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A framework for knowledge management in manual assembly processes

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Abstract

The role of workers in factories of the future is expected to change from labour-intensive to knowledge-intensive activities. Acquisition and formalisation of knowledge is a complex and time-consuming task limiting the performance of manual processes. This paper presents a framework to capture, manage and apply knowledge in a manual assembly process. The framework has been illustrated using an example of a riveting process. The proposed framework is intended to help in decision-making during a process, thereby minimising faults and improving productivity. In future, this framework needs to be validated, and if necessary updated, for other manufacturing processes.

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Keywords: Knowledge management; Industry 4.0; Smart manufacturing; Manual assembly process

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1. Introduction

The effect of Industry 4.0 technologies on the availability of jobs is difficult to predict, but the nature of jobs is changing from labour-intensive to knowledge-intensive activities [1]. Some believe that workplaces of the future will be worker-centric instead of task-centric, and the role of workers will increase [2]. Certain activities are very difficult to automate as they require implicit knowledge based on experience [1]. Therefore, manufacturing organisations should work towards augmenting workers, instead of replacing them, with current technologies [3]. Making people knowledgeable brings innovation and ability to deliver products and services of the highest quality, but it also requires effective knowledge capture, reuse, and building upon prior knowledge [4]. The lack of appropriate knowledge formalisation tools hinders the digitisation and automation of manufacturing and assembly tasks, causing loss of expertise [5]. Underdeveloped knowledge acquisition facilities are a major bottleneck in the wider application of expert systems [6]. Knowledge acquisition has traditionally been a manual process, which is tedious, time-consuming, and requires engagement of knowledge engineers with the expert to understand and translate expert knowledge [7]. While several methods have been developed to acquire knowledge [8], it remains a difficult task to automate [6].

In the domain of manual assembly, preparation of assembly plans is a major bottleneck in the time taken to bring new products to market [3]. The knowledge classes of interest identified in manual assembly are Issues, Constraints, Parameters and Solutions [9]. Prior knowledge of issues that may occur during assembly can be beneficial for Assembly planners [6]. For manual assembly processes, there have been some efforts to acquire knowledge from experts by means of questionnaire [6], from legacy text documents like fault reports by natural language processing [10], and to organise the knowledge in a structured way using an Assembly Situation Model [9]. In recent years data has become abundant due to availability of sensors at affordable costs; moreover, the means of analysing the data are more accessible due to affordable computing power and cloud computing. Consequently, knowledge acquisition is getting easier, but organising the knowledge in a way to make it readily applicable is challenging. This calls for the need to capture knowledge in a structured way, so that it can be applied easily.

One of the earliest representations of a manufacturing system was the Model of the Transformation System, which was defined as the sum of all elements and influences (and the

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relationships among them and to their environment) that participate in a transformation [11]. The major elements of the transformation system are: a process, an operand that is being transformed, and the operators that drive and guide the process. The operators consist of human beings, technical systems, information systems, management systems and the immediate environment. They may exert effects in the form of material, energy and/or information. The process has inputs and outputs, both of which may contain desired and unwanted elements. This model also accounts for feedback which involves measuring the output of a system or process, comparing it to the desired goal, and altering the input to make corrections. While this model is quite rich in its description, it applies primarily to the design phase; what we need is a model particularly suited to the manufacturing domain, with the aim of capturing data and acquiring knowledge from its processes.

Another representation of a manufacturing system was proposed in the ASTM standard E3012 – 16 for characterising environmental aspects of Manufacturing Processes [12]. It provides a way to characterise any manufacturing process through a graphical representation and a corresponding modelling language comprised of four elements (input, output, product and process information, and resources). The aim of their model is to support manufacturers in systematically identifying, collecting, structuring, and visualizing manufacturing information, and to support the development of tools to improve decision support capabilities. Although this guide is highly detailed, it does not capture the interactions between the resources, which is the essence of the process. It also ignores the effects of environmental factors on the process. Our framework intends to address these shortcomings.

2. Description

A unit manufacturing process is defined as the smallest element or sub-process in manufacturing that adds value through the modification or transformation of shape, structure, or property of input material or workpiece [12]. In case of manual assembly processes, the factors that affect assemblability were classified into five major groups related to part, person, process, tool and environment [13]. Drawing inspiration from that study, we represent a process as a set of interactions between four types of elements – Machine, Part, Human, and Environment as shown in fig. 1. These elements may be defined as follows.

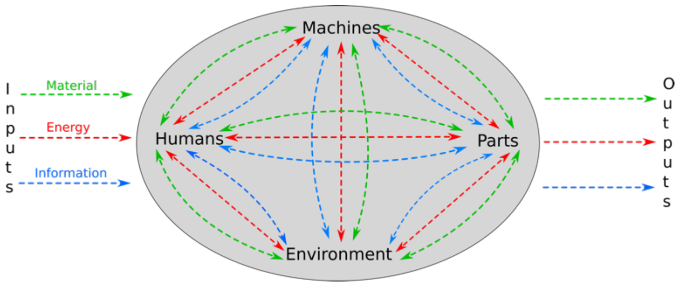

Fig. 1. Graphical representation of a unit manufacturing process.

- Part (Operand): Things being operated on.
- Machine: Things used for operation.
- Human: People involved in the process.
- Environment: Surrounding conditions to the manufacturing system.

Each process may consist of a set of activities, most often performed in a sequence. A process may take inputs and produce outputs in the form of Materials, Energy and Information. Each input, output, type of element and interaction between any two elements will have a corresponding class in the framework, and must contain the data types for relevant attributes. The process as a whole also has a class in the program, which will contain data about the overall process like procedure, duration, frequency, prerequisites, precursors, subsequent processes, etc. In a network of processes that converts raw materials into finished products, each process may be connected to other processes as a precursor, follower, or parallel.

An occurrence of fault can be highlighted in this representation in an input, element or interaction between two elements. A fault report can be documented in the form of a causal chain or network using this representation. Based on any feedback obtained on the results of the process, the knowledge base can be updated with information of faults by considering the context of application.

Any manual assembly process can be characterised by answering the following form:

Process name =
Parts being processed =
Machines used =
Humans involved =
Environmental conditions =
Consumables used =
Waste generated =
Energy consumed =
Energy generated =
Initial state of part/s =
Final state of part/s =
Procedure =
Prerequisites/preceding processes =
Subsequent processes =
Interactions by means of M-E-I (Materials, Energy and Information)
Human - Part =
Human - Machine =
Human - Environment =
Part - Machine =
Part - Environment =
Machine - Environment =

For optimising the process, if we identify a transformation equation of the process, we need to know how the inputs and other parameters affect the outcomes. In this framework, the primary outcome of our interest is the final state of the part/s being processed, whereas other outcomes may include outputs in the form of Materials, Energy and Information, and the final states of the other three types of elements – Human, Machine and Environment. The inputs for this purpose are not only those coming into the process in the form of Materials, Energy and Information, but also the attributes of all the elements involved.

3. Illustration

To illustrate the application of this framework, we take an example of a blind riveting process. As shown in fig2 the process occurs by the interaction between the operator (human), rivet gun (machine), metal sheets (parts) and shop floor (environment). The inputs come in the form of rivets (material) and work instructions (information). The outputs are seen in the form of broken mandrels (material) and result of the process (information). The process begins when the operator holding the rivet gun picks a rivet as an input material and refers to the work instructions as information input. He/she feeds the rivet into the gun transferring material from human to machine. Then he holds and aligns the holes in the metal sheets to be joined, exchanging information between human and part. He then holds the rivet gun over the aligned holes and pulls the lever or trigger of the gun to install the rivet. While doing so, he transfers energy to the gun by exerting a force on the lever, and also exchanges information with the gun by controlling it and getting haptic feedback from it. Meanwhile, the gun transfers material to the sheets in the form of the rivet, transfers energy to the rivet (which merges with the sheets) by exerting deformation force on it, and exchanges information with the sheets as it installs the rivet in proper orientation. During this process, the rivet gun and metal sheets emit sounds into the environment, which are heard by the operator. Certain environmental parameters like ambient light, temperature and humidity may also affect the performance of the operator.

The overall process of blind riveting has certain parameters like procedure, duration, frequency, prerequisites (sheets with holes drilled as per rivet specifications), precursors (drilling), subsequent processes (inspection, transfer to another assembly station by crane), etc.

Suppose there is a fault of mandrels breaking off prematurely during the process. The fault can be located in the material transfer from the gun to the sheets as shown in fig2. Upon investigation, the cause of the fault was identified as brittle material of the rivet shank, which can be located in the material input to the process. Another fault could be slippage between the jaws of the gun and the shank of the rivet, due to which the rivet fails to deform even after several pulls of the lever. The reason for the fault could be either improper setting of the jaws or ingress of oil in the jaws, which can be located in the gun's (machine's) attributes. The immediate consequence of both of the above faults can be placed in the information output of the process in the form of result (failure) of the process. In this way using this representation, a fault report can be documented in the form of a causal chain or network.

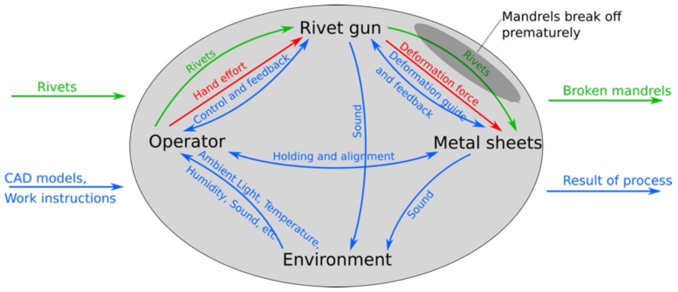

Fig. 2. Representation of a fault in a blind riveting process.

4. Conclusion and future work

In this study, we proposed a visual representation of a manual process; the representation supports showing interaction among Parts, Machines, Humans and Environment in the form of Materials, Energy and Information. We also illustrated how to locate faults, their causes and effects through an example of a blind riveting process.

Structured information of manufacturing processes facilitates exchange, sharing, and communication of data with other manufacturing applications like modelling, simulation, and analytics tools [12]. This framework should provide manufacturers a way to characterise any manual assembly process in a computer-interpretable way and to systematically identify, capture and describe relevant information to assess manufacturing performance. Based on the ASTM guide, a group developed an open web-based repository for capturing manufacturing process information [14]. Our framework can potentially support such efforts in a better way. Its systematic structure will make information more easily accessible to the user, and knowledge will be applied automatically based on the context, thus supporting decision-making during the process for minimising faults and improving productivity. It should play a major role in realising the concept of Digital Twin.

The data and information models corresponding to the elements, interactions, inputs and outputs in the visual representation will be elaborated in further studies. We are also working on demonstrating some transformation equations. For fault reporting, the causal chains often span across several processes, which will be illustrated in future studies. We acknowledge that dealing with tacit knowledge will continue to be a challenge, but this framework may help us locate where it comes into play, and thus identify the nature of human expertise involved in the process. The scope of this study was limited to processes, which are at the lowest level in the hierarchy of manufacturing networks. As such, this framework is applicable to manual assembly processes, but it may be extended to other manual processes in manufacturing and other domains. It may encompass automated processes where the role of humans is minimal or non-existent.

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