Methods and techniques for evaluating the productivity of production processes in the automotive industry

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Abstract. The main purpose of the article is to present methods of evaluation of the production process in the automotive industry. Various methods and techniques for assessing productivity are used for this purpose. Productivity assessment is most often performed to perform a comparative efficiency analysis between different production lines. The second often encountered reason for determining productivity is the need to assess reorganization activities eliminating waste. Calculation of productivity indicators in the automotive industry is based on data obtained from production reports for specific production periods, for individual machines, assembly lines, for individual production changes, for individual products, frequency of failures, downtimes, number of events consisting in the lack of components on individual lines or the frequency of occurrence of defective products. The information obtained from the above comparative analyses provides valuable information on the state of production. On the basis of this information, production managers are able to select the best and worst functioning production department, production line or production change. This allows you to identify potential system errors that can be eliminated. In the summary, the authors emphasize the usefulness of simulation models while streamlining production processes, as a complement to improvements achieved with the Lean Management tools.

1. Introduction

The origin of concept of productivity dates back to the twenties of our century and grows from the classical trend in organisational and management theory. However, the introduction of the concept of productivity into world literature is attributed to Adam Smith, who in 1776 in ‘Research on the nature and causes of the wealth of nations’ noted that the annual output of each nation can increase in its value by no other means than by increasing the number of productive workers or by increasing their productive power, i.e. labour productivity [1, 2].

Productivity can be related to systems at different levels, e.g. the national economy, branches, sector, economic region, enterprise, departments, branches, nests and individual jobs. Systems, and in particular production systems, can be isolated from the environment and defined in different ways [3]. However, experience has shown [4] that for practical efficiency analysis of a production system, the simplified model presented in figure 1 is sufficient:

- system outputs or products means goods or services produced in the system and sold to recipients,
• system inputs – are various sources of energy supply for the system: materials, energy, and information as well as system resources: people and capital (in the form of fixed assets and current assets), used for producing the output product.

From the point of view of measuring productivity, it is important that the system uses different types of input resources. It then provides an adequate number of products produced, in relation to the resources consumed or used, which determines the productivity of the system under investigation within a given time period [5]. In most cases, the different types of inputs and outputs are incomparable. It is, therefore, appropriate to use the sum of the number of individual stocks, determined by unit costs and the sum of each type of product, taking into account the agreed selling price.

The overall productivity of the \( P_i \) production system during the \( i \) period can be expressed as follows [6, 7]:

\[
P_i = \frac{\sum_{t=1}^{T} Q_t^0 p_t^0}{\sum_{r=1}^{R} Q_t^1 p_t^1}
\]

where:
- \( Q_t^r \) – type \( r \) input stock (\( I=\text{input} \)) used in the period \( i \), \( r = 1, 2,...,R \) – number of resource types consumed by the system,
- \( Q_t^0 \) – type \( t \) quantity of products (\( 0=\text{output} \)) produced and delivered to customers during the \( i \) period,
- \( t = 1, 2,...,T \) – number of product types manufactured by the system,
- \( p_t^0 \) – unit price per type \( t \) product obtained during the \( i \) period,
- \( p_t^1 \) – unit cost of the type \( r \) of resource paid in \( i \) period.

However, the complex reality of an industrial enterprise is difficult to describe with any single synthetic indicator. A set of indicators is needed. There are at least seven different, though not necessarily mutually exclusive, measures of performance of the system. These are [4]:
- efficiency,
- quality,
- profitability,
- productivity,
- quality of work life (QWL),
innovation.
Each organisation should have a system for monitoring the evaluation, control, and management of its functions using one or more of these seven measures. High scores, obtained by the organization in one or even six out of seven characteristic areas, do not guarantee success or survival.

1.1. Productivity and quality
The link between productivity and quality results from the very definition of quality [8–11]: product quality is the degree, to which it meets the customer's requirements. For industrial products, quality is the result of design quality, workmanship quality and quality of use. Quality of the design (design quality, type quality, construction quality) means a certain product model with a specific set of features to be produced, meeting the expectations of potential customers. Quality of production (quality achieved, quality of conformity, quality of workmanship) – this is the degree of conformity of individual units of the manufactured product with the adopted model (design, the specification of requirements). Quality of use is the degree to which the product reaches the right user and ensures optimal conditions of use.

Analysing this definition, the following areas of impact on productivity can be distinguished:

- pre-production quality – a set of product characteristics, which influence its ability to satisfy specific needs of customers and which can be improved by design change – has a direct impact on whether the product will find a buyer. The same product may meet the requirements of one group of customers and at the same time, it may not be acceptable to another group. From the point of view of the productivity definition, only those goods or services for which the recipient’s (external or internal) demand is required are considered as products (system output).
- quality in the manufacturing sphere – i.e. the level of effectiveness in meeting the requirements for a product at the manufacturing stage, by eliminating deviations from the technological documentation, waste, losses of delays and bad workmanship. This aspect affects the productivity of the production cells of the various stages involved in the manufacturing process. Removing errors and deficiencies in the production process, eliminating the consequences of bad, careless and uncompliant workmanship, require additional labour input for people and means of production, additional consumption of materials and energy, which reduces productivity. Defectiveness and delays in the delivery of materials and products from cooperation are connected with the additional effort of delivery control and possible purchase of additional materials from the same or another supplier. Deficiencies, depending on the type, have the following consequences of cost increases:
  - The non-repairable deficiencies are related to additional material costs and labour, energy, machinery and tooling losses in the production of the product, which has been withdrawn from further production as an irreparable failure,
  - Corrective deficiencies require additional operations to restore them to a quality level, which results in additional labour costs, consumption of fixed capital and energy.
Similar consequences result in quality control errors, such as approval of defective products for further production. This is because this involves labour, energy and capital expenditure on the execution of production operations on products, which will be detected as defective during further control in the process, during final inspection or even during operation on the part of customers (the later the higher the costs are).
- quality in the post-production sphere – i.e. customer satisfaction with the functioning of the product – is connected, among other things, with warranty and service services. The higher the costs of this service, the lower the product quality. These costs are charged to the production costs and therefore reduce productivity. Poor or insufficient quality may cause customers to change their orders, e. g. resignation from part of the orders.

Proposals for productivity management similar to the concept of comprehensive quality management can be found in the literature, as well as items on comprehensive productivity and quality management. Both concepts are based on a similar set of methods and techniques, including: 5S, Kaizen, Productivity Circle, Quality Circle, Factor Analysis, Pareto Chart, Cause and Effects Chart (Ishikawa), Checklists of
Questions, etc. The concept of integrated improvements in productivity and quality is introduced, thus emphasising the relationship between productivity and quality and the need for combined treatment [12–14].

2. Review of productivity indicators
Dynamic processes enable changes to production and deliver the ability to respond flexibly to disruptions [15]. There are many approaches to the analysis and measurement of productivity coefficients, more important of which are to be mentioned in the available literature:
- Multifactor Productivity Measurement Model MFPMM, also known as the American Productivity Center (APC) model [4],
- W. F. Christopher's approach, which states that the starting point for the analysis and evaluation of productivity is to draw up a structural diagram showing the organisation of the company's organisational units and their interrelationships. Each organisation unit should be described in detail, taking into account the following information: products (outputs) produced for each individual customer, requirements, and expectations of the customer, input resources consumed to produce the above outputs [6],
- Lawlor's approach, which proposes a comprehensive productivity measurement system. This system consists of a two-stage productivity audit seeking answers to the questions: ‘Where are you now?’ and ‘How much better can you be?’ [7],
- Yasushi Fukuda and Tohru Sase propose an integrated PQIP (Productivity and Quality Improvement Program) programme, in which the evaluation and analysis of productivity is carried out at three levels: strategic, coordination and operational, which is consistent with the hierarchical structure of the management system and the hierarchical planning system in the company [13].
Analysis of productivity indicators remains an important problem. The values of productivity indicators themselves often bear little relation to the production process examined [16–18]. Their interpretation is based on the comparison technique, mainly in the following aspects:
- comparisons over time (analysis of trends in indicators in subsequent periods),
- comparisons with others (e.g. with main competitors, industry averages),
- comparisons with values deemed to be exemplary (e.g. strategic objectives).

3. Methods and techniques for improving productivity
The basic rule for programming productivity improvements should be: ‘Sell more! Spend less!’ [19]. The general approach to identifying objectives and directions of productivity improvement is presented in figure 2.

![Figure 2](image_url)

**Figure 2.** Main areas of productivity improvement where A – reduction of fixed costs, B – reduction of variable costs, C – increase of revenues caused by price increase, D – increase of sales volume [19].
In automotive companies, the productivity of production processes is evaluated on an ongoing basis, based on production reports and selected productivity indicators [12]. This method allows for efficient collection and analysis of the required data. The basic source of information about the production process is a paper production report, filled in during production by the production workers. The construction of a production report – for each product – follows the following diagram:

**Step 1. Production preparation**

The first step is to collect basic information on the product and production line status before production begins:
- product number,
- lack of components,
- machine damage,
- equipment defects and damage.

**Step 2. Production**

The employees fill in the exact time of the start of the production process in the production report. During the production process, all downtimes are recorded in the report (the exact duration):
- machine failures,
- repair of machinery,
- lack of components,
- time taken by engineers (e.g. for testing),
- quality errors that occur.

**Step 3. Summary**

After completion of the production process, employees enter final information in the production report:
- the time of completion of production,
- the number of products produced,
- the quantity of scrap metal.

On the basis of information from production reports, the production leader edits production statements containing information about each product for the head of the production department:
- the date of manufacture,
- the number of the manufacturing section,
- production line number,
- production shift code,
- contract (planned quantity),
- production (quantity of production),
- other downtimes (minutes),
- machine-related failures (time in minutes).
- quality error codes.

### 3.1. Summary of the productivity indicators used

Based on production reports, the Head of Unit calculates selected production indicators:
- production indicators – i.e. compliance with the production plan:

\[
\text{ratio of production} = \frac{\text{production volume}}{\text{planned production}}
\]

- indicators of defective products:

\[
\text{defective product index} = \frac{\text{good products}}{\text{production volume}}
\]
component deficiency indicators:

\[
\text{deficiency rate} = \frac{\text{number of shortages}}{\text{production volume}} \tag{4}
\]

material consumption indicators:

\[
\text{materials usage index} = \frac{\text{production volume}}{\text{materials consumption}} \tag{5}
\]

For each machine, the OEE (Overall Equipment Effectiveness) is periodically calculated, supplemented by the usage of working time, and it is a popular indicator describing the overall efficiency of machine use. To determine this indicator, its components shall be calculated:

- the availability indicator is a percentage of the time when the machine/machine is available for the production process. Failures, change-over, repair and preventive maintenance are included in the period when the site is inaccessible for production.

\[
\text{availability} = \frac{\text{work time fund} - \text{standstill times}}{\text{work time fund}} \tag{6}
\]

- working time utilisation rate, which is the percentage of the actual working time of the machine over the time available for production. The inactivity times of the machine/machine due to lack of product, lack of operator, meal breaks, breaks for meetings of production personnel have an impact here.

\[
\text{working time utilisation rate} = \frac{\text{actual working time}}{\text{work time fund} - \text{standstill time}} \tag{7}
\]

- the efficiency index is calculated as the quotient between the actual capacity and the maximum capacity of the equipment in question.

\[
\text{efficiency} = \frac{\text{current efficiency}}{\text{theoretical max efficiency}} \tag{8}
\]

- the production quality indicator shall give an indication of the percentage share of good products in total output of the equipment concerned. Defective products are also considered to be those that are eligible for repair.

\[
\text{quality} = \frac{\text{good products}}{\text{total production of the site}} \tag{9}
\]

Calculation of these four components allows to determine the overall OEE equipment efficiency ratio:

\[
\text{OEE} = \text{availability x uptime x productivity x quality x 100%}. \tag{10}
\]

It should be noted here that the standard definition is that OEE is calculated as a product of availability, efficiency, and quality [20], without taking into account the use of working time. In addition to OEE, other common indicators from the area of machine and equipment reliability are also calculated:

- MTTR (Mean Time To Repair) – an average repair time, this indicator shows how much time is needed on average for repair at the moment of damage, i.e. failure. This indicator can be used to evaluate maintenance personnel and assess the effectiveness of repair tasks performed by maintenance personnel.

\[
\text{MTTR} = \frac{\text{downtime}}{\text{number of events}} \tag{11}
\]

- MTTF (Mean Time To Failure) – mean time to failure, this indicator indicates the average time remaining until the next potential failure or failure.

\[
\text{MTTF} = \frac{\text{gross availability time} - \text{failure free time}}{\text{number of events}} \tag{12}
\]
- MTBF (Mean Time Between Failure) – mean time between failures, this indicator shows the time of failure-free operation of a given technical object. This time is averaged and its value results from simple calculation operations. In practice, this indicator is also used to determine the frequency of preventive reviews.

\[ \text{MTBF} = \text{MTTR} + \text{MTTF}. \]  

(13)

4. Methods for improving productivity indicators

The data obtained from production reports as well as the above mentioned indices (presented in formulas up to 6 to 13) allow for effective comparative analyses:

- specific production periods,
- individual machines, assembly lines,
- the individual production changes,
- individual products,
- the frequency of failures, downtime, component shortages,
- on individual production lines,
- the frequency of defective products occurring on individual production lines.

Information obtained from these comparative analyses provides valuable information on the state of production. On the basis of this information, production managers are able to identify the best and worst-performing production department, production lines, production changes, which allow identifying potential system errors that can be eliminated.

In the applied set of selected indicators, there are no indicators concerning the productivity of individual employees. The selection of such calculations would allow us to accurately identify the group of employees for whom additional training should be carried out, both in terms of the proper operation of the machines and cooperation within the group [21].

4.1. Description and analysis of methods used to improve productivity

In automotive companies most often there are specialized departments which deal with the introduction of system improvements in the whole plant, according to the Kaizen philosophy. Below are presented tools that significantly improve productivity.

4.1.1. 5S Tool

The 5S approach is often a prerequisite, in addition to mandatory training, for implementing the Lean Manufacturing philosophy. 5S is a tool that helps to solve problems of improper organization of workstations, both in the production hall and in offices. The reason for low productivity, product defects, machine failures and delays can be caused by the inappropriate organisation, which is manifested by an excessive number of different types of objects in the workplace and their incorrect location. The mess and crowd system at workstations significantly reduces the field of vision and does not allow for early recognition of the symptoms of failure, or for quick and efficient identification of the objects necessary at a given moment of time for work.

Every employee is required to carry out a 5S audit once a week at a designated location (weekly different location). The audit is carried out in accordance with the so-called ‘check’ list, which includes all the elements to be checked. All offices, workstations, production lines, storage areas and warehouses should have a uniform visual standard. The visual standard concerns the maintenance of an appropriate level of cleanliness, storage of the necessary tools for work in designated places, storage of documents in identical, labelled files, etc.

An incentive system to keep jobs in an appropriate standard may be a bonus added to the monthly salary. In order to receive the bonus, it is necessary to not exceed the permitted limit of points above which the bonus is withheld.
4.1.2. Suggestions system

It is an effective tool for motivating employees, whose main task is to increase the involvement of employees at all levels in the analysis, evaluation and development of their positions, tasks, and processes. Every employee has the opportunity to improve his or her workplace through a suggestion system.

This method consists in writing ideas by employees to improve all kinds of processes, activities, and devices on a specially prepared form. All ideas go to the appropriate department, where responsible persons check the usefulness of a suggestion. As in the case of the 5S technique, a motivating tool for creating potential improvements is usually a cash bonus added to the monthly salary.

4.1.3. Total Productive Maintenance

Total Productive Maintenance (TPM) is a continuous process of operating machines and equipment implemented within the whole enterprise, by all operators and maintenance workers. The minimum conditions for the successful introduction of TPM seem to be:

- good level of 5S,
- working Suggestive System,
- Management Board involvement and energy,
- use of high-quality training materials.

The aim of Total Productive Maintenance is to achieve the following:

- increase the ability and motivation of employees to maintain and maintain equipment,
- expanding the sense of ownership and cooperation between operators, mechanics, process and quality engineers,
- improve equipment's 'lifespan' through employee responsibility for the equipment used and create continuous improvement.
- improve productivity and reduce costs,
- measurement and observation of line achievements,
- continuous improvement of line reliability,
- elimination of minor failures,
- visual control of the improvement process.

Total Productive Maintenance should be based on the promotion of teamwork:

- establishment of a management team,
- developing a development plan,
- selecting a pilot line,
- monthly checks on progress,
- electing the team of employees for the pilot line,
- weekly review of standards,
- develop and implement a training plan.

Total Productive Maintenance implementation can be based on two bases: Autonomous Maintenance Process and Process Reliability. Implementation procedure for the Autonomous Maintenance Process:

**Step 1. Bringing the line to the desired condition**

- identification of the non-compliance,
- preparation of cleaning tools,
- taking pictures of each machine before and after improvements,
- introducing a list of sources of dirt and hard-to-reach places,
- cleaning instructions,
- the schedule for cleaning the production line,
- complete step 1 with audit and verification.

**Step 2. Removal of sources of pollution**
• elimination of sources of pollution,
• eliminate hard-to-reach places,
• closing the anomaly cards in step 1,
• identification of control areas,
• training of staff teams in accordance with standards,
• using the ‘5 x why’ to eliminate the problem.

Step 3. Control equipment training
• training of operators in machine functions,
• visualisation of inspection and cleaning,
• improving inspection and cleaning instructions,
• maintenance and control points on the line are defined.

Step 4. Continuous improvement
• to continue improving procedures,
• the introduction of regular audits,
• introduction of an action plan to increase the level of autonomous maintenance,
• the frequency of inspection and maintenance of the machinery shall be checked regularly by the team.

The procedure for implementing the Reliability pillar of the process is as follows:

Step 1. Introduction of indicators
• Installation of TPM boards,
• TPM anomalies,
• Install PDCA boards for anomaly cards under the TPM board,
• Failures,
• Scrap metal,
• Downtime,
• 5S audits.

Step 2. Use PDCA to reduce volatility
• Creation of an action plan for all open anomalies,
• Involving TPM in weekly production meetings,
  Performing analysis sheets for sources of contamination and hard-to-reach places to provide improvements to other facilities.

Step 3. Improve OEE level
• Action plan to improve process reliability,
• Monitoring and reporting of OEE indicators,
• Improvements achieved through OEE and other indicators.

Step 4. Maintain OEE level
• Use of MTBF indicators (time before the error),
• Use of MTTR indicators (repair time),
• Continuous improvement of process reliability.

Consistency in the implementation of individual TPM steps brings a significant improvement in the functioning of the machine park [22, 23]. According to the analysis of the achieved results and indicators, after TPM improvements have been implemented, the machine park failure rate often decreases by more than 30%.

The Single Minute Exchange of Die (SMED) method is available for other Lean Management tools that have a significant impact on the level of key indicators describing the level. The SMED allows to reduce the equipment setup to the minimum by separation of internal and external actions [24]. When introducing the SMED concept, the most important step is to pay attention to the principle of dividing basic activities into internal and external ones, performed during the process of setting up the workstation.
5. Conclusions
Achieving better economic performance than competitors is a prerequisite for competitive advantage. Enterprises strive to optimise production processes and improve cooperation between organisational units. Productivity is becoming increasingly important in the face of the demands of globalisation.

The article presents a set of indicators which are used for calculating productivity of production processes. On the basis of the analysis of the accuracy of the indicators used, it can be concluded that the set of indicators used lacks calculations concerning the productivity of individual employees. The selection of such calculations would allow us to accurately identify the group of employees for whom additional training should be carried out, both in terms of the proper operation of the machines and cooperation within the group. The next step should, therefore, be to develop and practically implement a set of indicators that characterise employee productivity. One could draw on the general indicators used by HR departments.

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