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ECONOMICS OF MODELING AND SIMULATION: REFLECTIONS AND IMPLICATIONS FOR HEALTHCARE

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ABSTRACT

Arguably, it is widely known that there is much activity in modeling & simulation (M&S) in healthcare, particularly in decision support and analysis for care delivery systems (CDS). This is supported by recent literature surveys. However, there is limited evidence of reported cost, success and impact. To attempt to investigate the so-called 'economics' of M&S in this area, this paper aims to depict a general picture of the economics of M&S supported by available evidence and to develop an initial set of guidelines using a novel framework that may assist decision makers in assessing the usefulness and cost-effectiveness of M&S. Our paper concludes with an urgent call for research in this area, specifically in terms of using standardized qualitative and quantitative methods to gather evidence for analysis and dissemination materials that 'speak' to government-level policy makers.

1 INTRODUCTION

Healthcare systems around the world are grappling to improve delivery against heightened expectations and constrained resources. In the UK, an efficiency saving measure of £15-20 billion (or approximately 15-20% of the whole National Health Service budget) has been set out, while in the US, plans to roll-out affordable healthcare that will cover 32,000,000 citizens who currently lack provision has just begun.

In the modeling and simulation (M&S) community it is widely known that M&S can assist in identifying cost savings. There has been much activity in healthcare, particularly in decision support and analysis for care delivery systems (CDS). However, there is limited evidence of implementation (Brailsford et al. 2009). A recent study by Jahangirian et al. (2009) investigated simulation in health against a context of defense, manufacturing and business. Only 8% of healthcare papers report on a real problem or user engagement, compared with 38% of papers in defense and 49% in manufacturing and business. One might take the view that the cause of this is an entirely different set of challenges to implementation and evidence gathering in health against these other domains or, possibly unfairly, research is carried out to satisfy intellectual curiosity rather than to meet the demands of the system. Either way, the lack of evidence of impact of M&S in CDS makes it extremely difficult to show healthcare decision makers the value of M&S.

Is it possible to actually demonstrate the economics of M&S? Further, is it possible to demonstrate the economics of M&S in healthcare? A survey of simulation experts certainly identified that this is a key need (Taylor and Robinson 2006). To investigate this, the current paper aims to depict a general picture of the economics of M&S supported by available evidence, and to develop an initial set of guidelines using a proposed framework that might assist decision makers, particularly in the healthcare sector, on the usefulness and cost-effectiveness of M&S. This study builds on a holistic view on the application of M&S

in a variety of sectors, including manufacturing, business, defense, and healthcare, acquired through the RIGHT project (Research Into Global Healthcare Tools). RIGHT identified the lessons that could be learnt from applications of M&S in business, manufacturing and defense sectors and attempted to apply these to healthcare. It also aimed to develop a systematic way of selecting the best M&S tools for a given problem scenario.

Our paper is structured as follows. Section 2 presents a review of studies of M&S economics. Section 3 investigates the challenges of investigating M&S cost-effectiveness techniques. Section 4 presents a cross-section of evidence of M&S economics. Section 5 introduces our proposed framework. Section 6 reflects on the potential use of this in healthcare and section 7 concludes the paper.

2 PREVIOUS STUDIES

The structured study of economics of simulation dates back to the 1970s when Godin (1976) and Gray (1976) presented the concept, interestingly in the same year, perhaps for the first time. While Godin claimed that the amount of information available on the economics of simulation is very small, he attempted to improve this situation by proposing a framework for the collection and specification of the economics of simulation modeling projects as a method of urging management scientists to begin to collect and publish data on the economics of simulation projects. We shall return to this point in the conclusions.

Gray's work addressed the development of a methodology to estimate the costs of simulation projects over the four stages of a simulation process, namely 1) development, 2) initial operation, 3) modification, and 4) repeated operation. What is rather unique about Gray's work is that he used a decision tree method to model decisions made throughout the process, such as the choice of language, level of simulation details, etc. By using this methodology, one may be able to model all the feasible ways to carry out a simulation project and also to identify the minimum expected cost solution. However, one might also argue that this would lead to an explosion of possibilities. Regarding simulation benefits, Gray emphasized the difficulty with the estimation of benefits, especially when intangibles are involved. To address this, he suggested a two-step method by which one first compares tangible benefits with the costs and if there is a gain, the decision is straightforward. However, if they do not, then a further step of quantification of intangibles would be required before a decision would be made. An advantage of using decision tree to estimate the benefits of simulation is that simulation can also be seen as a method for gathering sample information to reduce the uncertainty involved. Thus a manager can decide if conducting a simulation study is worthwhile or not. Gray uses net present value (NPV) method to conduct cost/benefit comparisons.

In one of the few studies on the performance of simulation in manufacturing settings, Manzini et al. (2005) set up five indicators, representing programming efforts, duration, cost/benefit ratio, as well as cost proportion of a simulation project. They measured and reported these five indicators for five supply-chain management case studies. While the indicators seem straightforward, it is not certain if they take into account the project lifespan and also the time value of money.

Our search for previous work also found at least five articles written by defense sector researchers and practitioners specifically dedicated to the topic of economics of simulation, some of which were very long technical reports. It appears that the defense sector has done a substantial amount of work in this area, mostly in order to investigate and report the cost effectiveness of the huge money invested in defense M&S, most likely following a report published about issues in the management of M&S in the DoD and US congress discussions on the topic in the 1980s and early 1990s.

Worley et al. (1996) collected cost/benefit data about varied applications of M&S in DoD. A short review of the quantified impacts of M&S in three groups of applications, namely 1) acquisition, 2) training, and 3) analysis, are presented. The first application group is mostly concerned with the weapon design and testing, so-called 'physical design' application of M&S. On the other hand, the analysis of applications deal with decisions involving system evaluation, force sizing as well as combat operations. Having reviewed a number of cases studies for each group of applications reported with some tabulated ROI results, the authors conclude that while the impacts of M&S on acquisition and training are more quantifiable with ROIs as high as 57%, gathering quantified data about the cost effectiveness of the analysis applications are problematic. The report suggests a number of both quantitative and qualitative metrics to measure the effectiveness of M&S. They also exemplify four different methods of cost-effectiveness, namely 1) cost-saving or cost-avoidance calculation, 2) break-even analysis, 3) time needed to find some kind of disastrous errors in the system, and 4) comparing the costs and benefits of alternative solutions separately, in order to see if higher benefits are worth extra costs.

Carter (2001) provided a matrix representation of the empirical evidence which could be viewed as a guideline for decision makers about the cost-effectiveness of M&S in various defense applications throughout the phases of a system's life. This checklist provides ROI information for four categories of simulation, namely 1) Constructive (simulated people, equipment, and environments), 2)Virtual (real people, simulated equipment and environments), 3) Stimulator (simulated people and environments, real equipment), and 4) Virtual/Stimulator (real people and equipment, simulated environments), over four phases of a system's life, that are: a) Concept/technology development, b) System design/demonstration, c) Production/deployment, and d) Support/operations. While the categorization is devoted to defense applications, there seems to be some similarities with other sectors that can be cross-utilized with some adaptation.

Gordon et al. (2005) again studied the defense sector and made the contribution of providing further empirical evidence with an objective to develop a *best practice guide* for individual decision makers to know what to invest in M&S support for a specific task. They present a categorization of evidence based on defense applications similar to that of Worley et al. having three major categories, namely 1) acquisition, 2) readiness/training, and 3) investigation of alternative futures. The evidence quotes benefits in various metrics such as cost savings, ROI, staff efficiency, time reduction, etc. rather than a single one. It is claimed that acquisition applications seem to be the area of greatest financial pay-off for M&S use. Training applications tend to prove cost-effectiveness by saving staff time and costs, as well as increasing safety levels and the quality of training. The analysis of alternative futures spans applications from war operation planning, evaluation of innovations, evaluation of force structures, as well as manufacturing process/storage assessment and improvements. The authors also emphasized an urgent need for data, which requires that there be a way to systematically collect information about projects that allows a comparison of results.

Another study carried out by NSMG, a NATO special group on M&S, reports the progress on the cost-effectiveness of M&S (Summons & MacDonald 2005). A simple tool is proposed which will both present the existing evidence and aid the collection of new evidence.

3 CHALLENGES OF ASSESSING COST-EFFECTIVENESS OF M&S TECHNIQUES

The research community has expressed a consensus on various difficulties associated with collection and standardization of evidence to examine the cost effectiveness of M&S techniques (Gibson et al. 2003, Gordon et al. 2005, Gray 1976, and Engelstein 2007). While it is not difficult to find research articles stating the *benefits* of applying M&S techniques, there is difficulties finding *proof*. Further, there is a great deal of complexity surrounding this with respect to a cost-effectiveness study such as:

- intangible benefits: better understanding of the system and its processes, improved communications, improved skills, etc;
- various kinds of quantitative benefits: monetary benefits, time-based benefits, etc;
- overlapping benefits: result of adopting a combination of techniques including M&S;
- estimation of future benefits: considering the uncertainties associated with the environment.

While cost measurements are more straightforward, it is still difficult to find evidence on this in M&S literature. Additionally, a lack of standard metric system to measure and analyze the cost/benefit data adds more complication to the topic.

The DoD's case is an example where after about 20 years since the US DoD initiated research on the cost-effectiveness of M&S one of the task groups (NMSG 031/ TG-022) in a document acknowledged that "none of the work that has been published provides the fidelity of information required to build a robust business case and to fully illustrate where and when M&S should, and most importantly, should not, be utilized. This activity should bring together the national research, building a robust data set and forwarding the generic understanding of the cost effectiveness of M&S" (Lewis et al. 2007). This certainly reveals the difficulties associated with establishing a robust evidence-base on the cost-effectiveness of M&S. However, all these research efforts over the past two decades have provided enough evidence to support a US congressional resolution as well as the US government approval of M&S as a '*National Critical Technology*'. In a letter to the President, US congressional M&S Caucus congressman, JR Forbes, states that "M&S is the single most powerful tool available to support our nation's international competitiveness in a wide variety of economic sectors" (*ibid*).

4 EVIDENCE BASE

An available evidence can provide an opportunity for researchers to enhance methodology, as well as for the practitioners to find good practice. Based on a structured literature search within the Scopus database and Google using a set of keyword combinations, we found 42 cases out of which 22 report evidence in academic outlets and 20 remaining have been reported in the grey literature, each providing some data about benefits, costs and/or cost-effectiveness of M&S techniques. The evidence is more based in manufacturing (around 36%), defense (around 29%), transportation (around 7%), and other sectors (28%). As mentioned earlier, there is little evidence on cost-effectiveness cases as most articles report on benefits only (Manzini et al., 2005; Sud et al., 2009; Hueter and Swart, 1998; Worley et al., 1996; and Gordon et al., 2005).

While costs range from around $30k (Engelstein 2007) up to $20m (Gordon et al. 2005) (representing military acquisition programs), benefits are varied between $400k per year (CACI 2010) and $750m in a single year (Lin et al. 2000). The benefit/cost ratios reported in literature have been in the scale of 3-to-1 (Manzini et al. 2005) up to 560-to-1 (Sud et al. 2009). As one would expect, there is a great deal of variance as problems vary in size and resulting benefits vary in impact. There appears to be a frustrating lack of evidence concerning problems of similar 'sizes' in the same domain.

As for the metrics used particularly for cost-effectiveness, there seems to be a common desire to use the *'ratio of benefit/cost'*, where benefit would represent increased revenue, cost savings or cost avoidance. The metric *'break-even point'* has also been used in some articles. However, it is surprising to see that the concept of *'time value of money'* has not been dominant in the related literature, though there are some articles where *'net present value (NPV)'* or *'discounted cash flow modeling'* are adopted or recommended (Gray 1976, Carter 2001). Waite et al. (2008) looks specifically at the metrics of economics of M&S, presenting a more detailed list of metrics for costs, benefits and cost-effectiveness.

5 A POSSIBLE FRAMEWORK

Considering the fact that there are serious difficulties with a precise quantitative measurement of the cost-effectiveness of M&S techniques it may be more appropriate for research activities on this area to focus on the development of 'practice guidelines' for modelers and decision makers when they need a very quick, yet decisive answer to their needs at the time of an investment.

The purpose of this part of our research is to encapsulate the evidence base as well as any other form of useful information available, such as expert opinions, to develop and present some guidelines on the cost-effectiveness of M&S techniques. These guidelines are intended to become a knowledge-base which could be subject to an on-going enrichment process. Our work can be seen as a starting point for further developments in the related area that will be carried out by the community of researchers as well as practitioners.

As the guideline is going to form a knowledge-base, it can be represented in a similar format as a 'knowledge-base' can, which is quite varied from *'textual'* to *'schematic'* or *'tabular'* or a more formal *'decision rule'* or *'decision tree'* structure. Here, we intend to use a very simple type of schematic representation framework with a very simple and familiar structure for the managers, namely a 2-by-2 matrix (figure 1).

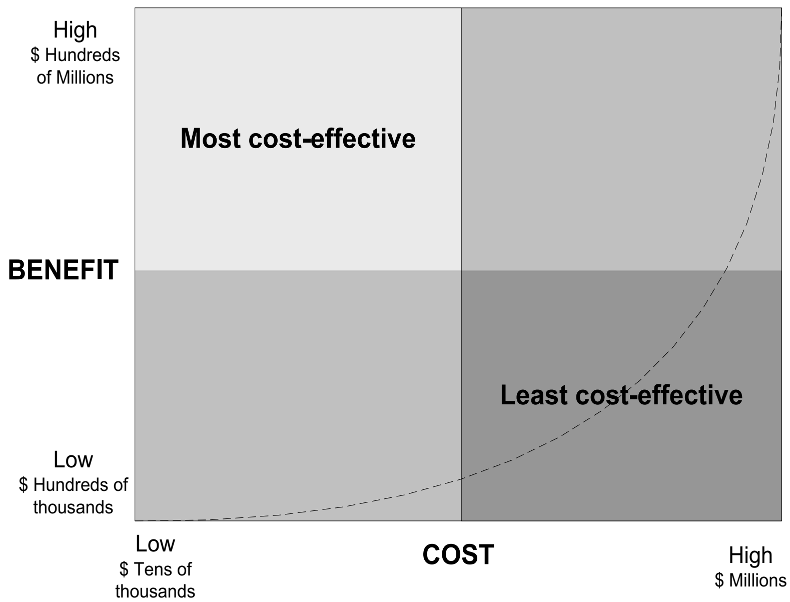

Figure 1: Proposed 2-by-2 Matrix framework for M&S cost-effectiveness

Some important points on our proposed 2-by-2 matrix are:

- Only the quantifiable parts of the cost-effectiveness study are taken into account.
- It is assumed that the costs and benefits are calculated based on the NPV method.
- The upper and lower limits of costs and benefits have been set differently, merely based on the prevalent evidence.
- The dotted curve in the matrices could represent the break-even line.
- The matrices would demonstrate some guidelines resulting partly from the literature evidence and partly from the authors' personal knowledge.
- The guide is by no means going to prescribe a recommendation for a specific problem, rather its purpose is to provide a general knowledge about the cost-effectiveness of M&S techniques. Obviously a precise leading practice guide would need to be supported by rigorous evidence base.
- Top-left and bottom-right boxes in the matrix represent the most and the least cost-effectiveness areas.

Perhaps the most known categorization scheme of the evidence is concerned with the applications, mostly grouped into three major categories, namely a) logistics, b) training, and c) physical design. Available evidence, especially the ones collected from the defense sector suggest that M&S costs associated with logistics, training and physical design applications increase respectively, due to a need to obtain more hardware and expensive devices for the latter two groups of applications. On the other hand, training and especially the physical design applications have shown benefits mostly in the higher range (Carter 2001). Figure 2 shows a possible cost-effectiveness of M&S techniques in terms of various applications. As shown, all applications express a cost-effective solution, while logistics applications demonstrate the highest level of cost-effectiveness, having a greater coverage of the top-left box in the matrix.

It is also interesting to know how various M&S techniques work in terms of the cost-effectiveness. Here, we focus on two groups of M&S techniques, namely a) mathematical modeling, such as mathematical programming, queuing models, Markov models, decision trees, etc. and b) simulation. Generally speaking, simulation techniques demand more man-hours and most likely more hardware requirements, while producing reliably high profits (if successful!). Mathematical modeling techniques, on the other hand, impose some assumptions that would normally simplify the solution (figure 3). Therefore, a general guide would be to see the suitability of mathematical modeling techniques first, before a simulation attempt is to be made.

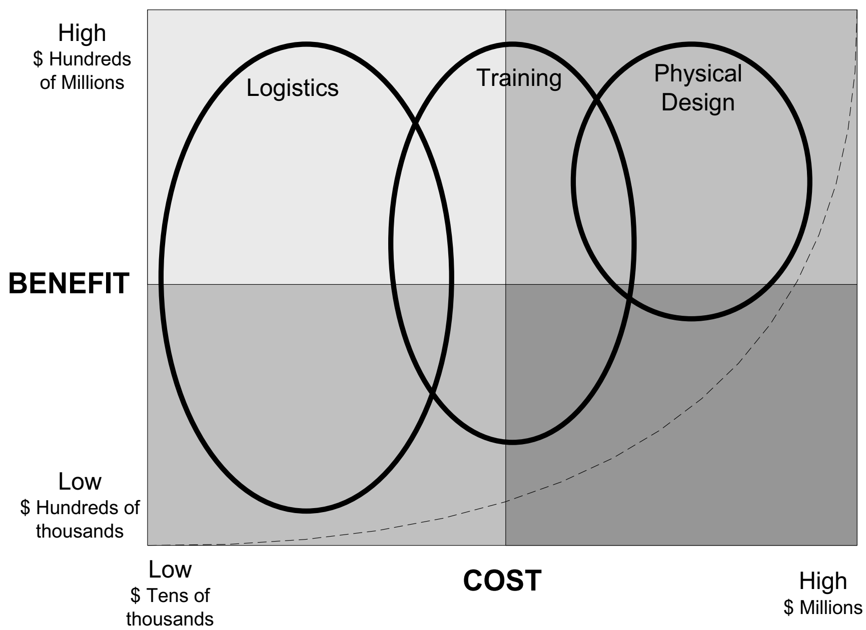

Figure 2: Cost-effectiveness of M&S on the basis of application areas

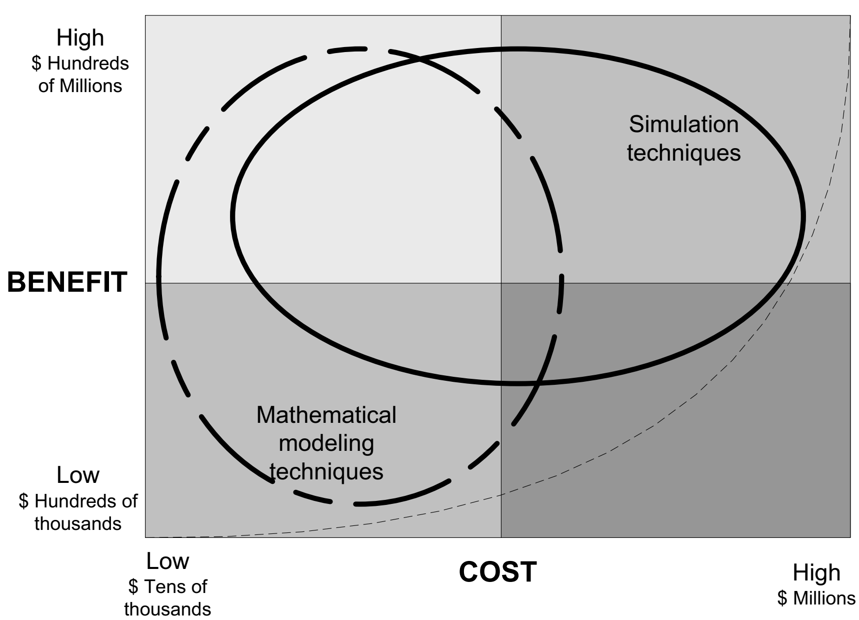

Figure 3: Cost-effectiveness of two groups of M&S techniques

Costs of M&S are to some extent independent of the size of companies, whereas the large companies can benefit more due to the fact that these companies are dealing with large-scale problems with potentially high impacts if the problem can be solved by M&S solutions (figure 4). Also, these companies may be able to reuse a model for its various business units with minor adjustment efforts, thus taking the advantage of 'economy of scale'. Examples are large electronic and computer manufacturers, working in very competitive markets, for which a moderate M&S investment can lead to huge savings (Nagali et al. 2008, Lin et al. 2000, and Billington et al. 2004).

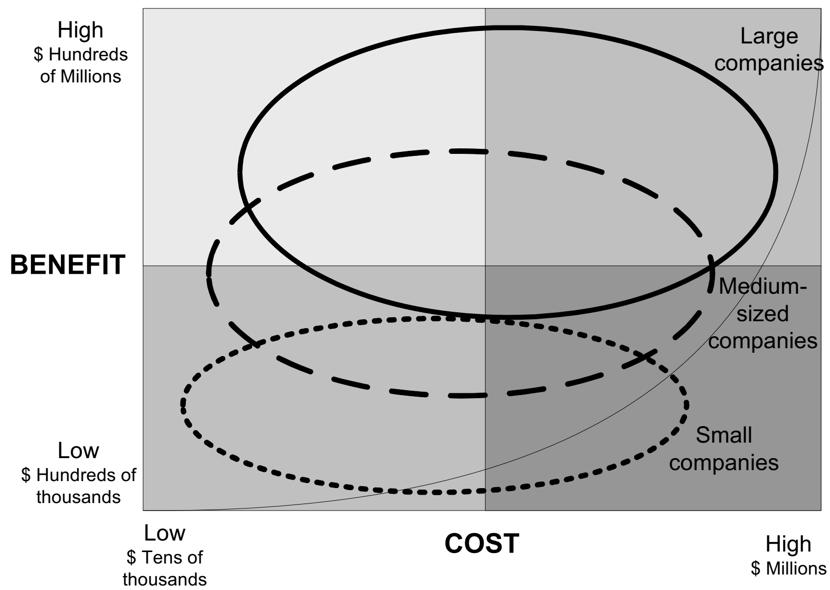

Figure 4: Cost-effectiveness of M&S on the basis of company size

So far, we have looked at the M&S cost-effectiveness topic from a general point of view - though supported mostly by evidence from non-healthcare sectors - making some general inference portrayed within a simple framework. In the next section, however, we will look at the distinctive features of healthcare systems and identify a set of implications of an M&S cost-effectiveness study in this sector.

6 REFLECTIONS AND IMPLICATIONS FOR HEALTHCARE

There is limited evidence of simulation modeling being used to drive change in the care delivery system (Jahangirian et al. 2009). The situation is even worse, when it comes to the study of M&S cost-effectiveness in health settings. Within our survey we were unable to find any article in this area.

We believe all the metrics in the previous section can be applied - to some extent – to healthcare. However several factors need to be accounted for. Healthcare systems are characterized by some distinctive, essential features that should come into consideration in a cost-effectiveness study. For example:

- Perhaps the most important point is that the majority, if not all, of cost-effectiveness studies in healthcare involve such key measures as 'human lives' or 'human health conditions'. Although the development of a measure called QALY (quality adjusted life year) has been helpful, it still adds extra complexities where it is to be combined with monetary metrics. But if a QALY only measure is of interest, our proposed simple 2-by-2 matrix framework can be adopted to compare various M&S techniques in terms of cost-effectiveness. Obviously, QALY needs to replace 'benefit' in the framework.
- A special feature of healthcare systems in the context of cost-effectiveness studies is that the extent of benefits in terms of lives are far greater than M&S expenses, and therefore it is even more likely that an M&S technique will be cost-effective in a healthcare setting compared to the status of M&S in other sectors.
- It is predicted that an M&S attempt within a healthcare setting would most likely cost more than the same attempt if carried out outside healthcare. This could be due to the fact that healthcare

processes are more complex (Jenkins et al. 1998 and Lowery et al. 1994), and also data gathering in a healthcare setting is more expensive as a result of ethical issues involved as well as the high cost of clinical staff times.

- According to figure 4, centralized healthcare systems, such as the UK National Health Service (NHS), may benefit the most from economies of scale as described earlier.
- One of the challenges of introducing M&S potential benefits to the healthcare sector is that the healthcare community is less familiar with the mathematical concepts of M&S than the manufacturing, business, and defense stakeholders are. This will make any awareness attempts including cost-effectiveness studies more critical for healthcare sector.

7 CONCLUSIONS

This study was initiated by a question as to why simulation modeling has had little reported impact in care delivery systems. After reviewing studies of M&S cost-effectiveness we discovered a wide variance of cost and impact in the few papers that reported on this. However, extrapolating from experience, as a possible way to show M&S cost effectiveness, we have proposed a simple 2-by-2 matrix framework to represent 'practice guidelines.' We have given possible examples that may 'speak' to managers and top-level decision makers.

Although healthcare systems are characterized by some distinctive features, the proposed framework can still be used with some minor adjustments, for instance in the case of QALY measures. This study also provided some insights into the comparative analysis of the economics of M&S for healthcare and other sectors. For instance, we maintained that some extra cost will be associated with M&S projects in the healthcare sector compared to other sectors. Yet, there are some other factors involved on the benefit side that generally make M&S projects more cost-effective in healthcare than it is in other sectors. This statement will be even more applicable to a centralized healthcare system such as the UK NHS. While our previous observations show healthcare has benefited from M&S mostly in training and medical device design, there is a massive opportunity there to make the best use of M&S in logistics where the cost-effectiveness is even higher. These implications and insights will play as a starting point for further detailed research in the future. Godin (1976) identified the lack of data on the economics of simulation. This is still the case. Compounding this with a lack of standardized metrics and meaningful dissemination mechanisms to healthcare policy makers, makes this one of the greatest barriers to the adoption of M&S this vital areas.

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