

improve by responses from a combination of both groups. However, we believe that a quantitative data-based approach adopted in our framework can mitigate possible biases in the evaluation process.

6. Conclusions

Traditional project management techniques take *cost, time* and *end product quality* factors—or so-called *Iron Triangle*—into account and provide the project managers with information only on these three attributes in order to plan and control the project. While they have been useful to some extent, research studies have suggested that it is difficult to manage projects using these traditional techniques (eg, Baccarini, 1996; Williams, 1999; Bryde, 2005; Pundir *et al.*, 2007). It is even more difficult in consulting projects, such as simulation studies, where the immediate products are rather intangible. For example Robinson (2002) highlights the greater importance of process over content. Therefore, it is important to recognise that the success of such projects cannot be linked only to the end products. A more *process-oriented* view with some attention to the intangible benefits needs to be taken on board. For example, a project that would not reach the final stage, might still gain some scores on such intangible criteria as ‘increased understanding of the system and potential system improvements in the future’.

The study of CSFs, which brings in a wide range of perspectives alongside the Iron Triangle, has become a popular area of research to address the complexity of projects and this paper shows its applicability in simulation projects. However, the mainstream research has not gone beyond the identification of success factors. There has been a clear gap in advancing this topic to the stage that a multi-faceted view of a simulation project could be quantified and then used to manage the project towards success. To address this, we present a top-down framework on the basis of KPIs linked to CSFs whereby the concept of *simulation project success* can be quantified. Such a multi-faceted approach allows a wider application.

The results of our survey on 9 exemplar cases and correlation analyses on the results provided some support for the reliability of our proposed framework. Further, an analysis of the results highlighted some areas that might represent a general pattern. For example, the 9 cases produced consistently lower scores on *the customer’s organisational capacity to support the simulation project*, which is crucial in securing the implementation of results. Simulation providers could fill the gap regarding the simulation awareness in the customer organisations with short training programs for key stakeholders during the early phase of the project.

The results suggest that our proposed framework and questionnaire could be used with some confidence to measure performance, to monitor and to benchmark simulation projects, but further testing is needed. Performance measurements using the questionnaire could be done both during the course of the

project or after its completion. The analysis of the performance measurements, through drilling down to the individual KPIs, could facilitate the identification of issues in a simulation project. A complementary research direction could be to study how the CSFs could be ‘embedded’ in emerging simulation methodologies and tools such as enterprise business process simulation (Liu and Iijima, 2015) and construction engineering (AbouRizk *et al.*, forthcoming).

This work is by no means complete and has its limitations. The selection of CSFs in our study, based on the work by Robinson and Pidd (1998), were informed by views from both the provider and the customer groups. However, our exemplar study used evaluation of the projects’ performance by providers only. This limitation, we believe, could be removed by involving customers in the future surveys. Further work might also be allocated to fine tuning our questionnaire constructs based on future surveys. New survey studies measuring simulation projects’ performances using our proposed framework could also provide some useful general insights into the areas of concern in simulation practice. These could be further complemented by studies of the impact of causal factors on the success of simulation projects (Jahangirian *et al.*, 2015).

While the scale of our exemplar study (9 exemplars) is similar in magnitude with the existing published research, the methodology will benefit from reflections on further exemplar studies. This research adopted data from health-care sector that were available to the authors; hence there might be a potential health bias. Similar studies using data from other sectors could provide insights on comparable findings. Further research could also be dedicated to confirm the weights used for each CSF.

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Appendix

1. *Communications and Interactions:*

1.1. Average number of communications (of any types such as f2f, phone calls, emails, written reports, etc.) per month throughout the project:

5 or more 4 3 2 1 or less

1.2. How much and how easy were the interactions and communications between customers and providers understood by both sides?

Very low: Poor understanding by both sides throughout the project with little or no improvement

Low: Some understandings mostly by one side, but with little or no improvement

Average: Some understanding by both sides, with little improvement

High: Good understanding by both sides, with some improvement

Very high: Excellent understanding by both sides all over the life of the project

1.3. How many out of this 7 items were shared with the customers in the project: (1) Potential benefits, (2) Objectives, (3) Plan, (4) Project specifications, (5) Model, (6) Progress, (7) Findings/results All 6 5 3–4 2 or less

2. *Competence of the simulation provider:*

2.1. Total no. of previous simulation projects carried out by the provider: 10 or more 6–9 3–5 1–2 None

2.2. Total number of simulation projects previously carried out by the provider in the sector: 5 or more 3–4 2 1 None

2.3. Number of provider's staff allocated to the project with formal simulation/OR training: More than 2 full-time or equivalent between 1 and 2 full-time or equivalent 1 full-time or equivalent 1 part-time None

3. *Responsiveness:*

3.1. No. of benefits obtained by the customers from this list: (1) Greater understanding of the process, (2) Improved

communication within the customer organisation, (3) Better team integration, (4) Better development of skills, (5) Risk reduction, (6) Operating cost reduction, (7) Throughput increase, (8) Faster implementation of changes, (9) Capital cost reduction. All 7–8 5–6 3–4 2 or less

3.2. Percentage of project's delay against the plan: Less than 30% delayed 30–60% delayed 60–80% delayed 80–100% delayed more than 100% delayed

3.3. Percentage of change requests from customers met by the provider over the course of the project: 80% or more 60–80% 40–60% 20–40% less than 20%

4. *Involvement:*

4.1. No. of steps from this list that customers have been actively involved in: (1) Problem definition, (2) Data collection, (3) Conceptual modelling, (4) Model building, (5) Model validation and verification, (5) Experimentation, (6) Analysis of results, (7) Dissemination, (8) Project review. All 7–8 5–6 3–4 2 or less

4.2. No. of people at customer's organisation that had an active role in the project: 8 or more 6–7 4–5 1–3 None

4.3. No. of customer's organisational units (Management, Specialists, R&D, Information Centre, ...) actively involved in the project: 4 or more 3 2 1 None

5. *Customer's organisation:*

5.1. No. of people at the customer organisation's *top management* level actively involved in the project: 4 or more 3 2 1 None

5.2. No. of people at the customer's organisation with Simulation/OR formal training who were involved in the project: 4 or more 3 2 1 None

5.3. No. of people at the customer's organisation involved in the *problem definition*: 5 or more 4 3 1–2 None

Table A1 Common features for the CSF 'Communication and Interaction between the provider and the customer'

<i>Statement of success</i>	<i>Common features</i>		
	<i>Frequency of communication</i>	<i>Communication effectiveness</i>	<i>Information to share</i>
There will be regular communication between the provider and customer	√	—	—
The customer will be constantly informed about progress on the project	√	—	√
The results will be in a format that is familiar to the customer	—	√	—
Presentations by the provider will be easily understood	—	√	—
A project specification will be provided	—	—	√
The customer will see the model	—	—	√
A written report of the findings will be provided	—	√	√
There will be a plan defining the deliverables and timing for each stage	—	—	√
Documentation and paperwork will have a neat appearance	—	√	—
Minutes of meetings will be provided	—	√	—
The results will be easily understood	—	√	—
The provider will be clear and concise about what the simulation will and will not do	—	√	√
Written documentation will be in a form/language that customers understand	—	√	—
The benefits of the work will be identified and communicated to management	—	—	√
The project specification will be split into its constituent parts, giving options for each level of modelling	—	—	√
The provider will understand and use the language of the customer	—	√	—
The reports will be as agreed to be appropriate	—	√	—
The provider will liaise with people at the right level	Relates to the <i>Involvement</i> dimension under <i>Key stakeholder groups</i>		
Telephone communications will be excellent	—	√	—
Presentation materials will be excellent	—	√	—
Status/interim reports will be provided	√	—	√
Testing plans will be provided	—	—	√
Results and recommendations will be presented successfully	—	—	√
The content of the report will be correct	—	—	√
Email will be used for communications	—	√	—
Results will be presented graphically in reports	—	√	—
Reports will be distributed to the relevant people	—	—	√
The project will be documented	—	—	√
Agendas will be provided	—	—	√
Presentations will not be too detailed	—	√	√
The results will be demonstrated to senior managers	—	—	√
The customer will not be given too much details in reports	—	√	√
The customer will be informed of how the data have been collected	—	—	√
The customer will be informed of how the model has been built	—	—	√
Information will be regularly communicated to the customer in small amounts	√	√	—
The provider will check the customer's understanding	—	√	—
The output from the model will be well marketed	—	√	√
All the results will be provided	—	—	√
The customers will be given the information they want	—	—	√
Information will be communicated using right media (eg presentations or written reports)	—	√	—
The provider will influence people and make them aware of problems	—	√	—

Table A2 Common features for the CSF ‘Competence of the Provider’

<i>Statement of success</i>	<i>Common features</i>		
	<i>Knowledge of simulation</i>	<i>Simulation experience</i>	<i>Knowledge of the context</i>
The provider will have a good knowledge of the process being modelled	—	—	√
The provider will be experienced with simulation	—	√	—
The provider will demonstrate a good level of expertise with the simulation package	√	—	—
The provider will be technically competent	√	—	—
The provider will be knowledgeable about the customer’s industry	—	—	√
The provider will give accurate time estimates for the project	—	√	√
The provider will be well trained in simulation	√	—	—
The provider will be proactive in suggesting improvements to the process	—	—	√
The provider will use simulation regularly and frequently	—	√	—
The provider will have support from expert simulation modellers	√	—	—
The provider will have a good understanding of the problem	—	—	√
The provider will be knowledgeable about the customer’s business	—	—	√
The provider will spend a lot of time up-front planning	—	√	—
The provider will manage the project	—	√	—
The provider will correctly estimate the complexity of the process	—	—	√
The provider will correctly estimate the complexity of the model required	√	—	—
The provider will be able to quickly assimilate all the information required	√	—	—
The provider will have a knowledge of a wide range of disciplines	√	√	—
The provider will employ a formal process for model development	√	—	—
The provider will have experience with similar models	—	√	√
The provider will be able to analyse the customer’s requirements	—	—	√
The provider will be <i>very good</i>	√	√	√
The provider will have some good ideas on how to simplify the model	√	√	—
The provider will have a natural modelling ability	√	√	—
The provider will use reasonable intelligence to carry out the work	√	—	—
The provider will have a methodical and sound approach	—	√	—
The provider will exclude infrequent events from the simulation	√	—	—
The provider will normally be able to solve any modelling problems	√	√	√
The provider will be used to developing very complex models	√	√	—
The provider will understand what is going on in the process	—	—	√
The provider will be able to build models quickly	√	√	—
The provider will know the limitations of the software	—	√	—
The provider will use methods of experimental design	√	—	—
The provider will correctly estimate the amount and precision of the data required	√	√	√
The provider will correctly estimate the amount of work the customer needs to input	√	√	√

Table A3 Common features for the CSF 'Responsiveness'

<i>Statement of success</i>	<i>Common features</i>		
	<i>Benefits for customer</i>	<i>Timescale for delivery</i>	<i>Flexibility</i>
The simulation will provide information which otherwise would not have been available	√	—	—
The objectives of the project will be achieved	√	—	—
The project will deliver a benefit	√	—	—
The provider will adapt to the customer's changing needs as the project progresses	√	—	√
The provider will be able to perform the project at the time the customer requires	—	√	—
The project will provide the results that the customer wants to hear	√	—	√
It will be possible to perform a lot of experiments	—	—	√
There will be time to perform all the experiments desired	—	√	—
The project will be completed quickly	—	√	—
A problem will be solved through the project	√	—	—
There will be mechanisms in place for controlling change to the project	—	—	√
The simulation will enable the customer to make a decision faster	√	√	—
The customer will learn something from the project and so make better decisions	√	—	—
The simulation will provide a selection of alternative courses of action	—	—	√
The simulation will be used a great deal	√	—	√
The provider will respond quickly to any requests	—	√	√
The provider will analyse any of the customer's ideas that are fed back	√	—	√
The simulation will provide a large volume of information	√	—	—
The provider will have time to perform the simulation project	—	√	—
The reports will be timely	—	√	—
The provider will ensure that the customer's requirements are reflected in the model	√	—	—
The provider will be flexible (willing to meet the customer half-way)	—	—	√
Backup support will be provided by the provider's organisation	—	—	√
The simulation will identify where the problem really is	√	—	—
The simulation will force the customer to think about things that had not previously been considered	√	—	—
The provider will help in an appropriate fashion	√	—	—

Table A4 Common features for the CSF 'Involvement'

<i>Statement of success</i>	<i>Common features</i>		
	<i>Continuity of involvement</i>	<i>Active involvement (teamwork)</i>	<i>Involvement of Key stakeholder groups</i>
The customer will be involved throughout the project	√		
Regular meetings will be held between the customer and the provider	Relates to the <i>communication and interaction</i> dimension under <i>regular communication</i>		
The project will be a team effort	—	√	—
The customer will be involved in the validation of the model	√	√	—
The customer will be informed about what contribution he/she needs to make to the project	—	√	—
A review of how the project went will be performed at the end of the project	√	—	—
Experiments will be performed during meetings with the customer	√	—	—
The customer will be able to perform experiments himself/herself	√	√	—
The customer will spend a lot of time working on the project	—	√	—
The customer will not become too involved in the project and its detail	—	—	—
The customer will buy-in to each stage of the project	—	√	—
Discussions will start at the beginning of the project	√	—	—
The provider will focus the customer on the task in hand	—	—	—
There will be several detailed walkthroughs of the model with the customer	√	√	—
The project team will be involved in verifying all the data	—	√	—
The equipment suppliers (eg machinery) will be involved in the project	—	—	√
The provider will understand the level of the customer's simulation knowledge and will work to that level	—	√	—
Experts in the facility being modelled will be involved in the project	—	—	√
Experts in the facility being modelled will be involved at an early stage in the project	—	—	√
The customer will identify with the simulation as early as possible	√	√	—
Those involved in the project will remain involved throughout	√	—	—
The customer will have input into how the model looks	—	√	—
The customer will be involved in data collection	√	√	—
Potential experiments will be discussed at the beginning of the project	√	—	—

Table A5 Common features for the CSF 'The Customer's organisation'

<i>Statement of success</i>	<i>Common features</i>		
	<i>Organisational support and commitment</i>	<i>Organisational knowledge of simulation</i>	<i>Shared organisational knowledge of problem</i>
Senior management in the customer's organisation will be committed to the project	√	—	—
The customer will be committed to the project	√	—	—
The customer will believe in simulation	√	√	—
The customer's organisation will see the simulation as a necessary part of the wider project	√	√	—
The customer will be able to clearly define the problem being tackled	—	—	√
All involved in the project will be willing to input to the process	√	—	—
The customer will not change the objectives as the project progresses	—	—	√
The customer will clearly define the experiments before the project starts	—	—	√
Simulation will be an accepted technique in the customer's organisation	—	√	—
The plans for the real facility will be fairly concrete before the simulation is started	—	—	√
The customer will have a good knowledge of the facility being modelled	—	—	√
The customer will be supportive and helpful	√	—	—
The customer will not have preconceived ideas about what the simulation will show	—	√	—
The provider will be accepted by those providing data	√	—	—
The customer will understand something of the simulation software	—	√	—
The customer will understand some of the problems the provider might face	—	√	√
Members of the customer's organisation will be available as and when they are needed	√	—	—
The customer will ask for a reasonable number of experiments to be performed	—	√	—
The customer's organisation will have formal procedures in place for requesting a simulation	—	√	—
Senior management in the customer's organisation will be willing to listen and be open to change	√	—	—
The provider will have responsibility and accountability to the customer	—	—	√
The customer will have been designated the task of being involved in the simulation	√	—	—
The management in the customer's organisation will have the foresight to see what simulation can do	—	√	—
There will be a middle-person between the provider and the customer who understands both simulation and the problem	—	√	√
The customer will have the structure for the model documented before work commences	—	√	—
The customer will listen to the results of the simulation	√	—	—
The customer will have sufficient time/resource to collect the data	√	—	—
The customer organisation will commit to the implementation	√	—	—
The customer will initiate the project	√	—	—
The customer will not have preconceived ideas about simulation being the correct technique for the problem being tackled	—	√	—
The customer's expectations will not be too high	—	√	√
The customer will communicate his/her expectations at the beginning of the project	—	—	√
It will be easy to gain access to the customers	√	—	—
The customer will recognise that there are limitations to the model	—	√	—
The customer will spend time interpreting the results	√	—	—
The customer will understand how to use the model	—	√	—

Table A5: *Continued*

<i>Statement of success</i>	<i>Common features</i>		
	<i>Organisational support and commitment</i>	<i>Organisational knowledge of simulation</i>	<i>Shared organisational knowledge of problem</i>
The problem that the customer asks to be tackled by simulation will be manageable	—	—	√
The customer will not think in terms of current practice alone	—	√	—



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