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ScienceDirect
Robotics and Computer-Integrated Manufacturing 24 (2008) 187–199
Robotics and Computer-Integrated Manufacturing
www.elsevier.com/locate/rcim

An integrated modelling framework to support manufacturing system diagnosis for continuous improvement

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Abstract

This paper proposes an integrated modelling framework for the analysis of manufacturing systems that can increase the capacity of modelling tools for rapidly creating a structured database with multiple detail levels and thus obtain key performance indicators (KPIs) that highlight possible areas for improvement. The method combines five important concepts: hierarchical structure, quantitative/qualitative analysis, data modelling, manufacturing database and performance indicators. It enables methods to build a full information model of the manufacturing system, from the shopfloor functional structure to the basic production activities (operations, transport, inspection, etc.). The proposed method is based on a modified IDEF model that stores all kind of quantitative and qualitative information. A computer-based support tool has been developed to connect with the IDEF model, creating automatically a relational database through a set of algorithms. This manufacturing datawarehouse is oriented towards obtaining a rapid global vision of the system through multiple indicators. The developed tool has been provided with different scorecard panels to make use of KPIs to decide the best actions for continuous improvement. To demonstrate and validate both the proposed method and the developed tools, a case study has been carried out for a complex manufacturing system.

Keywords: IDEF; Modelling tools; Manufacturing improvement; Manufacturing datawarehouse; Key performance indicators

1. Introduction

The high competitiveness of modern industry leads companies to a continuous refinement of their manufacturing processes. Time and motion studies and continuous quality improvement programs are very useful tools in the study of manufacturing systems. However, the high number of strategies, techniques and methods which can be implemented (JIT, TQC, TPM, SMED, QFD, etc.) make analysis of these systems difficult. The reasons are the complexity of the manufacturing system and the high number of implied factors. In many cases, the results obtained from conventional analysis are lacking in a detailed description of the system's current state. The effort that implies the use of process analysis charts, data summary panels, modelling tools, check lists or the use of quality tools is wasted due to a lack of integration of this information in subsequent phases.

Learning from the information structuring mechanisms provided by the system modelling and from the flexibility of the relational databases, this paper sets out a methodology for modelling manufacturing systems. This methodology allows a rapid analysis of the production and quality activities, and the creation of a data repository used in the evaluation of activities and in the exploitation of the system indicators. The developed methodology integrates the data acquisition cycle, graphical analysis and system evaluation in a single environment. The objective is to identify the activities without added value, the production capacity used and the technical–economical indicators of the system, mainly those related to productivity and costs. The application of this method implies it is oriented to supporting decision-making tasks in continuous improvement action planning that characterises new manufacturing strategies.

The proposed method has been used as a conceptual base in the development of reference software architecture

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0736-5845/$ - see front matter
doi:10.1016/j.rcim.2006.10.003

and new software oriented to the analysis and improvement of manufacturing systems. The developed method, architecture and tools have been used for the study and evaluation of a complex production plant, so the results obtained have validated the proposed method.

2. Review of modelling methods to support manufacturing systems analysis

Manufacturing analysis for continuous improvement is a technical area with high significance due to the increase of quality and flexibility requirements for end customers. There are many applications cases where manufacturing analysis through modelling methods is performed in order to take decisions [1]:

- Diagnosis of a disorder (material, information or control flow).
- Restructuring a manufacturing process to improve its performance.
- Business Process Reengineering (BPR).
- Implementation of Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) and Product Data Management (PDM).
- Tuning the organisation structure to face business change.
- Large-scale systems integration.
- Alignment or conformity to norms (ISO 9000, ISO 14000).
- Management decision (activity externalisation/internationalisation).

To the above applications we must add the following:

- Implementation of ABC cost accounting method.
- Implementation of JIT, TQM, TPM strategies.
- Diagnosis of wastes (capacity, resources or cost).

The diversity of existing techniques to support manufacturing systems analysis called for focusing the review of the state of art into five methods: IDEF,GRAI-Grid, simulation, Petri Nets and integrated modelling methods.

IDEF methodology [2] is the main technique of Business Process Modelling (BPM) for redesigning processes to obtain sustained improvements in the outputs of manufacturing systems [3–5]. It is a descriptive method based on graphical and text description of functions, information and data. The flexibility of the method resides in its capacity for allowing the analysis of complex systems, where there is a need to study multiple levels of detail in a way the analyst can understand the system. Analysing the different IDEF approaches may the IDEF0 be the most widely used version in manufacturing analysis. It consists of a hierarchy of diagrams, text and glossary. The diagrams represent a set of system functions such as boxes (activities), objects interface (arrows) and information. The attachment point between arrows and boxes indicates the interface type (input, control, output and mechanism). The generation of many levels of detail through the model diagram structure is one of the most important features of IDEF0 as a modelling technique.

However, IDEF is a descriptive method based on the graphical and text description of functions, information and data that is often only of use as an aid to documenting and validating processes. It is static and qualitative, which is a drawback to the analysis of processes. There are more IDEF methodologies covering others capabilities. Among them, IDEF1x has been widely accepted by industry. It supports the development of a conceptual schema and semantic structure oriented towards the development of manufacturing databases [6]. However, it is oriented towards being used by information experts, not by technical personnel involved in continuous improvement. The most recent applications include the generation of knowledge management systems based on databases [7,8]. In these cases, IDEF is used to generate knowledge structure but only from a functional point of view. Its graphical display and simple notation make possible to cover any subject from any point of view to any desired degree of completeness.

IDEF resolves specific problems in a manufacturing environment. However, a general manufacturing improvement analysis needs the formulation of a well-defined general manufacturing strategy For this purpose, other modelling methodologies such as GRAI-Grid [9–11] help to define the most important decisions in selected processes of the company and the information exchanged among the different functional areas. The main outcome of this model is the identification of improvement areas, which must be in line with the general strategic orientation. The decision centres identified in the GRAI-Grid are decomposed into detailed IDEF0 diagrams to be studied in a detailed way.

There are other theoretical approaches to overcome the limitations of modelling using techniques such as Petri Nets or Fuzzy Logic. Petri Net modelling is a very popular and powerful method for modelling and systems analysis that exhibits parallelism, synchronisation, non-determinism and resource-sharing features [12]. Most studies on Petri Net application in process modelling focus on either information aspects or on functional aspects. Bosil et a al. [13] have evaluated the suitability of IDEF and IDEF3 in conjunction with Petri Nets for modelling processes. The latest developments try to integrate function, information, resource and organisation to support complex, dynamic and distributed processes. As regards Fuzzy Logic, Ma et al. [14] have developed a formal framework to provide extensions to IDEF1x to represent fuzzy information. This data model can be converted into a fuzzy relational database model in accordance with some transformation rules. However, the real application of Petri Nets and Fuzzy Logic to end-users is difficult due to the complexity of the techniques.

The simulation technique has been used since the 1960s as a tool for investigating the underlying behaviour of