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Mirosław Dytczak
Grzegorz Ginda (gginda@zarz.agh.edu.pl)
Department of Management in Power Engineering, Faculty of Management,
AGH University of Science and Technology

Production engineering tools for civil engineering practice – the case of FMEA

Narzędzia inżynierii produkcji w budownictwie – przypadek FMEA

Abstract

This article is the first of a series of papers which discuss the usefulness of production engineering tools for general civil engineering. Applications of selected production engineering tools in civil engineering are presented in these papers. The diverse nature of the tools is considered while outlining detailed areas of their application in civil engineering. The features of the tools make them representative of production engineering methodology. Thus, information about the civil engineering applications of the tools also makes it possible to draw practical conclusions about the general usefulness of production engineering methodology in civil engineering. The applications of failure mode and effect analysis (FMEA) are utilised in this regard in the article.

Keywords: civil engineering, construction, decision, support, production engineering, tool, application, FMEA

Streszczenie

Artykuł rozpoczyna cykl prac poświęconych użyteczności narzędzi inżynierii produkcji w szeroko pojmowanym budownictwie. Uwzględniając zróżnicowany charakter wybranych narzędzi inżynierii produkcji, przedstawiono w cyklu szczegółowe obszary ich zastosowań w budownictwie. Cechy wybranych narzędzi sprawiają, że dobrze ilustrują one metodykę inżynierii produkcji. Dlatego, na podstawie informacji dotyczących ich zastosowań w budownictwie, można sformułować praktyczne wnioski na temat przydatności metod inżynierii produkcji w budownictwie. W artykule wykorzystano w tym celu narzędzie FMEA (*failure mode and effects analysis*).

Słowa kluczowe: budownictwo, decyzja, wspomaganie, inżynieria produkcji, narzędzie, zastosowanie, FMEA

1. Introduction

Production Engineering (PE) deals with rules for the design of products and processes as well as with foundations of control, usage, organisation, and the management of manufacturing processes. Therefore, its scope fits in well with supporting typical civil engineering processes like design, construction, usage, maintenance and the dismantling of buildings. Typical civil engineering processes thus seem to be a natural area of extended application for PE tools. This is why PE tools are worth knowing and adopting for civil engineering purposes.

The practical nature of PE tools manifests in their ability to aid decision making in situations where the necessary information is hard to obtain and of poor quality; therefore, the application of tools may facilitate the exploitation of available imperfect information which would otherwise impede the decision-making process in civil engineering.

A general survey of PE tools is presented in the following section, a popular PE tool is then selected. The tool and its applications are presented in section 3 to illustrate the potential of PE methodology in civil engineering. A short discussion of the general usefulness of PE tools in civil engineering concludes the paper.

The discussion of the usefulness of PE tools in civil engineering will be continued in forthcoming papers – these papers will deal with other PE tools.

2. Production engineering tools

PE tools are important components of production management methodology. This is the main reason for calling them production management and engineering tools. A comprehensive survey of such tools is presented by Halevi [1]. He proposed applying two main criteria to categorise the tools. The first criterion deals with features of the tools. The application of the criterion results in the following tool categories:

1. Technical tools which require the application of hardware (T).
2. Software tools which require computer-based systems (C).
3. Organisation and management improvement tools (M).
4. General management concepts (P).
5. Auxiliary tools which support achieving detailed goals (X).

The second criterion deals with the general goals of the tools. The following tool categories are obtained by means of the application of the second criterion:

1. Providing hardware basis for relevant activities (T).
2. Providing techniques for achieving general goals (X).
3. Production planning and control (X, M, P).
4. Progress in production management (P).
5. Production process implementation (M, P).
6. Market tools (P, M, S).
7. Organisational tools (X, M, P).
8. Extension of conducted analyses (M, P).

9. Product design (M, X, P, T).
10. Human resources management (P, M).
11. Environmental management (P, M).
12. Quality improvement (X, M).

Note that symbols included in parentheses refer to the five groups of tools which result from the application of the previous criterion.

Halevi [1] mentions the following most interesting areas of application for PE tools:

1. Project planning and on-time project *completion.*
2. Reduction of production costs and product lead time.
3. Agile product design to speed-up its adoption to changing market needs.
4. Quality control based on defect-free production.
5. No stock policy-based product turnover intensification.
6. Improvement in the following construction enterprise activities:
   - internal communication due to knowledge and information management;
   - cooperation within task teams;
   - relationships with customers and suppliers;
   - management and control of procurement processes;
   - management of human resources;
   - integration in a construction enterprise and a supply chain.
7. Market competition and globalisation-aware strategic planning
8. Continuous improvement
9. Environment-friendly production
10. Expansion of market share.

The above-mentioned application areas may be considered in PE within the following dimensions:

1. Organisational dimension.
2. Product life-cycle dimension.
3. Effectiveness measurement dimension.
4. Management function dimension.

The numerous tool categories and tool application areas confirm the diversity and potential of the PE methodology. The diversity of PE tools makes the selection of a proper tool a cumbersome task; therefore, Halevi [1] proposed several approaches for the single criterion and multiple criteria identification of the most suitable PE tool. These approaches consider several contexts of the application of PE tools while recommending the most suitable tool for a given task. The contexts deal with:

1. Hardware.
2. Software.
3. Production planning and control.
4. Advanced production management.
5. Manufacturing methods.
6. Marketing.
7. General organisation.

8. Advanced techniques of manufacturing organisation.
9. Product design techniques.
10. Human factors in manufacturing.
11. Environment-friendly manufacturing techniques.
12. Manufacturing quality techniques.

The suitability of many presented application areas of PE tools seems to promote the successful application of the tools in comprehensive civil engineering practice. Applications of PE tools are presented in the next section to support this statement.

3. The application of selected PE tools in civil engineering

3.1. Introduction

The improvement in quality and reliability of products, processes and services are fundamental goals in the application of PE tools [2]. The necessity for urgent total quality management (TQM) implementation in civil engineering was articulated in the early nineteen-nineties [3, 4]. This is why improvement in quality and reliability is very important for civil engineering practice.

The concept of TQM is based on the observation that people, together with their motivations, culture, and willingness to take part in team work, make decision regarding the quality of products and services. Therefore, the main feature of the concept deals with engaging all organisation members into activities which lead to the long-lasting customer satisfaction and general benefits both for themselves and for society. Farooqui & Ahmed [5, 6] proved that TQM is also an effective tool for forming ethical attitudes and leadership in a construction enterprise. It also proved to be a useful tool for implicit cost control of the implementation of a construction project [7].

The attractiveness of PE methodology with regard to improvement in quality and reliability is especially evident in the case of typical PE tools such as FMEA (failure mode and effect analysis). This is why applications of FMEA are considered in the remaining part of this section to illustrate the usefulness of PE tools in civil engineering. The detailed usefulness of other PE tools will be discussed in forthcoming papers.

3.2. Applications of FMEA

The main goal of applying FMEA is concerned with improvement in the reliability of products, services and processes. Achieving this goal is assisted through the identification of the most important causes of registered failure modes. This identification is achieved through the quantitative description of causes and effect relationships, i.e. through the description of failure modes (Fig. 1). A set of three distinct and dimensionless variables constitute the description. The variables express severity (S), occurrence (O), and detectability (D). The overall importance of the relationship between a given failure mode and its cause is expressed by the risk priority number (RPN):

$$RPN = S \cdot O \cdot D \tag{1}$$

The higher the *RPN*, the more important the relationship (and the related failure mode) is.

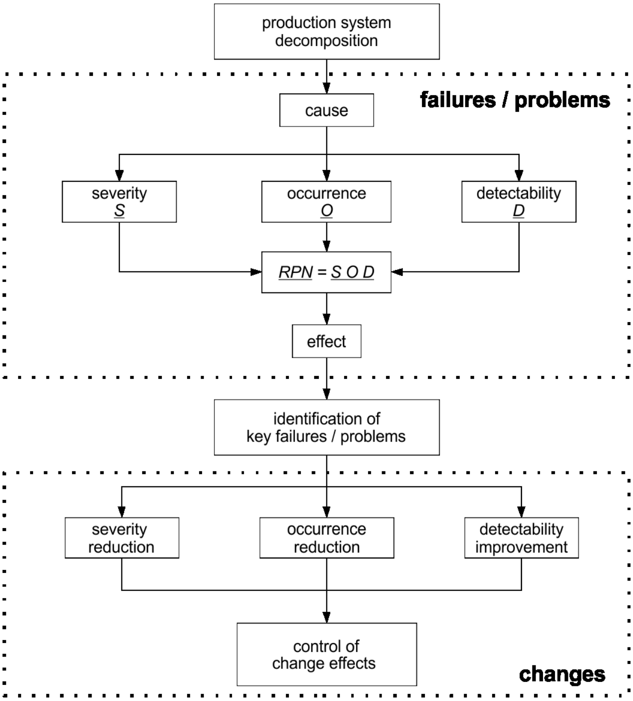

Fig. 1. FMEA procedure

The universal nature of FMEA results in the possibility of its application at different stages of the product life cycle [8]; therefore, civil engineering may benefit from the use of FMEA during planning and construction as well as during usage, maintenance and dismantling of buildings. There are almost forty records available in the well-known Scopus bibliographic database – this database considers the usefulness of FMEA for solving decision making problems in civil engineering. A description of selected applications of the tools follows below.

The FMEA tool is applied in civil engineering both alone and together with other tools for mutual enhancement; the tool itself has also undergone several enhancing modifications. These enhancements, both through being used in combination with other tools and through being modified, are utilised in almost half of all FMEA applications in civil engineering. The diversity of standalone, unenhanced applications of the tool is sufficient to characterise the usefulness of the tool for civil engineering; illustration of the usefulness of the tool is limited, therefore, only to such applications.

Initial applications of FMEA in civil engineering dealt with the preparation of cost-effective building maintenance strategies [9] and the selection of appropriate means for dealing with soil erosion and settlement control during roadworks [10].

Back in 2010, the FMEA was declared a promising tool for risk assessment in civil engineering [11]. Validity of the declaration was confirmed by numerous applications, for example [12, 13]. The detailed goals of such applications are as follows:

- prioritising measures which reduce accident risk in construction and the assessment of their effectiveness [14];
- improvement in the implementation of investment projects through the integration of risk assessments which deal with worker safety, environmental safety and quality [15];
- management of risk in the implementation of a construction project taking into consideration risk identification, assessment, analysis and monitoring as well as planning remediation activities [16];
- the identification of key risk factors in road construction projects relating to private-public partnerships [17];
- environmental risk assessment in water dam usage [18].

FMEA was also applied in civil engineering according to its original purpose. It enabled the identification of:

- damage mechanisms in concrete structures resulting from earthquakes [19];
- failure modes for earth anchor structures and responsibility for them [20].

Other FMEA applications pertained to management support are concerned with:

- building safety development [21];
- the assessment of barriers to innovation in order to facilitate their elimination due to skilful management of stakeholder competencies [22];
- technical infrastructure maintenance [23].

Current trends in the application of FMEA within civil engineering deal with the identification of key factors for:

- conflicts in construction project implementation [24];
- resolution of contract disputes [25];
- raising funds for the construction of modular structures [26];
- the degradation of external composite thermal insulation [27].

4. Conclusions

FMEA is a typically used PE tool, it therefore effectively characterises the potential of all PE methodology. Results of up-to-date FMEA applications in civil engineering confirm the features that are typical of PE tools, namely: universality, flexibility and openness. The features facilitate the easy adaptation of the tools to the needs of decision-making processes in civil engineering; this is due to:

1. The universality of the tools which makes them suitable for supporting the preparation and implementation of construction projects, exploitation of buildings and the dismantling of used buildings;
2. The flexibility of the tools which facilitates the consideration of imperfect information regarding the influence of the surrounding environment on construction, maintenance, dismantling processes etc.;

3. The openness of the tools which promotes their enhancement, either by improving the tools themselves or through using them in conjunction with other tools – both kinds of enhancements may contribute to further developments and expansions of the range of applications of PE tools within civil engineering.

PE tools are especially aimed at the improvement of the quality and reliability of products, services, and processes; therefore, the introduction of these tools within civil engineering promotes quality and reliability in building design and construction as well as in usage, maintenance and the dismantling of buildings.

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