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Pharmaceutical supply chain models: A synthesis from a systems view of operations research

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ABSTRACT

This research evaluates reconfiguration opportunities in Pharmaceutical Supply Chains (PSC) resulting from technology interventions in manufacturing, and new, more patient-centric delivery models. A critical synthesis of the academic and practice literature is used to identify, conceptualise, analyse and categorise PSC models. From a theoretical perspective, a systems view of operations research is adopted to provide insights on a broader range of OR activities, from conceptual to mathematical modelling and model solving, up to implementation.

The research demonstrates that: 1) current definitions of the PSC are largely production-centric and fail to capture patient consumption, and hence healthcare outcomes; 2) most PSC mathematical models lack adequate conceptualisation of the structure and behaviour of the supply chain, and the boundary conditions that need to be considered for a given problem; 3) models do not adequately specify current unit operations or future production technology options, and are therefore unable to address the critical questions around alternative product or process technologies; 4) economic evaluations are limited to direct costing, rather than systemic approaches such as supply chain costing and total cost of ownership.

While current models of the PSC may help with the optimisation of specific unit operations, their theoretical benefits could be offset by the dynamics of complex upstream (supply) and downstream (distribution and healthcare delivery) systems. To overcome these limitations, this research provides initial directions towards an integrated systems approach to PSC modelling. This perspective involves problem conceptualisation and boundary definition; design, formulation and solution of mathematical models, through to practical implementation of identified solutions. For both academics and practitioners, research findings suggest a systems approach to PSC modelling can provide improved conceptualisation and evaluation of alternative technologies, and supply network configuration options.

1. Introduction

With access to essential medicine being one of the building blocks of healthcare systems [1], policy measures aimed at reducing healthcare spending growth at the international level have targeted primarily the pharmaceutical industry, over the past decade [2]. In the UK, the healthcare system ranks higher for spending than for health outcomes [3], and pharmaceutical products have contributed to the lower end of manufacturing gross value added growth since 2010 [4,5]. At the same time, traditional pharmaceutical manufacturing is being challenged by emerging requirements, such as greater drug product personalisation, more participative healthcare enabled by the adoption of digital information and communication technology [6], and by the advancement of innovative technology interventions such as continuous manufacturing, which promise to achieve smaller footprints and greater responsiveness [7,8].

While these challenges have received greater attention in the mainstream business and engineering literature, it is still open to discussion whether, and to which extent, current approaches to PSC modelling adequately reflect and address such challenges. Research is now paying greater attention to the interdependences between Pharmaceutical Supply Chains (PSC) and the broader healthcare bundle [9]. Coordination between actors, and inventory management are still perceived to be the primary challenges in strengthening global health pharmaceutical delivery, however, the deployment of sophisticated inventory models is deemed insufficient per se to improve the current situation [10]. Novel approaches must be deployed to achieve greater “end-to-end” integration along the PSC through technology advances in medicines manufacturing and more patient-centric delivery models [7].

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The research presented in this paper aims to *inform* the debate on how to evaluate the multifaceted aspects of PSC reconfiguration opportunities enabled by technology interventions in medicine manufacturing, as well as more patient-centric delivery models. To do so it provides a critical synthesis of the state-of-the-art approaches commonly employed in the academic literature and industry practice to identify the relevant aspects of a PSC; to conceptualise those aspects through visualisation; and to quantitatively evaluate them. The following research questions are therefore addressed:

(1) "What is meant by PSC for modelling purposes?" (definition);
(2) "How is a PSC conceptualised through visualisation?" (conceptual models);
(3) "Which aspects of a PSC are expressed quantitatively, and how"? (mathematical models).

Gaps are identified by comparing and contrasting the characteristics of a PSC, which are currently modelled, with those that should be considered in a context where reconfigurations opportunities are being targeted, such as in [8].

The scope of this paper does not aim to include any type of models outlined to investigate a PSC. Models may be used, among other things, to rank multiple decision-making criteria, or establish statistical relationships between constructs as, for example, in surveys [11]. In line with the theoretical viewpoint taken by Carter et al. [12] it is, therefore, useful to distinguish between models for the advancement of theory building in supply chain *management* and models that contribute to the advancement of theory building in what is purportedly managed—the supply chain itself. The latter is the focus of this paper.

The paper is structured as follows. Section 2 sets out the terminology, materials, and methods. In Section 3 synthesising arguments are derived from the analysis of the literature to characterise archetypal PSC models. Theoretical and practical implications of each archetype are discussed in Section 4. Section 5 provides concluding remarks, and directions for future research.

2. Materials and methods

The rationale of a synthesis process is to achieve of a coherent conceptual structure of a topic, using the extant literature as the object of scrutiny [13,14]. The terminology, theoretical lenses, methods and materials relevant to this research are specified in the following sub-sections.

2.1. Basic terminology

As the focus of this research is modelling, it is necessary to define what is meant by a 'model' in this context.

In such fields as Operations Research (OR) how the analyst constructs a mental image of a problematic situation is often neglected. The analyst develops such an image by an *act of appreciation* from unorganised perceptions acquired through observation, and proceeds from such an image to formally represent the situation in symbolic terms [15]. Making reference to industrial systems Forrester [16] points out that models represent only what the analyst *believes* to be the nature of the system being studied, and each model is eventually shaped by a specific class of questions about such systems.

Conversely, a significantly high proportion of Supply Chain and Operations Management (SC&OM) research promotes a view of the researcher as tasked with discovering cause-and-effect relationships within an objective reality from which they postulate to detach themselves [17]. A common narrative in SC&OM is that an operations model is a miniature representation of a supply chain [18],

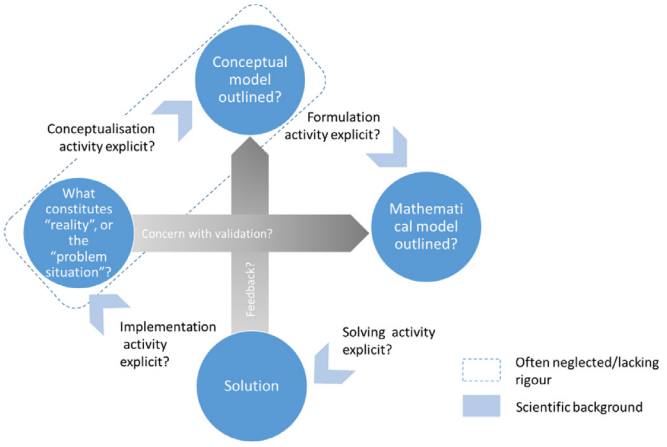

Fig. 1. Evaluation grid based on [15].

and the extent to which a model differs from the 'real thing', is a matter of comprehensiveness [19]. Insofar as sufficient quantitative data is available to populate a mathematical model, the problem situation is assumed to be well defined, and modelling a supply chain becomes a matter of implementing specific analytical tools [20–22]). This assumption is implicitly made in most models of healthcare systems [23], and pharmaceutical manufacturing [24].

Based on Wilson's [25] work on the analysis of organisation units a model is defined here as an intellectual construct explicitly describing a *way of thinking* about the real world. A model so defined acknowledges the perspective taken by an analyst who is making sense of a situation to reach a value judgment about it.

2.2. Theoretical lens

This paper adopts the systems view of OR, outlined by Sagasti and Mitroff [15], as the theoretical lens, hereafter referred to as the Sagasti–Mitroff research model. Although without explicit reference to supply chain modelling, the Sagasti–Mitroff research model captures generic aspects of the modelling activity, and it has previously informed methodological discussions in the SC&OM domain [19].

The fundamental dimensions to evaluate numerical and non-numerical aspects of PSC models proposed in the extant literature were derived from the Sagasti–Mitroff research model as shown in Fig. 1.

Unlike the original Sagasti–Mitroff research model, Fig. 1 does not identify a conceptual model with the analyst's own mental image of the problem situation. Rather, a conceptual model is understood here to be a description involving some degree of formalisation, for example in the form of supply network maps [26]; rich pictures [25]; and process diagrams [27].

2.3. Synthesis approach

Typically, the literature provides non-numeric evidence as it consists of words and symbolic data (e.g., text and equations). In the field of SC&OM the approach to content analysis, outlined by Seuring and Gold [28], is amongst the most explicit in terms of data gathering and data analysis, and has been used in works that explicitly take a supply chain modelling outlook (for example, [29,30]). Other works with a similar outlook tend to be less specific regarding the adopted approach for example [31,32]).

Methods for evidence-based research synthesis originally developed in healthcare research include, for example, Critical Interpre-