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A Performance Evaluation Concept for Production Systems in an SME Network

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Abstract

Industrial internet technologies offer new possibilities for information sharing, data integration platforms and communication interfaces in most SME manufacturing networks. To collaborate efficiently and maintain competitiveness, performance level of individual companies' production system needs to be known and visible within the network. A current lack of harmonized evaluation methods demands to define a performance evaluation approach for production systems in a network. We developed a performance evaluation concept for production systems in an SME's network that is based on identified key performance indicators and their real-time visualization. A case study demonstrated the relevance and feasibility of the proposed concept, which uses internet of things technologies.

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Keywords: Production systems performace evalution, SMEs Network, Key Performance Indicators, Internet of Things, Real-time visualization

1. Introduction

In recent years, technologies have been evolving rapidly, manufacturing is becoming more complex, and companies are more specializing in their respective fields. These changes have more impact on small and medium-sized enterprises (SMEs). Hence, it is hard to possess all the necessary technologies and expertise in one house. Due to those typical challenges faced by manufacturing enterprises, they are continuously seeking for collaboration with other enterprises and form a network. The network can be presented and work as a virtual enterprise (VE) to fulfill business opportunity and having identical goals. Thus, SMEs can stay competitive in the global market and able to compete with larger firms. Nevertheless, how to evaluate the performance of production systems and resources the SMEs possess, is still in need of attention and essential for network stability. If the efficiency of a production system cannot be assessed, then it cannot be properly controlled. This leads to waste of time, money, energy and overloaded staff.

There are methodologies available for analyzing the performance of a production system. Those are mainly devoted to sole assessment of a single system, which depends on particular key performance indicators (KPIs) related to that system. Moreover, those available methods hardly reflect the relation of particular KPIs of a production system to the whole network level [1, 2]. Therefore, studies of performance evaluation of production system in a SMEs network remains mainly unexplored. On the other hand, the advent of Industrial Internet of Things (IIoT) and the fourth industrial revolution has led production systems developing into digital ecosystems, where IIoT and Big Data play a vital role to manage the volume and variety of data at high rates [3]. IIoT enables the interconnection of industrial objects through embedded technologies. More and more devices, production tools, manufacturing equipment are equipped with sensors, and hence they can be connected and share information within a network. The digital transformation of industry enabled by the IIoT permits new ways for businesses to connect and co-establish value. New data-driven strategies will support the enterprises

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to evaluate their performance by gathering and analyzing data through the whole product and project lifecycle [4].

This paper proposes a concept of performance evaluation of a production system in an SME network with the help of Internet of Things (IoT) adoption in manufacturing. The proposed concept consists of the definition of a network process (an idea of a virtual enterprise), Selection of performance metric or Key Performance Indicators (KPIs), Process modelling, Data acquisition and analysis, Real-time monitoring and visualization.

2. Literature Review

The performance evaluation of production systems is a critical and vital task in a network whose success depends on the robustness of production systems. An efficient and effective performance evaluation may have a significant effect on the profitability of an industrial company [5]. Strategic decisions include the number of enterprises, their size and location, the variety of products to be produced, the processes to be outsourced, manufacturing technology to be used, the attribute of the transportation and material handling, etc. These crucial decisions from the perspective of the profitability of capital investments require formal and structured approaches to evaluate the performance of manufacturing systems [5, 6].

2.1. SME Network as a Virtual Enterprise

The initial idea of Virtual Enterprise (VE) was introduced by Byrne, who defined VE as "a temporary network of independent companies—suppliers, customers, even erstwhile rivals—linked by information technology to share skills, costs, and access to one another's markets." [7]. To sum up the idea and attributes from the different point of views highlighted in literature, VE can be defined as a new entity that is temporary created for goal fulfilment and dissolved after the goal is achieved. The Value Added Chain (VAC) structure of VE is similar to the structure of a physical enterprise. Furthermore, the VE members i.e., SMEs, bring their vital core activities to a new organization. The "Virtuality" of the entity also means the enterprise known as Focal Player (FP) that established a VE does not have sufficient physical resources for project realization alone and it is using the partner network resources [8-10]. The virtual enterprise can adjust the tactic to adopt market changes timely and can integrate all the advantages of the SMEs network to reach "win-win" situation.

2.2. Performance Indicators

Performance indicators or Key Performance Indicators (KPIs) eventually drive the performance evaluation of production systems. KPIs are the modern tools that facilitate keeping the performance at a high level in production [11]. Moreover, performance indicators do not just express what has happened; they signify what will happen, as they provide information to a decision maker, which may affect the future competitive position of the enterprise [12]. The role of production performance indicators is to reflect the current state of production, to monitor and control operational efficiency, to drive improvement programme, and to measure the effectiveness of strategic decisions [13]. The most commonly cited indicators to evaluate the performance of production systems are quality, cost, delivery time, and flexibility [14].

2.3. Business Process Modelling

Business process modelling has been broadly accepted in today's organizations for demonstrating the processes of an enterprise. It supports businesses by providing a set of tools and techniques to identify and analyze current processes in order to find opportunities for improvement, to implement the improved processes, and to monitor and control their execution in an automated way [15, 16]. Furthermore, process modelling is an approach to defining how businesses conduct their operations and typically includes graphical illustrations of the activities, events, and control flow logic that sets up a business process. Process models may also contain information regarding the involved data, organizational/IT resources, and potentially other objects such as external stakeholders and performance metrics etc. [17].

2.4. IoT Applications in Manufacturing

A. Data acquisition and analysis –The era of modern manufacturing, where most of the production systems are comprised of embedded technologies like smart sensors, together with the availability of cloud-based solutions, has led to data generation and collection in large scale. Consequently, collected data helps to estimate several KPIs and leads to proactive decision making. The fundamental aim of IoT applications in manufacturing (also known as IIoT) is to realize smart factories, in which machines and resources communicate and are connected in a network. For that purpose, production tools, resources and existing IT tools of an enterprise should be connected to the internet directly or through external adapters. Subsequently, production tools/systems will be transformed into "cyber physical system" upgraded with knowledge provided by data capturing and analysis [18, 19].

Data generated by the lower level of an enterprise, directly from the production systems and the human operators has a great importance to an enterprise, data can be used, analyzed and refined into meaningful information to the higher levels of the enterprise making them adaptive and flexible [4, 20].

B. Real-time Monitoring and Visualization – A great challenge the manufacturing enterprises face is the lack of timely, accurate and consistent information of manufacturing resources during manufacturing phase [21]. This challenge is more significant if production systems form a network, which is shared and concerned by more than one enterprise. Real-time performance indicator visibility and traceability allows decision makers to make intelligent shop-floor decisions.

IIoT enable real-time monitoring and help to visualize collected data and KPIs in order to evaluate the performance of a system. These advanced monitoring technologies identify areas of potential improvement, predict future outcomes and optimize operations, resulting in lower cost and higher productivity [18].

3. Methodology

In order to realize and signify the proposed concept of performance evaluation of production systems, a case study approach is used as a research method. Moreover, a literature review of the related context was carried out to describe and understand the key techniques that help to build a concept of performance evaluation. The concept can be depicted in the Fig. 1 and it is a continuous process.

Fig. 1. Performance evaluation concept for production systems

3.1 Realize & Define System

The first step is to describe a system nomenclature and mechanism of working. Since the focused production systems form an SME network, this step consists of definition of the SME network, its functions, and the formation of the VE.

The concept of VE describes as a SMEs network and it is developed within the context of a Sustainable Partner Network (SPN) [22]. The idea can be seen in the Fig. 2, which defines how it works i.e., the formation of a VE and its Value-Added Chain (VAC) from the sustainable partner network. Furthermore, the production systems are highlighted within the manufacturing activity.

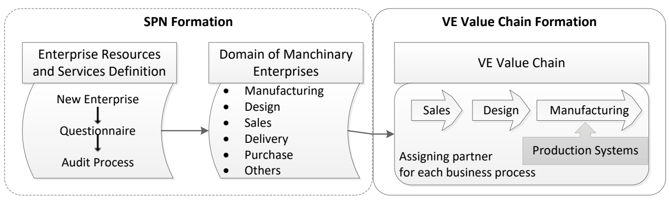

Fig. 2. VE formation as a SMEs Network [22]

3.2 Selection of KPIs

The second step is the selection of KPIs based on different enterprise levels in a hierarchal form. In this study, KPIs are categorized into three levels L1, L2 & L3: Starting from the lower level of factory floor followed by the middle level as tactical level and the top level as strategic level. Different literature [23, 24] were reviewed to map the KPIs and described their relations. The hierarchy in Fig. 3 shows the levels of KPI mapping and process modelling (next step of the proposed concept). Selected KPIs of each level 1, 2 and 3 are illustrated in the form of matrices as depicted in tables 1, 2, 3 and 4 respectively. L1 is divided into two groups i.e., level 1a and 1b, level 1a matrix designated for whole value chain of VE that includes main processes of sales, manufacturing and logistics etc. While matrix 1b represent the process of manufacturing, specifically production system or manufacturing equipment efficiency/productivity matrix. As this study is focused on performance evaluation of production systems, levels 2 and 3 are described within the domain of manufacturing equipment.

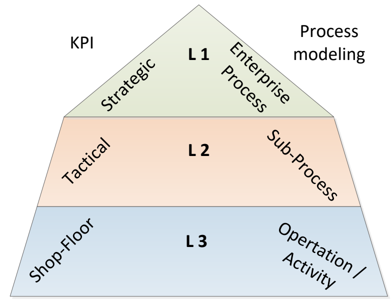

Fig. 3. Levels for KPIs and process modelling

Table 1. Level 1a matrix of KPIs for whole value chain of VE [23]

Performance Attributes	Performance Indicators (KPIs)	ID	Description	Formulation	Units
Reliability (RL)	Order Fulfillment	RL1	Right quality and quantity as required	(Total PO / Total NO) x 1oo	%
Responsiveness (RS)	Order Fulfillment Cycle Time	RS1	Speed to perfrom task	(Sum ACT of OD) / (Total OD)	Days; Hr
Agility (AG)	Flexibilty	AG1.1	Ability to and speed of change	Minimum time to achieve unplanned tasks or orders	Days; Hr
	Overall Risk Value	AG1.2		(P of RE) x (Impact of RE)	-
Cost (CO)	Cost to Serve	CO1	Labour, Material and Transportation cost	Labor + Material + Equipment + Transportation Costs	€
Asset Efficiency (AE)	Return on Investment	AE1	Ability to efficiently utilize assets (inventory & Resources)	(Revenue – Cost) / [(Inventory) + (Receivable – Payable)]	%

PO = Perfect Order NO = Number of Orders OD = Orders delivered

P = Probablity RE = Risk Event Hr = Hours

Table 2. Level 1b matrix of KPIs for a production system/equipment

Performance Attributes	Performance Indicators (KPIs)	ID	Description	Formulation	Units
Equipment Reliability & Responsiveness	Throughput	ER1.1	On time - Desired time to produce a product	(Process + Move + Queue + Inspection times) / (Total finish products)	Hr;min;sec
	OEE	ER1.2	Overall Equipment Effectiveness - Estimate an equipment truly productive time (productivity)	(Availability factor x Performance factor x Quality factor) x 100	%
	Utilization	ER1.3	Proportion of time an equipment is used	(Operational Time / Calendar Time) x 100	%

Table 3. Level 2 matrix of KPIs for a production system/equipment

Performance Indicators (KPIs)	ID	Description	Formulation	Units
Availability (A)	ER2.1	Time an equipment is actually available after downtime losses - convey maintenance effectiveness	(Operating time / Planned production time) x 100	%
Performance (P)	ER2.2	Time an equipment is operating on actual speed rather on ideal speed - speed losses - convey production effectiveness	(Actual Production Rate / Ideal Production Rate) x 100	%
Quality (Q)	ER2.3	Time an equipment is taking to produce good quality product only - defect losses - convey quality effectiveness	[(Total product produced - Rejected product) / (Total product produced)] x 100	%
Planned Production Time (PPT)	ER2.4	Difference of Schedule (shift) time and planned downtime (breaks time)	Total shift duration - Planned downtime	Hr;min;sec
Operating Time (OT)	ER2.5	Difference of planned production time and unplanned downtime (breakdown/failure)	PPT - Unplanned downtime	Hr;min;sec
Actual Production Rate (ACT)	ER2.6	Ratio of total product produced to operating time	(Total product produced / OT)	Product/min

Table 4. Level 3 matrix of KPIs for a production system/equipment

Performance Indicators (KPIs)	ID	Description	Units
Total Products Produced	ER3.1	Total number of product produced on production line or system	-
Finished Products	ER3.2	Number of good quality product produced	-
Rejected Products	ER3.3	Number of bad quality product produced	-
Failure or breakdown Time	ER3.4	Time to repair or fix a failure	Hr;min;sec
Activity Processing Time	ER3.5	Operational time of each activity or workstation or resource	Hr;min;sec
Ideal Production Rate	ER3.6	Product produced at maximum running speed of an equipment	Product/min
Total Run Time	ER3.7	Total running time of production line or production system	Hr;min;sec
Non-Processing Time	ER3.8	Non-operational time, queuing time, idle time of resources	Hr;min;sec

The relationship between the KPIs of all levels for a production system is portrayed in the Fig. 4, which should reflect a system reliability and responsiveness.

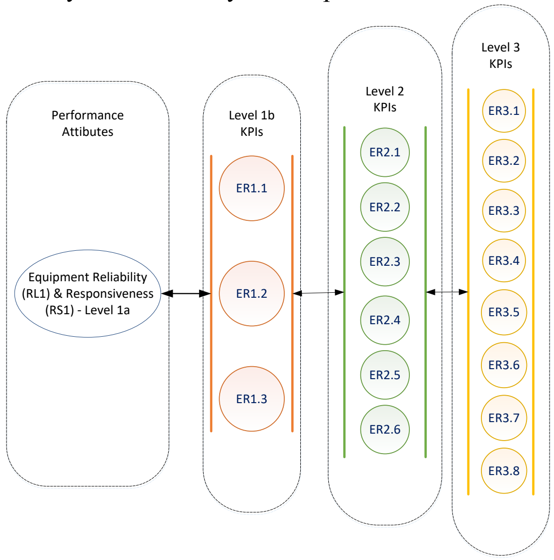

Fig. 4. Hierarchical linking between KPIs at all three levels

3.3. Process Modelling

Process modelling step enables the description of the business process. In this study, it is not only used to model the business process value chain, but also to model the lower level activities and process steps. Value-Added Chain (VAC) and Event-Driven Process Chain (EPC) techniques are adopted. The purpose of process modelling is to define the enterprise structure, process sequence with inputs and outputs, responsibilities and the process owner. The top-level process modelling or VAC comprises of business areas and the owner of those areas. It can be representing an SME as well. Process phases with their input and outputs, and responsible partners are demonstrated in the second level. The third modelling level, modelled through EPC technique, determines the sequence of process steps or activities and shows where the process value is generated. Fig. 5 shows the levels of process modelling of a VE. Focal Player (FP) is an owner and initiator of the VE. It has a business opportunity and needs the business resources from other SME partners. In the case study, there are two manufacturing enterprises having a production system and providing production services to the VE.

3.4. Data Collection

Data collection step proposes a procedure for acquiring data from production systems. It identifies the parameters that are needed to measure the defined KPIs. This step should recognize the type of data and means to access various data sources. Moreover, it states when and where to measure and who collects the data from the system. Due to the modern era of manufacturing and digitalization, production systems are often embedded with smart sensors and electronics. Therefore, the IIoT approach is used for data collection. Industrial internet includes the state of art set of technologies for data collection from the factory floor and enables enterprises to have real-time visibility of production processes. OPC Unified Architecture (UA) standard is usually adopted as it supports integration of equipment from different suppliers. It offers a platform for independent service-oriented architecture to communicate with industrial equipment and systems for data collection and control [25]. We also used a custom software application for communication interfaces and data acquisition.

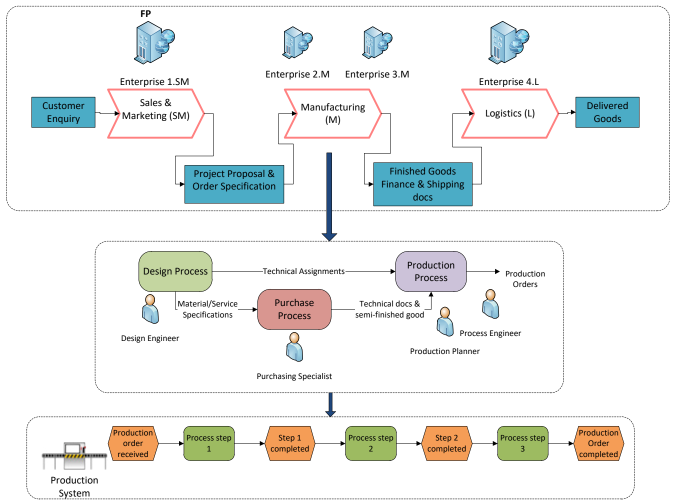

Fig. 5. Levels of process models

3.5. Real-time Monitoring and Visualization

The purpose of this step is to convey efficient real-time production data and related KPIs, as effective visualization provides the best insight to decision makers. Generally reporting incurs additional cost in most of the manufacturing environments. Real-time monitoring helps to improve factory information flow and production flow, while reducing reporting effort on the factory floor. We developed a dashboard for remote monitoring of the state of an automated production system. Commercial IoT platform [26] was used for execution.

4. Case Study

The developed performance evaluation concept was applied to two automated production systems that are situated at different locations. The first step of defining of production systems in a virtual enterprise can be seen in Fig. 6. Manufacturing business process of the VE has two systems, each belonging to an individual SME. Both systems have Manufacturing Execution System (MES) controllers embedded with sensor-enabled technologies and tools. Therefore, real-time process information transfer to a cloud-based storage through IoT layer is feasible for the real-time information sharing to VE. Second and third stages of the proposed concept are shown in Fig. 7. The process modeling of selected production systems was executed through EPC techniques that include a sequence of process steps, and inputs and outputs of each step.

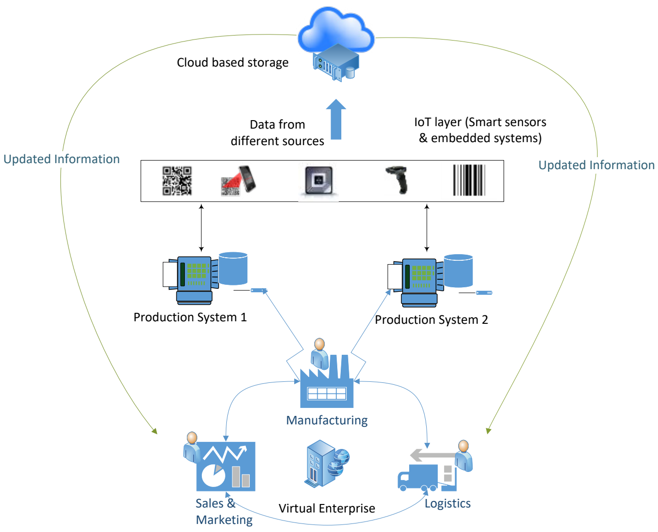

Fig. 6. Production systems at different location connected to VE.

Moreover, initial parameters were mapped into process modeling diagrams that are needed to calculate further KPIs. Both systems produce discrete products and are controlled by their particular MES. Each system consists of four main resources & modules. Production system-1 contains a storage, drill-machine, robot manipulator and inspection camera, while production system-2 comprises a storage, two robot manipulators and a milling machine. Beginning from production order received to the product completed, data and information of each step are sorted into the database. Most important parameters are the order number, step number, work plan number, resource ID & description, state of resource start and end times of orders, each step time in that order, failure (error) step, finishing of orders and steps.

The fourth and fifth steps of data acquisition and performance indicators visualization are illustrated in Figs. 8 & 9 respectively. Operational data stored in the databases is fetched by generating queries, so that it can be used for selected KPIs calculation. Application Programming Interface (API), precisely, app.js facilitates query generation and communication between systems databases and IoT platform via Hypertext Transfer Protocol (HTTP). Login page manages users based on their roles (operator, manager etc.) at different levels; hence, each role is able to visualize selected performance indicators based on relevancy. Fig. 9 portrays a model of visualization dashboard for one of the production system, and similar can be described for other systems in the network of SMEs or in the VE.

5. Conclusions

The proposed concept is a contribution to the performance evaluation of production systems in a virtual enterprise of SMEs. This work presents how the performance evaluation of production systems should be conducted in a harmonized way and how it may visualize in a network with the help of industrial internet of things. The test case enabled the visualization of individual production systems status within a network. With the identification of the key performance indicators, and by utilizing those we can enhance the proactive decision making and control of production flow among the network. Moreover, it can enhance the collaboration among SMEs to share their resources and be competitive in system level, so that they capable to earn value from a business opportunity. The case study with two production systems verified the implication of the proposed concept. The limitations in this approach is that while the technical challenges can be solved the cooperation aspects such as trust in the network and trust to data is not considered. The approach will be enhanced in future with more real test cases.

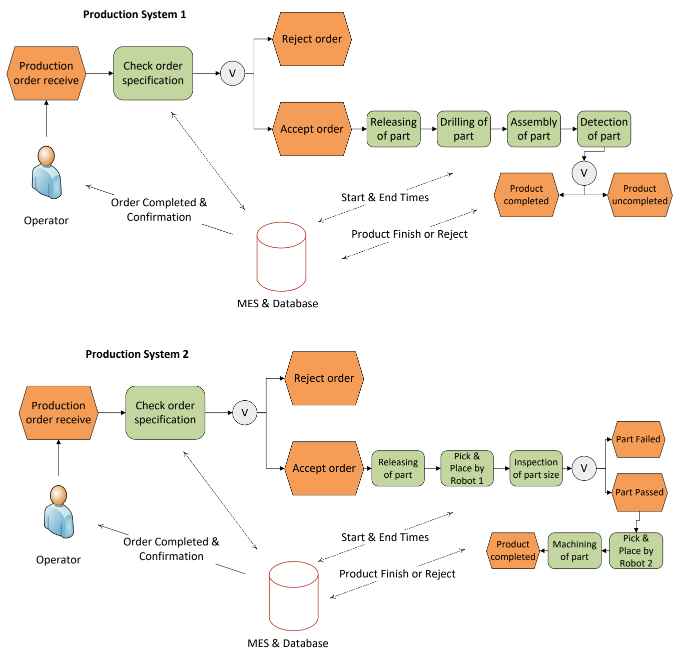

Fig. 7. Production systems process modelling and parameters.

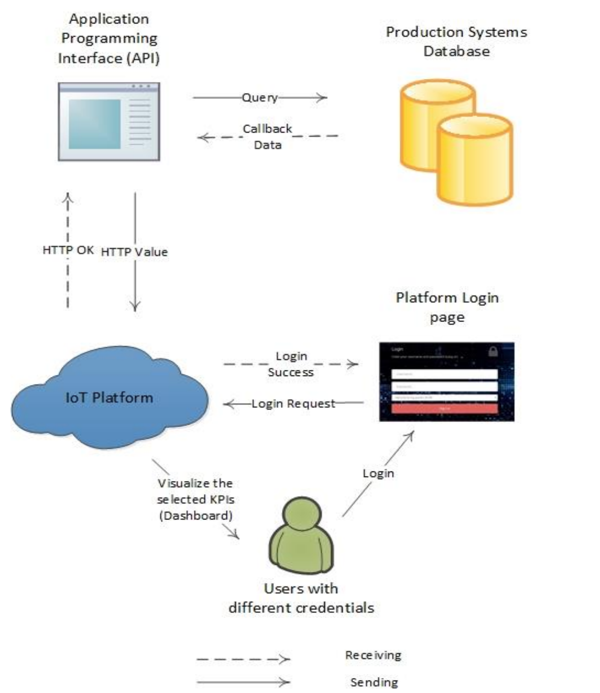

Fig. 8. Production systems data collection, conversion and communication

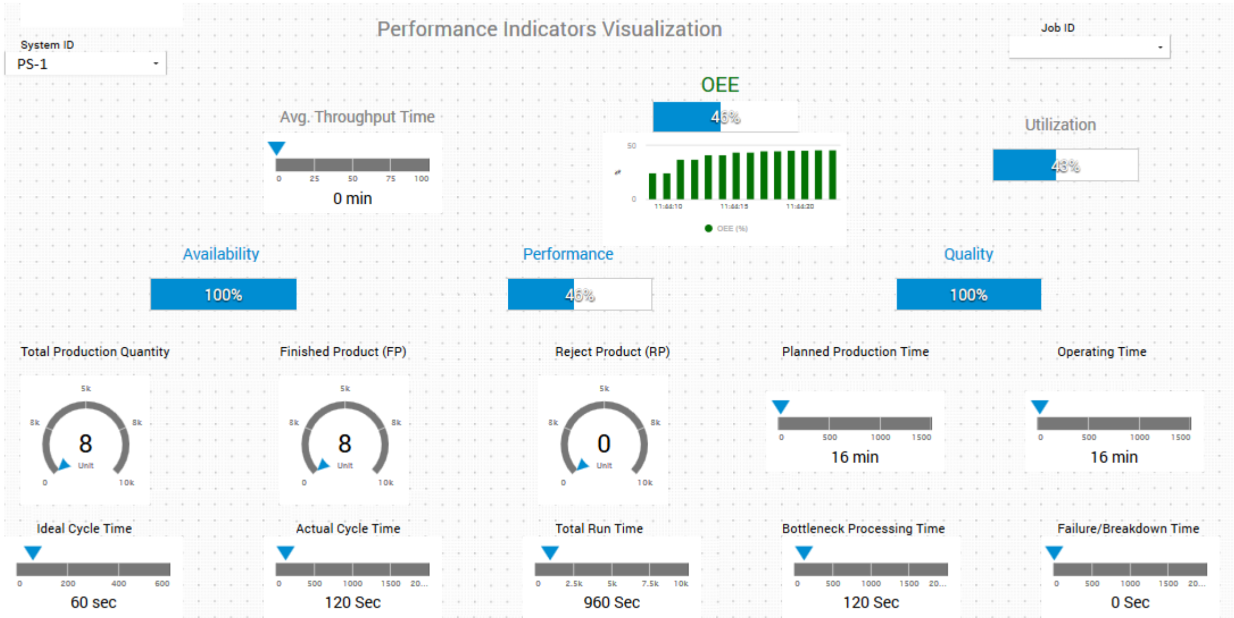

Fig. 9. Performance indicators visualization dashboard for production systems

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