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Additive manufacturing of biomedical implants: A feasibility assessment via supply-chain cost analysis

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ABSTRACT

The adoption of additive manufacturing (AM) for fabricating biomedical implants at hospitals provides many potential benefits. Relative to biomedical implants fabricated via traditional manufacturing (TM), typically available by suppliers out of the immediate region, biomedical implants fabricated through AM provides an opportunity to receive more patient-specific, customized parts with faster response, a lower inventory level, and reduced delivery costs. Despite the promising features of AM technologies, the make-or-buy decisions are not straightforward and require careful investigation due to the relatively high AM machine and production costs. Most of the existing studies focus on the analysis of process-level costs, which are usually evaluated/calculated based on individual AM processes. No research efforts, to the best of our knowledge, have been dedicated to the quantitative analysis of the costs of supply chains integrated with AM facilities, e.g., inventory cost, transportation cost, product lead time, etc. In this study, we propose a stochastic cost model to quantify the supply-chain level costs associated with the production of biomedical implants using AM techniques, and investigate the economic feasibility of using such technologies to fabricate biomedical implants at the sites of hospitals. The problem is formulated in the form of a stochastic programming model, which determines the number of AM facilities to be established and volume of product flow between manufacturing facilities and hospitals. A customized Sample Average Algorithm (SAA) is developed to obtain the solutions. We apply the cost model to a real-world case study that focuses on the use of biomedical implants for hospitals in the state of Mississippi (MS), and identify the conditions and cost parameters that have significant impact on the economic feasibility of AM. We find that the ratio between the unit production costs of AM and TM (ATR), as well as product lead time and demands, are key cost parameters that determine the economic feasibility of AM.

1. Introduction

Providing personal care tailored to the specific needs of patients is a promising approach for delivering high-quality and economically efficient healthcare in terms of on-demand production and customization. Because the anatomy of every single patient is unique, there is a significant need for customizing products in the biomedical sector for replacing hip/joint implants, dental work, vessel stents, and other biomedical implants. Additive manufacturing (AM) provides the opportunity to fabricate customized biomedical implants from the ground-up using a variety of metallic, plastic or ceramic materials, and on a patient-by-patient basis (i.e. 'on-demand'). With additive manufacturing, one can employ computer tomography to obtain patient anatomy data, from which a CAD model of the implant to-be-manufactured is generated and used to build a patient-specific customized implant. Custom implants can possess truly complex features which are difficult to machine using conventional, subtractive methods. Singare et al. [46] has demonstrated the superior functionality of AM biomedical implants, as well as the aesthetical appeal. Custom implants produced using AM technology have been used for a variety of applications including skull [46,53,9,45], knee joint [14], elbow [51], and hip joint [38].

The adoption of AM technologies for fabricating biomedical implants at the site alongside of operational hospitals, instead of ordering from off-site suppliers of traditionally-manufactured (TM) implants, may lead to faster response, lower inventory level, and

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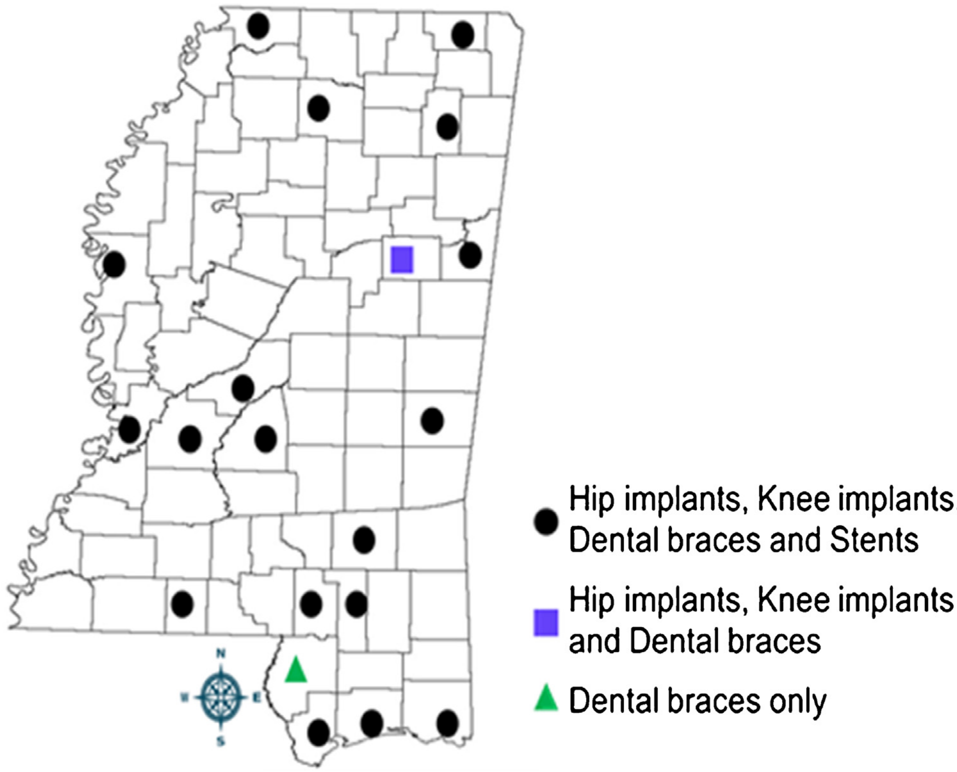

Fig. 1. Locations of major hospitals (by county) in the state of Mississippi.

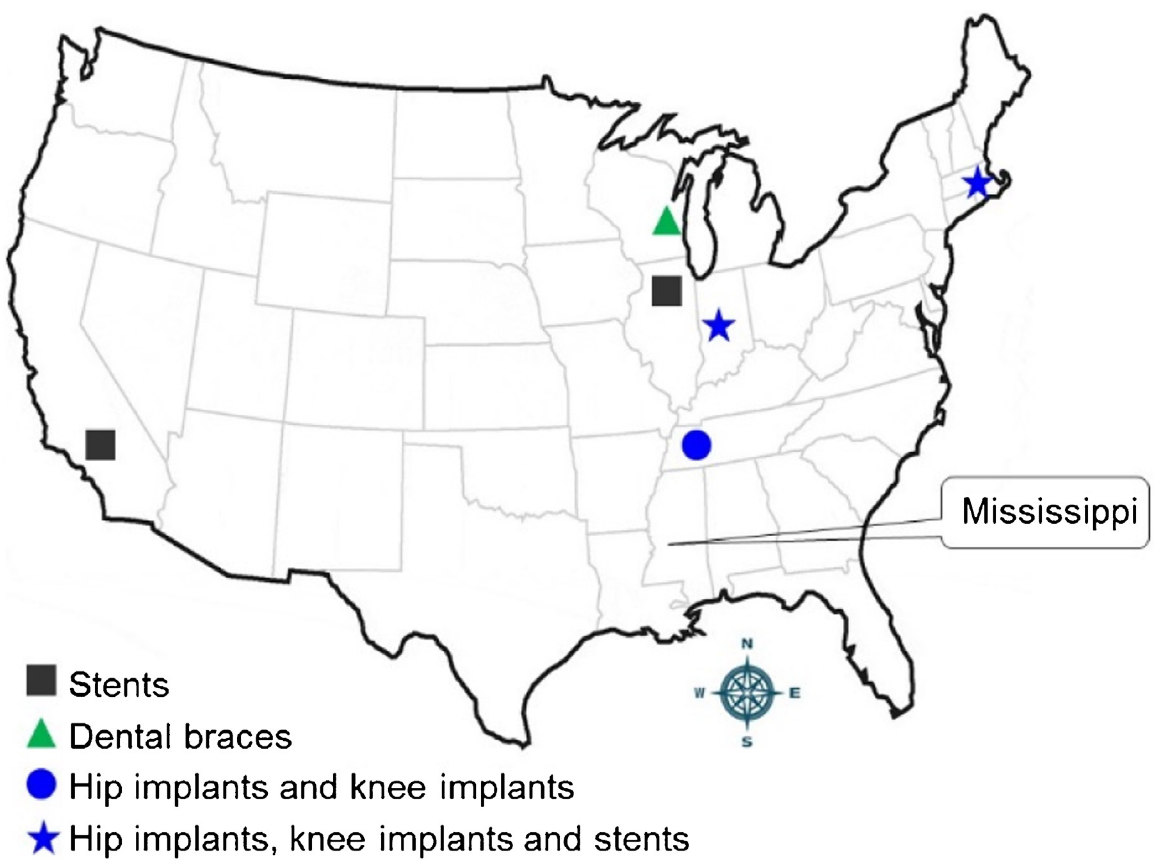

Fig. 2. Current suppliers of biomedical implants in contiguous United States (mainland) via traditional manufacturing.