for performance measurement systems, based on the definition of practices associated with each of the lean principles and concepts in three different adoption degrees.

The recommendations for further work involve lean evaluation method application of performance measurement systems maintenance and operation for other subways, transportation systems, commercial and residential projects, as well as another method development for lean evaluation in performance indicators systems of the design and construction phases.

6. References


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