**Proceedings of the 13th IFAC Symposium on
Information Control Problems in Manufacturing
Moscow, Russia, June 3-5, 2009**

The Origin of Operations: Interactions Between the Product and the Manufacturing Automation Control System ⋆

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Abstract: This paper investigates the interaction and relationship between the product design and the control logic design for manufacturing automation system. One important challenge during the development of a manufacturing automation system, is to handle the information related to the manufacturing control system (i.e PLC), since it influences almost every part of the manufacturing design and process. Therefore it is crucial to know when and how this information is created, to be able to increase the development quality and efficiency. This is especially true for the product related information that impacts the design of the control system. This paper studies the liaisons, the interfaces among parts and features in the product design, and its relationship with operations and resources in the manufacturing system. These liaisons must be considered in both product and manufacturing development since the inter-relation between liaisons and operations establishes the direct mapping of constraints and demands between the two domains. This paper further proposes how the manufacturing operations can be described during the development and how they are realized by resources in the manufacturing system. An example from automotive industry is included in this paper, to demonstrate the proposed concept.

Keywords: Manufacturing control systems, PLC, Logic control, Process design, Information handling, Liaison, Operation

1. INTRODUCTION

The communication between the product and the process design departments can sometimes be very troublesome. This interaction has been referred to as an *Over the Wall* mentality, which describes when the product designers do not consider the manufacturing of the product and only *throws* the finished design to the process designers (Boothroyd, 2005). Obviously this approach will never work in these days with highly intensive global competition, since a product must be launched as fast as possible with high quality and low cost. To accomplish that, the product and its manufacturing system must be tightly integrated throughout the complete development process. In industry today, methods like Design for assembly (Boothroyd, 2005), Concurrent engineering (Kusiak, 1992) and Product life-cycle management, PLM (Saaksvuori and Immonen, 2008), are wildly used to handle the interaction between different technical domains. But information handling still remains a key challenge (Sudarsan et al., 2005; Rampersad, 1995).

The research community has studied the relationship between the product design and the process design, especially how to integrate constraints and requirements from manufacturing into the product design process (Salomons et al., 1993), and how to assemble a product (Abdullah et al., 2003). But the important part for control design, related to operations, resources and sequence of operations, has not been the focus in this field. To identify the relationship between the control related information and the product, a more detailed analysis is needed.

This paper discusses the interaction and relationship between the product design and the design of the manufacturing control system. The manufacturing automation control system is best known by its abbreviation, PLC, which refers to Programmable Logic Controller. In an automotive assembly plant there are usually several hundred PLCs that control the manufacturing process. One challenge during the development of the manufacturing system - is to handle the information related to the PLC program, since the PLC logics influences almost every part of the manufacturing system (Lucas and Tilbury, 2003). Therefore it is crucial to know when and how this information is created and processed, to increase the quality and development efficiency.

There are many different issues and challenges related to manufacturing control systems design and development. A comprehensive review of current research activities has

⋆ This work was supported by GM R&D, SAAB Automobile, Teamster, CAPE research school and the Knowledge Foundation

been conducted by Morel et al. (2007). Different solutions have been proposed to handle the control logic design for a manufacturing system. One approach suggests to use UML with some modifications to aid the software design (Thramboulidis, 2004); others propose more formal methods using e.g. Automata or Petri nets (Frey and Litz, 2000). There are also some commercial tools available, for example Automation Designer from Siemens and V5 Automation from Delmia, which try to integrate mechanical, electrical and control design into a single process with simulation capabilities.

All of these methods and tools can improve the interaction and data exchange between the process design and the control design, since traditionally the *Over the Wall* mentality has been quite dominant between these two domains. Therefore, the identified challenges in industry have mainly been focused on this interaction. In reality the control design has not only an influence on the process design but also on the product design. To be able to understand and utilize these interactions, a better understanding of the origin of information is needed.

The objective of this paper is to identify how the product and the control system design influence each other. In the next section, Section 2, the product design is studied based on a given assembly example and related literature research. Section 3 investigates the interactions between the product and the process design. In Section 4, a formal structure and definition of operations and resources is specified. After the product related operations and resources are designed, other operations and resources are needed, which is discussed in Section 5. The paper ends with a conclusion.

2. PRODUCT DESIGN

A typical car consists of more than 2000 parts, but the purpose and functionality of every part is sometimes hard to identify. This is due to that the manufacturing of the car, influences the parts the car consists of. To be able to develop and launch new products faster, with better quality and higher customizability, different aspects of the product and the manufacturing development must be integrated. When a new car is developed, the product and manufacturing designers are therefore working closely together to make the car producible, which has made a tremendous impact on the development quality and efficiency.

2.1 Parts and features

A product consists of parts and features. Both parts and features are equally important elements of the product. We can make the following definition:

Definition 1. *Parts and features are entities that build up the product and have interfaces with other parts and features.*

Parts are usually standalone entities that are assembled together in the manufacturing process. It can be sheet metal, rivets, glue, bolts, screws, a CD-player or even a software program. How the parts in the product are put together, will define the overall layout of the manufacturing system. This relationship has been studied intensively, since it has a direct impact on manufacturing cost, quality and throughput. To include manufacturability knowledge and constraints in the product design, different methodologies have been proposed. Design for assembly is a set of methods that includes rules and guidelines for product developers to follow a structured procedure to assess suitable design solutions for better manufacturability and product break-down(Abdullah et al., 2003).

Features are in some sense harder to define since the term does not have the same meaning in different engineering disciplines. In feature-based design, features are usually properties that defines what will be removed by a machine, like a hole, a shape or a slot. These properties are used to integrate machining information in the product design (Salomons et al., 1993; Ames et al., 1996).

In this paper, the scope of feature is much broader, which also includes other information like spot welds and reference points. A feature can for example be a position on a part where the robot holds it, with a gripper. The gripper will enforce a constraint on the product design, since a product change will impact the gripper design. Another example are features needed for transportation and storage that can for example be holes or shapes on the parts.

One important remark though, is that parts and features are only related to the product, not the manufacturing system, e.g. the feature is the position for the clamp not the clamp itself. To sum up we make the following definition:

Definition 2. *Parts are physical product entities, while features include abstract and logical product entities.*

A simple example will be studied in next section, to show the interaction between the product and the control system. This example is from an automotive company and the corresponding manufacturing system is installed in the Robot and Automation Lab at Chalmers University of Technology.

2.2 A case study

The example in Figure 1 is a simple product assembly consisting of two parts of sheet metal, part A and B, put together by seven pop rivets (Table 1). To be able to insert the rivets, there are seven holes in A and B. These holes are called Rivet hole 1 to Rivet hole 7 (Rh1-Rh7), and the rivets are named Rivet1 to Rivet7 (R1-R7).

Table 1. Parts and features

Parts	**Features**
Sheet metal A (A) Sheet metal B (B) Rivet 1-7 (R1-R7)	Reference position 1-3 on A (Ap1-Ap3) Reference hole 1-2 on A (Ah1-Ah2) Reference position 1-3 on B (Bp1-Bp3) Reference hole 1-2 on B (Bh1-Bh2) Rivet hole 1-7 (Rh1-Rh7)

For both A and B, there are five reference points, referred to as datum, defined. The purpose of these is to specify how to fixate each object in all directions and how to measure them efficiently. A reference point can be a position, where the part is clamped or a hole or guide for a location pin. It can be reused throughout the manufacturing. For the given example, the positions to fixate part A and B are called Ap1, Ap2 and Ap3, and Bp1, Bp2 and Bp3, respectively. In part A there are two holes, reference hole Ah1 and Ah2, and in part B, reference hole Bh1 and Bh2. Guide pins will fit into these holes to position the parts.