Capability-based ontological resource model and rules for describing and assigning resources in sheet metal manufacturing

Citation
Järvenpää, E., Lohtander, M., & Tuokko, R. (2013). Capability-based ontological resource model and rules for describing and assigning resources in sheet metal manufacturing. In *2013 IEEE International Symposium of Assembly and Manufacturing (ISAM), July 30th – Aug 2nd 2013, Xi'an, China* (pp. 105-108). (International Symposium on Assembly and Manufacturing). Piscataway: Institute of Electrical and Electronics Engineers IEEE. https://doi.org/10.1109/ISAM.2013.6643500

Year
2013

Version
Peer reviewed version (post-print)

Link to publication
TUTCRIS Portal (http://www.tut.fi/tutcris)

Published in
2013 IEEE International Symposium of Assembly and Manufacturing (ISAM), July 30th – Aug 2nd 2013, Xi'an, China

DOI
10.1109/ISAM.2013.6643500

Capability-based Ontological Resource Model and Rules for Describing and Assigning Resources in Sheet Metal Manufacturing

Eeva Järvenpää[1], Mika Lohtander, Reijo Tuokko

Abstract. In order to ensure full utilization of modern multi-functional manufacturing technologies, it is important that up-to-date information of the resource capabilities is always available for the design and planning activities. This paper presents an ontological approach for representing resources and their capabilities, and a framework in which the resource capabilities are matched with product requirements. The paper integrates two separate works of different universities, TUT and LUT. In order to show a practical example of the usage of the capability model and capability matching developed by TUT, the approach is applied to a case study from sheet metal manufacturing. The extensive research of LUT on the interconnectedness of turret punch press machines and tools with product properties is used as an input for the formulation of the capability description of turret punch press and for formulating the rules for the detailed capability matching.

Keywords: Adaptation, Capability, Ontology, Production system, Resource description

1.1 Introduction

The modern manufacturing technologies are turning into multi-functional and changeable systems, trying to cope with flexibility and adaptivity requirements of today's rapidly changing operation environments [7]. This multi-functionality means that the systems have multiple different manufacturing capabilities. Also the complete manufacturing system (CMS) concept, followed by some suppliers, has increased the amount of different capabilities inside one company. It is often criticized that flexible systems contain excess capacity and capability, which is never utilized in their full potential [4, 6]. The authors believe that this drawback

[1] E. Järvenpää (✉)
Tampere University of Technology, Department of Production Engineering,
Korkeakoulunkatu 6, 33720 Tampere, Finland
e-mail: eeva.jarvenpaa@tut.fi

can be overcome by enhanced planning and design in which the capabilities of the existing resources are considered throughout the design and planning process. In order to enable this, accurate and up-to-date information relating to the resource capabilities has to be always available for the planning activities.

This paper combines the work performed by two research groups in Tampere University of Technology (TUT) and Lappeenranta University of Technology (LUT). The research group in TUT has developed a generic ontological resource model for describing the resource capabilities and a framework by which this model can be utilized to match the product requirements with the resource capabilities [2, 3]. In LUT detailed studies on the characteristics of punch press machines and their relations to achievable product features and manufacturability, have been conducted [6]. This paper describes the capabilities of a punch press machine in a way that they can be matched with the requirements of a selected sheet metal product. In order to perform this matching, the capability-matching rules are also defined.

1.2 Introduction to Capabilities and Formal Resource Modeling

In the approach proposed, capabilities are functionalities of resources such as *"drilling", "moving", "punching"* and so on. This functionality determines the capability concept name. Capabilities have parameters, which present the technical properties and constraints of resources, such as "speed", "torque" or "payload". Capabilities are divided into "simple capabilities" and "combined capabilities". Combined capabilities are combinations of other capabilities, usually formed by a combination of devices, such as a robot and a gripper. [3]

The capabilities are modeled and managed with formal ontology saved to a Knowledge Base (KB). The CoreOntology, originally developed by [5] to model product, process and resource related information, has been extended with the capability-domain. The overall resource description consists of the capability, lifecycle, business and interface information. Also measured values and values probability (or values with distributions) from the factory floor can be attached to the description and be used to update the capability description over time.

In the ontology, the combined capabilities are modeled using capability associations as links between the simple and combined capabilities. In the resource ontology, the devices are assigned the simple capabilities they possess. Based on the defined capability associations, the device combinations contributing to a certain combined capability can be identified and queried. The capability model defines the generic capabilities, i.e. a pool of capabilities that can exist on the factory floor and can be assigned to the resources. When these generic capabilities are assigned to the resources, they are filled with resource-specific parameter values such as speed, acceleration or accuracy. Examples of simple, combined and resource-specific capabilities, in the domain of sheet metal manufacturing, can be found from the case-study section. For more detailed information about capability modeling and the structure of the resource model, please refer to [2] and [3].

1.3 Capability-matching Framework

Fig 1.1 represents the framework of the capability-based matching of product requirements and system capabilities. In the proposed approach the product requirements are expressed in the form of a pre-process plan. The pre-process plan defines the capabilities in an abstract level, like “material removing”. More details about pre-process planning done with feature recognition software can be found from [1].

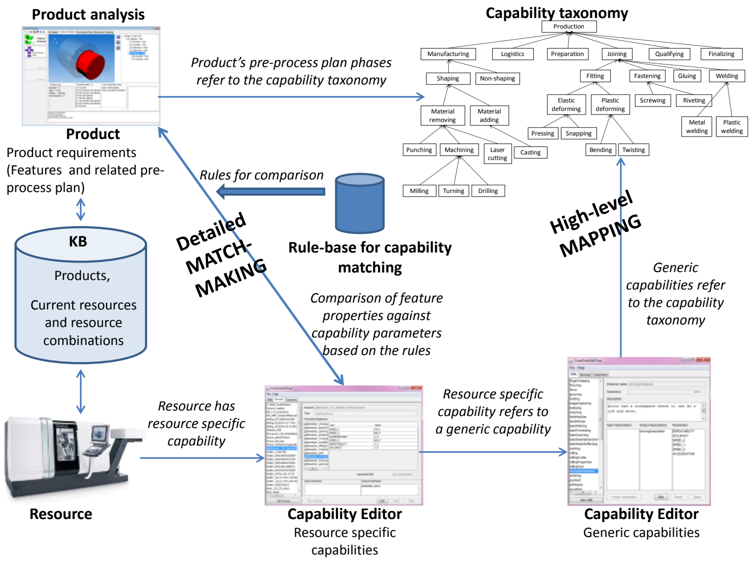


Fig 1.1 Capability-matching framework [2].

The high-level capability mapping is based on the capability taxonomy included into the CoreOntology. The pre-process plan phases have a reference to a certain level in the capability taxonomy. Similarly, the generic capability instances refer to a certain level in the taxonomy. This way, the existing resources providing required capabilities on a capability concept name level, can be found. The taxonomy level, to which the pre-process plan refers, depends on how in detail the designer has predetermined the desired processing method. The taxonomy allows searching for different resources that are able to perform the same function (e.g. “material removing”) by different behavior (e.g. “milling”, “turning”, “sheet metal cutting”). The detailed reasoning with the capability parameters is done based on different types or rules, explained in detail in [2] and exemplified in the next section.

1.4 Case study: Sheet metal manufacturing

Fig. 1.2 shows the most relevant capabilities and their parameters of the existing turret punch press machine. Due to the limited space all the existing capabilities are not included into the figure. The machine is able to cut sheet metal by mechanical punching, nibbling and laser. As seen from the figure, the combined capability *"mechanicalSheetMetalCutting"* requires the sheet to be moved within a certain workspace, to be hold in a position, and to be punched with a punching tool. Therefore *"movingWorkspace", "holding", "punching" and "punchingTool"* capabilities are required. In case of combined capability *"thermalSheetMetalCutting"*, instead of *"punching"* and *"punchingTool"* capabilities, *"laserProcessing"* capability is required. These capabilities are assigned to the individual resource elements as shown in Fig. 1.2. Those simple capabilities, which are not associated with any combined capability, e.g. *"itemMaxSize"*, are not functional capabilities, but provide important information when matching the product requirements with suitable resources.

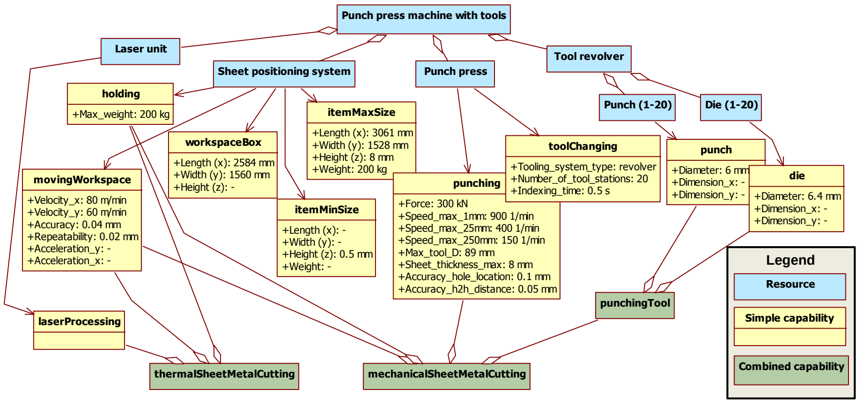
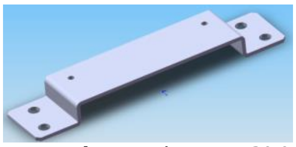


Fig 1.2 Capabilities of the existing punch press machine (Finn-Power LP6 – Series 10).



Feature	Dimension	Unit	Pcs.
Round hole	3,3	D (mm)	2
Round hole	6,0	D (mm)	4
Chamfer	2,0	D (mm)	4
Bending	90,0	Angle (°)	4

Fig 1.3 The case product. Part's size is 30,0x158,6 mm. Material thickness is 2,0 mm. Material is galvanized steel. Attributes related to the geometry are presented in the table.

Fig 1.3 represents the case product to be manufactured. The pre-process plan indicates that product requires *"materialRemoving"* and *"bending"* capabilities, which are specified by the feature characteristics in the figure. The high-level mapping reveals that the existing system is able to remove material by punching and by laser. The rules in the rule-base are then used to define if the capabilities of the existing punch press machine fulfill the product requirements in detail. See examples of the rules in Fig. 1.4. The reasoning results, that all the needed capabilities exist in the current system, and the different sizes of cut outs can be accomplished by just changing the tool. The part's cut outs can be manufactured with several different tool shapes, but the larger the tool, the greater the material loss becomes. From the machine capabilities (Fig. 1.2) it is possible to see, that because the maximum size of the tool that the punch can handle is smaller than the product dimensions, the external forms of the product can not be manufactured by one hit. The designer should consider this existing capability information already during the product design phase, in order to reduce the material loss and the number of needed hits.

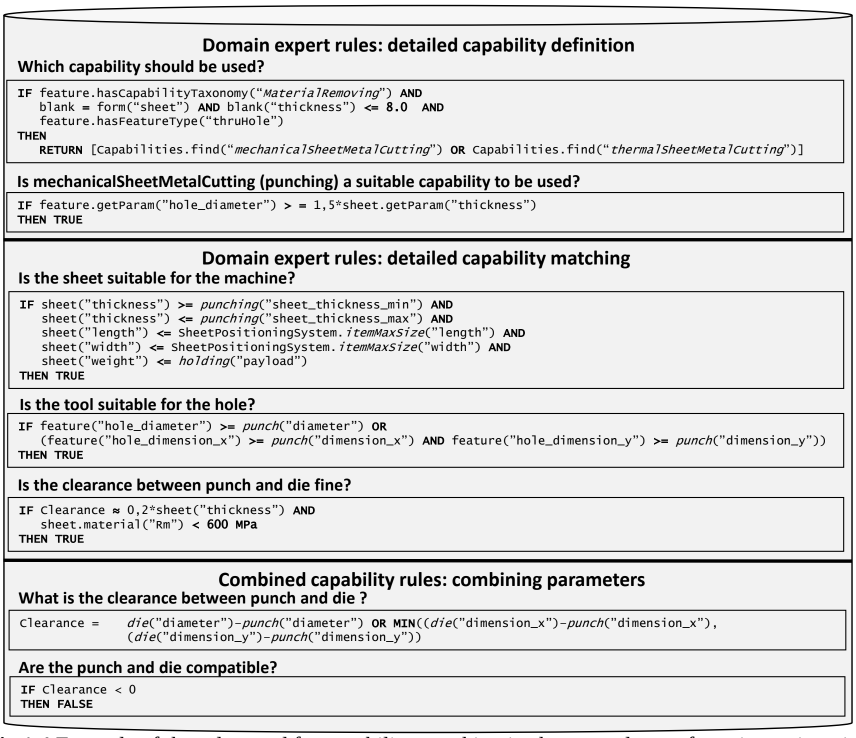


Fig 1.4 Example of the rules used for capability matching in sheet metal manufacturing written in pseudo code.

The presented capability-matching approach is able to find resources that fulfill the product requirements from the technical perspective. In order to select “the best” resource from various alternatives and furthermore to optimize the usage of the resources, also financial profitability (time and money) and process parameters need to be evaluated. The capability model itself considers the capabilities of the resources independent from the product properties or any external factors. However, for example, the acceleration of a sheet positioning system is dependent on the weight of the blank. An approach, considering these aspects in sheet metal manufacturing, has been developed in LUT and presented in [6]. The work is based on optimizing the manufacturing method based on the product and resource descriptions. It models the interconnectedness of product (including raw material) properties and the machine and tool properties. The work targets to enhance the selection of resources and processing parameters that can optimize the efficiency of the sheet metal manufacturing. The work aims also for better design of the sheet metal products, taking into account their manufacturability. The detailed analysis of the dependencies between machine, tool and blank properties by [6] has been utilized when structuring the capability model for sheet metal cutting and when formulating the rules for the capability-matching (examples seen in Fig. 1.2 and Fig. 1.4).

1.5 Conclusions

This paper presented an approach to represent the capabilities of a punch press machine with a formal ontological model, and a framework to match these capabilities with the product requirements. It supports automatic filtering of information and finding suitable system solution proposals from a large search space, thus reducing the manual information-processing required during resource allocation and system design. In a small factory with only a few resources, management of the resource information is not a problem. In large factories and production networks with multi-functional resources, automatic management and filtering of this information has substantial potential for reducing the amount of manual work, and thus reducing the time used for planning activities.

The approaches developed in TUT and LUT can nicely complement each other in sheet metal manufacturing. While the capability-based matching is used for finding the resources that are technically possible, the approach of LUT can be used for evaluating the financial feasibility of the found resources and for optimizing the usage of the resources, e.g. by selecting the correct processing parameters. The capability model can provide the needed information for the optimization of the manufacturing method. It can also be used to convey the information of the current resource capabilities to the product designers, so that the capabilities can be considered already during the product design phase. Formal model describing the resources, taking into account the lifecycle variation of the capabilities, supports better utilization of today's multifunctional resources with various capabilities.

1.6 References

1. Garcia, F., Järvenpää, E., Lanz, M. & Tuokko, R. (2011). Process Planning Based on Feature Recognition Method. ISAM, 25-27 May 2011, Tampere, Finland.
2. Järvenpää, Eeva. (2012). Capability-based Adaptation of Production Systems in a Changing Environment. PhD Thesis, Tampere University of Technology. 190 p. Available in: http://URN.fi/URN:ISBN:978-952-15-2940-5
3. Järvenpää, E., Luostarinen, P., Lanz, M. & Tuokko, R. (2011). Presenting capabilities of resources and resource combinations to support production system adaptation. ISAM, 25-27 May 2011, Tampere, Finland.
4. Landers, R.G., Ruan, J. & Liou, F. (2006). Reconfigurable Manufacturing Equipment. In A. I. Dashchenko, ed. Reconfigurable Manufacturing Systems and Transformable Factories. Sringer, pp. 79-110, ISBN 3-540-29391-4.
5. Lanz, M. (2010). Logical and semantic foundations of knowledge representation for assembly and manufacturing processes. PhD thesis, Tampere University of Technology, Finland. 138 p.
6. Lohtander, M. (2010). On the development of object functions and restrictions for shapes made with a turret punch press. PhD thesis, Lappeenranta University of Technology, Finland. 182 p.
7. Wiendahl, H.-P., ElMaraghy, H.A., Nyhuis, M.F., Zäh, M.F, Wiendahl, H.-H., Duffie, N. & Brieke, M. 2007. Changeable Manufacturing – Classification, Design and Operation. CIRP Annals – Manufacturing Technology, Vol. 56, No. 2, pp. 783-809.