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AN INVESTIGATION OF HYBRID SIMULATION FOR MODELING SUSTAINABILITY IN HEALTHCARE

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ABSTRACT

There is increasing awareness among stakeholders in healthcare that the present day reforms in this sector need to be structured around financial, environmental and social sustainability. This arguably serves as a motivation to investigate ways to incorporate sustainable development measures into their planning cycles, and furthermore to implement these plans through delivery of sustainable services. Use of Modeling & Simulation (M&S) is essential for such planning as it provides the stakeholders with a tool to experiment with alternative strategies and to evaluate the resultant simulation output in terms of both productivity-related criteria and sustainability-related metrics. This paper presents a hybrid M&S approach for sustainability analysis that relies on both "Discrete" and "Continuous" elements for the purpose of modeling strategic and operational aspects of the underlying healthcare system. An existing case study is discussed through the lens of the proposed new Hybrid Simulation Framework for TBL Modeling (HSF-TBL).

1 INTRODUCTION

Sustainability-related research has seen an exponential increase in recent decades and continues to be amongst the fastest-growing research areas in scientific literature. This is however not surprising considering that there is a growing body of evidence which suggests that the international community is faced with drastic environmental challenges related to climate change and global warming. In healthcare, sustainable development is important as the sector has historically demonstrated negative environmental and social impacts. For example, in England, the healthcare sector is responsible for approximately 5% of the country's greenhouse gas emissions (NHS 2012); in USA, around five million tons of waste and energy expenditure of USD 8.3 billion per year is attributed to healthcare (Singer 2010).

Greater demand for healthcare services combined with the need to make major cost savings mean even greater challengers to sustainability in healthcare (NHS 2009), which, if not met may have a spiraling negative effect on society and patient care (WHO 2012). In order to respond to these sustainability-related challenges, adherence to which are gradually being incorporated in both national and international legislations and regulations on sustainability, healthcare decision makers are required to shift their management discourse towards sustainable development discipline (Sadler et al. 2011). This is leading to an awareness among healthcare stakeholders that their success is now also dependent on striving for and establishing a balance between the economic, social and environmental responsibilities with respect to their strategic priorities through the lens of the "Triple Bottom Line" (TBL) framework (Gimenez et al. 2012). There are several studies that have reported on the advantages of sustainable development on organizational performance (i.e. Elliott 2012; Reid 2013; Blewitt 2014; Winn 1995). However, from an operations

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management perspective, it is important that the TBL strategies are implemented in practice. In pursuance of this goal it is arguable that computer Modeling and Simulation (M&S) is a valuable tool in the hands of the decision makers. It allows for the experimentation of alternate TBL-centric strategies and to compare the results of the simulation in a meaningful way. M&S studies have been widely used in industry to gain insights into existing or proposed systems of interest. However, our review of literature (Fakhimi et al. 2013) shows that here has been a dearth of empirical research on integrating sustainability factors with systems' modeling studies; this is particularly the case with healthcare. Most of the existing papers in this area of research are from the Journal of Simulation special issue (published in May 2015) which was devoted to modeling for sustainability in healthcare (Mustafee and Katsaliaki 2015).

We define a TBL-based model as an abstraction of an underlying system of interest that is developed to analyze the system based not only on productivity criteria (e.g., resource utilization, service time) but also on environmental and social criteria. According to a literature review conducted by Fakhimi et al. (2013) there are five main reasons why TBL modelling is challenging: vagueness and ambiguity, data complexity, uncertainty, difficulty in balancing TBL, and factors relating to morality and social norms. Due to these unique characteristics of TBL-based systems it is arguable that modelling such systems is complex!

In order to develop a model with such characteristics this research proposes a hybrid simulation approach for TBL modeling in the healthcare context. Hybrid simulation can be defined as the combined application of techniques from the continuous and the discrete modeling paradigms or indeed it can be the use of two or more techniques from either of the aforementioned paradigms (Mustafee et al. 2015). The assertion is that a combined simulation approach will provide a more realistic representation of the underlying behavior of the TBL system (vis-à-vis modeling using a single simulation technique) and in realization of this it is essential to develop a framework to support TBL modelling. Out paper is essentially on the framework and its underlying justifications.

The remainder of the paper is organized as follows. The next section presents a literature review on M&S for modeling TBL systems and articulates the need for a framework to support modeling of hybrid TBL systems. Section three presents the Hybrid Simulation Framework for TBL Modeling (HSF-TBL). Section four outlines a case study in healthcare. This is followed by the application of the HSF-TBL framework. Section five is the concluding section of the paper. It summarizes the research and highlights its contribution, discusses future research and draws the paper to a close.

2 M&S FOR MODELING TBL SYSTEMS

TBL-based systems can be complex and uncertain and they frequently incorporate different levels of managerial decision making, for example, strategic and operational. This is more so in the case of healthcare as it combines various subsystems and includes multiple stakeholder groups. Developing models to respond to such complexities require insight into the characteristics of sustainability and the system that is to be modeled; it may also necessitates a rethink on the methodological aspects of M&S techniques which lend itself to modeling of TBL systems.

According to Pidd (2009) in any successful modeling practice there needs to be close fit between modeling methodology, system and problem. A practitioner will therefore need to reflect on the nature of the system and the problem prior to modeling and method/technique selection (Chahal and Eldabi 2008). Therefore, in order to find a systematic approach to modelling sustainability the authors analyze TBL modeling using a three-legged integrated approach which comprises of, (a) problem perspective, (b) system perspective, and (c) methodology perspective. The objective of this analysis is to provide guidelines that would enable practitioners to select the most appropriate modeling approach for TBL modeling. A similar form of analysis is used by Chahal and Eldabi (2013) in the context of hybrid modeling in healthcare.

2.1 Problem Perspective

It has been argued that sustainable development in organizational context is mainly a strategic concept (Jain et al. 2013; Gimenez et al. 2012). However, the realization of strategic and policy decisions is usually only possible through operational implementation. Taking an example from healthcare, sustainable operations management requires a holistic understanding of the interplay of TBL (including political factors) at the strategic level; at the same time it may also require an understanding of the detailed operational elements of the system being modeled, such as, the pattern of patient arrivals and resource usage. Thus the chosen modeling approach for sustainability analysis should ideally be able to represent both the operational and the strategic elements of the system being investigated. Hence we argue that a simulation approach chosen for TBL modeling should include both "Discrete" and "Continuous" modeling capabilities in order to address both the strategic and operational aspects of the problem.

2.2 System Perspective

The nature of the system being simulated is an important consideration because there needs to be a close fit between the model/modelling technique and the system that it represents (Morecroft and Robinson 2006; Pidd 2009). From systems perspective it is important to take into consideration the impact a system will have as a result of stakeholder decision-making. This impact could either be long-term or short-term. To maintain sustainability of the underlying system, long and short-term questions needs to be easily addressed by changing the level of abstraction of the underlying model. Long-term impact mostly arise from strategic decisions; they usually demonstrate relatively low uncertainty are more holistic in nature (Tako and Robinson 2009; Chahal and Eldabi 2013). The processes with long-term effects should be composed into an aggregate level of analysis in TBL modeling. On the other hand, short-term impact generally are an outcome of operational-level decision making. The level of uncertainty demonstrated in such processes is high and concern primarily with the microscopic view (Tako and Robinson 2009; Chahal and Eldabi 2008). The processes with these characteristics should be analyzed at individual level in more detailed manner. However, our findings shows that there are very few studies reported in the literature (i.e. Gunasekaran and Irani 2014; Ratan et al. 2010; Seuring and Muller 2008) that have used M&S in the context of Sustainable Operations Management (SOM) and which have taken into account the strategic and operational-level strategies that may need to experimented in a simulated environment prior to implementation.

Using multiple simulation methods can reduce the gap between *'what is to be modeled?'* (TBL-based system) and *'what can be modeled?'* (using individual simulation techniques). Using a combination of simulation techniques is also known as Hybrid Simulation and it allows for the investigation of systems using techniques which can be discrete-time or continuous-time (Mustafee et al. 2015). Thus the use of ABS-DES (discrete-discrete) is an example of hybrid simulation, as also SD-DES (continuous-discrete), SD-ABS (continuous-discrete) or indeed SD-DES-ABS (continuous-discrete-discrete) (Mustafee et al. 2015).

Within the overarching sustainability-related theme hybrid simulation could facilitate greater insights to problem solving where strategic questions (with possible long-term impact) may be answered more efficiency using scenarios developed using continuous models having the capability of aggregate analysis (lower level of details), and scenarios developed using discrete-modelling techniques may be used for detailed-level analysis. TBL modeling may benefit from a framework to aid the development and analysis of such hybrid TBL-based models. The level of abstraction of the models has to be flexible and easily adjustable based on the questions that need to be answered using the TBL based models. In pursuance of this objective we propose the *"H*ybrid Simulation Framework for TBL modeling (HSF-TBL)*."*

2.3 Methodology Perspective

This section presents an analysis of TBL modeling from methodology perspective. This refers to inherent characteristics as well as technical capabilities of the M&S method. This would in turn help a modeler to adopt the most appropriate technique to evaluate TBL-based systems.

According to our findings, the combined application of Discrete Event Simulation (DES) and System Dynamics (SD) could cater for characteristics of an ideal TBL model. Through a review of literature it has been identified that DES and SD are among the most applied M&S techniques for sustainability analysis (Fakhimi et al. 2013). Yet another literature review has highlighted healthcare modeling studies that have applied a combination of SD and DES (Fakhimi and Probert 2013). There have been comparative studies on SD and DES which have highlighted their technical and philosophical differences, differences in interpretation of the problems and visualization of the systems, and the difference in the way these techniques have been applied (i.e. Morecroft and Robinson 2006; Lorenz and Jost 2006; Tako and Robinson 2009). A common limitation of the existing frameworks is that they focus mostly on *'what needs to be measured?'* rather than *'what needs to be answered?'*. However, it is arguable that the latter is an important consideration for TBL modelling. Existing studies (Brailsford and Hilton 2001; Chahal and Eldabi 2013) have not considered the characteristics of TBL models while selecting specific techniques; our work has built on existing research on technique selection and have applied this to TBL models . The purpose of Table 1 is to provide guidance with regard to selection between SD and DES based on the consideration of the combined view of system, problem, methodology and TBL analysis. As can be seen from the table, SD-DES combination fits the aim of this research and could offer significant benefits to the TBL modeling objectives. However, using these features in order to design a hybrid model with the aim of analyzing the sustainability of the system requires further insights into the characteristics of the TBL based system and the methodology for designing the combined SD-DES model.

Table 1: Criteria for Selection between SD and DES for TBL modeling.

Criteria	**DES**	**SD**
Problem Perspective		
Purpose	Productivity based decisions: TBL based optimization, comparisons and comparison	TBL monitoring: strategic decision makings and learning
Problem Scope	Productivity related operations	Strategic
Importance of randomness	High	Low
Importance of interaction between TBL KPIs	High	Low
TBL system's Perspective		
System View	Detailed view	Holistic view
Dealing with complexity	Detail complexity	Dynamic complexity
Evolution over time	Event-based	Continuous
TBL Analysis Perspective		
Required level of Resolution	Detailed individual level	Aggregate high level
TBL impact	Short-Term	Long-Term

3 HYBRID SIMULATION FRAMEWORK FOR TBL MODELING (HSF-TBL)

As discussed earlier this research argues that a TBL-based hybrid M&S approach may to help decision makers to identify the interactions and alignments between 1) strategic and operational decision-making, 2) long-term and short term planning, and 3) simultaneous micro and macro analysis of the system. In order to meet the requirements of TBL modeling, the HSF-TBL framework is proposed and it includes a five step modeling process. This section presents and outlines the proposed HSF-TBL together with detailed discussions on steps of the framework. The composition of the steps is based on Robinson (2011) and Shannon (1998) contributions to the model development process. The five steps of HSF-TBL are:

- Problem identification and Conceptualization (Section 3.1)
- TBL Key Performance Indicators (KPIs) (Section 3.2)
- Method Selection (Section 3.3)
- Combined Models (Section 3.4)
- TBL Analysis (Section 3.5)

3.1 Problem identification and Conceptualization

The first step is to identify the problem and the objectives of the model. Problem definition will aid the professionals in suggesting the interventions that should be done in the system. Arguably, and unlike productivity based modeling, problem identification in TBL modeling does not follow linear casual (command and control) principles. A linear casual relation principle (Boudon 1965) tacitly perceives that the problem is well bounded, clearly defined, relatively simple and linear with respect to cause and effect of the problem (Holling and Meffe 1996; Moffatt et al. 2001). Hence, dealing with sustainable development and TBL systems via linear and mechanistic thinking make the modelers view the highly complex sustainable development as “engineered structures” prone to management with predictable and well controlled results (Baghri and Hjroth 2007). This research argues that in order to identify and analyze the cause of TBL-related problems, mechanistic and linear thinking approach is outdated and dynamical non-linear system thinking or in other words synergistic principles (Knyazeva 2004) should be followed instead. Identifying and analyzing the problem would help the modeler to formulate the objective of the simulation practice.

After identifying the problem and the objective of the modeling, the next step is to make the ideal TBL system more visible and understandable. A conceptual model can be helpful for this purpose. The conceptual model will enhance the understanding of how the whole system works (Pidd 2009), and helps the modelers to understand the domain and support communication between the modelers and users (Robinson 2011). Objective decomposition will facilitate the building of the TBL-based conceptual model. The processes in TBL systems are too complex and vague and, unlike productivity based models, modularizing them will be too difficult and can be more confusing. Also, the process should not be decomposed into three parts based on their respective TBL pillars (Environmental, Social and Economic). Therefore, the authors suggest decomposing the main objectives into several sub-objectives, then determining the techniques that are suitable for application.

3.2 TBL Key Performance Indicators (KPIs)

As mentioned earlier, in TBL modeling the first question to be answered is not what do we want to measure?, rather, what question do we want to answer? Therefore instead of getting distracted by numerous number of TBL factors modelers are required to omit those factors that are less likely to affect the whole system as a result of the interventions. In general, indicators can be useful when no direct measurement tool can understand and assess the complexity of the situation. They will also help the decision makers to focus more on the affected area of the system and suggest relevant intervention and, thus, it will be time-saving for the purpose of modeling. To achieve these aims, modelers are required to first identify the Key

Process Indicators (KPIs). Subsequent to the TBL KPIs having being identified, modelers are to define the TBL bottlenecks that may exist in the system.

KPIs in TBL modeling should point to areas in the system where the links between the economy, environment and society are weak. In this research the weakest link in the underlying system referred as a TBL-bottleneck. TBL- bottlenecks may be defined as the component(s) that may have a significant sustainability issue and has the most significant impact on the sustainability of the whole system that is under investigation. Identifying “TBL Bottleneck” could assist problem owners to keep their system sustainable. Identifying TBL bottleneck(s) and KPIs of the system will help the modelers define the scope and boundaries of the model. This is a crucial step for reducing the complexities of modeling such systems. Identifying the TBL bottleneck(s) and KPIs in this step should be followed by justifying the affected components of the model in terms of why and how it affects the model in the long- or short-term period. The impact of KPIs on the overarching social, environmental and economic strategies should also be clear and traceable. Furthermore, access to historical data could help the modelers to ensure TBL bottleneck(s) and KPIs are identified correctly. Access to data for such modeling is a challenge as it may need to capture the TBL elements of the underlying system. Moreover, our findings suggest that there are no standard and generally accepted set of sustainability indicators (metrics). The modeler can seek advice and opinions from the sustainability experts and healthcare sector professionals.

3.3 Method Selection

This step will help the modeler to recognize what is expected from each technique before actions are taken for implementing the model through a computer simulation software. Method selection will be based on the criteria of each sub-objective. This research proposes two criteria to facilitate the method selection phases in HSF-TBL, a) level of analysis (aggregated or individual), and b) Impact (long-term or short-term). DES will be used for individual level analysis in order to explore short-term scenarios. DES will be used to address the productivity related issues. SD will be used for aggregate analysis for providing long-term projections of the scenarios. Table 2 shows the techniques based on the criteria mentioned above.

3.4 Combined Models

The fourth step in HSF-TBL focuses on combination of SD and DES for TBL modeling. This step initiates with identification of the interaction formats between models. Identification of the formats could provide the context of what is exchanged between techniques (Brailsford et al. 2010).

For SD-DES interaction in hybrid format, the leading model in this hybrid union should be DES which causes changes in dynamics of the whole system. In this format, fluctuations in operational interventions represented by DES can be captured by SD and sustainability of the whole system can be evaluated by feedback loop in response to this interactions in model. SD models represent the holistic view of the system (low resolution) and DES provides modeler with the detailed view (high resolution). The KPIs will continually exchange information until both models are in a stable state based on predefined thresholds. Monitoring the dynamic interactions of operational interventions with the whole system through the lenses of TBL framework could ensure the sustainability of the system. There are some studies that have applied similar format for analyzing long term impact of the interventions at operational level from a wider perspective (i.e. Umeda and Zhang 2008; Reiner 2005).

Table 2: Selection of suitable technique for each criteria.

Criteria	**TBL KPI**	**Suitable Simulation technique**
Type of analysis	Individual	DES
	Aggregate	SD
TBL impact	Short-Term	DES
	Long-term	SD

Our findings shows that linking TBL KPIs within the same model or between two different models could be complex and needs to be planned in advance. Identification of influencing TBL KPIs may reduce this complexity. This will guide the modelers on how different models holding several TBL KPIs should be linked internally (within their common model) and/or externally (with their respective indicator in other model). Identifying the influencing and influenced TBL KPIs in the model would facilitate monitoring the target TBL KPIs (i.e. TBL bottleneck) as well as implementation of TBL feedback Loop in the model.

3.5 TBL Analysis

The last step of HSF-TBL is focusing on result analysis using TBL assessment framework principles. Harmonious synergies achieved through TBL can deliver a 'win-win' situation that realizes multiple interconnected aims (economic, social and environmental). Therefore, analyzing the results of TBL modeling requires an integrated approach to enable balanced consideration of all three sustainability-related dimensions. To achieve this modelers should assign measurement scales and weighting to TBL KPIs.

Unlike traditional productivity-based models which are based on "Command-and Control" managerial disciplines, sustainability analysis requires to become more integrated, flexible and robust (Hjroth and Bagheri 2006). In the context of healthcare, sustainable healthcare management is, actually, a continuous "experimental learning" process to face the social, environmental and economic uncertainty surround the healthcare units. Making decisions upon systematic approach would help the healthcare unit to actively adapt to the constant changes and be open for renewal and improvement. Hence, in order to analyze the TBL modeling result, models are required to be dynamic and flexible, not rigid and static. This research argues that the TBL-based model should be responsible for monitoring the observing system against TBL framework and strategic priorities. The results also needs to be supervised regularly to ensure: a) all of KPIs dealing with either of TBL pillars are within the boundaries of the threshold being set for them (in case of healthcare modeling, social responsibility KPIs are always first priority); b) the decisions must be made based on the impact of KPIs on system performance in the long term and short term. Short- term and long-term monitoring is static unless it continuously links to strategies and assessment of different futures (Holling 2001). Therefore, TBL modeling should be considered as learning method rather than a forecasting tool. To establish the proposed HSF-TBL approach for TBL modeling, a case study in healthcare context is used. The original case study is based on Mustafee et al. (2011).

4 CASE STUDY AND APPLICATION OF THE FRAMEWORK

Abertawe Bro Morgannwg (ABM) University Health Board (UHB) is amongst the largest health boards in Wales. At the time of writing the original case in 2011, it employed around 17,000 staff serving a population of approximately 600,000 and covering the areas of Bridgend, Neath Port Talbot and Swansea (ABMUHB 2011). It operated a total of 16 hospitals, with four of them having 24-hour A&E - Morriston Hospital (MH), Princess of Wales Hospital (PWH), Neath Port Talbot Hospital (NPTH) and Singleton Hospital (SH). The catchment area of ABMUHB is logically divided into the West zone (which comprises of MH and SH) and the East zone (PWH and NPTH). SH houses the Cancer Centre and the Department of Hematology and serves the entire ABMUHB catchment area. The Department of Hematology in 2011 operated a centralized resource pool consisting of seven consultant hematologists. These consultants were responsible for outpatients, day patients and inpatients in all the four hospitals (these hospitals, in turn, received referrals from the other ABMUHB hospitals and the GP clinics). At the time the original study (Mustafee et al. 2011) was conducted, the structure of delivery of hematology OPD services consisted of outpatient clinics that were held in all the four hospitals.

A study conducted by ABMUHB and the Royal College of Pathologists recommended a proposed reorganization through consolidation of outpatient clinics from four hospitals to two. It proposed that the clinics are to be based in SH (catering mainly to the West Zone) and PWH (catering mainly to the East Zone). The central pool of hematologists can be allocated to clinics in any four of the hospitals. Most of the clinics run weekly at a predefined day of the week and time (there are two clinics that take place in alternative weeks). Each clinic has a fixed number of appointment slots, e.g., clinic X may have 5 NP appointment slots (comprising of, for example, two 10-day slots, one urgent slot, and the two regular slots) and 7 FUP slots. Also, some clinics may have several consultants assigned to them, for example, an afternoon clinic in SH has three hematologists, who between them, are responsible for a total of 3 NP and 56 FUP. The recommendations looked into the efficiency aspect of the operation. However, they did not take into account the cost implications and environmental impacts on this plan.

As discussed earlier, in any healthcare reform the three main responsibilities (social, environmental and economy) have to be taken into consideration. However, their recommendations only considered the social aspect of the service reconfiguration. Accordingly, the model presented in Mustafee et al. (2011) did not taken into the consideration the TBL factors. This study extends the existing model which focuses on productivity-related metrics and incorporates aspects of TBL modeling through use of the framework-driven approach.

4.1 Application of the HSF-TBL framework

Step 1 (Problem identification and Conceptualization): The main objective of our model is to analyze the outpatient clinics' consolidation plan against the TBL framework.

Step 2 (TBL Key Performance Indicators): To illustrate our approach, we decided to include at least one Key Process Indicator (KPI) for each of the TBL pillars. The followings are assumed in support of TBL KPIs:

- **Social responsibility** can be modeled in terms of quality of service and efficiency aspects of operations which is measured with the Referral To Treatment (RTT) waiting time – focusing on the capacity and demand issues for hematology OPD across SH, MH, NPTH and PWH (presently 26 weeks with first appointment at 18 weeks; ABMUHB cancer services have a goal of reducing this to 17 weeks with first appointment at10 weeks);
- **Economic responsibility** can be modeled in terms of costs relocations and reorganization of resources (i.e. provision of specialist clinics);
- **Environmental responsibility** can be modeled in terms of CO2 emission which is a function of transport and applies to both the patients and doctors/specialists (business travel within the NHS Trust and other types of vehicles are not modeled). It is expected that the consolidation of outpatient clinics will have an impact on the distance that has to be travelled by both the patients and specialists to attend a clinic;

Step 3 (Method Selection): According to our TBL modelling criteria (Section 3.3), subsequent to the TBL KPIs being identified, appropriate simulation techniques will need to be selected. DES will be used to analyze the system at individual level and examine the short term impact of implementing the consolidation plan on ABMUHM's social, environmental and economic responsibilities. DES is the leading model in our hybrid union format and fluctuations in operational interventions representing by DES is capturing by SD. SD will be applied to analyze the system at aggregate level.

Step 4(Combined Models): As mentioned in section 3.4, identification of influencing TBL KPIs may reduce complexity of combining two models. This is facilitated by the implementation of a feedback loop in ABMHUHM model. The feedback loop will function in the system in order to ensure the system will not go beyond the predefined threshold assigned for each TBL KPI. The TBL KPIs will continuously exchange information until both models are in a stable state based on predefined threshold. Table 3 depicts an example of TBL indicators identification for the purpose of our case study and suitable technique can be used to capture them.

Step 5(TBL Analysis): It is to be noted that this is an on-going study and we are further developing the model and incorporating more TBL KPIs to the model. We expect to present the detailed modelling process against HSF-TBL framework in a stepwise manner and the results of the simulation experiments in a subsequent publication.

Table 3: Identifying how TBL KPIs are influencing each other in SD-DES format.

TBL KPIs "Influence" (Suitable Captured by DES)	**TBL KPIs "Influenced" (Suitable Captured by SD)**
Resource provision (i.e. allocation of specialists)	Economic Responsibility (e.g.,. expenses, salaries, transportations costs); Environmental Responsibility (e.g., reduction in vehicle pollution, reduced emission of greenhouse gases); Social responsibility (e.g., availability of specialists in the catchment area)
Capacity and demand management	Economic Responsibility (e.g. performance improvement); Social Responsibility (i.e. reducing waiting time)
Patients and specialists transportation	Economic Responsibility (i.e. transportations costs, reduction in ambulance fleets etc.); Social Responsibility (i.e. patients and staff preference, etc.); Environmental Responsibility (reducing fuel consumption and air pollution, etc.)

5 CONCLUSION

This paper presents a novel framework-based approach towards modeling for sustainability analysis. It is argued that an ideal modeling approach for such a complex and uncertain system is hybrid M&S, which is a result of a combination of discrete models representing operational aspects of the system and continuous models representing strategic dimensions. There is a dearth in studies that have applied hybrid discrete-continuous methods in an integrated way for TBL modeling in the healthcare context. In order to meet the ideal requirements of TBL modeling we have proposed the HSF-TBL framework. The proposed framework could assist M&S practitioners to develop reliable models that neither ignore sustainable development dimensions nor mislead decision makers into making decisions that ignore productivity and efficiency measures. It is argued that the proposed framework can be applied in various scenarios for sustainable development planning within the healthcare context. The application of the framework is discussed in relation to an existing healthcare model (hematology OPD case study); it focuses on the requirement of fulfilling both productivity-related objectives as also the TBL KPIs. To support out proposed hybrid approach only one representative for each TBL pillars is considered. In future research this will be extended for all the TBL pillars. The SD-DES model is currently under implementation and future research will thus extend the hematology OPD model through the application of the HSF-TBL framework, and analyze the results from the TBL framework perspective.

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