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OPTIMIZING TDG MANAGEMENT IN A CAR SERVICE: CASE STUDY ON OPERATIONAL AVAILABILITY AND COSTS

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Abstract: This study evaluated the impact of implementing a digital monitoring system on the management of TDGs used in an automotive service workshop through a simulated case study based on representative technical and economic assumptions. The results demonstrated significant improvements in operational performance, including a reduction of approximately 58% in non-productive time and an increase in the operational availability of TDGs from 90.8% to 97.4%. These operational benefits were also reflected in the economic performance, with annual operating costs reduced by nearly 60%, enabling recovery of the initial investment within approximately eight months. The main contribution of the research is the development of a performance evaluation model for TDG management that integrates operational and economic indicators, highlighting the role of resource traceability in improving the efficiency of automotive service operations. However, the findings should be interpreted in the context of the simulated dataset, and future research should validate the proposed model using real operational data while exploring the integration of RFID, IoT, and artificial intelligence technologies to further optimize technical resource management.
Keywords: TDGs management, digital monitoring system, car service, operational availability, maintenance management, operational costs.

1. INTRODUCTION

Digital transformation has become one of the most important strategic directions for improving competitiveness and operational efficiency in modern industrial organizations. The emergence of the Industry 4.0 paradigm has accelerated the integration of cyber-physical systems, the Industrial Internet of Things (IIoT), cloud computing, artificial intelligence, and advanced data analytics into manufacturing and maintenance processes. These technologies enable continuous monitoring of physical assets, real-time acquisition of operational data, and informed decision-making, thereby improving productivity, reliability, and resource utilization, [1]. More recently, the Industry 5.0 concept has extended this vision by promoting human-centric, sustainable, and resilient industrial systems, where digital technologies support both operational excellence and human-machine collaboration, [2].

Maintenance management has experienced a significant transformation during the last decade, evolving from corrective and preventive approaches toward predictive and intelligent maintenance strategies. Digital maintenance solutions combine sensor technologies, cloud platforms, mobile applications, digital twins, and advanced analytical methods to continuously monitor equipment condition, optimize maintenance planning, and improve asset utilization throughout their lifecycle, [3–5]. Consequently, organizations adopting digital maintenance systems have reported reductions in equipment downtime, maintenance costs, and production interruptions while increasing overall operational efficiency, [3,4].

Besides production equipment, maintenance activities also depend on the efficient management of auxiliary resources, including tools, devices, and gauges (TDGs). These resources constitute essential operational assets in maintenance departments and automotive service workshops because their availability directly affects maintenance quality, intervention duration, technician productivity, and workstation utilization. Although the individual acquisition cost of many tools may be relatively low, their temporary unavailability frequently results in delays, increased non-productive time, inefficient work scheduling, and additional operational costs, [5].

Recent advances in industrial digitalization have encouraged the development of intelligent systems for monitoring maintenance resources. Identification technologies such as radio-frequency identification (RFID), barcode systems, wireless communication, and IoT-based platforms enable the continuous monitoring of

maintenance assets, improving traceability, inventory accuracy, and lifecycle management, [6,7]. These technologies considerably reduce the time required to identify and locate tools while providing complete historical information regarding their utilization, calibration, maintenance interventions, and operational status, [6]. As a result, digital monitoring systems contribute not only to improving operational efficiency but also to supporting strategic asset management decisions throughout the entire lifecycle of maintenance resources, [7].
Among the enabling technologies of Industry 4.0, Digital Twins have attracted considerable research attention due to their capability to integrate physical assets with virtual models that continuously exchange operational information. Digital twins facilitate real-time monitoring, simulation, predictive maintenance, and decision support by combining sensor data with analytical models, [8]. Hassan et al. [9] demonstrated that implementing digital twins in industrial maintenance environments significantly improves maintenance planning, reduces equipment downtime, and enhances maintenance decision-making through continuous monitoring of operational data.
Although numerous studies have investigated digital maintenance solutions in manufacturing industries, considerably fewer contributions have addressed the digital management of maintenance resources in automotive service workshops. In these environments, maintenance performance depends not only on technicians' expertise but also on the availability of specialized diagnostic equipment and maintenance tools. Efficient management of these resources has a direct impact on workshop productivity, service quality, customer satisfaction, and operational costs. Sánchez-García et al. [10], proposed a mobile application supporting maintenance documentation and workshop management, demonstrating improvements in information accessibility and reductions in administrative processing time. Similarly, Pratomo et al. [11] analyzed inventory optimization for special tools in automotive workshops and showed that demand-based inventory policies significantly improve tool availability while reducing inventory-related costs.

2. MATERIALS AND METHODS

2.1. Case study description

To evaluate the impact of implementing a digital monitoring system for tools, devices, and gauges (TDGs), a simulated case study was developed based on the operational characteristics of a medium-sized automotive service workshop. The decision to adopt a simulation-based approach was motivated by the difficulty of accessing comprehensive databases regarding the utilization and availability of TDGs within automotive service facilities, as well as by the need to analyze controlled operational scenarios.
The analyzed service workshop consists of 12 workstations and 18 mechanics, organized to perform vehicle diagnostic, maintenance, and repair activities. A total of 243 TDGs are used in daily operations, including hand tools, special tools, measuring devices, and gauges required for service procedures.
Based on their utilization rate and request frequency, the TDGs were considered shared resources used by technical personnel according to the requirements of each intervention. In the initial situation, their management is carried out through electronic files and internal records, without the possibility of real-time identification of the location and status of each item.
To analyze operational performance, two distinct scenarios were compared:
Scenario S1 – Traditional TDG management system;
Scenario S2 – Digital monitoring and traceability system.
In *Scenario S1*, the identification and distribution of TDGs are performed manually, while information regarding their utilization and availability is updated periodically. In *Scenario S2*, each TDG is individually identified through a unique QR code, and all issuing, return, and inventory operations are automatically recorded in a centralized database.

2.2. Performance indicators analyzed

The efficiency of the TDG management system was evaluated using three categories of operational and economic indicators.
The first indicator analyzed is the non-productive time associated with TDG identification and localization activities. This represents the time spent by technical personnel searching for the resources required to perform maintenance and repair tasks and is expressed in minutes per month.
The second indicator is the operational availability of TDGs, defined as the ratio between the number of available TDGs and the total number of TDGs managed within the service workshop.
Operational availability was determined using equation (1):

$$D_{SDV} = \left(\frac{N_d}{N_t} \right) \times 100 \quad (1)$$

where: N_d represents the number of available TDGs; N_t represents the total number of TDGs recorded in the inventory.
The third indicator analyzed is the operational cost associated with TDG management. This includes the costs generated by mechanics' non-productive time, costs associated with the loss or damage of TDGs, and administrative costs related to inventory and record-keeping activities.
The total operational cost was calculated using equation (2):

$$C_{tot} = C_t + C_p + C_a \quad (1)$$

where: C_t - cost of non-productive time; C_p - cost of losses and damages; C_a - administrative costs.

2.3. Proposed digital system

The proposed solution involves the implementation of a digital monitoring system based on the individual identification of each TDG through a QR code and the automatic recording of usage operations in a centralized database. When a TDG is issued, the operator scans its associated QR code using a mobile device. Information regarding the user, date, time, and location is automatically stored in the system. Upon returning the TDG, the process is repeated, enabling the instant updating of the resource status.
The system allows the automatic generation of reports regarding TDG utilization rates, the identification of unavailable equipment, and the monitoring of inspection or calibration deadlines for measuring devices.

2.4. Simulation methodology

The comparative analysis was conducted over a period of 12 months. For each month, data were generated regarding the time lost in identifying TDGs, the number of unavailable items, and the costs associated with management activities. The parameters used in the simulation were established to reflect the operating conditions of a medium-sized automotive service workshop, characterized by an annual workload of approximately 4,200 repair and maintenance work orders.
The results obtained for the two scenarios were analyzed comparatively, to determine the reduction in operational costs, the decrease in non-productive time, and the increase in the operational availability of TDGs resulting from the implementation of the digital monitoring system.

3. RESULTS AND DISCUSSIONS

3.1. Analysis of non-productive time generated by TDG management

The first indicator analyzed in this study is the non-productive time associated with the identification, localization, and retrieval of TDGs required for maintenance and repair activities. Within the analyzed automotive service workshop, these activities are performed frequently throughout the working day and can significantly affect the productivity of technical personnel.
To evaluate the impact of implementing the digital monitoring system, the values recorded for the two analyzed scenarios were compared: the traditional record-keeping system (S1) and the digital monitoring system (S2).
Table 1 presents the evolution of the monthly non-productive time associated with TDG management over the analyzed period.

Table 1. Non-productive time associated with TDG management

Month	*Traditional system S1 (min/month)*	*Traditional system S2 (min/month)*
January	1842	792
February	1768	741
March	1914	806
April	1827	758
May	1985	823
June	2054	861
July	1961	817
August	1872	784
September	2037	848
October	2115	879
November	1948	812
December	1863	773

The analysis of the data highlights significant differences between the two scenarios. In the case of the traditional system, monthly non-productive time ranges between 1.768 and 2.115 minutes, with an annual average value of approximately 1.932 minutes per month. These values are primarily associated with difficulties in locating TDGs, the lack of up-to-date information regarding their availability, and periodic inventory activities. In the case of the digital monitoring system, non-productive time is considerably reduced, with recorded values ranging between 741 and 879 minutes per month. The annual average value calculated for this scenario is approximately 808 minutes per month. The average annual reduction in non-productive time is approximately 58.2%, indicating a significant impact of digitalization on the operational efficiency of the analyzed service workshop. The results suggest that the use of an individual identification and real-time monitoring system facilitates rapid access to information regarding the location and status of TDGs, contributing to the reduction of non-value-added activities.The obtained results are consistent with the trends reported in the literature regarding the use of digital technologies for optimizing maintenance activities and the management of technical resources, [1–3].

Figure 1 illustrates the evolution of non-productive time recorded throughout the analyzed period for the two studied scenarios. It can be observed that the values corresponding to the digital system are significantly lower than those of the traditional system throughout the entire period under analysis. The observed differences confirm that the implementation of a digital monitoring system contributes to reducing the time required for the identification and localization of TDGs, leading to improved efficiency of activities carried out within the automotive service workshop.

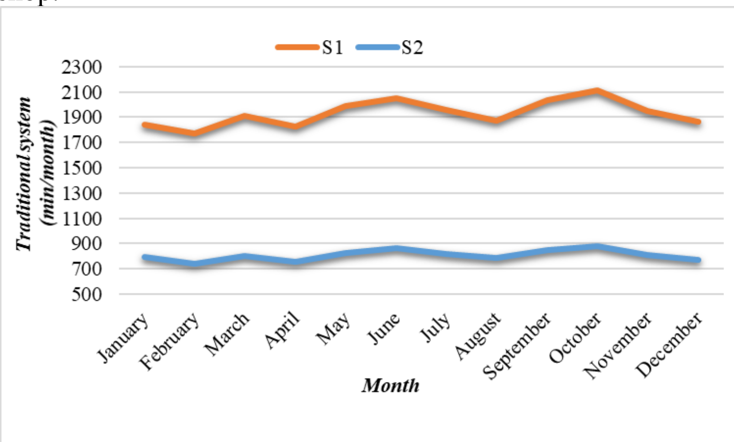

Fig. 1. Evolution of non-productive time associated with TDG management

3.2. Analysis of TDG operational availability

Operational availability of TDGs represents an essential indicator for evaluating the performance of the technical resource management system within an automotive service workshop. A low level of availability may lead to delays in service activities, increased waiting times, and reduced productivity of technical personnel. In the present study, a TDG was considered unavailable when it could not be located within a reasonable period of time, was in use without the corresponding record being updated, or was temporarily withdrawn from service for inspection and repair. To evaluate the impact of implementing the digital monitoring system, the monthly evolution of the number of unavailable TDGs was analyzed for the two considered scenarios. The obtained results are presented in Table 2.

Table 2. Evolution of the unavailable TDGs number

Month	*Traditional system S1 (piece)*	*Traditional system S2 (piece)*
anuary	21	6
February	19	5
March	22	7
April	20	5
May	23	7
June	25	8
July	24	7
August	21	6
September	24	7
October	26	8
November	22	6
December	20	5

The data presented highlight significant differences between the two analyzed scenarios. In the case of the traditional system, the number of unavailable TDGs ranges between 19 and 26 units per month, with an annual average value of approximately 22.3 TDGs. In contrast, for the digital monitoring system, the values range between 5 and 8 TDGs per month, with an annual average of approximately 6.4 TDGs.
Considering that the analyzed service workshop manages a total of 243 TDGs, the average operational availability was determined using Equation (1). The obtained results indicate an average availability of approximately 90.8% for the traditional system and 97.4% for the digital monitoring system.
The increase in operational availability is driven by the ability to rapidly identify the location of each TDG, the real-time updating of information regarding its utilization, and the reduction of situations in which resources cannot be located or are incorrectly recorded. Furthermore, the digital system facilitates the monitoring of equipment undergoing inspection or repair and enables more efficient planning of maintenance activities.
Compared with the initial situation, the implementation of the digital system leads to a reduction of approximately 71% in the average number of unavailable TDGs and an increase in operational availability of 6.6 percentage points. These results confirm that the digitalization of the TDG management process directly contributes to improving the operational performance of the automotive service workshop and to reducing the non-productive time analyzed in the previous section.
Figure 2 illustrates the monthly variation in the number of unavailable TDGs for the two analyzed systems. In the case of the traditional system, a significantly higher number of unavailable items can be observed, directly affecting the execution of service activities. The implementation of the digital system considerably reduces such situations by enabling continuous resource monitoring and the rapid identification of the location of each TDG.

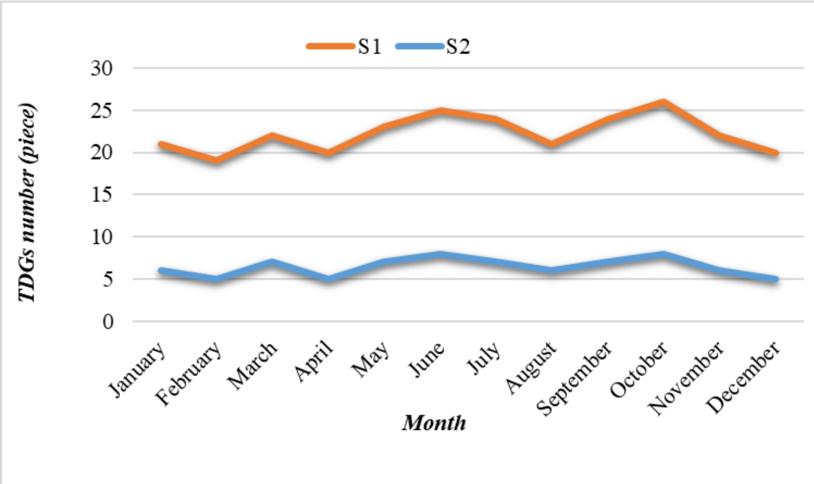

Fig. 2. Evolution of the number of unavailable TDGs

The obtained results are consistent with the trends reported in the literature regarding the implementation of digital systems for monitoring and traceability of technical resources [1–3], demonstrating that the use of dedicated information technology solutions can contribute to increasing resource utilization rates and improving the efficiency of service activities.
The results summarized in Table 3 highlight the positive impact of implementing the digital system on all analyzed indicators. A significant reduction in non-productive time and in the number of unavailable TDGs can be observed, accompanied by an increase in operational availability. These improvements create the conditions for reducing the operational costs associated with TDG management, an aspect analyzed in the following section.

Table 3. Summary performance indicators of the TDG management system

Indicator	*Traditional system S1*	*Traditional system S2*	*Modificare*
Average non-productive time (min/month)	1932	808	-58.2%
Unavailable TDGs (average/month)	22.3	6.4	-71.3%
Operational availability (%)	90.8	97.4	+6.6 pp*

* pp – percentage points

3.3. Analysis of operational costs associated with TDG management
The costs generated by TDG management represent an important component of the operational expenses within an automotive service workshop. Although the individual impact of a lost tool or an unavailable device may

seem limited, the cumulative effect of non-productive time, administrative activities, and equipment replacement can lead to significant long-term costs.
Within the study, three main categories of costs were analyzed: costs generated by technical personnel's non-productive time, costs associated with the loss or damage of TDGs, and administrative costs related to record-keeping and inventory activities.
Based on the non-productive time determined in Section 3.1 and considering an average labor cost of 75 RON /hour, the annual costs associated with TDG localization and management activities were calculated.

Table 4. Annual operational costs associated with TDG management

Cost category	*Digital system S1 (RON/year)*	*Digital system S2 (RON/year)*
Non-productive time cost	28 980	12 120
Cost of TDG losses and damages	12 000	4 500
Administrative cost (record-keeping and inventory)	10 800	4 200
Total annual cost	*51 780*	*20 820*

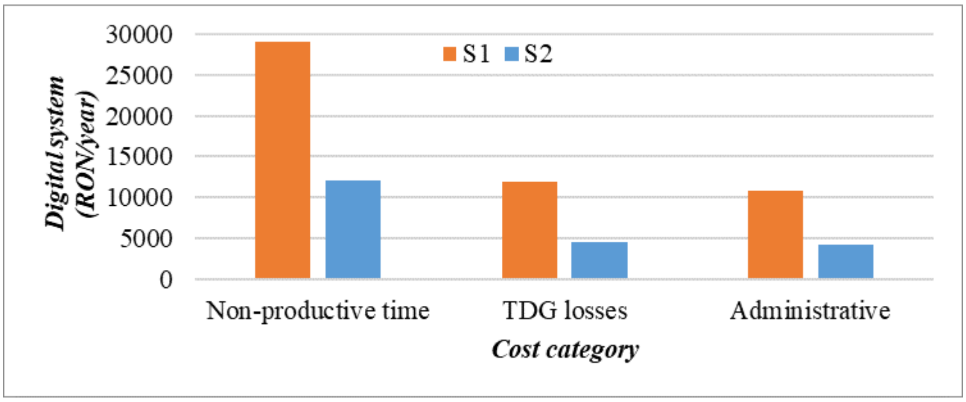

Fig. 3. Structure of operational costs associated with TDG management

The analysis of the results highlights significant differences between the two analyzed scenarios. In the case of the traditional system, the total annual cost associated with TDG management is estimated at approximately 51.780 RON. The most significant component of this cost is the non-productive time of technical personnel, which generates losses of nearly 29.000 RON per year.
The implementation of the digital monitoring system leads to a substantial reduction in all analyzed cost categories. Costs associated with non-productive time are reduced by approximately 58%, as a result of the decrease in the time required to identify and locate TDGs. Furthermore, continuous resource monitoring enables a reduction in the number of lost or damaged items and simplifies administrative inventory activities.
Compared with the traditional system, the estimated total annual cost of the digital system is approximately 20.820 RON, corresponding to a reduction of about 59.8%. The resulting annual savings amount to approximately 30.960 RON.
The results demonstrate that the benefits of implementing a digital monitoring system are not limited to increasing the operational availability of TDGs but are also directly reflected in lower operating costs and improved economic efficiency of the activities carried out within the automotive service workshop.
By correlating the results obtained in the previous sections, it can be observed that the approximately 71% reduction in the number of unavailable TDGs and the more than 58% decrease in non-productive time generate significant annual savings. These findings confirm that the digitalization of the TDG management process can represent an effective solution for enhancing the competitiveness and operational performance of automotive service facilities.

3.4. Economic analysis of the digital system implementation

The implementation of a digital TDG monitoring system requires an initial investment associated with the acquisition of hardware equipment, the development or configuration of the software application, and personnel training. To evaluate the economic feasibility of the proposed solution, a simplified analysis of implementation costs and the savings generated through the reduction of operational costs was carried out.
In the case study, the implementation of a system based on the individual identification of TDGs using QR codes and a dedicated application for managing issuing, return, and inventory operations was considered. The estimated implementation costs are presented in Table 5.
Based on the results presented in the previous section, the implementation of the digital system leads to an

annual reduction in operational costs of approximately 30.960 RON. This value represents the estimated annual savings achieved through the reduction of non-productive time, the decrease in the number of lost or damaged TDGs, and the simplification of administrative activities.

Table 5. Estimated costs for the implementation of the digital system

Component	***Estimated cost (RON)***
QR code generation and labeling for TDGs	1 200
Mobile scanning devices (2 units)	4 800
Software application development and configuration	8 500
Database and IT infrastructure	2 500
Personnel training	1 500
Implementation and testing costs	1 500
Total investment	*20 000*

The payback period was determined using equation (3):

$$PR = \frac{I}{E_a} \tag{3}$$

where: PR represents the payback period (years); I represent the initial investment (RON); E_a represents the estimated annual savings (RON/year).
By substituting the values obtained in the study, the following result is obtained:

$$PR = \frac{20000}{30960} = 0.65$$

The result indicates an estimated payback period of approximately 0.65 years, or about 8 months.
From an economic perspective, the obtained value highlights the attractiveness of the proposed solution. Recovering the investment in less than one year indicates that the benefits generated by implementing the digital system significantly outweigh the initial costs required for its deployment.
In addition to the direct economic advantages, the implementation of the digital system also provides indirect benefits that are difficult to quantify, such as improved operational discipline, enhanced traceability of technical resources, reduced conflicts regarding TDG usage, and increased satisfaction among technical personnel. These benefits contribute to improving the overall performance of the service workshop and enhancing its long-term competitiveness.
The obtained results demonstrate that the implementation of a digital TDG monitoring system can represent a viable solution from both operational and economic perspectives, being capable of generating significant savings and ensuring the rapid recovery of the initial investment.

4. CONCLUSIONS

The objective of this research was to evaluate the impact of implementing a digital monitoring system on the management of TDGs used in an automotive service workshop. In the absence of real operational data, the analysis was conducted through a simulated case study developed on the basis of technical and economic assumptions considered representative of the operations of a medium-sized automotive service center.
The obtained results highlighted the significant influence of TDG management practices on the operational performance of the organization. The analysis of non-productive time showed that the implementation of the digital system reduced this indicator from an average value of 1,932 min/month to approximately 808 min/month, corresponding to a decrease of about 58.2%. The reduction in the time required to locate and identify TDGs directly contributes to improving the efficiency of service activities and to the more effective utilization of human resources.
Regarding the operational availability of TDGs, the results indicated a reduction in the average number of unavailable items from 22.3 to 6.4 units per month. Consequently, operational availability increased from 90.8% to 97.4%, demonstrating that the use of a digital monitoring system improves control over technical resources and significantly reduces situations in which they cannot be used when needed.
The economic analysis revealed that the operational benefits are directly reflected in lower operating costs. The annual operational cost associated with TDG management was estimated at RON 51,780 for the traditional

system and RON 20,820 for the digital system, representing a reduction of approximately 59.8%. The resulting annual savings, estimated at RON 30,960, allow the recovery of the initial investment within approximately 0.65 years, or about eight months.

The main contribution of this study lies in the development of a performance evaluation model for TDG management based on the correlation of operational and economic indicators specific to automotive service activities. Unlike most studies reported in the literature, which analyze digitalization at the level of general maintenance or production processes, this research focuses specifically on TDG management and highlights the direct impact of resource traceability on operational availability and operating costs.

One limitation of the study is the use of a simulated dataset generated on the basis of technical and economic assumptions considered representative of a medium-sized automotive service workshop. Although the adopted methodology enables the assessment of the impact of implementing a digital monitoring system on key operational and economic indicators, the obtained results should be interpreted within the context of the assumptions made. Validation of the proposed model using data collected from the actual operation of an automotive service workshop represents an important direction for future research.

Future studies may focus on validating the proposed model using real-world data from automotive service workshops and extending the analysis to the integration of RFID, IoT, and artificial intelligence-based solutions for monitoring and optimizing the use of technical resources.

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