Reengineering of the design process: An industrial case

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Abstract. In this article, a Business Process Reengineering (BPR) approach is applied to the design process of electric motors. The objective is to improve the quality, reduce costs and duration of the design process by bringing radical change to the process allowing breakthrough improvements rather than obtained by continuous improvement. For this purpose, the Design Structure Matrix (DSM) is used to represent and analyse the design process. This method is particularly adapted to capture the repetitive aspect of design tasks. Indeed, iterations, an inherent feature of the design process, represent a key factor in the determination of the design process duration and cost. In this study, the number of iterative tasks is reduced by 50%. The implementation of the reorganized process needs an organisational change in the design office but the expected benefits are worth the effort.

1. Introduction
International competition forces manufacturing companies to be more and more efficient in order to remain competitive. In addition to continuous improvement initiatives, they must sometimes bring breakthrough changes by introducing radical changes to their working methods. This goal could be reached by adopting a Business Process Reengineering (BPR) approach.

The design process is one of the major business processes that any manufacturing company should consider as a key factor in the successful reduction of the product development lead time. Engineering design is a multidisciplinary and complex process. It requires different approaches to be studied, analysed, and improved. This justifies the existence of various design process models. This is not surprising, and the variety of models have to be considered as complementary and not competing.

In this paper, the design activity is looked at as an information intensive process. Because design tasks are linked to each other as a complex information dependency network, it is not possible to perform the design process in a single procedure. Some design tasks are executed more than once before obtaining an acceptable solution. This repetition of design tasks, called iteration, is a fundamental characteristic of the design process. Understanding and controlling the repetitive characteristic of design tasks can improve the design process, and reducing iterations would reduce the product development cycle time. For this purpose, we need a tool that captures the iterative aspect of the design process. Design Structure Matrix (DSM) is the most appropriate method and tool capable to fulfil this need.

The rest of this article is organized as follows. We introduce in the next section a definition of the BPR concept. The DSM method is then described in section 3. The application of these concepts to reengineer the design process in a company is presented in section 4.

2. Business Process Reengineering
Business Process Reengineering (BPR) is an important management approach developed in the mid-1990s. The concept is credited to Professor Michael Hammer who initially introduced it in his paper [1].
The main idea underlying BPR was that companies should completely modify their processes instead of automating tasks. The concept was then developed with James Champy and published in their famous book [2]. Reengineering is defined by its authors as the fundamental rethinking and radical redesign of business processes to achieve high improvements and boost key performance indicators, such as cost, quality, service, and speed. The fundamental principal of BPR is to encourage reflection on the whole process rather than focusing on individual tasks. This will allow the creation of a new process in which all processes that do not add value for the customer will be removed or reduced. To implement BPR, managers should follow defined steps. (1) Develop a business vision to explain the reason for the change. Process objectives should be clarified to explain the importance of changes and their necessities for the employees. (2) Identify the process that will be reengineered. The current process needs to be mapped out. The DSM method will be used in our case to achieve this step. (3) Develop a new process. An appropriate algorithm applied to the DSM obtained in the previous step will lead to a new process. (4) Implement the new process. Organisational changes will be needed to implement the new process. That’s why, in the first step, it is very important to inform and prepare as early as possible the employees to the future changes.

3. Design Structure Matrix (DSM)
DSM is a method based on a matrix representation of the tasks of a design process and their interactions. It was first introduced by Steward in the 1970’s [3] to capture and analyse information flow in complex systems. DSM was then adopted by Eppinger [4] in the early 1990’s at MIT and applied to various industry projects in the manufacturing industry.

For a product development process or a design process, the DSM representation will use a square matrix to map the interactions between the design tasks. In the DSM method, it is assumed that each design task will use information supplied by other tasks to create information for other ones. Hence, a design task is considered as an information processing task. In a design process, three forms of task relationships can be observed: serial (one task is dependent on another one), parallel (tasks are independent from each other) and coupled (tasks are interdependent). Figure 1 shows these relationship forms and their DSM representations.

![Figure 1. Task relationships in a DSM model.](image)

The original DSM model is a square matrix with one row and one column per element. For a design process model, the tasks are sorted in a roughly chronological sequence of execution. In a binary DSM, diagonal elements of the matrix have no particular meaning. Off-diagonal elements indicate task relationships (Figure 2).

The elements in each row indicate all the tasks whose output is required to execute the task corresponding to the row. The elements in each column indicate all the tasks which receive output from the task corresponding to the column. Upper diagonal elements of a DSM indicate feedback information flows and thus depict the existence of iterations. The number of upper diagonal elements can be reduced or eliminated by a convenient reordering of the DSM elements. This operation is known as partitioning or sequencing. The remaining information cycles are resolved by running several iterations until an acceptable solution is reached. The re-sequenced elements of the DSM matrix shown in figure 2 are presented in figure 3.
Several researchers [5] [6] [7] proposed heuristics or exact methods to partition a DSM. These heuristics or methods generally differ in the way they identify the cycles in the DSM. The heuristics try then to find the sequence of the design tasks so that each task do not begin until all the information necessary to its completion is received from its predecessors.

In its beginnings, the DSM method was a binary matrix and its elements did not contain quantitative information. Hence, the strength of the interaction between matrix elements was not captured. Since then, several extensions have been developed in an attempt to add quantitative measures. Over the last decades, DSM was used in different industrial domains, including product development, systems engineering, project planning, and team building. This allowed the development of different types of DSMs. Browning [8] proposed a classification of DSM models as shown on figure 4.

In this paper, an activity-based DSM is used to model, analyse and reengineer the design process.

4. Industrial application case
In this section, we present an industrial application of the use of the DSM method to reengineer the design process in a company specialized in the design and manufacture of electric motors. These motors are intended to be used in various industrial sectors such as food, marine, nuclear, and pharmaceutical.

This study started with a knowledge management project in the design office of the company. Indeed, in this design office, engineers and technicians use more than 800 documents where the rules are defined. There are design rules, operating procedures, engine or component supply specifications, and so on. Of the 800 documents, some are obsolete, and most of them need to be updated. This project was an opportunity to review the entire design process. During the project, it appeared that a reengineering of the design process would bring a considerable improvement in its performance.

Identifying the steps of the design process was a project lasting about six months and was done in parallel with the knowledge management project. The work was done by an internship engineering student in cooperation with company experts.

The design process includes specifications, electric design, mechanical design, and specific parts design. Thus, company expertise from various disciplines was captured in the design process tasks and
their interdependencies. During this project, the need for a structured approach gradually emerged, and the use of the DSM method to model the design process was a relevant choice since the objective was to capture the iterative aspect of the design tasks.

**Figure 5.** DSM of the main steps of the design process.

The main steps of the design process are represented in the DSM shown in figure 5. The tasks are represented in a sequence that has been defined over many years of practical experience.

- Specifications
- Electric design
- Mechanical design
- Outer frame
- Flange
- Rear bearing
- Shaft
- Ventilation
- Terminal connection box
- General motor design

| Specifications | A | B | C | D | E | F | G | H | I | J |
|----------------|---|---|---|---|---|---|---|---|---|---|
| Electric design|   | X |   |   |   |   |   |   |   |   |
| Mechanical design|   |   |   |   |   |   |   | X |   |   |
| Outer frame    |   | X | X | X | X | X | X | X | X |   |
| Flange         |   | X | X | X | X | X | X | X |   |   |
| Rear bearing   |   | F | X | X | X | X | X | X |   |   |
| Shaft          |   | G | X | X | X | X | X | X |   |   |
| Ventilation    |   | H | X | X | X | X | X |   |   |   |
| Terminal connection box | I | X | X | X | X | X | X |   |   |   |
| General motor design | J | X | X | X | X | X | X | X |   |   |

**Figure 6.** Parameter-level DSM.

The DSM identifies seven coupled tasks forming a circuit involving outer frame, flange, rear bearing, shaft, ventilation, terminal connection box, and general motor design. To analyse the process in enough detail, tasks A through J were expanded to the parameter level. The resulting matrix, before resequencing, is given in figure 6.
In the detailed DSM, activity A (specifications) is represented by task 0, activity B (Electric design) is decomposed to tasks 1-13, activity C (Mechanical design) is decomposed to tasks 14-17, activity D (Outer frame) is decomposed to tasks 18-30, activity E (Flange) is decomposed to tasks 31-45, activity F (Rear bearing) is decomposed to tasks 46-60, activity G (Shaft) is decomposed to tasks 61-66, activity H (Ventilation) is decomposed to tasks 67-68, activity I (Terminal connection box) is decomposed to tasks 68-78, and activity J (General motor design) is decomposed to tasks 81-83. Tasks 79 and 80 were removed from the model after discussion with the experts. The content of these tasks was integrated to tasks 81-83.

Using a standard partitioning algorithm, we re-sequence the detailed DSM to arrive at the DSM in figure 7. The number of upper-diagonal elements in the new DSM is reduced from 24 to 12 elements.

![Partitioned parameter-level DSM.](image)

Figure 7. Partitioned parameter-level DSM.

The subtasks in the new DSM are sequenced in a different order than in the original DSM. It is obvious that the new design process requires a new reorganization of the design office and a fortiori the modification of the role of each expert, designer, or technician in this process. Deploying the new design process is therefore a significant project that may face the challenges of resistance to change. Reengineering issues and expected results are so attractive that such reorganization of the design process remains attractive and the approach is worth the effort.

In this study, we used a qualitative DSM model since it does not contain quantitative information about design tasks and their interactions. Our objective is to pursue the research effort to obtain a quantitative DSM model. In a quantitative DSM model, we can include in the matrix the duration of the tasks, the rework probabilities, and the rework impact probabilities. Using a quantitative DSM model
will allow the estimation of the new design process duration and compare it with that of the original process. This will help managers to have better arguments to justify a reengineering approach of the design process. Hence, for our industrial case, the next step of the project will be the quantification of the DSM elements and the estimation of the total duration of the design process, even if the new DSM shows clearly a significant improvement of the process.

5. Conclusion
In this paper, we presented a reengineering approach of the design process based on the Design Structure Matrix model. The approach was applied in the design office of a company specialized in the design and manufacture of electric motors. DSM was chosen to model the studied design process because standard project management tools such as PERT and CPM do not allow the representation of iterative tasks.

The detailed process of electric motors studied in this research work is composed of 83 tasks linked to each other in a complex way. We have identified 24 iterations in the original process. After partitioning, using a DSM resequencing algorithm, the number of iterations was reduced to 12. The new design tasks sequence needs a new reorganization of the design office and a modification of the role of each designer. The reengineering effort is important and challenging but the benefits are so attractive that the approach is worth the effort. This study will be continued in order to introduce quantitative evaluation of the DSM elements.

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