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Application of a fuzzy axiomatic design methodology for ergonomic compatibility evaluation on the selection of plastic molding machines: a case study

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Abstract

This paper presents the application of a Fuzzy Axiomatic Design Methodology for Ergonomic Compatibility Evaluation on the selection of Advanced Manufacturing Technology (AMT). A case study on the selection of CNC plastic molding machines for an AMT training center was developed. The purpose of this methodology is to establish a decision aid for decision makers to perform evaluation of AMT in a more complete manner, while considering human factors and ergonomic aspects. These aspects are found to be scarce in AMT evaluation and selection models. A multi-attribute axiomatic design perspective was used supporting the selection of AMT. An Ergonomic Compatibility Survey was used and the procedure for the data analysis is described. The Ergonomic Compatibility construct was tested and validated using Cronbach Alpha Test observing good reliability of the instrument. A numerical example is presented by the application of the model with the participation of three experts. The alternative which best meet established Design Ranges in terms of Ergonomic Compatibility was selected among three alternatives, according to the Ergonomic Incompatibility Content in a fuzzy environment.

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Keywords: Fuzzy Multiple Attribute Decision Making (FMADM), Advanced Manufacturing Technology (AMT), Ergonomic Compatibility (EC), Human Factors and Ergonomics (HFE), Axiomatic Design (AD).

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1. Introduction

Advanced Manufacturing Technology (AMT) has taken major changes in manufacturing systems in the world´s industrial scenery. It is considered one of the main elements towards efficiency and competitiveness of enterprises. It generally includes CNC (Computer Numerical Controlled) equipment, CAD/CAM (Computer Aided Design/Computer Aided Manufacturing), FMS (Flexible Manufacturing Systems), robotics, rapid prototyping, environmentally sustainable technologies, etc. [1,2]. Aiming to optimize manufacturing systems, AMT selection plays an important role in decision making nowadays, this implies a large amount of information and uncertainty, Decision Makers continuously face the problem of evaluation and selection of equipment among a wide variety of alternatives, because often involve multiple attributes and conflicting criterion. AMT has been largely used in modern industries around the world and there are evaluation tools and models available to support equipment selection processes, even though the publications on this subject are limited [3,4]. Several authors recognize that AMT decision making and management constitutes a complex problem that involves multiple aspects, which are sometimes difficult to consider totally among these models and methods. In this way, evaluation models regarding planning and selection of AMT equipment are found to be scarce of the adequate and desirable Human Factors and Ergonomics (HFE) aspects (attributes) and their importance is under estimated among DM and Decision Making Models (DMM) as well. A numerical example is presented using the approach; in this case DM faced the problem of selecting Plastic Moulding Machines among three alternatives for a university manufacturing laboratory. It was important for them to consider ergonomic and safety aspects additionally of economic and technological ones. The main purpose of this paper is to present a fuzzy axiomatic design approach that was used to assess the selection of the equipment taking into account ergonomic attributes of equipment. An Ergonomic Compatibility Survey (ECS) was applied in order to measure the Ergonomic Compatibility (EC) of these artefacts. The EC construct was validated using Cronbach Alpha test. Also a fuzzy axiomatic design approach was used to obtain Ergonomic Incompatibility Content (EIC); the alternative which has the minimum EIC was selected as the best for this purpose.

2. Literature review

Axiomatic Design approaches for AMT evaluation and selection of equipment and facilities are found in literature in the state of the art of AMT evaluation and selection models and methodologies involving crisp and fuzzy modalities. A consensus of these applications can be found in [5]. Evaluation and selection processes using the Information Axiom seem to offer several advantages for authors, emphasizing its capability to evaluate designs following the designers', judges' or experts' appraisal necessities stated as Functional Requirements with their correspondent Design Ranges, these ranges state what the design must accomplish and they are designer-specified. The alternative which best meet such requirements according to their System Design Range is selected as the best for the particular purposes. Nevertheless, human factors and ergonomics requirements have been neglected in the evaluation of AMT; in this way, the Ergonomic Compatibility Evaluation using a Fuzzy Multi-Attribute Axiomatic Design approach for AMT is considered innovative. EC is a construct used in this work evoking the concepts of human-system and human-artefact compatibility introduced by Karwowski [6,7,8,9] which offer comprehensive treatment of compatibility in human factors discipline. It intends to measure in a subjective way the probability of a design to satisfy ergonomic requirements using the EIC in a fuzzy environment. For this, the theory of Axiomatic Design extended by [10,11] and adopted by [7,9,12] was also evolved. For this approach a Hierarchical Fuzzy Axiomatic Design Survey for Compatibility Evaluation of AMT was designed based on a pragmatic perspective and a large amount of literature that was reviewed and presented in [13].

3. Methods

In this work, Ergonomic Functional Requirements (EFR) represented as desirable ergonomic attributes of the equipment, and the alternative's ratings of each attribute are evaluated by each expert, also the importance of each attribute is defined using the experts' opinions. Axiomatic Design theory requires that Design Ranges, Appropriate aggregation procedures for the importance or weight establishment and the determination of the System Design Ranges which are given to each attribute. Equations for the Weighted Ergonomic Incompatibility Content and Membership Functions are also needed.