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Analyses of Outcomes That Used Simulation Modelling Towards Building Theory

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Abstract

This study is an extension of an earlier study that examined by using a systematic literature review if the application of simulation modelling in operations management did consider more than just positivist approaches. Based on the earlier results, this paper aims to further analyse the outcomes of the use of simulation modelling guided by a framework. The analyses based on the framework involved reviewing outcomes of methods and tools that apply the simulation modelling with regard to types of building theory approaches, objectives and data used. Within the framework, building theory is examined by the simulation models through theories that use simulation models to test and verify, paradigm shifts to validate, design rules and principles to test and experiment, and to triangulate rules and principles to analyse their effectiveness and usability with regard to design of operations.

Keywords: Simulation Modelling; Post-positivism; Theory Building;

1. Introduction

As Ackoff [1] emphasised, Operations Research (OR) needs system thinking to encapsulate the answers for dynamically changing problems, and designing and invention are the main qualities of system age. Following this

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thought, managing open purposeful systems through active controlling and improvement, and by deploying proper design approaches and methods rather than passive adaptation to prediction are required [1]. Based on this stance, simulation modelling, referred to as one of most popular and ubiquitous technique used in OR and Operations Management (OM) disciplines [2][3], lacks proper evaluation and discussion in both OR and OM literature with regard to the use of results; this is particularly the case for theory building processes [4], since theory building aids the advancement of the simulation field and the effective application of simulation modelling to real problems [5]. Note that constructivist simulations with post-positivist perspectives could be an alternative of Mode 2 research [6]. Positivist, rational and deterministic perspectives are discussed in the OR/OM literature [1][7][8] and uneven development of theory building in OM across research methodologies is reported [5].

Accordingly, the aim of this study is, first, highlighting the characteristics of simulation modelling by comparing the conventional theory-driven research to design-oriented research together with research philosophies, and then, second, to examine the relationships between different theory building and testing stages in OM by considering simulation methodology. Thus, this study proposes a theory building framework, and extends the analyses of the former systematic literature review study by Kabak et al. [9] towards the better use of simulation modelling under the post-positivist perspective. It is noted that rather than discussing the philosophical aspects of simulation modelling, research philosophies are bridging simulation modelling with post-positivist perspectives. Analysis of the proposed framework would increase the relevance of simulation modelling.

The paper is organised as follows. In Section 2, the terminology used within the text is defined. This is followed by a review of research paradigms and philosophical assumptions of simulation in Section 3. After, theory building is briefly described, the theoretical value of simulation modelling is discussed and a proposed framework is introduced in Section 4. The analyses of papers based on the former study by using the framework are presented in Section 5. Finally, the paper ends with concluding remarks in Section 6.

2. Terminology

Since the terminology such as ‘method’, ‘technique’, ‘methodology’ and ‘paradigm’ are frequently used in this text, and also need of consistent research paradigm vocabulary is highlighted by DeLuca et al. [10] in Information Systems (IS) research, and further to preclude the misposition the research in this study, the terminology is briefly explained similar to the definitions given in the studies by Mingers [11] and Mingers [12] in IS. Accordingly, ‘research method’ or ‘technique’ is considered as a particular activity that encompasses a well-defined purpose [12]. In this context, ‘methodology’ is used as in its most general form of encapsulating a set of activities to obtain credible research outcomes, and it may involve more than one method [11]. In this study only simulation modelling methodology is considered. Further, a ‘paradigm’ is assumed as a particular set of philosophical constructs that consist of ontology, epistemology, methodology, axiology and ethics [11].

3. Research Paradigms

Discussion on rigor and relevance in OM literature has a crucial place on the classification of research paradigms. This discussion is attributed to the search for a broader perspective on systems development as an alternative to positivist research [13]. Mingers [11] points out that two main paradigms are mentioned in most of IS research. These paradigms are: positivist (empirical-analytic, objectivist, functionalist) and interpretive (subjectivist, constructivist). The same distinction is also given epistemologically by DeLuca et al. [10]. To illustrate, Hevner et al [13] highlight this distinction as design-science and behavioural science and consider them as complementary to each other. Similarly, Holmström et al. [14] argue that problem-solving research and theory-oriented academic research can be two sides of the same coin, whereas they use design science (DS) for connecting practice and theory in the OM field. The main philosophical distinction of DS is ontological, because the artificial phenomenon (i.e. artefacts) to be examined are generated first [11]. Therefore, it has a pragmatic research interest rather than a theoretical-cognitive [1][12][7][14], and it tackles solving problems rather than explaining or predicting theoretical grounds [14]. However, the main paradigm of DS is attributed as pragmatism [1][15][7]. However, OR has the scientific determinism with positivist, rationalist and deterministic nature [7]. On the other hand, logical empiricism is considered as the dominant paradigm in OM research in which theoretical hypotheses are developed and tested by empirical research [14].

With regard to simulation modelling, Meredith et al. [16] consider that simulation has an 'artificial reconstruction of object reality' perspective in natural and artificial dimension, and a 'logical positivist/empiricist' perspective in rational and existential dimension in the generic framework for classification of paradigms. In the former perspective, it uses highly abstracted and simplified models to achieve a high degree of reliability and internal validity, and is highly controlled, whereas in the latter one, it has moderate levels of deduction, formal structure, objectivity and methodological prescription [16]. Likewise, Bertrand and Fransoo [17] place simulation as axiomatic quantitative research in OM.

Winsberg [18] highlights that simulation modelling has its particular individual epistemology. Mingers [12] presents the philosophical assumptions of visual discrete event simulation (DES) in a framework according to his root definition of generalised management science methodology. Consequently, according to the results of an earlier study by Kabak et al. [9], the philosophical nature of simulation modelling can mainly be considered as a classical positivist perspective in which a researcher obtains knowledge by observing the real system, independent with respect to the real system, and in general, a study is not conducted in it natural environment . Also, it employs mostly quantitative rather than qualitative methods [9]. Additionally, only few studies are found to have a post-positivist perspective, with involvement and influence of a researcher in this study. Further, a post-positivist perspective could have falsifiable hypotheses and qualitative methods to strengthen the study [19][10]. Thus, this study argues that the real benefit from simulation modelling studies lies in the post-positivistic perspective with the aid of a framework presented in Section 4. The next section briefly reviews theory building, discusses the theoretical value of simulation modelling and introduces the framework.

4. Theory Building and Simulation Modelling

4.1. An Overview on Theory Building Process

Theory building is necessary for having a structure for analysis, developing appropriate methods that are crucial for the advancement of a particular field and ensuring applicability to real-world problems through providing adequate explanations [5]. In the first motive, the structure can provide insight on differences of opinion. With regard to the second argument, methods and tools derived from theoretical conceptualisations increase consistency across specific application, while accounting for contingencies. At the same time, these methods also allow to verify the theoretical knowledge base. This should be interpreted as 'building upon current theory' by Wacker [5]. The testing of this body of knowledge could lead to better understanding and also will allow comparisons between competing theories [5]. With regard to the third argument for the necessity to build theory, more justifications for the comparison of alternative approaches and achievable measures arise when applying theoretical conceptualisations to real-world problems [5]. Based on these three arguments, the importance of theory-building is summarised by 'there is nothing as practical as a good theory' [5][20].

Theory is defined as 'consisting of constructs linked together propositions that have an underlying, coherent logic and related assumptions' [4]. Similarly, Wacker [5] distinguishes four components of a theory. These are: '(1) definitions of terms, variables 2) a domain where a theory applies 3) a set of relationships of variables and 4) specific predictions.' For example, definitions of variables answer questions about who and what. And virtues of good theory, for instance, 'generalisability', addresses to which domains the theory is limited (see [5]).

Various theory-building steps are defined in the literature [21] [22]. Nonetheless, these are reported for particular research studies [5]. A more general and process independent of research methods is described by Wacker [5]. In his theory-building process, four steps that follow on each other are defined, similar to the components of theory. These steps are: conceptual definitions, domain limitations, determining relationships and predictions. Also, he discusses these steps in the context of two main research methods: analytical (formal) and empirical. Each of these methods is sub-divided into three categories [5]. Similar to Wacker [5], Meredith [8] compares field research and case studies research with the more traditional, rationalistic research approaches with regard to theory building process of identification, explanation, prediction and understanding. In short, the aim of theory building is to progress from a simple theory to a mid-range theory and then to a more general or grand theory that has high level of abstraction and generalizability [5][4].

4.2. Theory Building and Simulation Modelling

With regard to simulation modelling and theory building processes, Davis et al. [5] position simulation -n-between theory creation and testing methods. Wacker [4] considers it as part of analytical mathematical methods, and less strictly Meredith [8] places it under traditional, rationalistic methods, and simulation is considered as more suitable for verifying and testing existing theories. Similarly, Winsberg [18] states the concern was more on justification of theories in comparison to their application in simulation. The value of simulation is attributed to those studies where the focus is longitudinal, nonlinear, or when hardly any empirical data have been obtained [4]. Another strong point of simulation studies is that they require construct and internal validity [4][16]. Construct validity is explained as 'the accurate specification and measurement of constructs' [4]. Internal validity is considered as 'algorithmic representation in software' [4]. It is similar to the internal consistency virtue that theory explains all relationships sufficiently [5]. Furthermore, Davis et al. [4] state that main benefit of simulation is obtained from the development of simple theories. Particularly, simulation starts with a simple theory that is defined as undeveloped theory having a few constructs with propositions and limited empirical level [4]. In addition, having a tension, such as long-run or short-term implications in research questions, leads to effective simulation, because their nonlinear results could be hard to examine with other research methods [4]. Further, simulation allows systematic experimentation beyond computerised representation by changing constructs that support also justification and development of the theory. However, simulation has some drawbacks with regard to theory building. As a rationalistic approach, these could be trivial data, dependence on sampling procedures, lack of comparability across studies and difficulty in implementation [8]. The value of simulation with regard to the external validity in the literature could be low, too. External validity includes the validation of the model. That is comparison of the simulation results with the empirical data from the real-world system to have an acceptable model that supports 'the generalisability and predictability of theory' [4]. A similar stance is reported by Meredith [8] as predictive validity.

Specific to simulation modelling, a roadmap for theory development is presented by Davis et al [4]. Accordingly, the methodology of simulation modelling starts with defining a problem and a simple theory, choosing a simulation approach and creating representation. This is followed by checking, modifying and confirming the theory. After which, experimentation can be conducted to further develop the theory that is examined [4]. Additionally, Holmström et al. [14] argue different types of theories as outcomes of OM studies across with different phases of research design. These types of theories are explained together with the steps of the proposed theory building process in the following section

4.3. Framework for Building Theory

The proposed framework for theory building is schematically presented in Figure 1; is it derived from Dekkers et al. [23], who looked at the use of theory for decision making on outsourcing. In the case of the application to simulation modelling, it starts with defining a simple theory and specifying the domain of the theory according to research objectives; thus, the purpose of a study can be viewed from two general objectives, teleological and building theory similar to the process of analyses discussed by Meredith [8] and Wacker [5]. In the first way (i.e. fact-finding) [5], the study is assumed to be purposeful, and the function and criteria can be operationally defined, observed and measured in actual settings [1]. In such an instance, transferable, reusable or generalizable design is aimed for [7]. Hence, the step of evaluation can be considered as how to design, how to manage and how to serve different purposes1]. Data gathering works well under this purpose. However, direct observation and understanding could be difficult for complicated operational processes since many criteria might affect these processes. These multi-criteria could be cost, quality, lead time, flexibility or reliability [17]. This is attributed to 'perceptual triangulation' by Meredith [8]. Also, selected criteria could have differing long-run or short term impact (i.e. dynamic tension) based on the context. Later, justification of these criteria is conducted without having theory-based relationships and predictions using the facts collected from the defined context [5]; in such cases, construct validity depends on a detailed literature review. If the external validity together with the integration of facts satisfies the purposes of the study and validates findings from literature, a purposeful model or method (i.e. a new theory) could be obtained [5]. Informal theory that is considered as 'technological rules' can be obtained by the external validity over the context that provides restricted support [7]. They can be developed to a method or model as given in Figure 1.

In the latter case, theory could be developed from either single theory verification (B1) or comparative studies on theories (B2) by deterministic causal types of relationships. With regard to B1, theory-based explanations and predictions are conducted first, before this step verifies the single theory (simple theory) by deductive logic and empirical data. It is noted that this step does not necessarily have a dynamic tension, or it is assumed as timeless [7]. Then, it is justified by theoretical propositions or sensitivity analyses [4]. This step could have a substantive theory or context-dependent theory that has been applied within a confined context through empirical analysis [14]. Also, these studies could be used to develop contingences. However, in some instances, a substantive theory may not be justified when it has falsifiable assumptions with regard to the research objectives.

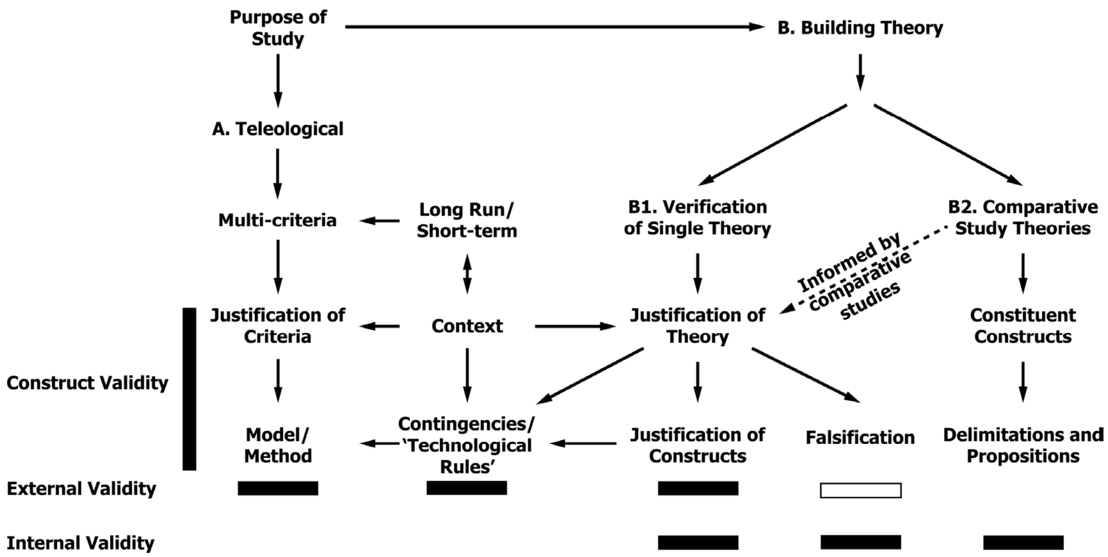

Figure 1: Theory building framework.

Later, substantive theory could be developed by accurate representation of artefacts (i.e. interval validity). For external validity, the level of theory could be positioned as mid-range. Afterwards, it could develop a technological rule with limited application. With regard to B2, simple theory can be developed from comparative studies. This step is referred to as 'triangulation'. That is, theories are examined in comparative studies to validate the data by incorporating the data, methods or observations [11]. This step also may inform the justification of the simple theory as given by dashed lines in the framework. Later, theory can be justified through the confirmation of accurate computerised representation and measurement constructs (i.e. construct validity). Construct validity involves validation of constituent constructs. Similarly to B1, constituent constructs could lead to propositions and delimitations. The step for external validity could be treated as inductive-theory building, and supports the development of formal theory. It is noted that a profound literature review is crucial in this framework and its function is depicted by filled horizontal and vertical bars. It emphasises the requirement of a broad literature review to ensure that theory satisfies the related step. Similarly, the role of research objectives is given by empty bars.

5. Analyses Based on the Framework

The proposed typology for theory building is evaluated based on the in-depth analysis of 49 papers retrieved from the systematic literature review by Kabak et al. [9]. First, the factors to categorise the retrieved papers according to the types of research purposes are specified in Subsection 5.1 and the sample is examined. Then, studies are analysed according to the proposed framework for each type of purpose in Subsection 5.2. Finally, studies are evaluated with regard to their outcomes in Subsection 5.3.

5.1. Categorisation of Studies with Regard to Research Objectives

The first factor on the identification of a study purpose is the definition of the problem. Since a problem should exist in real-world settings and provide a transferable solution (i.e. not one-off) for teleological studies [7]. Therefore, in general, hypothetical problems obtained from the earlier study are not considered. However, two studies are taken as exception since they explicitly mention on the purpose of the design purpose and report implementation in real-world setting. Another factor identified is the involvement of researcher with regard to the system [7]. With these two factors, 'classical post-positivist' and 'participatory post-positivist' studies having a real problem from the earlier study are considered under the first type of purpose. Table 1 shows the results of the categorization of each study on its purpose and problem definition.

Table 1. An example of a table.

		Data Type		
Purpose of study	ED	HD	SED	Total
Teleological	5	1	1	7
RP	5	-	-	5
HP	-	1	1	2
Verification of single theory	15	25	2	42
RP	8	3	-	11
HP	7	22	2	31
Comparative study of theories	-	-	-	-
RP				
HP				

RP: Real Problem, HP: Hypothetical Problem ED: Empirical Data SED: Semi-empirical Data HD: Hypothetical Data

According to Table 1, only seven studies are considered as 'teleological', these studies are assumed to have post-positivist perspective, because the researcher participates, the problem is a real-world problem and they use empirical data with two exceptions only. One of these two exceptions is the continued version of a preceding one, however, another one targets to build a new tool for managerial decision-making from a design perspective. With regard to studies that aim to verify a single theory, more than half of the papers uses a hypothetical problem and data. Nonetheless, none of comparative studies is found in the retrieved papers. In short, traditional positivist studies are dominant with regard to theory building. The next section provides a more detailed analysis on two distinct types of studies.

5.2. Categorisation of Studies with Regard to Use of Simulation Modelling

In this step, the studies under each purpose are evaluated in more detailed according to the framework for building theory =. Accordingly, teleological studies are assessed on the following characteristics: 1) criteria, 2) time tension 3) context 4) simulation purpose 5) construct validity and 6) internal validity; see Table 2. It is observed that most of these studies are based on the use of multiple criteria and only two mention the temporal dimension. However, it is noted that simulation modelling is used more constructively as a design tool rather than a theory-testing tool. Also the framework represents for the construct validity, four of the studies uses literature search and internal validity is based on simulation experiments.

Table 2. Analysis of teleological studies.

Study	Characterization of study	Criteria	Time Tension	Context	Purpose of simulation modelling	Construct Validity
Lejtman et al. [24]	RP, ED	Flexibility, Design cycle time, Time to market for new products, Reduced order time	N/A	Agricultural production	Validation of schedule and layout.	Extensive literature search
Mendes et al. [25]	RP, ED	Flow times, Resource utilizations Throughput	N/A	Assembly Line	Stochastic behaviour of assembly line (complementing heuristic method). Fine-tuning of workload.	Literature search,
Costa and Jardim [26]	RP, ED	Delivering on time, prices quoted, quality	Short-term decision making	Jobbing Industry	Simulation used as tool for planning	Continuing study from a preceding study
Shnits et al. [27]	HP, HD	Flexible schedules	N/A	Flexible Manufacturing Systems (FMS)	Tool for scheduling.	Tested by dynamic scheduling principle, control methodology
Zülch et al. [28]	RP, ED	Labour cost, Lead time, workload	Short-term, mid-term, long-term	Personnel Assignment	Supporting decision-making for allocation of staff. Impact of priority rules.	Modelling abilities, restrictions are shown
Lin and Cochran [29]	RP, ED	Throughput time	N/A	Production Planning System	Optimising flow line behaviour by adequate production planning	N/A
Baldwin et al. [30]	HP, SED	Product quality, cost efficiency, customer relationship and schedule adherence	N/A	Complex Systems Thinking	Visualisation and comparison of perceptions and impact (decision support)	Quantitative questionnaires, simple semi-structured interviews

On the other hand, positivist studies are investigated based on the focal step of theory justification. To do this, first the studies are examined if they have any type of validity assessment (or not). Table 3 classifies the positivist studies according to the validity assessment. Accordingly, only two studies do not have validity out of nine real-world problems. This is attributed to the testing of propositions by using empirical data. However, only 10 out of 31 studies investigating hypothetical problems have a validity assessment and a significant of them does not. It could be posited that the significant number of hypothetical studies either has narrow implication or they have falsifiable assumptions. Furthermore, the validated studies are examined according to the type of validity. It is seen that most real problem studies have external validity, however, only few have it for the hypothetical problem studies. It shows more validity assessment is needed for hypothetical problems.

Table 3. Analysis of positivist studies.

		Internal Validity or External Validity		
Data Type		Va	NVa	Total
RP		9	2	11
	ED	6	2	8
	HD	3	-	3
	SED	-	-	-
HP		10	21	31
	ED	3	4	7
	HD	5	17	22
	SED	2	-	-

Va: Validity NVa: No Validity

Table 4. Analysis of positivist studies.

	Internal Validity or External Validity		
Data Type	Va	Internal Validity	External Validity
RP	9	5	6
HP	10	7	3

Va: Validity NVa: No Validity

5.3. Categorisation of studies with Regard to Transferability

Third, transferability of the results from the studies is evaluated separately in Table 5. Based on these evaluations, there is no study that has warranted complete external validity. Most do not compare the results to extant studies. And, even though some contain implementations in the real world, they actually provide very little evidence to substantiate their findings.

Table 5. Analysis of teleological studies.

	Theory Building?		
Study	Implementation in natural setting?	Comparison to extant studies?	External Validity?
Lejtman et al. [24]	N/A	N/A	N/A
Mendes et al. [25]	N/A	N/A	N/A
Costa and Jardim [26]	Though implemented, very limited evidence from practice	N/A	Partial
Shnits et al. [27]	Implementation indicated but lacks further detail.	N/A	Partial
Lin and Cochran [29]	N/A	N/A	N/A
Baldwin et al. [30]	Building on previous work by author.	N/A	Partial
Zülch et al. [28]	Implemented but little evidence	N/A	Partial

Table 6. Analysis of theory claims.

Theory Code	Theory	Number of Claims
ABC	Activity Based Costing	1
FMS	Flexible Manufacturing Systems	3
LS	Lot Sizing	2
Mai	Maintenance Process	1
PC	Production Control	4
PM	Process Management	3
PN	Petri Nets	1
QT	Queueing Theory	1
Sch	Scheduling	8
	Total	24

Table 6 provides number of theory claims under each subject considering all studies, accordingly, half of the retrieved studies claim a theory with a total number of 24, but they do not have implementation in real-world settings.

6. Concluding Remarks

Using a framework derived from theory-building for decision making on outsourcing [23], this study has looked into extant literature how building theory in operations management has been supported by simulation modelling; it is an extension of a previous systematic literature review [9]. For this purpose, it was also necessary to consider research philosophies in operations research and operations management. The analysis of relevant simulations studies utilising this framework combined with the earlier study leads to the following main conclusions:

- The dominant research philosophy in the retrieved set of simulation studies is the positivist paradigm. This means that the theory is justified by an independent researcher who only observes the real system and the study is not conducted in its natural settings. Also, justification of theories does not include the comparative studies.
- Further simulation studies need to drift away from this perspective if they want to contribute to building low-range and mid-range theories.
- Design science could be one of the alternatives for simulation modelling, since similar discussions exist in the literature on design approach, particularly for the deterministic rationalistic and positivist OR approach [7]
- Simulation modelling needs to be more explicit and exploit an iterative methodology similar to the design-test-evaluate cycle in design science [7]
- The theoretical value of simulation modelling with regard to external validity is not obvious, most of studies do not implement results obtained from simulation models. Also, there are no comparisons to relevant literature and not to different methods, either.
- The proposed framework could also be evaluated for an approach to justify theories and to obtain technological rules and validated methods.

Future research could be extended by including different research methodologies, which is referred to as pluralism [11], or it can be expanded to cover different simulation approaches and their analyses with respect to the theory building process. Also, philosophical assumptions of simulation modelling could be discussed from a broader perspective.

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