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Object-oriented modeling of manufacturing resources using work study inputs

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Abstract

Resources are the core of manufacturing models. They provide information about the people and equipment that perform activities on the shop floor. Comprehensive representations of equipment are common but human resources are often defined to a very limited extent. This paper presents how work study data can be applied as input to detailed modeling of human manufacturing resources. The purpose is to provide a valid representation of manual work tasks on a shop floor level. If implemented in manufacturing models the valid representation will contribute to improve planning, control and execution of production. It also facilitates and encourages production improvement initiatives.

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1. Introduction

Manufacturing models are representations of manufacturing entities (i.e. processes, activities, and resources). The models can be conceptual, but the application is usually in software, such as simulation tools, planning systems, and so on. Consequently, manufacturing models are ever present in the domains of computer integrated manufacturing (CIM) and manufacturing execution systems (MES). In product development are manufacturing models used to capture the information needed to select manufacturing processes and resources, and also to make product design decisions. Representation of manufacturing resources is essential in manufacturing models. They provide information about the people and equipment that perform activities on the shop floor. For manufacturing equipment there are well established systems and standards for data acquisition and information exchange. ISO 15531"MANDATE" (MANufacturing management DATa Exchange) is the international standard for manufacturing data management [1].

Several publications concerned with manufacturing resource modeling provide comprehensive specifications for activities performed by automatic equipment, such as machine tools [2-5]. Human resources are often defined to a very limited extent or even neglected. For manual activities, e.g. assembly and set-up activities, there is a great uncertainty in what to measure and how to measure it and further in how to use the measures for improving the planning and control of production [6]. Despite the increasing automation of industrial processes, human resources are still essential to most manufacturing systems [7]. Valid representations of manual activities on a shop floor level are of interest to any system application, e.g. planning, control or discrete event simulation. These aspects represent the motivation for this paper.

The solution is found in conventional work study techniques which provide information of human resource's capabilities and capacities and their relation to manufacturing productivity and economy [8]. In addition, previous research has shown how work study input can be used for analysing the profitability of a manufacturing unit [9]. In this paper it is presented how and why work study data is of importance as input to manufacturing models and the modelling of human manufacturing resources.

Next section describes the different dimensions of work study data followed by a production system

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definition model with an explanatory description of how work study data can be applied.

2. The dimensions of work study input

Work study techniques are used for the examination of human work in all its contexts. It includes both work measurement and method studies. The purpose of applying work study techniques is to systematically investigate factors which affect the productivity and economy of the situation being reviewed, in order to seek improvements. [10]. Productivity at an activity level can be improved through better methods (M), increased performance (P), and increased utilization (U). This can be expressed in the following equation [8]:

$$\text{Productivity} = M \times P \times U \qquad (1)$$

The method factor (M) is defined as the ideal or intended productivity rate. It is the inverse of the ideal cycle time for the specific work task. In order to determine the ideal cycle time for manual work tasks it is necessary to use a predetermined time system. There are a number of available systems and most of them are based on MTM [11]. The time for the work task can then be timed with stop watch, but the resulting time will not be the ideal cycle time; it will be affected by the P and the U factor in equation 1.

The performance factor (P) corresponds to the speed the work is carried out at in relation to the ideal cycle time. For manual work the performance factor can be both below and above 100%. The normal speed in MTM is set to be valid for a "normal" person working at this speed for 8h a day and for the whole working life without getting exhausted or injured. The performance rate is lower for not fully trained workers and for people with disabilities.

The utilization factor (U) represents the time that is spent on performing the intended work in relation the total planned time. Utilization can never go beyond 100%. The planned production time is usually defined as the paid working time minus planned stops, such as weekly meetings or planned maintenance stops. The U-factor for manual work is measured through a work sampling study [11].

To be able to use P and U as input to modelling of manufacturing resources it is necessary to specify the different P and U losses and divide them into several separate variables, as shown in table 1.

It is important to differ between utilization and capacity. Utilization is always in relation to the planned, intended, paid, or manned time. It is always measured as a percentage. Capacity is measured as products per time unit. Two different capacities are used in this paper: Paid and Real (table 2).

Table 2: Capacity definitions

Variable	Definition
Paid capacity (CAP_P)	The paid capacity corresponds to the shift time, i.e. the time that the facility is manned. It can also be the intended capacity if there is a plan to run the facility partly unmanned.
Real capacity (CAP_R)	The real or "practical capacity" takes into consideration the losses based on the P and U factors.

Table 1: Performance and utilization definitions

	Variable	Definition
P	Personal performance rate (P_P)	The personal performance rate is affected by the individual's physical ability and his or her motivation to work at a high speed (relative the MTM norm), independent of work task.
	Skill based performance rate (P_S)	The skill based performance rate is the individual's speed at performing a specific work task depending on the training and the experience the individual has for the task.
U	Need based utilization rate (U_N)	The need based utilization rate depends on the need for relaxation and personal time. It is often regulated by agreements at the work place. It includes paid breaks and losses before and after a break.
	System designed utilization rate (U_S)	The system designed utilization rate is defined as the balance losses designed into the system. It can be balance losses on an assembly line as well as losses in a semi-automated work station.
	Disturbance affected utilization rate (U_D)	Disturbance affected utilization rate corresponds to the losses caused by different random disturbances. It includes the lost time from discovery of the disturbance until the work is performed at full speed again.

3. Production system definition and modeling

A generic definition of a production system is a prerequisite in order to describe how work study input is applicable to the modeling of human manufacturing resources. Figure 1 shows how a factory consists of subsystems and workstations. It is expressed using the Unified Modeling Language (UML) which is the industrial standard for object-oriented notations [12].

A factory represents the actual manufacturing facility and is the top system level of the model. It can be broken down into subsystems which correspond to defined areas of the manufacturing facility, e.g. the storage area, the painting area, or the assembly area, etc. A subsystem consists of one or several workstations which are defined areas within the subsystem. The different system levels in this hierarchy are subclasses to the entity Facility.

In a Facility one or several Manufacturing processes are executed. "*A Manufacturing process is a structured set of activities or operations performed upon material to convert it from the raw material or a semi-finished state to a state of further completion"* [1]. The hierarchal composition of the production system definition enables a manufacturing process to be described from the views: Factory, Subsystem, or Workstation. Hence, a Manufacturing process can be seen as the entire process of converting raw material into finished products (Factory view) or as a specific set of activities performed in a Subsystem or at a Workstation. The entities Resource (with subclasses equipment and human) and Manufacturing process are defined as in ISO 15531. The decomposition of the entities Facility and Activity (in Figure 1) are not part of the standard.

An activity consists of sub-activities that constitute a specific part of an activity, expressed as a sequence of elements. For example: count components, put components in box, deliver box from position A to B. The elements are standard movements, such as get, put, use etc. defined in a predetermined time system. In the production system definition are activities formulated as time equations, which are elaborated from Time-Driven Activity Based Costing by Kaplan and Anderson [13]. In a time equation each sub-activity can be assigned a time driver and the time consumption per sub-activity is the sum of element times for that sub-activity. The result of a time equation is therefore the time consumption per activity. Following sequence describes an activity that prepares components for a machine set-up:

$$print\_list + get\_list + get\_missing\_\ material \times X_1 + pick\_components \times X_2 + pick\_special\_components \times X_3$$

Where X_1, X_2 and X_3 are time drivers

X_1 = Material is missing, yes = 1, no = 0
X_2 = Number of standard components/product
X_3 = Number of special components/product

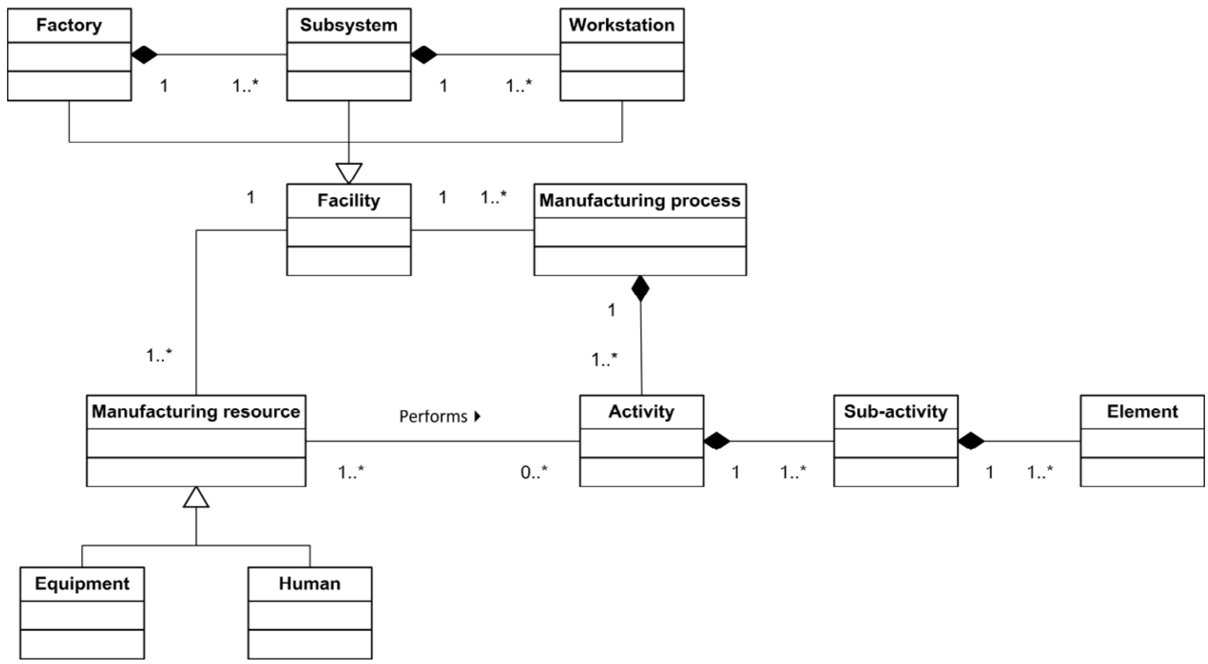

Figure 1: Production system definition

Let's assume that the activity *Prepare set up* is part of a manufacturing process that produces three different product families. By expressing *Prepare set up* as a time equation it is possible to model differences between the product families, in this case the number of standard and special components per product. If, for instance, the same product family is produced in two succeeding batches then there probably will not be any material missing and time driver X_1 for the second order can be set to 0 and consequently eliminate that sub-activity. If a product family requires a completely different set of activities to be produced, it should be defined in a separate manufacturing process.

The underlying rationale for the production system definition is that resources perform activities. The entity Resource includes two subclasses: human and equipment. Human resources are considered as specific means with a given capability and a given capacity. Those means are considered as being able to be involved in the manufacturing process through assigned tasks [1]. Each resource, equipment and human, is described using the resource characteristics defined in ISO 15531 (table 3). Henceforth, description of resources will only concern human resources.

Table 3: ISO 15531 definition of resource characteristics (adapted from [1])

Structure of resource characteristics	
Characteristic	ISO 15531 definition
resource_administration	Describes administrative information of a manufacturing resource.
resource_capability	Describes the functional aspects of manufacturing resources. In particular this comprises the specification of tasks of the activity which a manufacturing resource can execute.
resource_constitution	Describes the constitution of manufacturing resources. The description of the constitution comprises information about the actual status of manufacturing resources.
resource_capacity	Describes the capacity of manufacturing resources. The description of the capacity comprises information about the potential workload of manufacturing resources

The entity *resource_capability* has a list, or a reference to a list, to what activities the resource can perform and consequently comprises the specification of activities the resource can execute. The capability of the resource can be further classified using performance related attributes (P_P or P_S) for each activity. The entity *resource_administration* has information of what or which manufacturing processes the resource is assigned to. It also specifies the resources cost per time unit. The capacity of the resource, described in the entity *resource_capacity*, is expressed as paid capacity (CAP_P) which corresponds to the resource's working schedule and consequently its availability. The entity *resource_constitution* is not applicable for human resources since it primarily concerns equipment related attributes such as functions, tolerances, and technical specifications [1].

4. Applying work study inputs

This section explains more specifically how work study input can be applied to modeling of human manufacturing resources. The example is based on empirical findings from five case studies conducted at different electronics manufacturing facilities [14]. The manufacturing process described is final assembly of a box-built product from an electronics manufacturer, henceforth referred to as *Final assembly*. Simplified, this means to mount a circuit board into a casing, containing a display and a keyboard, perform a functional test, and thereafter to pack the product for shipping.

The entity manufacturing process contains a list, or a reference to a list, of all the activities performed in *Final assembly*. Each activity is expressed as a time equation with identified time drivers on sub-activity and element level. The time consumption and definition of the activities is the result of a method study using the MTM-based system Sequence based Activity and Method analysis (SAM) [15]. *Final assembly* concerns two product families which are expressed as quantified values of the time drivers.

Product_familyA: {X1=1, X2=28, X3=4, … , Xn}
Product_familyB: {X1=1, X2=45, X3=2, … , Xn}

Performance rating [11] has been conducted for selected activities in *Final assembly*. For instance, mounting a circuit board into a casing and performing the function test are complex activities. During the performance rating it was shown that a novice was only able to perform those activities at 80% of normal speed while a more experienced operator could perform same activities at 100%. Consequently, two skill based performance ratings (Ps) are defined and assigned to those activities; Ps_ novice = 0.8 and Ps_ skilled = 1.0. Remaining activities were considered possible to be performed at 100% of normal speed, independent of the resource's level of skill. Also, it was identified that one of the resources assigned to *Final assembly* could only perform the packaging activity to 60% of normal speed due to a physical disability. A personal performance rate (P_P) was therefore defined for the packaging activity, P_P_disability = 0.6.

In *Final assembly* a manufacturing order states what product to produce and the product is part of a defined product family. Assigning a product family to a manufacturing process will through assignment of the values of the time drivers generate an ideal process time and consequently the ideal time consumption required for producing the specified amount of products. Different product families will have different ideal time consumptions e.g. dependent on differences in number of components to assemble.

Final assembly is performed in a Facility and in this example the subsystem view is used. One work sampling study per product family was conducted in the subsystem. The need based utilization rate (U_N) was the same for both product families since all the resources were working according to the same schedule and need for relaxation and personal time did not differ. No product family specific disturbances (U_C) were identified. Instead, what causes the difference in utilization rate between the product families is the system design utilization rate (U_S) since there were considerably more balancing losses when producing product family B. As a consequence, the general utilization rate for the subsystem was 67% when producing product family A and 74% when producing product family B.

One batch of Product_familyA shall be produced followed by one batch of Product_familyB. The productivity rate for the entire process is determined by the productivity rate of the constraining activity, e.g. the bottleneck. In this case it is the activity *Function test* which is expressed as a time equation:

$$prepare\_test + get\_workorder \times X_1 + get\_component\_specific \times X_2 + set\_test\_rigg \times X_3 + \ldots$$

The quantified time drivers (e.g. number of specific components) of each product family give the ideal time consumption:

C/T_A = 1min 40s
C/T_B = 2min 0s

The inverse of the ideal time consumptions are the ideal productivity rates:

M_A=36 units/h
M_B=30 units/h.

When assigning resources to the process their individual capabilities are correlated with the activities that are to be performed. The process utilized four resources; all of them capable of performing the ingoing activities. However, one operator was a novice and for the first batch, when producing Product_familyA, that operator was assigned to the activity function test for training purposes. After resources have been assigned, the real capacity (CAP_R) of the process is presented in table 4.

Table 4: Real capacity of the activity *Final assembly*

Final assembly	
Product_familyA	Product_familyB
M_A= 36 units/h	M_B=30 units/h
P = 80%*	P = 100%*
U = 67%	U = 74%
CAP_R= 19,3 units/h	**CAP_R= 22,2 units/h**

*Determined by the capability of the resource assigned to the bottleneck activity

As can be seen, the real capacity (CAP_R) when producing Product_family_B was higher despite a greater ideal capacity (M) of Product family A. This exemplifies how the actual utilization of resources and their capabilities affects the outcome of a manufacturing process.

With this in mind, production improvement actions can be initiated. The manufacturing process can be improved by training and motivation actions and subsequently the increasing the performance of resources. Also efforts can be made to improve the utilization of resources by for instance focusing on production system design, improved scheduling or to decrease disturbances. However, the largest impact will most likely come from improving the method (M) [8]. When a method has been altered, improved, or re-designed, the old U and P values are no longer valid. For instance, improving the method for Product_family_B might result in an increased ideal capacity (M_B), but can in turn generate additional balancing losses and consequently decrease the utilization. New P and U ratios can be very hard to estimate due to unexpected synergies.

5. Conclusion

Manual work tasks are of outmost importance even in highly automated production. By using work study input the human resources ability to perform defined activities is taken into consideration based on facts. As a result, neither planning systems nor manager will require the human resources to exceed their capabilities, skill based or personal based, risking personal injuries or product quality defects.

Furthermore, work study input such as the results of work sampling enables an enhanced definition of resource utilization beyond using only the ratio between available time and planned time. The utilization of human resources when manufacturing a specific product family can be measured and assessed considering production system design-, disturbance- and need based aspects. Consequently, the real capacity of a manufacturing process can be defined based on a valid representation of human resources and manual work tasks.

As stated, human resources are often defined to a very limited extent compared to equipment. This paper has shown that human manufacturing resources can be described and modeled with a high level of detail using the ISO 15531 and work study input.

If implemented in manufacturing models the real capacity will contribute to improve planning, control and execution of production. It will also facilitate and encourage production improvement initiatives.

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