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Procedia CIRP 107 (2022) 902–907

www.elsevier.com/locate/procedia

55th CIRP Conference on Manufacturing Systems

Exploring the Added-Value of Integrating Real-Time Location Systems for Tracking Critical Maintenance Tools

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Abstract

Searching and optimally locating maintenance tools is an important undertaking that influences productivity. The efficiency lost can be high for intensive maintenance processes, particularly in instances where technicians share critical (and expensive) tooling. Real-Time Location Systems (RTLS) can serve as a feasible solution for minimizing travel and search times, by tagging tools, thereby dynamically tracking their spatial location real-time. Moreover, RTLS can be deployed alongside Automated Guided Vehicles (AGV's) thereby supporting smart material handling.

In this paper, we propose a model for exploring the added value of implementing RTLS with AGV to better support maintenance processes in high-demand manufacturing and maintenance shop floors. The NetLogo (multi-agent programmable environment) simulation model mimics interactions of maintenance technicians, tasks, and critical tooling within an aircraft maintenance facility. To evaluate the added value of tagging critical tooling to better enhance efficiency locating tools, we define three use-cases. The first case mimics a current scenario in which critical tools are untagged, hence assuming significant search and travel times are incurred by technicians. The second case explores scenarios where tools are tagged, and trackable within the spatial environment of the hangar. The third case integrates both RTLS and AGVs to support both locating tools, and minimising travel times by technicians. Initial simulations results show significant added value for the second and third experiments, verifying suitability of implementing RTLS for complex maintenance and manufacturing processes.

Keywords: Real-time location systems; Agent-based simulation; Tool location; Maintenance; Aircraft hangar.

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1. Introduction

Optimization is an important focus for many organizations, irrespective of the business domain. This extends to companies involved in value addition activities, such as manufacturing, assembly, and maintenance. A critical bottleneck for operator efficiency often includes the process of searching for tools or equipment necessary to perform manufacturing or maintenance operations. This includes machining or diagnostic equipment. Depending on the layout, inventory and storage practices, travel and search times ends up constituting a sizable portion of productive or value-added times. A study investigating the influence of tool search time in a machine shop observed efficiency reduction of up to 32% of the total productive times [1].

For maintenance-service oriented organizations, such as large aircraft hangars, tool search time can account for a considerable proportion of non-productive time. Fig. 1 illustrates the contribution of diagnosis and repairs times on overall system availability, here quantified using Mean Time to Diagnose (MTTD) and Mean Time to Repair (MTTR) [2]. These two phases rely on specialized diagnostic and repair tools, including vibration analyzers. Hence, optimization of

10.1016/j.procir.2022.05.082

search and service times is critical to improve overall system availability.

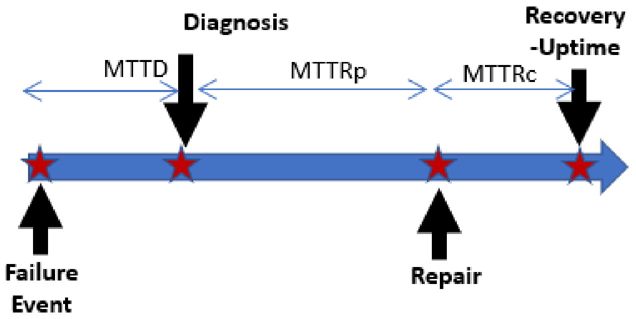

Fig. 1. Illustration of contribution of diagnosis and repair times on overall system availability [2]).

For an aircraft hangar, depending on scarcity of tooling, studies show that on average, technicians can walk as much as 12 km per shift to retrieve tools and materials they require for maintaining aircraft systems [3-5]. Therefore, localization of tooling is an important leverage to optimize maintenance turn-around times. Important variables influencing tool search time, includes the facility layout, cataloguing of tooling, and variety of tooling kept in stock [5].

To address the tool search problem, information-technology enablers are explored for minimizing search times and improve maintenance turn-around times. Few examples include intelligent manufacturing systems, RFIDs, and operations monitoring systems via internet-of-things [6]. Other studies explore indoor localization systems, for object tracking using QR codes, or computer vision [7]. Real-Time Location Systems (RTLS) offers potential advantages that allows efficient tagging and tracking of critical tools and materials in large manufacturing and maintenance facilities. Although the benefits are intuitive, few studies explore the added value of RTLS for enhancing 'tool search times,' especially for manufacturing and maintenance operations. Fig. 2 illustrates location of tooling stations in an aircraft hangar.

From an operations management perspective and to improve productivity, it is necessary to quantify contribution of search and travel times to better formulate improvement strategies. Few papers study this contribution, especially, the added value of integration RTLS to enhance the efficiency of tool search. Further benefits are possible through integration of smart material handling systems, including Autonomous Guided Vehicles (to mitigate travel times).

This paper attempts to address this gap by proposing an agent-based simulation approach, to quantify the operational benefits of implementing RTLS. Moreover, optimizing tool search and travel times. A case study of maintenance processes in a large aircraft hangar is discussed. The paper is organized as follows. Section 2 discusses the state-of-the art and explores gaps in literature on the added benefits of RTLS on tool search and travel times. Section 3 describes the use case, methodology, agent-based simulation approach, assumptions considered, and variables implemented in the model. Three simulation experiments are also considered.

Section 4 presents first insights from the simulation experiments, where benefits on search and travel times are demonstrated.

Fig. 2. An aircraft maintenance hangar showing tooling stations [8]).

2. State-of-the art

The 'tool search time' problem can be seen from a broad research perspective linked to worker productivity. Attempts to address the problem, so far considers development of solutions, such as autonomous aerial robots for search and delivering tools, for instance, explored in Perez-Grau et. al. [9]. Though they address design consideration, including navigation, and sensor-based localization, opportunities for operational decision-making are unclear. For instance, quantifying benefits for tool search and travel times.

Lean management (focusing on the 5S approaches) are discussed as a solution for improving tool search and travel times. Ideally, the suggestions here focus on workplace organization, structured cataloguing of tools, and improving documentation processes [4]. Ebuetce et al. [10] shows the improvement potential to turn-around times, though its contribution to enhancing operation efficiency from an operations management perspective is unclear. This limits exploration of information technology enablers, here localization and intelligent material handling systems (e.g., AGV's).

RTLS technologies presents robust opportunities for localization, by allowing real-time tracking of tools and materials on the shop floor [11]. RTLS compares with technologies, including, Radio Frequency Identification (RFID), GPS, or QR-codes, but with the added advantage of spatial location and real-time tracking of items and materials on the shop floor [11]. Fig. 3 illustrates a RTLS set-up in a production facility, showing tags placed on AGV's and fixed anchors for collecting real-time localization information.

Applications of localization technologies are explored in studies, e.g., Pereira et al. [12] where order picking in a warehouse setting is discussed. An extensive review of in-door localization technologies and strategies is discussed in Morar et al. [7]. Thiede et al. [11] reviewed applications of RTLS in a factory setting, and explored interesting use cases, including managing logistics elements such as AGV's, and strategies for optimizing material flow. Additional applications in healthcare are discussed for locating critical surgical equipment [13, 14].

Use cases of RTLS in maintenance are also discussed, for instance, in [15] and [16], although a document search by the authors indicated pre-dominant use-cases for tool search in the healthcare domain. Accordingly, we observe that studies exploring the added value of RTLS for optimizing tool search in manufacturing and logistics are sparse. This extends to product/process retrieval in manufacturing, where search time plays a critical role towards optimizing worker and operational productivity.

Apart from tracking items and equipment on the maintenance shop floor, the support function of RTLS extends to improving the efficiency of production systems. For example, as an enabler of locating the real-time status of products and tooling, efficiency monitoring, navigation of people and tools, automatic booking to tools to cost centers, optimization of routing and facility layouts to mention a few examples Racz-Szabo et.al. [17].

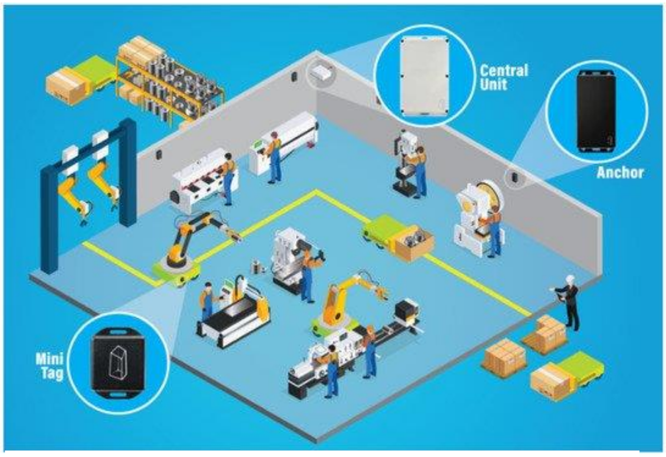

Fig. 3. Illustration of an RTLS set-up showing tags and anchors for collecting real-time data from tags [17]).

3. Methodology

3.1. Description of use case

The use case considers an aircraft maintenance facility discussed in [3]. The goal of the project was to enhance operational efficiency of an aircraft maintenance hangar, considering architectural re-design changes (facility layout modification). The technicians usually travel from their respective workstations to fetch tools from either tooling stations within the hangar (illustrated in Fig. 2), or collect from a centralized MRO (maintenance, repair, and operations) warehouse. Additional maintenance activities for the use case include [3]:

- A 9-hour typical shift involving twenty technicians performing maintenance tasks on aircraft equipment (Boeing 737-800). This includes scheduled breaks.
- The hangar dimensions are provided, allowing modelling of travel distances in the Net-logo simulation model used in this study.
- A typical shift starts with a short planning meeting, followed by technicians traveling to the stockroom to collect specialized maintenance tooling, e.g., digital-diagnostic aids (PC's and tables).
- After retrieving tools, technicians walk to their maintenance stations, where they perform tasks
- In the event a tool is lacking they may opt to retrieve the tool from their colleagues (in case they are aware of the location of the tool) or walk-back to the tool warehouse.

Additional auxiliary information necessary for modelling the maintenance activities, travel times, and travel speeds of technicians were derived from Dalal [18]. This includes the layout of the facility, including spatial location of the aircraft equipment, stockrooms, position of tooling cabinets, and average walking speed of the technician (1.7 m/s). Additional information from [18] includes the type of maintenance activities, insights on maintenance tooling required, and especially important, tasks requiring specialized tooling often shared among different maintenance teams.

This meant that if the tooling was allocated to a specific group, it was unavailable to other groups when required for a task, implying such groups had to switch tasks to maximize their productivity.

Moreover, there were risks of teams advertently or inadvertently failing to return specialized tools to the stock rooms after completing of tasks. Such risks further negatively influenced productivity, therefore potentially benefits from tooling localization.

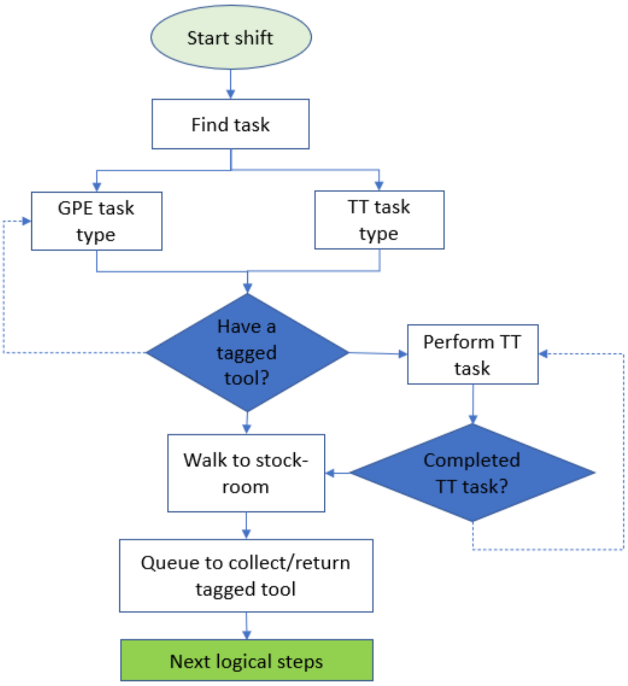

Fig. 4. Example of behavioural attributes for a maintenance technician (only considering 'YES' decision pathways). TT refers to Task requiring Tagged Tooling. GPE refers to General Purpose Equipment

3.2. Implementation in NetLogo

NetLogo uses 2D *worlds* to model real life scenarios. A 2D *world* includes agents (objects or beings such as a car, a mechanic etc.) of interest whose behavior we want to simulate under a variety of conditions. Diverse types of agents can be modelled in NetLogo, in our case, AGV's, tagged tools, and technicians. The agents are assigned attributes, such as unique colors for differentiation, but also behavioral attributes, allowing the technician agent to move and mimic searching or collecting tools. Fig. 5 illustrates implementation of the hangar layout in the NetLogo simulation environment, including modelled static and dynamic agents.

Furthermore, based on assigned behavioral attributes two types of agents were defined in NetLogo: static and dynamic agents. Examples of static agents include, the maintenance work-spot, tooling cabinet, planning room and stock room.

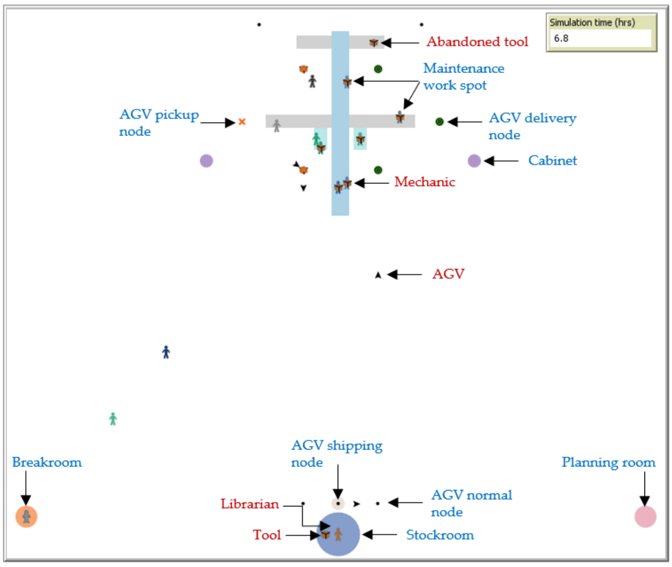

Fig. 5. Simulated hangar in NetLogo showing static and dynamic agents, situated on the spatial hangar layout.

For these agents, their behavior is not influenced by interactions with other agents.

Dynamic agents form the second type, and include the librarian, AGV, and maintenance technician. Their behavioral attribute allows dynamic agents to interact with static agents, based on a sequence of decision steps or modelling logic specifying procedures/steps the agent must execute. The steps corelates to real-world behavioral attributes. Fig.4 shows an example of the logic diagram modelling the expected behavior for a 'mechanic/technician agent' in the NetLogo model. In this logic, attributes considered include the type of maintenance tasks to perform based on planning, and the required tooling (tagged or untagged), search and travel decisions.

Likewise, logical steps were modelled for execution of mechanical tasks for the aircraft sub-systems, tooling retrieval by librarian agent, requisition of tooling by AGV's, leading to varying and multiple real-world decision pathways. This includes the decision logic for 'recalling' tooling using an AGV by a technician (illustrated in Fig. 6).

3.3. Interface elements (variables) and descriptions

The simulation model allows implementation of variables (or interface elements) to realistically mimic maintenance activities in the aircraft hangar, while integrating behavior and interactions of different agent types. The interface also includes plots for visualizing the performance of agents in the simulation environment. Furthermore, interface elements such as buttons, choosers, sliders, and switches were used to influence the behavior of agents, e.g., probability of non-return tools by technicians (after completion of tasks requiring critical tagged tools).

Table. 1 shows examples of variables (interface elements) implemented for the 'maintenance technician' agent. By varying the interface variables, realistic real-world scenarios can be defined, considering dynamics occurring on the shop floor. For instance, for our study, diminished mean tool search time with implementation of tagging for critical tools.

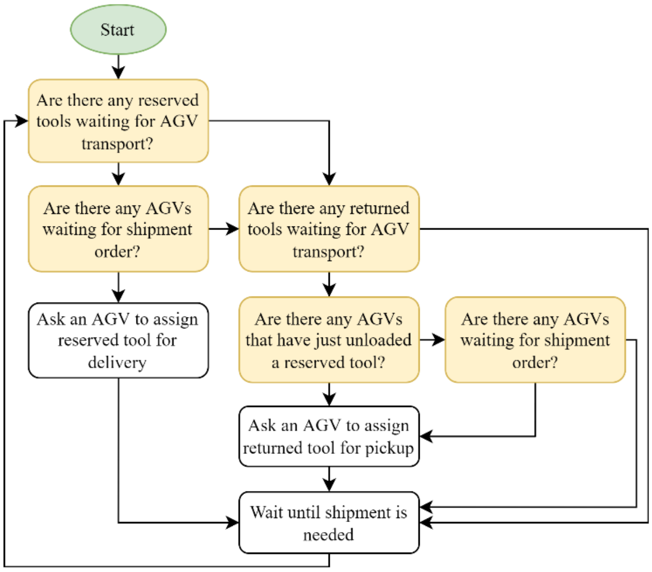

Fig. 6. Decision logic for delivery of tools using AGV's.

Table 1. Example of interface variables for the 'technician' agent.

Maintenance technician agent	
Variable	**Description**
Number-Maintenance-Technicians-Fuselage (#)	• Specifies the number of technicians solely working on the fuselage part of the aircraft.
Mean-Time-Task-Identification (min)	• Specifies the amount of time spent by a technician to find tasks using tablets based on shift plan.
Mean-Time-Tool-Search-Cabinet (min)	• Represents the amount of time a technician spends searching tools in one of the two cabinets.
Mean-Duration-Task-Type (min)	• Controls how long a GPE task lasts.

3.4. Design of experiments

To quantify the added value of RTLS and smart material handling aided by AGV, three simulation experiments were defined:

3.4.1. Experiment 1: Simulation of the base case

The first experiment explores the current case where RTLS and AGV's are not implemented for optimising tooling search and travel time by maintenance technicians. For this experiment, the current processes are modelled considering maintenance tasks implemented during a shift, task and travel times, and tooling locations (cabinets and centralised tooling storages). The base case forms the reference point of evaluating the added value of implementing RTLS and AGV's.

In this experiment, we assume that technicians require to collect tools from either tooling stocking points, or the centralised MRO warehouse. The search times are influenced by a logic model, assuming that location of the tooling is not known Apriori.

3.4.2. Experiment 2: Tagging tools with RTLS

The second experiment explores the added value of tagging critical maintenance tools shared by the technicians. It is often the case that specialised diagnostic kits are shared among teams either because of its cost, rarity, or obsolescence. For instance, tooling for maintaining old aircraft. Consequently, it would be interesting to explore the advantages of tagging such tools on mean tool search and travel times.

For this experiment, we assume that tagged tools are identifiable real-time via RTLS, determining its spatial location in the aircraft hangar. This influences positively search times since the technician can travel directly to tooling localisation point. The results of this experiment are compared to the base case (experiment 1) and experiment 3 (combining RTLS and AGV's for smart material handling).

3.4.3. Experiment 3: Integrating RTLS and AGV's

The third experiment explores the added value of implementing tool tagging for minimising search times and AGV's for retrieval and delivery of tools. In this instance, a logic is defined (see Fig. 6) allowing the technician to 'ask' for a tool to be delivered using an AGV. The AGV's are modelled as dynamic agents that interact with other agents, such as maintenance technicians, librarians, other maintenance teams. Furthermore, we explore the benefits of tracing tools in the spatial workspace, thereby potentially reducing search times in the tooling warehouse, cabinets, and maintenance stations.

4. Results and discussion

For each of the experiments, multiple scenarios were explored, including the number of tasks completed requiring (specialised) tagged tools, number of general tasks (where tool availability was not necessarily a constraint), average distance travelled by technicians to fetch tools, and percentage utilisation of technicians and the librarian (tool stockist).

Fig. 7 illustrates preliminary results of the added value of tagging critical tools. Experiment 1 (orange trend) shows results of the base case, or current situation considered in this study. Experiment 2 (green trend) shows results of implementing tool tagging, while experiment 3 (blue trend) shows results where critical tools are tagged and AGV's integrated alongside to minimise travel distances and times. From the results, significant improvements of completed maintenance tasks requiring critical tagged (TT) tools is demonstrated.

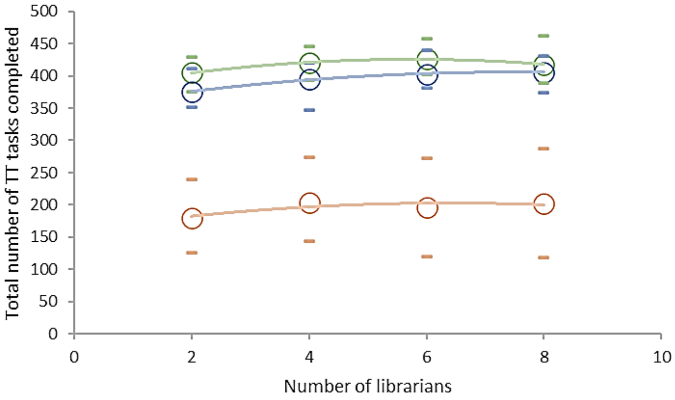

Fig. 7. Influence of number of librarian agents on the number of tasks completed requiring tagged tooling (TT). Trends: orange (experiment 1), green (experiment 2), blue (experiment 3).

Although an improvement is also noted for experiment 3 compared to the current/base case, the number of AGV's implemented on the shop floor is seemingly a constraint. Often considering the current situation, any maintenance technician agent can walk to the MRO warehouse to pick tooling. Hence, a higher number of technician agents compared to AGV's implies higher collection instances for human compared to AGV agents (leading fewer TT).

Fig. 8 illustrates the added value of tooling localization on the intensity of maintenance tasks requiring specialized tooling. In this instance, a percentage variable is used to mimic increasing demand of maintenance tasks requiring tagged tooling.

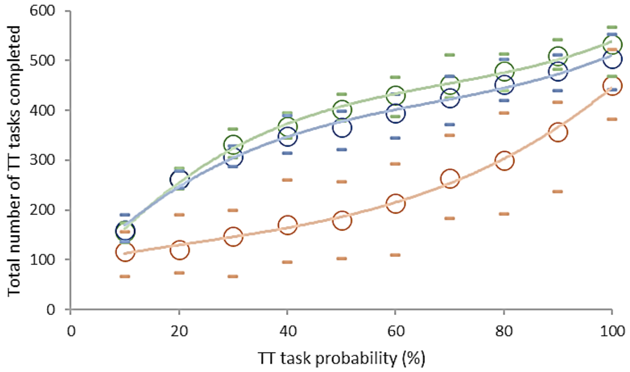

Fig. 8. Influence of percentage increase of TT tasks on tasks completed. Trends: orange (experiment 1), green (experiment 2), blue (experiment

From the trends, a lower percentages of maintenance tasks requiring tagged tools shows limited influence on completed TT tasks. This is intuitive since a substantial proportion of tasks are general and completed using general purpose tools that are assumed to be readily available at tooling stocking points at the maintenance stations. However, as the demand on tagged tooling increases (based on higher percentages of TT tasks), benefits of implementing RTLS and AGV become apparent at low percentages (from 20%).

At higher percentages, the available number of technicians and AGV's becomes a constraint, shown from separate results of resource utilization. In this instance, the model shows the technicians and AGV's become highly utilized, diminishing the added value of tooling localization and AGV's to requisitioning tooling.

Overall, improvements were observed on travel distances, and productivity of maintenance technicians and librarians.

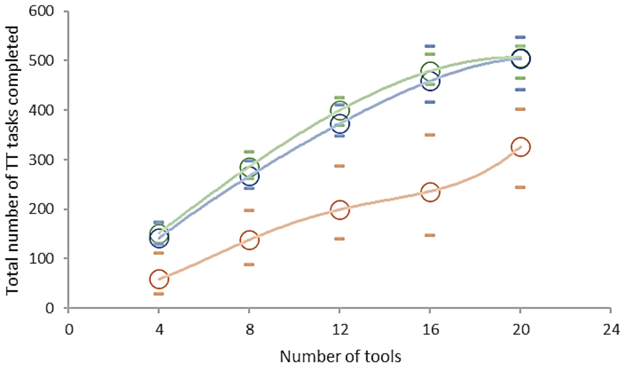

Fig. 9. Influence of number of tagged tools on the number of tasks completed requiring tagged tooling (TT). Trends: orange (experiment 1), green (experiment 2), blue (experiment 3).

Fig. 9 shows the added value of the number of specialized tagged maintenance tooling, corelating to investments on tooling. The number of available tools is varied, from a minimum of 4 to 20 tagged tools. The corresponding influence on the number of tasks requiring tagged tooling increases, with significant benefits across all experiments. For instance, for four available tagged tools, we observe a significant improvement on the number of tasks completed requiring tagged tools (up to 165% increase). This is simply by tagging and tracking location of critical tools.

Corresponding improvements were observed on travel distances, and productivity of maintenance technicians and librarians. Although investments were not quantified, value of implementing RTLS is evident, corelating to improvements observed from the results of this experiment. For brevity, influence on travel times, and productivity were not included in this paper, even though were positively impacted.

5. Conclusion

In this study, we explore the added value of implementing RTLS and AGV for mitigating tool search and travel times. From the simulation results, important insights on operational efficiency are apparent by implementing RTLS in combination with AGV's. More importantly, significant improvements can be noted by implementing intuitive and low-intensive solutions, for instance, tagging to improve localisation. Especially, this is useful for scenarios characterised by high task demand, but low-tooling availability. Moreover, implementing localisation of tooling is beneficial for maintenance and production planning, since tasks demanding scarce tools can be better optimised considering scarcity.

The benefits intuitively extend to machine shops and intensive manufacturing organisations where critical tooling influences worker and overall operational productivity. However, to better improve insights from agent-based modelling, data and logic accuracy is an important consideration. This extends to accurate and reliable data on parameters such as travel and search times that varies depending on use cases. Moreover, the modelled logic may defer for dynamic shop floors, influencing generalisability and realism especially for operational decisions of complex manufacturing and maintenance-intensive organisations.

Careful formulation of design of experiments is also critical to reach improvement goals for manufacturing and maintenance intense organisations, and therefore an important benefit of the modelling approach.

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