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Evaluation of the effect of product demand uncertainty on manufacturing system selection

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Abstract

The use of advanced manufacturing systems is widespread; however, manufacturers frequently face difficult decisions when it comes to selecting the most appropriate system. Uncertainty regarding product demand makes this process more difficult, as many factors are influencing simultaneously. This paper focuses on analyzing the demand uncertainty on the performance of modular drilling manufacturing systems versus other alternatives and evaluating the uncertainty's impacts on the final decision. To do so, a model is suggested and the effect of demand uncertainty on the output is investigated. Three automotive components of varying complexity are used to examine the approach for making reliable decisions.

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Keywords: Manufacturing system selection; Modular manufacturing system; Decision-making; Uncertainty; Product demand

1. Introduction

Manufacturing industries have to adapt quickly to current production challenges such as new production requirements and rapid market changes [2]. To cope with these requirements and stay competitive, new manufacturing systems with advanced technology that effectively responds to market changes are required. Modular

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manufacturing systems are a relatively new technology designed based on current and future market requirements which are leading economic production solutions for drilling-related operations [3]. These systems do not have a rigid bulky structure and consist of several components such as machining and sliding units, support columns, rotary or sliding indexing table, and other accessories (Fig 1). Their modular character allows these machines to manufacture similar products by rearranging their components. Proper utilization of such machines can significantly increase the productivity and profitability of industries. However, an appropriate analysis is required to justify modular manufacturing system utilization versus other available alternatives.

In a competitive environment, one of the key decisions a manufacturing industry has to make is selecting the most appropriate manufacturing system from a wide range of alternatives. Improper selection of a manufacturing system has an effect on productivity and a manufacturer's capabilities and may cause different problems, such as decreasing the profitability and productivity of the facility [4]. Indeed, selecting a new manufacturing system is a difficult decision- making process which requires advanced engineering knowledge and expertise [5]. To make a proper decision, many factors and a large amount of information need to be evaluated [6]. Besides, today manufacturers face uncertainty of product demand which does not have forecast patterns [7, 8]. Accordingly, the process of selection a new manufacturing system becomes more difficult as demand variation influences many factors simultaneously. Samvedi, et al. [6] found that the selection of the appropriate manufacturing system is an important initial investment decision for industries which influences the profitability of the facility. Accordingly, a reliable decision should be made before make an investment in the production method.

Cost analysis is a fundamental criteria in manufacturing decisions [4]. Several research publications have applied cost analysis in various engineering disciplines such as manufacturing system selection [4, 9, 10], the automotive industry [11], and the molds and dies industries [12] . Hazir, et al. [13] believe that the number of researchers who use cost analysis in the manufacturing field is increasing. Cost analysis provides important information about a manufacturing system selection process. However, one of the challenges for companies which use cost analyses is product demand uncertainty which may influence the manufacturing system performance and consequently the final decision on utilizing a manufacturing system at the preliminary stages. Moreover, the evaluation of investment decisions becomes more complicated when the estimation of input parameters are made in the presence of uncertainty [14]. Accordingly, in order to make a robust decision, an additional analysis is required to investigate product demand uncertainty and its effects on the cost model output.

For studies concerning the evaluation of future or unpredicted situations, uncertainty analysis (UA) is utilized to determine the range of possible outputs which are the result of imprecise input parameters [15]. Essentially, sensitivity analysis (SA) defined as an extension of an uncertainty analysis which is applied to analyze the contribution of estimated uncertainty ranges in the output resultsof a model [15, 16].

Fig. 1. Modular drilling manufacturing system

Such analyses provide a better understanding of the relationships between input and output variables in a model. In addition, UA and SA may provide additional information and robust measures for the decision-making process in the presence of uncertainty [17]. Over the last few years, increasing attention has been paid to the application of these analyses in different engineering decision-making processes, such as the selection of the configuration of MRRC for low-temperature refrigeration systems in petrochemical industries [18], the optimal design of the biofuels [14], and slicing system selection [19]. A literature review reveals that several papers applied UA and SA in order to make accurate decision; however, adequate studies have not yet been published on manufacturing system selection under conditions of product demand uncertainty.

This paper focuses on selecting the most appropriate manufacturing system for a given product by considering product demand uncertainties. The main aim of this paper is to perform uncertainty and sensitivity analyses to observe the effect of product demand uncertainty on the final decision. To achieve this, a model is suggested which is helpful in manufacturing system evaluation when selecting the most productive system. In this model, the demand is assumed to be independent and uncertain. Accordingly, the contribution of demand uncertainty in manufacturing system performance is investigated. Three automotive parts of varying complexity are used to examine the proposed approach and the results are discussed. The results show that considering demand uncertainty in the manufacturing system selection problem provides critical information and leads users to make logical decisions.

Nomenclature

C_1	Salvage value at the end of manufacturing system's useful life
$F(x)_{sale}$	Total sale during life cycle production
$F(x)_{system}$	Capital investment
$F(x)_{material}$	Total material cost during life cycle production
$F(x)_{machining}$	Total machining cost during life cycle production
$F(x)_{maintenance}$	Total maintenance cost during life cycle production
$F(x)_{overhead}$	Total overhead cost during life cycle production
x	Demand uncertainty
$x_1, x_1, \dots, x_n$	Uncertainties

2. Manufacturing system selection framework

At the initial stage of a manufacturing system selection problem, reliable information is not always available and estimations are made in the presence of uncertainties. This is one of the key issues which have led this research to investigate the effect of uncertainties on the final decision. Fig.2 clearly represents the required steps of this method, as described below:

(1) Developing a cost simulated model: for manufacturing system selection, a cost model which is proposed by Vafadar, et al. [3] is utilized to develop a model for investigating the effect of uncertainties. This mathematical cost model is developed based on product properties, manufacturing system characteristics, and production requirements to estimate the unit profit of life cycle production.
(2) Allocating distributions to uncertain input parameters: uncertainty may arise from input data with different types and ranges of distributions.
(3) Performing uncertainty analysis: different combinations of input parameters may be considered in the analysis to evaluate the effect of each individual uncertainty on the output. This analysis indicates how uncertainties influence the performance of a system.
(4) Performing sensitivity analysis and identifying sensitive parameters: this analysis enables decision makers to identify the parameters with significant effects that deserve high attention. This analysis also helps to identify less sensitive parameters that can be considered as constant.

(5) Evaluating the results and making final decision: the results can be investigated and discussed for different alternatives to the facilitate selection process.

2.1. Model for investigating product demand uncertainty

The developed model includes capital investment, sale, and cost components including the costs of material, machining, maintenance, and overheads, which are the functions of uncertain variables. The performance of each manufacturing system is measured by the net present value of unit profit as an economic indicator. To perform SA, the one-at-a-time technique is assigned to the cost model as below [20]. Interested readers may refer to the author's works which illustrated the drilling modular system [21] and the relevant equations in details [8, 22].

$$\frac{\partial}{\partial x}(F(x)_{sale} - F(x)_{system} - F(x)_{material} - F(x)_{machining} - F(x)_{maintenance} - F(x)_{overhead} + C_1) \quad (1)$$

Different distributions in terms of type and range can be considered in this model. De Moel, et al. [15] recommended that in the cases where information about distribution properties is little to no uniform distribution, uniform distribution may be considered for the analysis. Since sufficient data and literature is not available on future market requirements and manufacturing selection at the initial stages of utilizing a modular system, a uniform distribution is used in this study. Due to the unpredictability of market demands, the range of product demand is estimated by engineering knowledge and experts.

In the above equation, product demand - an uncertain input variable which effectively influences the output - is varied at a time within the estimated range while other variables are fixed to monitor the behavior of modular systems and other alternatives simultaneously. The results of uncertainty analysis show that product demand uncertainty has considerable influence on the performance of a manufacturing system which may be a key element in the decision-making process. The results of uncertainty analysis for case studies and relevant discussions are presented in Section 3.1.

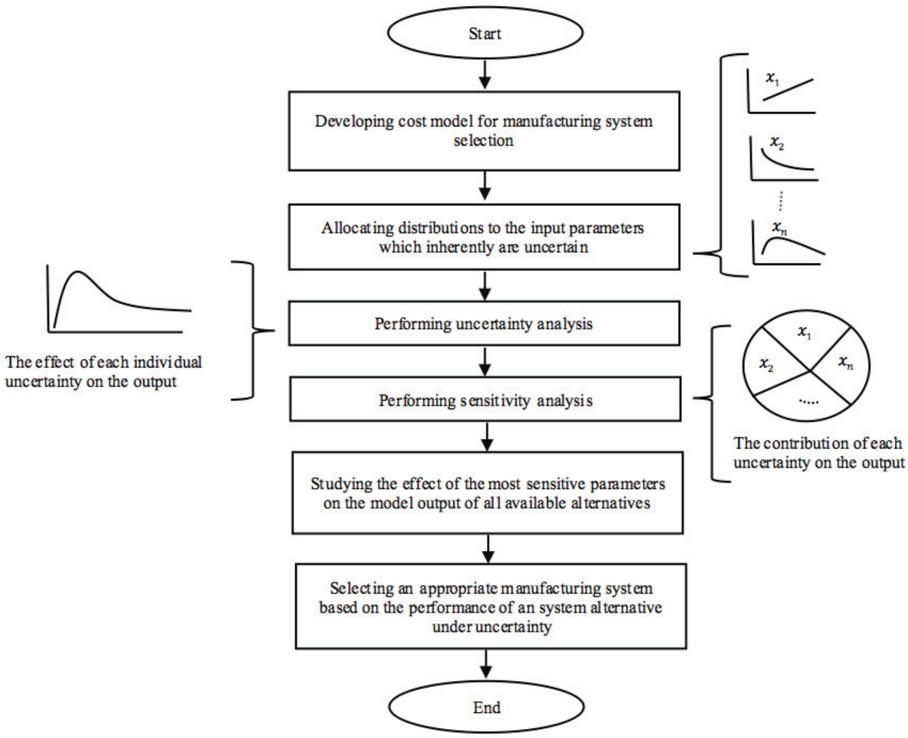

Fig. 2. Schematic representation of manufacturing system selection under uncertainty

The sensitivity index of product demand for each manufacturing system are required to be estimated: this index is achieved by performing a sensitivity analysis. Sensitivity indices can be calculated as below by considering minimum and maximum values of the cost model, $F(x)_{min}$ and $F(x)_{max}$ respectively, which are achieved by changing the variable over its range [23].

$$\text{Sensitivity index} = (F(x)_{\max} - F(x)_{\min}) / F(x)_{\max} \qquad (2)$$

(2

3. Case studies

In this section the developed model is examined to investigate the contribution of product demand uncertainty on manufacturing system selection. To achieve this, three automotive products with different complexity are analyzed (Fig.3).These parts include holes which are categorized into different groups. Each group may consist of one or several similar holes which can be drilled by using one or more multiple heads. Table 1 represents the number of holes, part properties, modular system configuration and different manufacturing system types which are used to produce these parts. Table 2 shows the sensitivity index of the available manufacturing systems which are estimated by using Eq. (2). From the table it can be seen that product demand uncertainty has considerable influence on the output of the utilized manufacturing systems. Accordingly, Section 3.1 below analyses and discusses the behavior of each manufacturing system in order to select an appropriate system.

3.1. Results and discussion

Fig.4 shows the effect of product demand uncertainty on the performance of each manufacturing system for the production of a power steering pump body, brake disc, and throttle body, respectively. It can be seen that each manufacturing system has a saw-tooth behavior versus product demand changes. Each decline of the saw-tooth function indicates that an additional machine set up is required. The saw-tooth function frequency may provide additional insights for selecting a manufacturing system.

Figs.4a, 4b, and 4c show the effect of product demand changes on the production of a power steering pump body. These figures indicate that the saw-tooth frequency of the drill press is more than CNC and modular machine, respectively.

Since the machining operations of the modular system is parallel and automatic, machining time is low; whereas the drill press is sequential and non-automatic and consequently has more machining time comparing to the CNC, which is sequential and automatic. As the number of required manufacturing systems is a function of machining time, the number of drill presses required, and consequently its frequency are more than CNC and modular system, respectively.

It can also be seen that the maximum achieved unit profit is provided by the modular system which is more profitable than the CNC and the drill press, respectively. Since unit profit is a function of machining time, modular systems provide the highest profits, and drill press systems the lowest. When the requested product demand is high, the modular system can provide a high unit profit and may be an appropriate choice. For lower demands, the CNC and the drill press may be better choices as modular machine does not make high profit. Figs.4a and 4b show that at less than 10,000 units, the CNC provides a higher unit profit than modular system as the number of CNCs is not high and the capital investment is lower than it is for modular systems.

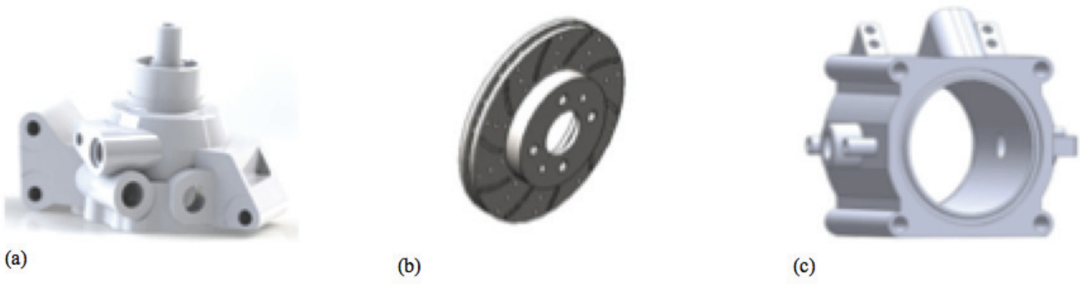

Fig. 3. Automotive parts: (a) power steering pump body, (b) brake disc, and (c) throttle body, downloaded from [24-26]

Table 1. Part properties and selected manufacturing systems

Part name	Material	Number of holes	Hole diameter (Length of cut) (*mm*)	Selected manufacturing system
Power steering pump body	Aluminum alloy	17	7 (27) - 5.6 (52.2) - 11 (20) 14.5 (20) - 16.5 (2.5) - 15 (13.5) 5.6 (52.5) - 11 (6.5) - 7 (13.5) 7 (4) - 7 (13.5) - 5 (15.5) - 7 (5.36)	Modular manufacturing system with ten stations and rotary table CNC Drill press
Brake disc	1023 carbon steel	36	5 (22) - 8.8 (7) - 12.7 (7) 14.7 (1)	Modular manufacturing system with single station and rotary table CNC Drill press
Throttle body	aluminum alloy 5083	14	5.1 (66) - 3.5 (8) - 8 (76) 2 (9.5) - 3.5 (10) - 4.2 (6) 8.2 (25)	Modular manufacturing system with six stations and sliding table CNC Drill press

Table 2. Sensitivity index of product demand

Product name	Uncertainty range (*units/per*)	Sensitivity index		
		Modular system	CNC	Drill press
Power steering pump body	1 – 500,000	4,200	4,120	921
Brake disc	1 – 500,000	1,570	2,409	507
Throttle body	1 – 500,000	2,498	4,634	834

Figs. 4a1, 4b1, and 4c1 show the effect of product demand changes on the production of a disc brake. These figures demonstrate that the modular system and the CNC have relatively similar behavior, whereas product demand uncertainty has different influences on a drill press's behavior. The designed modular system has a single rotary layout with setups which are sequential. Machining operations are also performed sequentially by CNC.

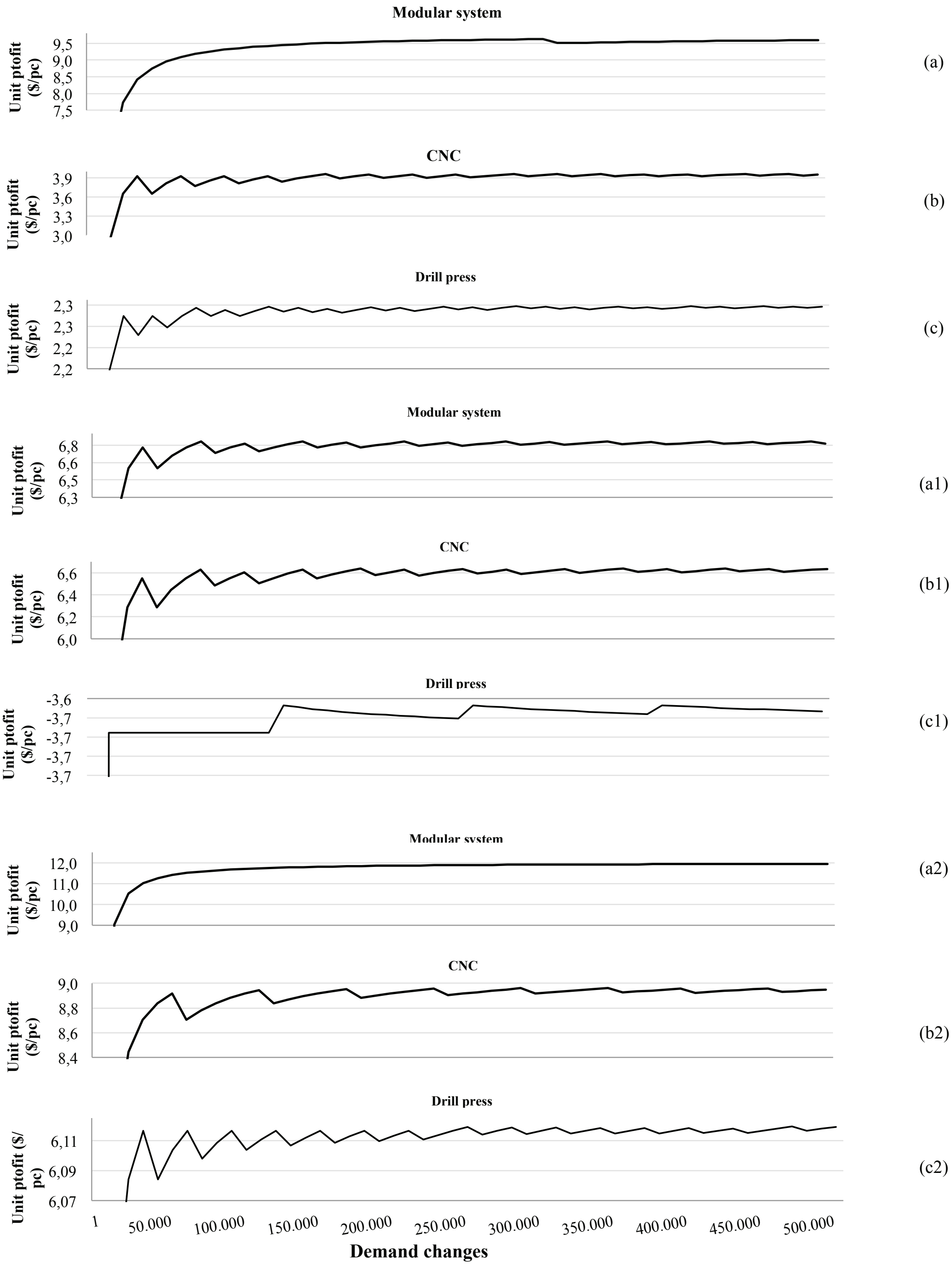

Fig. 4. The effect of product demand uncertainty on manufacturing system behavior; (a), (b), and (c) production of power steering pump body, (a1), (b1), and (c1) production of disc brake, and (a2), (b2), and (c2) production of throttle body.

Accordingly, the machining time of the modular system and the CNC are almost the same and consequently the machining, maintenance, and overhead costs for different demands are the same. Since the capital investment of the designed modular system is less than the CNC, the modular system provides greater profit than the CNC and may be an appropriate choice to produce this part. It can be seen that the drill press does not make any profit for different demands. As the machining time of the drill press is high, by increasing demand, the number of required systems increases rapidly: accordingly, capital investment and machining, maintenance, and overhead costs increase noticeably whereas sales and salvage values increase slightly. Thus, drill press is not recommended for production of this part. Figs. 4a2, 4b2, and 4c2 show the effect of product demand changes on the production of a throttle body. The curves indicate that the saw-tooth frequency of the drill press is higher than the CNC and the modular machine. It can also be seen that for larger demands the modular system provides greater saving and profit. In this case, the machining time of the modular system is less than the CNC and the drill press. Since machining, maintenance, and overhead costs are a function of machining time, the costs of the modular system is less than the CNC and the drill press, respectively, and accordingly this system makes a greater unit profit than the other two choices.

From the above it can be concluded that generally, a drill press may be an appropriate selection when product demand is low since it can provide a greater unit profit than the other manufacturing systems. Because of machining time, modular systems are usually the least and drill press systems the most sensitive to product demand uncertainty especially for higher demands, whereas CNC lies somewhere between the other two alternatives. Accordingly, in the cases CNC can provide a greater unit profit than other alternatives, this system may be a suitable selection for production of a given part. It is noteworthy that where manufacturing industry has limited factory space, decision makers generally should also take into consideration the number of required manufacturing systems, which may influence the final decision.

4. Conclusion

This paper focused on the influence of product demand uncertainty on the performance of the modular manufacturing system versus other alternatives. To this end, a model was developed and the production of three automotive parts was examined using the model. The results indicate that performing uncertainty and sensitivity analyses on a defined range of product demand may provide more comprehensive understanding of the relationship between product demand and a system's performance and may help decision makers to make more informed decisions at the investment stage.

The proposed model can form the basis for future work to investigate the other uncertain parameters which may significantly influence the final decision. Moreover, this study can be improved by investigating the variables which may influence the performance of a manufacturing system which is subject to product demand uncertainty. These variables may change the interactions between product demand and output. Furthermore, different distributions can be identified and allocated to the product demand uncertainty for future work.

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