Real-time simulation strategies : Implications for operational excellence and sustainability performance

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Abstract

This chapter identifies possible strategies for utilizing real-time simulation in the context of industrial production. The literature review offered provides a framework to assess and map the crucial elements of real-time simulation. Empirical data from Small and Medium-sized Enterprises (SMEs) in the manufacturing sector is used to test the relationship between the strategic-level integration of real-time simulation models and sustainability performance. In doing so, the chapter develops a new way of characterizing real-time simulation based on the different tiers of data integration, and therefore a novel approach to defining different real-time simulation strategies. The results show that performance enhancement is strongly connected to the degree of data integration within production operations. Researchers and practitioners can apply the cluster solution of real-time simulation strategies to identify, develop, and evaluate the use of real-time activities for sustainable value creation.

Keywords: real-time simulation, strategy, production, manufacturing

4.1 Introduction

A real-time simulation model is defined as “a computer model of a physical system that can execute at the same rate as actual time” (Lee *et al.*, 2004, p. 1441). Therefore, real-time simulation models imitate a primary system (machinery, etc.) by emulating its behaviors (Lee *et al.*, 2004). To realize this similarity, it is necessary for the physical system to have some characteristics such as programmability, addressability, sensibility, communicability, associability, and the ability to memorize (cf., Yoo, 2010; Yoo *et al.*, 2010). These characteristics make it possible to build a higher level of sustainability value compared to traditional production, because they demonstrate high levels of data integration. It is necessary, therefore, to study the application of real-time simulation in industrial production. In response, Chen *et al.* (2012; 2015) have presented several important sustainability subthemes and indicators for industrial production that may be tackled by utilizing real-time simulation. They report that the economic aspects of sustainability performance include energy use, material consumption, waste management, profitability, and manufacturing costs. The social aspects include working conditions, the work's impact on long-term worker health, employee turnover, the proportion of permanent employees, and employee empowerment. Finally, the environmental aspects include its positive impacts on climate change, sources of energy, water quality through radiation heat transfer, water quality through solid waste, and water and soil through acidification. (Chen *et al.*, 2012; 2015)

On the other hand, many researchers argue that to get the best out of digital technology, digitalization must be a strategic issue (Matt *et al.*, 2015; Hess *et al.*, 2016; Ukko *et al.*, 2019). For example, Hess *et al.* (2016) present that the alignment and coordination of companies' many strategies in the light of digital transformation has led some researchers to argue for a digital business strategy that combines IT with business strategy. However, this kind of strategy usually consists of a company's vision for future digital business models while ignoring guidelines on the actual transformational steps (Hess *et al.*, 2016). Another stream of researchers highlight a standalone digital transformation strategy that signposts the way toward digital transformation and guides managers through the transformation process resulting from the integration and use of digital technologies (Matt., 2015; Hess *et al.*, 2016). These implications may also be relevant in the context of real-time simulation. Consequently, it is essential to determine if real-time simulation can be considered a digital transformation strategy or whether its elements (programmability, addressability, sensibility, communicability, associability, and the ability to memorize) can be considered actual transformational steps. In other words, does the explicit presence and integration of these elements in the company's real-time simulation strategy positively affect operational excellence and sustainability performance?

Therefore, this chapter empirically analyzes the real-time simulation strategies of companies. It makes use of empirical data from SMEs in the manufacturing sector to test the relationship between the strategic-level integration of real-time simulation models and sustainability performance. In so doing, the chapter develops a new way of characterizing real-time simulation based on the different tiers of data integration, and of defining different real-time simulation strategies. Each of the identified strategies is characterized by a different tier of data integration, representing the degree of integration of the simulation model into company production operations. The evidence showed that performance enhancement was strongly connected to the degree of data integration within production.

The chapter proceeds as follows. First, it presents prior literature on the contribution of real-time simulation to sustainable development. Next, the chapter reveals the research methodologies and results from 116 manufacturing companies. Finally, some implications of these findings for manufacturing and operations management research and practice are presented.

4.2 Real-time simulation for sustainability

4.2.1 Characteristics of real-time simulation models

A real-time simulation model is "a computer model of a physical system that can execute at the same rate as actual time" (Lee *et al.*, 2004, p. 1441). In other words, real-time simulation models simulate, in real time, the behaviors of the systems being modeled (Lee *et al.*, 2004). To make this similarity, it is necessary for the physical system to have some characteristics such as programmability, addressability, sensibility, communicability, associability, and the ability to memorize (cf., Kallinikos *et al.*, 2013; Yoo, 2010). All these characteristics require a high level of data integration. Embedded software in a physical system enables it with programmable characteristics so it can accept new sets of logic to adapt functions and behavior. Standardized protocols such as IP addresses enable addressability of physical systems, so they can individually reply to messages sent to a group of similar devices. In combination with embedded software, sensors give sensibility to the physical system enabling it to monitor and react to different situations.

In transportation, for example, Google Maps can be considered a simulation model that, with the support of embedded GPS chips in mobile phones, can recognize a person's location and propose the shortest, safest, and least congested routes. Combining a communication network with physical-system addressability makes the physical system communicable, enabling it to send and receive messages. Including internal and external memory devices gives a physical system the ability to memorize, so the simulated system can record and store generated, sensed, and communicated information. Tags, keywords, or affiliation patterns can be set up as enablers to give the physical system associability so it can be connected and recognized by other devices, places, and persons based on specific shared features (Kallinikos *et al.*, 2013; Yoo, 2010).

4.2.2 The concept of sustainability performance

Brundtland *et al.* (1987) has defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." From a company perspective, this means considering the level of substitutability of different forms of capital such as manufactured, natural, human, and social (Figge and Hahn, 2004). Managing sustainability performance necessitates linking a company's management of environmental and social issues with its business strategy and processes (Schaltegger and Wagner, 2006). Therefore, sustainability performance for companies will be determined by how well the company can carry out its daily activities while securing its economic, environmental, and social performance (Figge and Hahn, 2004; Hahn *et al.*, 2007).

To gain sustainability performance, companies need to pay attention to cost awareness, quality, and flexibility. According to De Ron (1998), this requires continuous improvement. Continuous improvement in efficiency, quality, and flexibility makes it possible for companies to attain sustainable operations and production (De Ron, 1998). Also, Adams *et al.* (2016) conclude that both operational optimization and organizational transformation must be taken into account to develop sustainability-oriented practices and processes. Operational optimization is doing the same things better in terms of compliance and efficiency. Organizational transformation involves doing new things in terms of novel products, services, or business models. Therefore, the current study applies the concept of operational excellence to describe a company's operational performance and renewal capability that contributes to its sustainable value creation.

4.3 Empirical examination of real-time simulation strategies

4.3.1 Data collection

Data were collected from a survey of top SME managers in the manufacturing sector. To assess the six elements of real-time simulation models, survey respondents were requested to express the degree to which they agreed with the consequent items using a seven-point Likert scale (1=strongly disagree, 2=disagree, 3=slightly disagree, 4= neither agree nor disagree, 5= slightly agree, 6=agree, 7=strongly agree). The items were as follows.

- In our company, all the devices are programmable.
- In our company, all the devices can be uniquely identified.
- In our company, all the devices are aware of the respond to changes in their environment.
- In our company, all the devices can send and receive messages.
- In our company, all the devices can record and store all information.
- In our company, all the devices can be identified with other devices, places, or people.

Items included in the survey were identified from prior literature and adapted as required by the researchers. Sustainability performance was assessed by asking respondents to evaluate the success of their company over the last three years with respect to three dimensions of sustainability: financial, social, and environmental. In addition, operational excellence was assessed by asking respondents to indicate their company's operational performance and renewal capability over the last three years. The response scale for the items of sustainability performance and operational excellence ranged from 1 to 4 (1= weak, 2=satisfactory, 3=good, 4=excellent). For classification purposes, the survey included items related to company size (number of employees and revenue), maturity (years established), and type of business (business-to-business or business-to-consumer).

The survey received 116 responses. To evaluate non-response bias, responses to all study items were compared for early-wave versus late-wave respondents. According to Armstrong and Overton (1977), late-wave respondents can be used as representatives for non-respondents. There were no significant differences found between the early-wave and late-wave respondents, which suggests that non-response bias are not likely to exist in the data.

Responding companies included raw material, component, and final product manufacturers in different industries such as forest, metal, food, plastic, and machinery. Responding companies ranged in size from 49 or fewer employees (64 percent of sample) to over 50 (36 percent of sample). Median company size was 31 employees. Only 9 percent of the responding companies had been in operation less than ten years. The majority of the companies (65 percent) had operated over ten but less than 50 years, whereas the remaining 27 percent of the companies had operated more than 50 years. Median company age was 34 years. The majority of the surveyed companies operate in business-to-business markets (93 percent of sample), and only 7 percent operate in business-to-consumer markets.

4.3.2 Cluster analysis results

To identify possible strategies for utilizing real-time simulation in the context of industrial production, cluster analysis was employed to group the companies into homogenous categories. The clustering was performed based on the tiers of data integration, that is, specifically how programmable, addressable, sensible, communicable, associable, and memorizable the companies real-time simulation models are. Cluster analysis refers to a method of classifying objects with similar attributes into groups (Hair *et al.*, 1998). In this study, the K-Means clustering method was used, because it is suitable for grouping based on conceptual issues.

K-means cluster analysis was used to divide companies into groups based on the tier of data integration within real-time simulation models. Responses to the items on the six elements of real-time simulation were used to perform the clustering, *i.e.*, to sort the 116 cases into the three different real-time simulation strategies (Table 4.1). For example, responding companies that were in the top level of data integration within the real-time simulation model were classified as companies that follow a “data wisdom” strategy. Their real-time simulation models were highly programmable, addressable, sensible, communicable, associable, and memorizable. Companies who reported high integration levels in programmability and addressability were categorized as following an "in the game" strategy. However, the level of data integration was below average in terms of sensibility, communicability, associability, and the ability to memorize. Finally, companies that reported low levels of integration in all the elements of real-time simulation models (programmability, addressability, sensibility, communicability, associability, and the ability to memorize) were labeled as companies that follow a "bystander" strategy.

Table 4.1. Cluster analysis results.

Elements of real-time simulation	**Mean**			
	Overall (*n* = 116)	**Cluster 3 (*n* = 32)**	**Cluster 1 (*n* = 33)**	**Cluster 2 (*n* = 51)**
Programmability	3,39	5,66	3,82	1,75
Addressability	4,15	5,53	5,15	2,65
Sensibility	3,05	4,94	3,00	1,94
Communicability	3,03	5,50	2,79	1,67
Associability	3,08	5,34	3,06	1,69
The ability to Memorize	3,15	5,41	3,03	1,78

4.3.3 Characteristics of the real-time simulation strategies

The three tiers of data integration representing "data wisdom", "in the game", and "bystander" strategies were tested using analysis of variance to identify significant differences between their levels of improvement for sustainability performance and operational excellence. Table 4.2 shows there were several significant differences ($p<0.1$) between the three different real-time simulation strategies. Further, Table 4.3 shows the descriptions of the companies following each strategy. The information provided in these two tables is used to describe the characters of the companies following each strategy.

The "data wisdom" strategy

Of the companies surveyed, 27.6 percent carry out the "data wisdom" strategy. The companies following this strategy with the highest levels of data integration outperform other companies in terms of operational excellence (both renewal capability and operational performance) and financials, one of the three dimensions of sustainability. A similar statistically significant difference in comparison to other strategies was not found with respect to the social and environmental dimensions. This cluster comprises mostly small companies and young companies that have been in operation for less than 30 years.

The “in the game” strategy

The “in the game” strategy is followed by 28.4 percent of the companies surveyed. Companies following this strategy also performed above average in terms of operational excellence (both renewal capability and operational performance). However, companies following this strategy did not outperform in terms of the financial, social, and environmental dimensions of sustainability performance. Medium-sized companies are more represented in this group. A large portion of them have been in operation more than 30 years, and the companies are more mature than the average surveyed.

The “bystander” strategy

The remaining 44 percent of the surveyed companies embrace the “bystander” strategy. These represent the lowest level of data integration, and they perform worse than average considering all the studied performance dimensions. Medium-sized companies are also more represented in this group. Having been in operation more than 30 years, the “bystander” companies are more mature than the average surveyed company.

Table 4.2. The means of the sustainable value dimensions in each cluster.

Performance dimensions	Mean				Sig.
	Overall (*n* = 116)	**Cluster 3 (*n* = 32)**	**Cluster 1 (*n* = 33)**	**Cluster 2 (*n* = 51)**	
Operational excellence					
Renewal	2,67	2,94	2,78	2,43	0,005*
Operational performance	2,79	2,97	2,84	2,67	0,089*
Sustainability performance					
Financial sustainability	2,71	3,03	2,63	2,59	0,080*
Social sustainability	2,93	3,00	3,03	2,84	0,352
Environmental sustainability	2,84	2,84	2,88	2,84	0,967

Sign. *p ≤ 0,1

Table 4.3. Descriptions of the clusters based on size, maturity, and type of business.

	All		**Cluster 3 (n=32)**		**Cluster 1 (n=33)**		**Cluster 2 (n=51)**	
No of employees	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
Small	**62**	**53,45 %**	19	59,37 %	17	51,52 %	26	50,98 %
Medium	**54**	**46,55 %**	12	37,50 %	16	48,48 %	24	47,06 %
Missing	**0**	**0,00 %**	1	3,13 %	0	0,00 %	1	1,96 %
	116	**100,00 %**	32	100,00 %	33	100,00 %	51	100,00 %
Revenue	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
Small	**67**	**57,76 %**	18	56,25 %	19	57,58 %	30	58,82 %
Medium	**49**	**42,24 %**	14	43,75 %	14	42,42 %	21	41,18 %
Missing	**0**	**0,00 %**	0	0,00 %	0	0,00 %	0	0,00 %
	116	**100,00 %**	32	100,00 %	33	100,00 %	51	100,00 %
Maturity	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
below 30 years	**42**	**36,21 %**	16	50,00 %	10	30,30 %	16	31,37 %
above 30 years	**74**	**63,79 %**	16	50,00 %	23	69,70 %	35	68,63 %
Missing	**0**	**0,00 %**	0	0,00 %	0	0,00 %	0	0,00 %
	116	**100,00 %**	32	100,00 %	33	100,00 %	51	100,00 %
Type of business	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
B2B	**108**	**93,10 %**	27	84,37 %	30	90,91 %	50	98,04 %
B2C	**8**	**6,90 %**	4	12,50 %	3	9,09 %	1	1,96 %
Missing	**0**	**0,00 %**	1	3,13 %	0	0,00 %	0	0,00 %
	116	**100,00 %**	32	100,00 %	33	100,00 %	51	100,00 %

4.4 Conclusions: Sustainable strategies for real-time simulation

This chapter empirically analyzes the strategies used by 116 manufacturing companies to employ real-time simulation. It takes empirical data from SMEs in the manufacturing sector and tests the relationship between strategic-level integration of real-time simulation models and sustainability performance. In doing so, a new way of characterizing real-time simulation based on the different tiers of data integration is developed, thereby defining different real-time simulation strategies. The main contributions of the chapter can be summarized as follows.

Theoretical implications

First, the analysis shows that it is possible to define real-time simulation strategies that are characterized by different tiers of data integration. The most advanced strategies include the adoption of real-time simulation models that are highly programmable, addressable, sensible, communicable, associable, and memorizable. Second, the comparison reveals that in terms of renewal capability, operational performance, and financial sustainability, real-time simulation strategies with the lowest levels of data integration also demonstrate the lowest levels of operational excellence. From this, it can be concluded that an advanced real-time simulation strategy with a high level of data integration improves the performance of a company. Third, small and young companies seem to be more advanced than larger and more mature companies in their approach to adopting advanced real-time simulation strategies.

Managerial implications

The following suggestions are offered for managers implementing real-time simulation strategies. In terms of their attitudinal and demographic properties, SMEs fall into three categories. Implementing a comprehensive real-time simulation strategy such as “data wisdom” with the highest tier of data integration is not essential for all companies. However, it serves as an example for companies willing to increase the level of data integration in their production operations. Furthermore, managers can benefit from an increased understanding of the benefits of real-time simulation when considered as a strategic issue. Adopting real-time simulation to achieve operational excellence is justified, but it can also more broadly provide sustainability value.

Limitations and further research directions

First, the survey and the data used in this analysis covers only one country. More research will be needed to validate the results for other regions. Second, self-reported measures were used to establish the characteristics of real-time simulation models and company performance. This is a practical approach that is widely used in collecting data, but it may come with some problems in terms of validity and reliability. In research terms, the validity and reliability were achieved by following an exact procedure to carry out the statistical analysis, from data collection to interpretation. Therefore, in terms of the research, the results can be considered valid and reliable.

This study provides some avenues for future research. First, as this study has used quantitative data, it needs to be accompanied by qualitative and longitudinal research providing insights into SME real-time simulation strategies. In-depth research is required to study the additional characteristics of real-time simulation to assist in the realization of sustainable strategies. Second, it is not clear whether or not or to what extent the characteristics of real-time simulation models correlate with different usages (learning, control, etc.). This could be a fruitful avenue for future study. This research suggests a positive relationship between real-time simulation and sustainability performance. Therefore, more in-depth research will be needed on the real-time simulation-performance relationship accounting for the mediating effect of company-level features and processes.

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