Challenges to Represent and Manage Transport and Material Handling Systems in Manufacturing Systems

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Abstract - **Transport and Material Handling Systems (TMHS) are characterized by behaviors, properties, rules and restrictions which makes their representation challenging. The literature about representing and/or modeling TMHS is not extensive, despite its acknowledged importance. Several challenges to represent TMHS are identified and discussed in this paper, such as TMHS with several devices, restrictions, shapes of networks, places to visit, transport and handling activities to execute or communication with manual and automatic equipment. The synchronization and integration of transport and handling activities with the remaining processes of manufacturing systems is also one of the main challenges discussed. Finally, the authors suggest that this research gap should lead to the development of new models and techniques to represent TMHS in manufacturing systems – preferably based on a generic approach to meet the requirements of different organizations and TMHS. The authors have selected two research questions to structure the paper but further research is also necessary on this topic.**

Keywords - **Industry 4.0, manufacturing, logistics, transport and material handling systems**

I. INTRODUCTION

Everything that can be digitized will be digitized at an incredible speed and Transport and Material Handling Systems (TMHS) will not be an exception. TMHS take a critical role in the demand for more efficient manufacturing practices since they are designed to get the right material, in the right place, at the right time. Over the last few years, more attention has been paid to these systems – particularly in the context of Industry 4.0 and Smart Factories, since they have a huge influence on the overall performance of manufacturing systems [1]–[4].

A TMHS consists of a set of transport and handling devices. A device refers to any equipment that handles and/or transports materials or other objects – from traditional equipment, such as tugger trains, forklifts, trucks, cranes and conveyors, to fully automated equipment, such as automated guided vehicles (AGV) or full-automated storage equipment. Fig. 1 depicts some examples of transport and handling equipment and other entities of a manufacturing system (traditional equipment, industrial robots, warehouses, customers or suppliers).

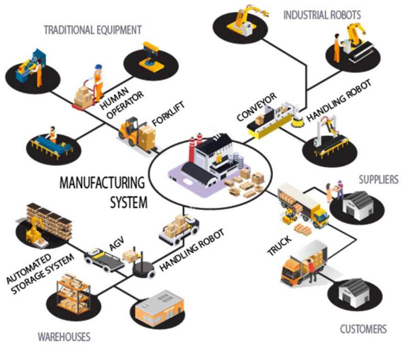

Fig. 1. Examples of different entities in a manufacturing system

The goal of this paper is to encourage further discussion and research on this topic. This paper highlights the importance of managing transport and handling activities at manufacturing systems and, within this context, discusses some of the main challenges to represent TMHS – but surely further research is needed in this field. This work is part of an ongoing research project that aims to develop of a generic model to represent TMHS for manufacturing systems. This paper addresses the following research questions:

Q1) What is the current status in the literature about representing and/or modeling TMHS in manufacturing systems?

Q2) What are the main challenges to characterize transport and handling devices in manufacturing systems?

The methodology followed to answer the research questions implied a systematic observation, description, analysis and interpretation of several examples of TMHS and devices - to ensure that most of the challenges were recognized and identified. This work is only valid for discrete manufacturing systems – since transport equipment in continuous manufacturing systems, such as a water pipeline, may have other characteristics. This paper has four more sections. Section II presents a review of previous studies and existing models to represent TMHS. Section III shows the behavior diversity of TMHS and presents some characteristics that should be considered. Section IV relates the findings with the research questions and section V sums up the conclusions.

II. BACKGROUND LITERATURE

The literature about representing and modeling TMHS is not extensive, despite its acknowledged importance [5] [6]. Most representations of TMHS apply traditional analytical techniques, such as VSM, from-to charts, flow-process charts or flow diagrams [7]. These tools are useful to represent material flow, identify waste and propose improvements, but their application in today's manufacturing environments is challenging due to the diversity of products, process complexity and operation rules of manufacturing systems [2].

Some research has been conducted to address this issue over the past years – but no model or technique was identified capable of managing transport and handling activities, integrating TMHS in manufacturing systems and synchronizing several device activities in the same network. Some IT support systems for manufacturing were also partially studied. Most of the studies reviewed focus on introducing new technologically advanced equipment in manufacturing systems (such as [8]), optimizing performance indicators [9]–[12], or, as referred previously, identifying wastes to introduce improvements [2], [7]. Most of the studies do not study and represent the synchronization rules between different devices and with other manufacturing system equipment or workstations [1], [13], and they only represent transport activities and do not consider handling activities (probably because most of them refer to the transporting sector - services to move people and goods) [14], [15]. Finally, to the best of the author's knowledge, no model to represent TMHS has been effectively applied in different industry types, devices and organizations.

III. CHALLENGES TO REPRESENT TMHS

The main objective of this section is to show the diversity of behaviors and present some elements and characteristics that should be considered to represent TMHS. Each one of the following subsections addresses a different issue of TMHS.

A. TMHS with several devices, routes and rules

The terminology about TMHS networks is wide and can have different meanings. In this paper, a **link** (Fig. 2a) represents a single transport between two nodes or workstations (Fig. 2b). A **route** (Fig. 2c) represents a sequence of workstations that a device can visit and the activities that can be executed at each workstation. A **network** (Fig. 2d) represents the framework of device routes of the entire manufacturing system.

Each device is defined by a route that includes information to manage the transport of materials – including physical aspects of each manufacturing system and internal organizational procedures [16].

Set of workstations. A route of a device identifies a set of workstations, the order between them and, in some cases, the distances between its nodes – which implies that a route can have several shapes, such as circular or star. One example that influences the definition of a route is the approach to deliver materials – materials can be delivered directly to the destination or collected from several locations across a pre-defined route [17].

Set of activities. A route of a device identifies the activities that can be executed at each workstation. The definition of which activities can be executed at each node is mostly defined by internal organizational procedures, characteristics of the equipment and features of the manufacturing system. A device, such as a tugger train, can be able to execute several activities such as loading, unloading, picking or storing, but the device may be only authorized to load or unload volumes at some places [18].

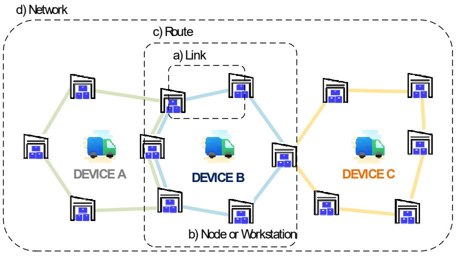

Fig. 2. Representation of a Link, a Route and a Network

B. Places that a device can visit

Manufacturing systems are characterized by several types of entities that can be visited by a device to be executed a activity, such as execution workstations (any workstation that executes manufacturing operations), warehouses or supermarkets, transfer and control points, or external entities (such as a supplier or a customer) – in this paper all places are referred as a **workstation**. External entities are important to integrate the entire supply chain – namely inbound and outbound logistics. An AGV may have only to deliver materials at execution workstations and warehouses, but a truck can also have to deal with external entities or warehouses located outside a manufacturing plant.

C. Load transfer process between different devices

An integrated solution often requires more than a single piece of equipment and a **transfer workstation** represents a workstation where materials can be transferred between devices.

Types of transfer workstations. The transfer process of materials between devices can have different rules. Two main behaviors are described. First, a device can load a material at a workstation and unload it at a transfer workstation (without waiting for another device to load the material) - the materials stay placed at the transfer workstation to be later loaded at another device. Some examples are the transfer between of a material or a pallet between two tugger trains or two forklifts. The second behavior refers to a load that must be transferred directly between both devices – so when the material is unloaded from one device, the material is at the same time loaded at the following device. Under these circumstances, both devices must be placed in the same transfer workstation. Some examples are the load transfer between two AGVs with handling equipment or between a crane and a truck.

D. Storage areas of workstations

The management of handling activities, such as picking or storing, implies the definition of how a workstation is organized to identify the physical areas where materials are placed or where they should be stored. A **storage location** can be any physical area of a workstation where materials are located or can be stored – such as a storage structure or an overhead crane hook.

E. Objects that can be handled and transported

The transport of materials through networks often requires the handling and transport of different types of volumes or objects. In this paper, a **volume** can be any storage, handling or transport unit in a manufacturing system (a single item, a set of materials, a batch, a container, etc.). An **object** is a generalization of any volume or other object that can be handled and transported within an organization - it includes a volume and set of volumes that can be handled and transported simultaneously, such as a pallet or a storage rack.

Type of volumes. Manufacturing systems are characterized by a huge quantity and diversity of volumes that need to be handled or transported by devices. Items have different weights, shapes and unit loads. Devices can transport materials, machine components, tools, equipment, etc. Even materials can refer to a certain quantity of items identified by a part number or to a certain quantity of products that are being manufactured.

Type of objects. Devices can also transport different objects. An object can be the smallest handling unit in a system (such as a single product, a batch or a container) or it can combine several packages (such as dollies or wooden pallets). With the introduction of higher technology and automation, the range of possibilities increased even more since tasks that seemed impossible, now can be possible – such as transporting storage racks. The identification of the object that can be transported in a device is important to manage device activities that should be executed at each workstation. Volumes are mostly picked and loaded at a workstation and unloaded at the destination. Nevertheless, in the transport of a storage rack, the storage rack may be loaded at a workstation and volumes may only be picked at the destination workstation (for instance, an AGV Goods-To-Person). Moreover, a device may be able to unload the storage rack at the destination workstation or just transport it to the workstation to be picked the required volume and then bring the storage rack back.

F. Transport and handling activities

An **activity** represents either a manual or mechanized transport or handling task that can be executed at a workstation [2], [19]. The following paragraphs identify the main issues to characterize an activity – that is, to define what can be executed, when, how and by whom.

Type of actions. Devices can execute several types of actions at a workstation. First, devices can transport objects between workstations which implies three main actions – go-to a workstation, departure from a workstation and arrive at a workstation. Second, devices can load and unload objects at a workstation. Finally, devices can pick and store volumes – which implies the actions of picking a volume from a storage location or storing the volumes when required.

Synchronization of device activities with workstations. Most of volumes are delivered when a device arrives at a workstation, the request is finished and the device is available to execute a new activity. Nevertheless, in some cases, after a device arrives at a workstation, a volume can only be unloaded when the workstation is ready to start the job that triggered the request or just when the job is finished (for instance, when parts can be consumed directly from the volume that is placed in the device) – so device should wait to unload the volume. There are still examples, such as some AGV Assembly Lines, where a device transports a volume (for instance, a car body) throughout several workstations to execute jobs without unloading the volume.

Definition of who must execute the activity. Depending on the characteristics and functions of the equipment, an activity can be executed by a device or a workstation. For instance, an AGV equipped with a powered roller conveyor or a robotic arm can load a volume autonomously. An AGV without handling equipment requires another resource to load volumes – an external piece of handling equipment or a human operator. In other cases, the execution of these activities may be controlled by the fleet management system of the equipment and not by the equipment – such as an AGV fleet management platform. Under these circumstances, communication may be required to these systems (to identify what needs to be executed), but the activities are controlled by the equipment management system.

Activities that can be executed simultaneously. Some devices can execute activities simultaneously at different workstations - for instance, a conveyor can load or unload volumes at different workstations at the same time.

G. Communication with industrial equipment

Communication with industrial equipment implies not only the definition of the activities to execute at each moment but also a different approach since some semi-automatic and automatic equipment require instructions to execute activities in the manufacturing system. An **instruction** represents an order with a specific format and function that is sent to an equipment or system - for instance, an instruction that is sent to an AGV to move between workstations. Standardizing the process to trigger and send instructions to different equipment is a huge challenge for industrial applications due to the variability of equipment and information required.

Diversity of equipment or systems. There are many different equipment for transporting and handling, with different functions and from different suppliers – which makes each instruction unique. An instruction to trigger an activity for an AGV is necessarily different from an instruction for automated storage equipment.

Time and data. Each instruction should be triggered at a specific time and requires specific data. For instance, an instruction to trigger an unloading action of an AGV at a workstation should only be sent after the AGV arrives at the workstation. The data necessary to define an instruction to be sent to an AGV to unload a volume is different from the data necessary to send an instruction to move between two workstations, or from the data to be sent to an automatic storage system.

H. Restrictions

Devices can have several restrictions that are linked to the specifications of the equipment or the manufacturing system. A **restriction** represents a rule that must be taken into account to identify which objects can be handled and transported by a device.

Type of restrictions. Two types of restrictions have been identified. A restriction can identify if a volume can be transported by a device – for instance, an organization may intend to distinguish devices that transport products based on the product type (one for raw materials and the other for final goods). On the other hand, a restriction can also identify when a device load-carrier is full to recognize if, at a given time, a new object can be loaded in a device - for instance to define the maximum capacity of a device (size, weight, quantities, etc.).

Diversity of restrictions. The definition of restrictions implies different input data and mathematical expressions to evaluate if an object can be transported by a device. For instance, a restriction to define the maximum weight of a device implies the identification of the weight of each object and the sum of all object weights that are loaded at a device to evaluate if a new object can be loaded.

I. Tracking transport and handling activities

The rigor and efficiency of processes to manage the transport and handling activities of devices depends on the capacity to recognize what is really happening in a manufacturing system. Besides that, the quality of several processes of manufacturing systems, such as sequencing and scheduling, is highly affected by information from the monitoring and tracking functions [20] – which makes it important to provide information about each device of the TMHS (activities assigned/executed, availability, etc.), the status of each transport (executed, waiting for loading, etc.) and historical data of the activities executed.

J. Synchronize and integrate transport and handling activities

Scheduling and sequencing transport and handling activities, and achieving good results, is not something easy to achieve – especially because it is part of real-time operations in manufacturing systems and there is a clear objective to reduce batch sizes and inventory levels, so it must be obtained quickly [13]. In this paper, a **transport request** refers to an order to transport a volume between two workstations of a manufacturing system within a time interval. Scheduling and sequencing device activities implies the assignment of transport requests to devices and the management of device activities.

Assignment of transport requests to devices. The assignment of transport requests to devices requires the definition of a path. A **path** is the sequence of links selected to satisfy a transport request. The assignment of transport requests can be an easy task when there is just a device capable of executing the request. By contrast, this process can be complex when, for instance, there are alternative devices to execute the request, there are multiple requests to be satisfied or the request can combine several devices with different restrictions.

Management of device activities. Managing the activities of several devices in an integrated system is challenging - the activities of a tugger train, a conveyor, an AGV or an automated storage system are extremely different. A tugger train expects to receive information about which activities should be executed at each workstation. A conveyor expects information about what needs to be transported and to which workstations. An AGV receives information about which workstation it should move. An automated storage system expects to receive information about the volumes that must be prepared or stored, and so on. The management of device activities implies the definition of which activities a device should execute at each moment – ensuring the integration with scheduling and sequencing of manufacturing jobs and the synchronization of several device activities. In conveyor systems the management of device activities may be simplified since volumes are moved through a structure free of external influences, but, when vehicles can move freely in manufacturing systems, this process can be extremely complicated.

IV. DISCUSSION

This section is structured by the research questions of the paper. The idea is to provide evidences that can lead to further research on this area and not definitive answers.

Q1) What is the current status in the literature about representing and/or modeling TMHS in manufacturing systems?

The main conclusions from the literature review are that further research is required in this field (this topic is barely addressed despite its knowledge importance) and that new models to represent TMHS need to be conceived and developed to deal with the physical and information flow of manufacturing system environments [6]. Other author statements also support this conclusion. Reference [21] stated that, despite the increasing interest in this topic and recognized potential, there is still restricted literature about how Industry 4.0 affects supply chain and logistic activities - in particular, TMHS for internal logistics. Reference [2] stated that "modeling internal logistics by automatically mapping event data to physical logistics activities is not addressed yet" in the literature. Reference [22] stated that the effects of product diversity, process complexity and time-dependent constraints are mostly neglected in studies about internal logistics. Reference [1] stated that the "theoretical foundations" to integrate manufacturing and logistics activities are rarely considered, namely "how to upgrade traditional manufacturing planning and control strategies" to manage manufacturing activities and jobs in an "integrated, coordinated and synchronized manner".

Q2) What are the main challenges to characterize transport and handling devices in manufacturing systems?

The main challenges to characterize transport and handling devices in discrete manufacturing systems are presented in the previous section – different routes, workstations, volumes and objects, transport and handling activities, etc. Several behaviors and examples are presented at each point which amounts to hundreds of possible combinations - showing that representing all behaviors, managing device transport and handling activities and ensuring the integration and synchronization with the remaining devices and workstations of manufacturing systems is not something easy to achieve.

V. CONCLUSION

This paper shows the diversity of behaviors that characterize TMHS and presents the main elements and characteristics identified in the research project to represent TMHS and manage transport and handling activities of devices. The quantity and diversity of behaviors, elements and characteristics identified show why the representation of TMHS is so challenging but important, and should lead to further research and developments. Besides that, it highlights the importance of applying a generic approach to meet the requirements of multiple organizations, TMHS and devices – modeling each device and behavior would be an exhaustive and endless effort using a specific approach and the solution would be constantly outdated with the introduction of new equipment (requiring high development, maintenance time and costs).

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