Productivity tool for automated guided vehicles: OEE indicator perspective

L C Ng Corrales\textsuperscript{1,2*}, M P Lambán\textsuperscript{1}, J A Royo\textsuperscript{1} and M E Hernández\textsuperscript{1,2}

1 Design and Manufacturing Engineering Department, Universidad de Zaragoza, 50018 Zaragoza, Spain.
2 Department of Industrial Engineering, Universidad Tecnológica de Panamá, Ciudad de Panamá 0819-07289, Panamá

*Corresponding author: lisbeth.ng@utp.ac.pa

Abstract: Productivity is a measurement of the efficiency of the resources, constant changes in the environment promote that companies regularly measure their activities. This study aims to define a new metric based conceptually on the traditional OEE. The new indicator measures the efficiency of logistic equipment in this case a system of automated handling: automated guided vehicles (AGVs). The indicator was developed by parameterizing the variables and defining the losses found in the process. It was applied in a factory of car parts and spare parts, two AGVs were analyzed in two different routes. The new indicator was effectively adapted to measure the performance of a logistics equipment. The OEE_{agv} results obtained are those expected by the company, although some authors value the indicator with a higher percentage. Also, the result has shown that a new route could be added for more efficient use of the two AGVs.

Keywords: Overall equipment effectiveness, OEE, Performance, Automated guided vehicles, AGV.

1. Introduction

Industry 4.0 is the future of global manufacturing which connects systems to things that makes dynamic management and self-organizing, improving the value chains of life cycle products [1]. The industry moves faster, the period of change or innovation is shorter, the decision must be made in less time, that is why tools should be used to help identify losses caused during a production process. Global competitiveness promotes companies to reinvent themselves, to improve their processes and quality without affecting their profits. The availability of the production resources (e.g. facilities, human resources, machine) enhance the competitiveness of manufacturing companies [2]. Companies have been forced to apply new approaches in manufacturing processes to improve the results and to predict indicator outcomes [3].

The Overall Equipment Effectiveness (OEE) introduced by Nakajima (1988) is a measurement tool developed from the TPM concept [4]. This quantitative indicator is commonly used in production to measure the effectiveness of equipment, identifying losses that occur during the process. Losses are

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classified into three dimensions of effectiveness: actual availability, performance efficiency, and quality output. OEE is increasingly popular used in industry for measure productivity and monitoring the equipment, furthermore as an indicator of process and performance improvement [5,6]. Since the 1980s performance measurement systems have become relevant to scholars and practitioners [7]. As part of the performance measurement system and continuous improvement, this indicator will help companies to increase their competitiveness. In the same way, it contributes to the scientific community by broadening the knowledge and scope of this productivity measure and its application in other sectors besides production. To the best of our knowledge, the OEE indicator has not been used to measure the effectiveness of cargo movement equipment in a warehouse. The objective of this study is to define a new metric based conceptually similar to the traditional OEE to visualize the hidden waste in a material movement process. The new metric measures the efficiency of logistic equipment in this case a system of automated handling: automated guided vehicles (AGVs). The AGV is a widely used automatic guidance vehicle for the movement of raw material or finished product. This indicator provides updated information concerning the productivity of this type of equipment and the losses in the process. This information helps decision makers to implement continuous improvements.

This paper is structured as followed: section 2 explained the methodology used in this case, a literature review of the OEE, and AVG concept. Section 3 presents the new indicator’s parameters and loss identification of the process. Besides, the case study is described, and the results obtained are presented and analyzed. Finally, section 4 describes the conclusion.

2. Methodology
The methodology followed to achieve the main objective is based on 3 steps. First, a literature review was conducted to understand the evolution of the indicator outside the production area. Secondly, parameters were determined, and variables were characterized for the calculation of the new performance indicator. In this step, losses related to performance, availability, and quality parameter were identified in the AGV. The variable to be considered were shift, average route times, number of routes, and average AGV speed. Thirdly, the indicator was applied to the AGV’s to evaluate the metrics formulation and performed an analysis of the results.

2.1 Overall equipment effectiveness (OEE)
The original definition of OEE was established by Nakajima and it considers three dimensions: availability, performance, and quality. The availability (A) measures the productive time of the equipment, performance (P) contrasts the real vs the ideal production time, and quality (Q) is focused on meeting established requirements. The OEE is the product of these three factors:

\[ OEE = A \times P \times Q \]

Through these factors, six major losses that reduce effectiveness are identified (table 1). Losses could be chronic (small, hidden, and complicated to identify) or sporadic (obvious, irregularly, and with dramatic effects) [8,9].

| Table 1. Six big losses. |
|-------------------------|
| **Availability**         | Equipment failure |
|                         | Setup and adjustments |
| **Performance**         | Idling and minor stops |
|                         | Reduced speed |
| **Quality**             | Production rejects |
|                         | Start-up rejects |

Over time, OEE has been modified to measure effectiveness in different industries applications [10]. Muchiri and Pintelon [11] state that the OEE tool has been modified and expanded to take a broader perspective to include other factors that influence the productive system. Some modified formulations
of the indicator not only consider the equipment performance, otherwise identifies the bottleneck and measure the factory level performance [12,13]. Following this direction, other authors adapted the indicator to measure the performance of the production line in the manufacturing system [14,15]. The mining sector also has implemented OEE to measure the performance of their equipment (e.g. shovel, trucks, and draglines) [16,17]. Domingo and Aguado [18] incorporated the sustainability concept in the OEE to identify and measure losses in a lean and green manufacturing environment. García-Arca et al. [19] adapted the indicator to improve efficiency in road transportation, focused on the concept of routes. Table 2 presents a comparison of the characterization of availability, performance, and quality between Nakajima [4] as the original author of the indicator in production equipment and García-Arca et al. [19] one of the several later authors who adapt the OEE to the logistics sector. The availability ratio is defined by both authors as the total time minus unplanned stoppages, Nakajima focused on the production time and García-Arca in routes time. On the other hand, for the quality ratio, Nakajima considered the total amount of production minus production defects, while Garcia-Arca considered the number of services on the routes minus the number of quality incidences in the route. Finally, for the performance ratio both authors considered the ideal versus the real time, in addition García-Arca included a factor that measures utilization level of a vehicle on the route.

Table 2. Characterization of the availability, performance, and quality.

| Variable       | Nakajima 1988                        | García-Arca et al. 2018                                      |
|----------------|--------------------------------------|----------------------------------------------------------------|
| Availability   | loading time – downtime / loading time| total route time – stops / total route time                   |
| Performance    | ideal cycle time * output / operating time | [(standard time devoted to route) / (real time devoted to route)] * [truck use outbound + truck use return] / 2 |
| Quality        | input – quality defects / input      | # services on this route – # incidences / # services on this route |

Acceptable OEE ranges have differed among authors over time. Some authors consider 85% to be an ideal value [4,20], others established ranges between 30% to 80% [9]. Dal et al. [21] state that there is no optimum value of OEE and that variation occurs depending on the criteria and industry in which it is applied.

2.2 Automated guided vehicles (AGV)
The automated guided vehicle (AGV) was introduced in 1953 by Barret Electronics of Northbrook [22]. The AGV is an autonomous and flexible intelligent transport system capable of moving without a driver, they are widely used in industry to transport products from one point to another along a predetermined route. They are used to perform repetitive and high-frequency tasks, have a series of batteries that power them, and allow them to work for hours.

The AGV is controlled and monitored by centralized software. The system allows us to control the sending of orders to start, to stop, and changes of route, also we can monitor the AGV status, battery level, route in real-time, number of AGVs, among others.

The AGV system is used to simplify intralogistics and material handling in industrial environments like manufacturing, medicine, and cargo movement [23]. These systems provide advantages such as increased speed, savings in stock damage due to mishandling, and optimization of productivity in the movement of materials, generating flexibility, profitability, and return on investment if there is an appropriated utilization.
3. Results and discussion

According to our methodology, we obtained a new effectiveness indicator of an AGV, based on the well-known OEE. In a planned route were calculated the three components of the OEE. Availability (A) can be expressed as the ratio of operating time to working hours. It measures the total time that the AGV is not operating because of losses due to breakdowns, stops (accidents) or AGV discharged. The performance measures the ideal or standard time against the real-time the AGV is running. Losses that affected the performance are caused by minor stoppages or reduced speed. The quality rate measures the number of runs that were made without incident.

The OEE_{agv} is calculated as follows (equation 1):

\[
OEE_{agv} = A \times P \times Q
\]

(1)

The operating time is the time that AVG is running. It is calculated by subtracting the availability breakdown losses from the working hours. The working hours are considered the shift hours minus the planned downtime (meeting, snack break). The planned downtime was considered due to the start of the operation by the request of the operator, in other words, without an operator there will be no AGV requested. The ideal time is the standard time the AGV must make the route and the real-time is the actual time it took. The quality includes the total number of trips made by the AGV and the seamless runs. The identified losses of an AGV are shown in table 3.

| Category          | Losses                          |
|-------------------|---------------------------------|
| Availability      | Time without a work order       |
|                   | Unplanned downtime              |
|                   | • Breakdowns                    |
|                   | • Accidents                     |
|                   | • Discharged                    |
|                   | Planned downtime                |
|                   | • Meeting                       |
|                   | • Snack break                   |
| Performance       | Minor stoppages                 |
|                   | Reduced speed                   |
| Quality           | Seamless runs                   |
|                   | Runs with incidents             |

A general outline of the new calculation of the OEE_{agv} is presented in figure 1.

This indicator was applied in a factory of car parts and spare parts in Spain. The company works 8-hours per shift, there are three shifts morning, afternoon, and night. The workers are entitled to a 30-minute snack break established by law. The OEE_{agv} was measured on 2 AGVs that can travel on 2 different routes. The operation starts with the AGV requested by an operator to remove a full container of products from the production facilities and replenish an empty one. The AGV transport the full container for storage.

The AGV step-by-step movements as follows. Initially, moves to the production line, load the container and then moves with the cargo to the warehouse. Next, it unloads the full container and loads the empty one. Afterward, it moves to the line, unloads the empty container, and returns to the initial position. Table 4 presents data considered for the indicator calculation. The standard time for the routes was obtained using averages with a deviation between 2% and 5%.
Figure 1. General outline OEE diagram.

Table 4. AGV and Factory data entry.

| Item          | Measure                  |
|---------------|--------------------------|
| Shifts        | Morning, Afternoon, Night|
| AGV           | 2 units                  |
| AGV average speed | 0.4 m/s       |
| Route 1       | 348 second by mean       |
| Route 2       | 643 second by mean       |

Figure 2 shows the OEE_{agv} results obtained by each AGV in different shifts, which ranged from 45% to 65%. The results are quite stable; however, it should be noted in figure 3 that the factor that remains the lowest is availability. The other two factors are almost 100%, due to the few incidents or slowdowns that occur during the trip. The availability factor is mostly affected by the time the AGV is without work orders.

Figure 2. OEE_{agv} per shifts of the two AGV.
Figure 3. OEE$_{agv}$ parameter of the two AGV per shift.

Figure 4 shows the OEE$_{agv}$ of each AGV for the two routes on which they can travel. The results are lower and range between 20% and 30%, the factor that determines this decrease is the availability it has for each route. This indicates that the AGV is out of work orders by maintaining a low availability. The results show that route 2 maintains a higher percentage of OEE$_{agv}$, even though fewer trips are made on this route, the time spent on the route is greater, as shown in table 4, which means a higher percentage of availability.

Figure 4. OEE$_{agv}$ of the two AGV considering the route.

The results obtained show similar behaviors, this is since the AGV is automated equipment that performs the work constantly, having predetermined routes. General losses in the performance are due to particular situations such as the discharge of the equipment, which in this case the AGVs always returned to their charging station. Discharge of the AGV did not occur during this study. Another cause is the decrease in speed when encountering an obstacle on the route, which causes an increase in travel time, affecting its performance.
4. Conclusion
This paper has presented the development, definition, and application of a new metric based conceptually on the OEE. The framework offers a novel way to measure the effectiveness of logistic equipment. Through this adaptation is possible to know the effectiveness of this type of equipment in a factory, moreover, the indicator aid decision making and decrease wasting time in the AGV operation.

The main research findings can be summarized as follows:
1. The new indicator was effectively adapted to measure the performance of logistic equipment.
2. The OEE_{agv} results obtained are those expected by the company, although some authors value the indicator with a higher percentage.
3. The results of this indicator may vary in comparison to what is done in the traditional OEE for production equipment, because the AGV does not always go at its maximum speed due to turns, movement spaces, among others, that may affect its maximum movement capacity.
4. For efficient use of the AGVs, a new route is being proposed for the factory to increase the availability percentage in the future.

As future work, this framework could be implemented and validated in other organizations where more AGVs and routes can be considered.

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