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Research on manufacturability optimization of discrete products with 3D printing involved and lot-size considered

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ABSTRACT

Most of the present researches in production management under the influence of three-dimensional (3D) printing technique are qualitative. The manufacturability optimization of production combining 3D printing and traditional manufacture is discussed from a point of quantitative view in this paper. A mathematical model of manufacturability optimization considering lot-size is proposed and a differential evolution (DE) algorithm is introduced to optimize the model. Numerical tests on the model and the algorithm reveal the quantitative changes with bringing in 3D printing. The model can be applied to optimize the manufacturability considering lot-size that combines 3D printing and traditional manufacture. The research is expected to offer a reference to promote the practical application in the way of 3D printing industrialization.

1. Introduction

In recent years, 3D printing as a promising and fast developing technology has become more sophisticated and entered an era of laser printing, while materials employed are expanded such as ceramic and metals to replace resin, which leads to the possibility of manufacturing any component directly. Applications of 3D printing cover a vast variety of industries like automotive, consumer goods, medical devices, aerospace, defense, etc. Considering the broad prospect, 3D printing has been mentioned in "Made in China 2025" and "German Industry 4.0" as a key technology in the new industrial revolution [1,2]. Although in principle, either traditional methods or 3D printing can manufacture any component, they have their own advantages in practical production [3]. Traditional ways can attain scale economics effect and 3D printing is good at those individualized and complicated products [4]. Therefore, it is imperative to combine 3D printing with traditional methods in a long period to decrease total cost and production cycle and it is important to study on optimizing manufacture process under the combination of the two methods [5–9].

At present, *researches* on 3D printing mainly focus on technical fields as manufacturing craftwork, processing materials and quality control, as well as aspects of the application review and development prospects. Among them, scholars as Atzeni E. [10,11], Dolphin J. [12], Cesaretti G. [13] et al· *study* on 3D printing technical elements and development tendency. Their researches evidence that currently 3D printing can be affordable, economically convenient and competitive to traditional methods for small to medium batch production of metal parts, and give some advice on what organizations and enterprises need to know and do about it. Scholars in China as Yongnian Yan [14], Bingheng Lu [15], Huaming Wang [16] et al. *launch* researches on its technical principles and industrialized applications. They have made several breakthroughs in manufacturing advanced, complicated, integral and reliable components which expanding the application ranges of 3D printing. When referring to the influence of 3D printing on production management, Tuck C. *indicates* that the use of 3D printing will have particular impact on supply chain management paradigms (such as lean and agile), and has particular strategic fit with mass customization [17]. Holmström J. describes and evaluates the potential approaches to introduce rapid manufacturing (RM) in the spare parts supply chain [18]. Nyman H. J. explores the opportunities and barriers of 3D printing technology in a supply chain context and proposes a set of principles that can act to bridge existing researches on different supply chain strategies and 3D printing [19]. Other Scholars have many papers on the changes of concept, form and management strategy of supply chain after importing 3D printing technologies [20–23]. However, while most of them are literature review or qualitative researches, few of them referred to the principles of the optimized decision under the combination of 3D printing and traditional manufacturing ways, which is the key point of the present paper.

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2. Optimization

2.1. Problem description

Process planning decides the way of manufacturing products, which is essential during preparation and act as the basis of all production processes. The craftwork optimization on account of cost factors is drawing attention in modern manufacture management [24]. Yet, the whole problem offers a total different essential change after introducing 3D printing. For discrete manufacturing in traditional ways, the manufacturing methods of components which stayed at the end nodes of the product structure tree are needed to be planned, and then step-assemble the components to final product. In this way, the only thing changed after introducing any new technology is the manufacturing method of a certain component. Therefore, in traditional manufacturing methods, optimization on product cost and manufacture cycle during producing largely *rely* on process planning [25]. What is significantly different for 3D printing from traditional methods is that, any components on any nodes or layers in the structure tree could be produced directly. Consequently, the production and assembling process of components below the improved layer are simplified. It means that the product structure is changed simultaneously when choosing 3D printing. The product is re-designed in this way, rather than merely considering process planning. Hence, the craftwork design of the whole manufacture system should be redefined and reconsidered after importing 3D printing.

Manufacturability is about the optimization of given manufacturing resources that meets the requirement of customers, concerning cost, time, fabrication property, assembly property and other factors. The manufacturability assessment plays a key role in CE (Concurrent Engineering) project [26]. Since 3D printing is brought into the manufacturing system, product design and process planning turn into a process of parallel interaction that significantly illustrates and implements the fabrication-oriented concept in CE project. The manufacturability is therefore employed to research the craft optimization considering the costs under the influence of 3D printing.

Considering the direct expense of products is highly relevant to lot-size using traditional methods. We take the lot-size as a factor to discuss the problem of discrete products manufacturability optimization using 3D printing. Graph theory and matrix are firstly adopted to accurately describe the product structure and its changes during the optimization. Then, the relations between costs and lot-size are analyzed in different manufactory parts. In this way, different optimization models could be established based on the cost and lot-size functions, which could be solved by differential evolution (DE) algorithm and applied by lot-size data in different order of magnitudes. Therefore, when carrying out manufacturability optimization in both 3D printing and traditional methods, the change of proportion in discrete production manufacture with different lot-size can be discussed. The irrelevance between unit cost and lot-size in 3D printing is therefore verified in a quantitative way. Other than that, the better regime choosing from 3D printing and traditional methods is provided for one product under different lot-size.

Meanwhile, this paper bases on three assumptions in order to simplify the question and give prominence to the theme. (1) The component manufactured by traditional methods could be substituted by 3D printing in the prospect of technical characteristic. (2) The 3D printing and traditional methods are generally discussed ignoring specific manufacturing craftwork; (3) Production cost is the only factor researched when discussing the manufacturability optimization using two different methods.

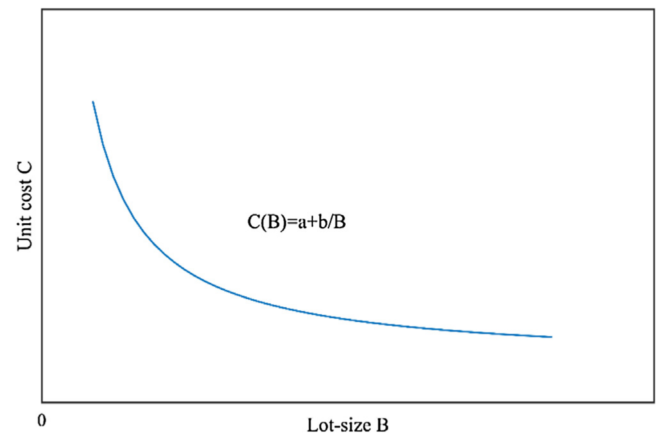

Fig. 1. Function diagram of lot-size and unit cost in furniture industry.

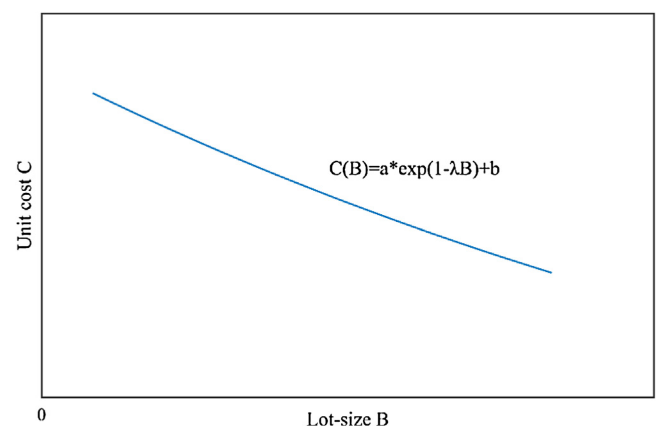

Fig. 2. Function diagram of lot-size and unit cost in shipbuilding industry.

2.2. Relation between lot-size and cost

In traditional methods, production unit cost decreases when lot-size increases referring to scale economy. For instance, in small size consumer manufacturing industry as furniture, take C as production unit cost and B as the lot-size, then function between the two is shown as:

$$C(B) = a + \frac{b}{B} \tag{1}$$

Among which, a, b are constants and related to production equipment type and complexity of manufacturing.

As shown in Fig. 1, in consumption product industry as furniture, the decrease of production unit cost is closely relevant to the increase of lot-size. The decrease tendency is more obvious primarily and slows down after the lot-size reaches certain amount.

For large size and expensive equipment manufacture industry as ships and airplanes, similarly, define C and B as production cost and lot-size, then the function is shown as:

$$C(B) = ae^{(1-\lambda B)} + b \tag{2}$$

Among which, a, b are constants and related to production equipment type and complexity of manufacturing.

As illustrated in Fig. 2, while still showing an obvious trend of decease of production cost with the increase of lot-size, the speed of decrease is more average and smooth which is greatly different from the quick decline in consumption industry.

From the above, it generally presents an inverse trend between lot-size and unit cost in traditional business while the actual laws vary in different industries.