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A HYBRID AGENT-BASED AND DISCRETE EVENT SIMULATION APPROACH FOR SUSTAINABLE STRATEGIC PLANNING AND SIMULATION ANALYTICS

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ABSTRACT

Modern healthcare reforms are required to be financially, environmentally and socially sustainable in order to address the additional constraints of financial resources shrinkage, pressure to reduce the environmental impacts and demand for improving the quality of healthcare services. Decision makers face the challenge of balancing all three aspects when planning. However, implementing such an approach, particularly in healthcare, is not a trivial task. Modeling & simulation is a valuable tool for studying complex systems. This paper investigates the application of a hybrid approach that combines Agent-based Modeling & Simulation (ABMS) and Discrete-Event Simulation (DES) for analyzing sustainable planning strategies for Emergency Medical Services. The paper presents a case study that shows how combined ABMS and DES models can support strategic planning and simulation analytics, respectively. The generated data from the ABMS is fed to the DES model in order to analyze the different strategies and the preliminary results are promising.

1 INTRODUCTION

The "Brundtland Commission", formally known as the World Commission on Environment and Development (WCED) defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). The concept of “sustainability” has spread across society. In healthcare, sustainability is important as the sector has major negative environmental and social impacts. In England, the healthcare sector is responsible for approximately 5% of the country’s Green House Gas (GHG) emissions (NHS 2012). In the USA, around five million tons of waste per year and a spend of USD 8.3 billion on energy annually is attributed to healthcare. 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). Healthcare services have begun to undergo some changes in response to these challenges as sustainable development issues have become more prominent in all sectors of society (Sadler et al. 2011).

Healthcare systems can incorporate sustainability measures into their facilities, services and operations for many reasons, as there are many positive benefits that result from addressing environmental and economic responsibilities (Bettley and Burnley 2011). There is increasing awareness among healthcare stakeholders that their success is heavily dependent on a balance between economic, social and environmental responsibilities with respect to their strategic priorities through the lens of the

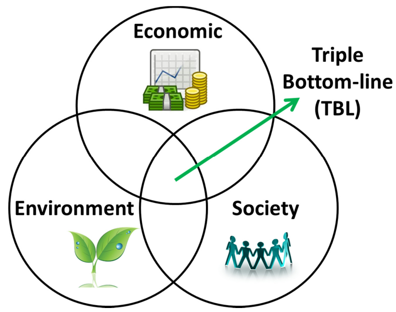

Figure 1: The spheres of sustainable development.

"Triple Bottom Line" (TBL) (see Figure 1). In order to address recently introduced international and national rules and regulations on sustainability, healthcare decision makers are required to shift their management discourse towards sustainable development disciplines.

Although, interest in sustainable development practices has increased over recent years, hindrances remain to designing, implementing and improving such practices in healthcare on a regular basis. As sustainability is becoming more vital for healthcare, dealing with its challenges are also becoming more complex and costly. Computer simulation could be valuable in providing this understanding and insight in coping with such systems with high levels of complexity, dynamic behavior and uncertainty. The main reason for developing simulation models for sustainability is to provide supporting tools that help to understand the impact of sustainability-related issues on decision making in healthcare. However, despite this need there is only a small number of simulation systems that address aspects of the complex interplay of economic, environmental and social values. A review of contemporary M&S studies have also shown an imbalance in the treatment of economic, social and environmental aspects of sustainability, for example very few studies incorporate all three aspects (Fakhimi et al. 2013). The scarcity of literature and empirical models in this field, arguably, shows that challenges still remain in implementation and validation of such models particularly in the healthcare sector.

TBL-based systems can be very complex and uncertain, particularly in healthcare, as they combine various subsystems consisting of many elements and stakeholders with very different interests. Thus, TBL-based systems have complicated needs, characteristics and problems in different given contexts. Developing models to respond to these complexities requires insight into the characteristics of sustainability and sustainable systems, and also a major rethinking on studying sustainability beyond existing modeling disciplines. Sustainability can entail a set of vague, unending and non-deterministic processes with the optimum not known in advance (Bagheri and Hjorth 2005). Therefore, measuring sustainability is not easily feasible (Bell and Morse 2003). It may be the case that the different characteristics of different elements of a TBL-system may require a combination of modeling techniques. Furthermore, analyzing the output of different sub-models of a potentially large and complex models introduces another degree of complexity. To attempt to investigate and tackle these challenges, the research work presented in this paper proposes a hybrid modeling & simulation approach that uses both Agent-Based Modeling and Simulation (ABMS) and Discrete-Event Simulation (DES) to study and support a simulation analytics of large and complex systems in the strategic planning of sustainable systems.

In this paper, we explore an unconventional use of this hybrid ABMS-DES modeling approach that not only includes the measures of central tendency of sustainable systems, but also measures the dispersion of outcomes. Inspired by the panel discussion at the 7th Simulation Workshop (SW14) of the Operational Research (OR) Society in the UK (www.theorsociety.com/SW14) and the CloudSME project workflow management framework (www.cloudsme.eu), a DES model is developed as such in order to manage and analyze the complex output data from a low level TBL-based simulation model studying sustainability. We developed an individual-level ABMS model of a healthcare organization, namely the London Ambulance Service (LAS), taking into consideration environmental and social factors together with financial benefits for the healthcare unit. The resulting data of the model is analyzed in a DES model that was developed as an intelligent workflow that combines and compares the outputs of the simulated scenarios in the ABMS model. It is hoped that this demonstrates the potential of hybrid M&S together with simulation analytics approaches in this area.

The next section presents background knowledge of ABMS-DES hybrid modeling approaches for sustainability analysis. Section 3 describes the modeling approach and section 4 discusses the development of the case study. The results from the application of the proposed approach are discussed in section 5. Section 6 concludes the paper with a discussion of future research directions.

2 BACKGROUND

ABMS, DES and System Dynamics (SD) are the three most applied M&S techniques for sustainability-related analysis, according to a review conducted by Fakhimi et al. (2013) and included journal and conference papers that appear in the ISI Web of Science® from 1970-2012. Each of these techniques have unique as well as common underlying theoretical and methodological foundations (Mustafee, Katsaliaki, and Taylor 2010). It therefore follows that specific modeling techniques may be more appropriate for modeling particular classes of operations' problems. However, as mentioned in Fakhimi and Mustafee (2012), the complexity of systems being modeled and their multi-faceted relationships may mean that combining simulation methods will reduce the limitations and increase the capabilities of the individual methods, thereby potentially realizing synergies across techniques and facilitating greater insights to problem solving.

Hybrid M&S, in the sense of combining different simulation paradigms, is attracting more interest as a research area (Jahangirian et al. 2010). It has been employed in a wide range of application domains and in various combinations. For example, AbouRizk and Wales (1997) combined DES and continuous simulation in the construction sector; Mustafee and Bischoff (2013) used ABMS and analytical optimization (heuristics) modeling to study the problem of container loading; in healthcare, Chahal and Eldabi (2008) combined SD and DES in a hospital setting; ambulance management policies were analyzed by Aringhieri (2010) using a combination of ABMS and DES in a single simulation package; and Nouman, Anagnostou, and Taylor (2013) used distributed simulation to develop an interoperating hybrid ABMS-DES model for holistic analysis of Emergency Medical Services (EMS).

In this paper, the authors propose a novel approach for hybrid ABMS-DES modeling that support strategic planning and simulation analytics. therefore, we briefly introduce the main concepts of ABMS and DES.

ABMS is being used to model complex adaptive systems that consist of interacting elements (Heath et al. 2011). It is a technique that has become a major area of M&S research effort (Viana et al. 2014; Taylor et al. 2013). ABMS is used mainly to model decentralized, complex systems that consist of many inter-dependencies. Comparing with other modeling techniques, ABMS can provide a more realistic view of a system that has these properties. In ABMS, agent characteristics and behaviors may vary, they may have a goal to reach, and agents may learn from their environment and change their behaviour and goals accordingly. Therefore, arguably, ABMS could help modelers to develop models for social-environmental systems (Hare and Deadman 2004). However, literature reviewed for the purpose of this research indicates that there is a little practical support for applying ABMS techniques and how to implement them for such purposes (Fakhimi et al. 2013).

DES is widely used to study organizational processes, mainly as queuing systems. DES also is one of the most applied simulation techniques used in sustainability or green management related models (i.e. (Jain et al. 2013; Jaegler and Burlat 2012; Nageshwaraniyer et al. 2011; Moeller et al. 2009). However, in this research DES modeling is seen from a different perspective. The event-driven simulation engine can facilitate the analysis of temporal incoming data. Furthermore, the visual environments of the commercial

DES packages, provide sophisticated data analytics visualization capabilities. Therefore, DES is applied as a simulation analytics tool in the proposed hybrid approach.

The relatively new term of simulation analytics is used to describe the comprehensive analysis of a system with the use of simulation techniques, the analysis of the input and output data, the visual representation and the way the results are displayed. Simulation analytics is mainly concerned with the results of simulation. Currently, after searching the academic databases, it is evident that there is little academic literature in the field. Generally, practitioners use the term to communicate the outcomes of simulation studies to stakeholders. With the emerging interest in big data, data analytics and simulation analytics there is much research that needs to be addressed in this area.

In line with these emerging challenges, we now introduce briefly the modeling approach adopted for the purpose of this research.

3 MODELING APPROACH

As mentioned in section 1, two events were the main inspirational trigger behind this research work. First, at the panel discussion of the 7^{th} Simulation Workshop of the UK's OR Society (SW14) (www.theorsociety.com/SW14), which was focused on simulation analytics, experts in the field (Barry Nelson (Northwestern University, USA), Mark Elder (SIMUL8), Ken McNaught (Cranfield University, UK) and Christine Currie (University of Southampton, UK) expressed their views on novel ways of using simulation analytics. It was pointed out that the emerging challenges of big data, data analytics and simulation analytics, for example, will encourage modelers to alternative ways of practicing and applying simulation. For example, simulation can be seen as a system that generates vast amounts of transactional and temporal data. In most cases, this can be categorized as big data in a sense of falling into one or more of its four Vs (Volume, Variety, Velocity, Veracity) characteristics. Moreover, simulation can generate and analyze data for systems that exist or do not exist.

However, simulation analytics is not just the analysis of output data, but rather the way this analysis is presented. Sophisticated DES software can provide (or potentially provide) interactive ways of visualizing output data analysis. For example, automatic charts and data tables can display time series data. This feature of DES software, can offer insight in the dynamic behavior of the performance measures, or Key Performance Indicators (KPIs), of a system.

Second, the workflow management framework of the CloudSME project (www.cloudsme.eu) was the stimulus for developing an intelligent workflow-based DES as a simulation analytics tool that combines and manages incoming data generated from another model. In this case, the LAS ABMS model that incorporates all three pillars of the TBL framework for exploring strategic planning for sustainable development.

Figure 2 illustrates a high level of the proposed hybrid modeling approach. The first component of the hybrid model is an ABMS model that analyzes a system in an individual level. This component therefore produces data for the existing system (base case) as well as for systems to test strategic planning scenarios. The second component is the intelligent workflow-based DES that takes as inputs the incident data that is generated from the ABMS base case and scenarios. The DES model then combines the temporal input data, and compares the KPIs between the simulated scenarios.

In the current implementation, the DES model is called seamlessly from the ABMS model code when

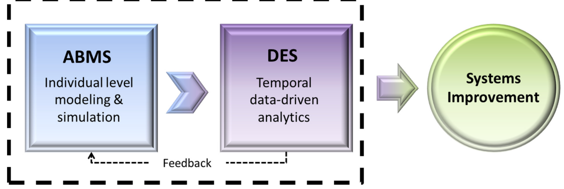

Figure 2: Modeling approach.

a simulation run is completed. This analytics component of the hybrid system displays the outputs in customized tables and graphs. Furthermore, the feedback loop indicates that the DES model compares the outputs of the simulated scenarios and suggests a new set of input parameter to the agent-based model according to some preset constraints and targets.

One can argue that similar type of analysis can be, and is already, done by well-known spreadsheets, e.g., MS Excel. However, this requires a vast amount of complicated macros, while DES packages have already a built-in intelligence to implement such an analytics tool with a simple workflow-based DES model.

We now introduce an exemplar case study where a hybrid ABMS-DES model is developed to investigate sustainable strategic planning in a complex healthcare system with simulation analytics.

4 CASE STUDY

Climate change and global warming are the results of the exceeded concentration of certain atmospheric gasses, known as GHG. From the six main GHG, carbon dioxide CO2 is the major man-made gas that is released by fossil fuels burning. According to a report commissioned by the National Health Service (NHS) Sustainable Development Unit (SDU) in the UK, NHS England represents the 25% of the total English public sector GHG emissions (SDU 2008). To support the reduction of the greenhouse effect, the NHS SDU developed strategies (Carbon Reduction Strategy 2009, and Sustainable Development Strategy 2014-2020) to meet the Climate Change Act (HMSO 2008) targets of 26% reduction in GHG emissions by 2020 and 80% reduction by 2050 (www.sduhealth.org.uk).

A significant proportion of the NHS GHG emissions are caused by traveling. In the carbon footprint report (SDU 2008) it is stated that the travel GHG emissions accounted for 18% of the total NHS emissions in 2004. In the report, travel includes all business travel, fleet, and patients and visitors travel to healthcare facilities. Each NHS Trust published policies for contributing to GHG emissions reduction and conformance to Climate Change Act targets. The focus of this paper is on the London Ambulance Service (LAS). The LAS carbon footprint in 2010 was 17,885 tons of CO_2 emissions in total. Approximately 12,500 tons CO_2 was caused by the fleet. Carbon footprint refers to the total set of GHG emissions produced by an organization or a person (GrEAN 2011).

From October 2013, in the UK, it is mandatory for big companies to report direct and indirect GHG emissions (DEFRA 2013). Direct and indirect emissions are defined by the GHG Protocol (www.ghgprotocol.org) as: "Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity. Indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity." Further classification categorizes the GHG emissions into three scopes: Scope 1: All direct emissions, Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam and Scope 3: Other indirect emissions.

Due to the nature of ambulance services, the major part of GHG emissions is caused by the fleet. For this reason, and due to the lack of detailed data on indirect emissions, in this research only direct emissions from ambulance fleet is used (scope 1). Furthermore, from the six GHG, only CO_2 emissions information is reported and therefore this is included in the model.

As mentioned in section 3, the first component of the proposed hybrid modeling approach is an ABMS model that analyzes a system in an individual level, in this case the ambulances of the LAS system. The ABMS model generates data for every emergency incident as this is simulated dynamically with the progression of time. The second component is a DES that analyzes the incoming data and finds the best set of input parameters. The implementation of the two components of our approach is explained next.

4.1 ABMS Model Development

Ambulance services, in an outline, include the emergency call center, or centers, the vehicles and the crews. The call operators have to respond to the emergency call, assess the incident severity in order to send the appropriate vehicle and crew, find the closest available vehicle to the site of the incident and send the vehicle to the patient. The crew, in turn, apart from the medical treatment on site, has to decide whether the patient needs to be transferred to a hospital or released after the on-scene treatment. If the patient has to be transferred, the closest available hospital and the fastest route should be found (see Figure 3).

The LAS model is developed using the free and open-source REPAST ABMS simulation system (www.repast.sourceforge.net). REPAST suite is an ABMS toolkit that comes with a Java application programming interface. Its basic simulation engine is the `Schedule` class, which is a discrete event engine. More details on the model development can be found in Anagnostou, Nouman, and Taylor (2013).

As part of the NHS England, LAS NHS Trust contributes to the NHS carbon reduction strategy. In 2010, as part of the Corporate Social Responsibility report, LAS published the planned carbon reduction activities (www.londonambulance.nhs.uk). These include, among others, cycle response and low emission fleet. According to SDU (2009), the low emission fleet is currently redundant but is considered for future years.

Finding data for sustainability modeling is a challenge as it needs to address all the elements of the TBL framework. In this work, we attempt to include at least one of each representative KPIs for TBL. To illustrate our approach we assume the following data in support of KPIs. Social responsibility is modeled in terms of quality of service which is measured with the ambulance response time, that is the time taken to answer the emergency call to the time that an ambulance vehicle arrives at the incident scene. Economic responsibility is modeled in terms of fuel consumption by the emergency vehicles for every incident. The average driving speed in London is 15mph (Steinbach et al. 2012), while cycle speed is considered, based on experience, as 10mph. Finally, environmental responsibility is modeled in terms of CO_2 emission by the emergency ambulance fleet (business travel within the Trust and other types of vehicles are not modeled). Information about the CO_2 emission of the ambulance vehicles can be found online (www.whatdotheyknow.com/request/fleet_list_57 and http://www.fleetnews.co.uk/costs/van-running-costs/36/90000/Mercedes-Benz/Sprinter/#search). The first source links to a response by the LAS Information Governance Manager, dated 27 February 2013, to a public enquiry and provides a spreadsheet that lists the type of vehicles that are used by the organization. According to this response, LAS uses Mercedes-Benz Sprinter vans for emergency ambulances. The second link provides detailed information about the specific car make characteristics. From the above, we use an approximation of fleet CO_2 emission and fuel consumption per mile travelled. Consequently, the fleet CO_2 configuration of the ABMS model is considered as 240 gr/Km (converted to 386.243 gr/mile) for the current emergency fleet and 180 gr/Km (converted to 289.682 gr/mile) for the low emission emergency fleet. According to the emergency vehicles characteristics, in an urban environment they travel 25 miles per gallon of fuel. Thus, the fuel consumption was converted to 0.1818 liter/mile.

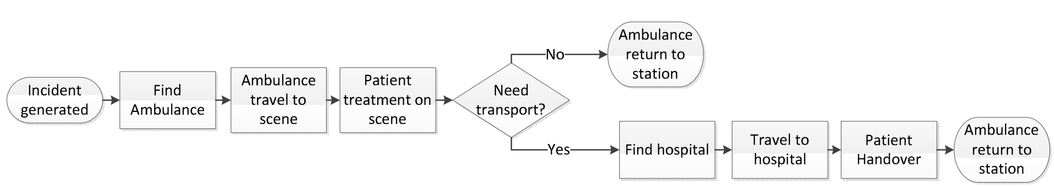

Figure 3: ABMS flowchart.

4.2 DES Model Development

The DES model was developed using the commercial package SIMUL8 (www.simul8.com). SIMUL8 provides a user-friendly, drag-and-drop environment for model development. It provides components as objects that have the default logic of the DES paradigm. Further logic can be added by the package-specific programming language, namely Visual Logic. Moreover, the software provides sophisticated tools for simulation analytics, such as customizable tables and graphs that display the outputs dynamically as the simulation time progresses.

A screenshot of the developed simulation analytics environment is shown in Figure 4. This includes the model, tables that state the configurations of each scenario, tables that display numerical results, and graphs that display the temporal outcome of the KPIs for the different scenarios. These will be explained in the next section.

The entities upon arrival read data from CSV files that are generated from the AMBS model. Each entity holds a data set item that has as attributes (called labels in SIMUL8) all the data units for one incident. The assignment of all attributes happens in the initialization work station, as shown in Figure 5. The next step is to combine all scenario-specific input items into larger data sets that hold information about every scenario that was imported. For example, a combined data set *S* at a time *t* holds all data units from each scenario subset for the same time *t*. Thus, if there are *n* input scenarios, the relationship can be described by the union of all subsets.

$$St = \{S_1t \cup S_2t \cup \ldots S_nt\}$$

The logic for comparing and analyzing the data items is programmed in the next workstation. The queue objects between the workstations do not have any functional purpose, however for modeling good practice are added in the model (i.e. verification checks).

At the end of the run, a simple heuristic algorithm is called in order to compare the output of two reference scenarios in order to propose an improved set of input parameters for the ABMS. In the current implementation, this happens manually, however the hybrid system can be modified in order to automate the process.

Next, we present the experimental results and discuss the findings.

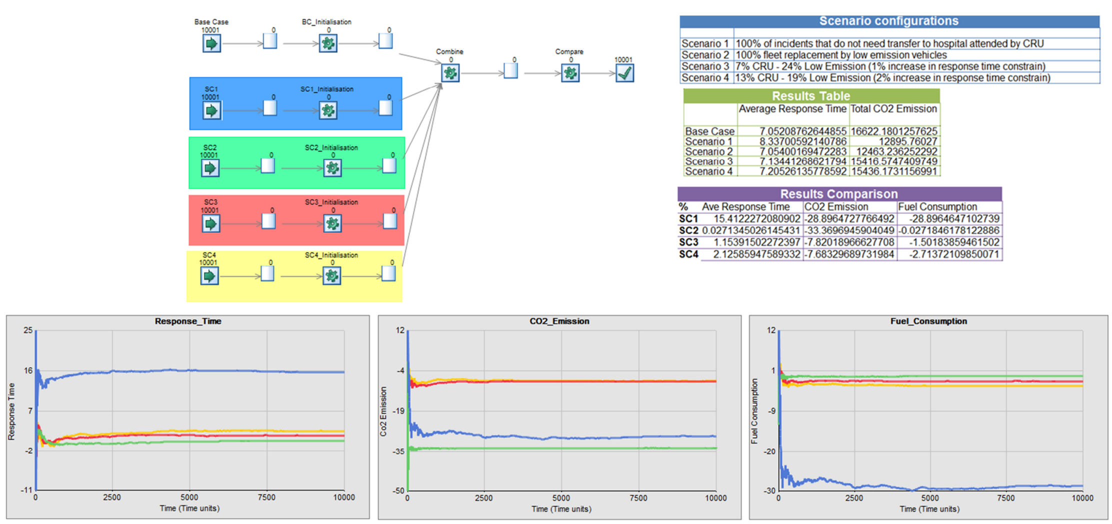

Figure 4: DES simulation analytics environment.

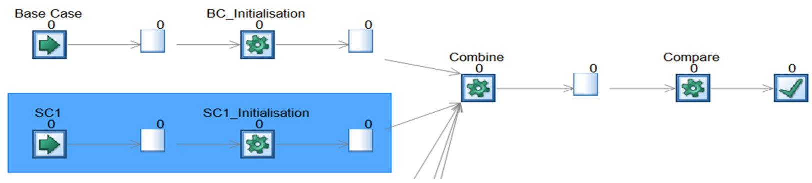

Figure 5: Workflow-based DES model.

5 EXPERIMENTAL RESULTS AND DISCUSSION

Experiments were conducted based on the NHS's carbon reduction strategy and the LAS's planned activities to support it, as explained in section 4.1. In order to find the impact that each of the two activities has on the KPIs, we first simulated the scenario that all emergency incidents that do not need transfer to a hospital are attended by the Cycle Response Unit (CRU) (scenario 1). We then simulated the scenario that all ambulance vehicles are replaced by low emission vehicles (scenario 2). From the first experiment, we expect a negative impact on the response time, while from the second experiment, we expect a positive impact on the CO_2 emission. These first two experiments (scenarios 1 and 2, as shown in Figure 6) represent the extreme impact of the two tested policies. For a comprehensive sustainability analysis of LAS, all possible policies and parameters combinations should be tested. However, for purposes of illustration, we show two possible scenarios that are generated using a simple heuristic algorithm. To achieve this, we use the comparison of the first and second scenarios. Due to the nature of the ambulance services, response times cannot be reduced significantly. At the same time, we do not want to reduce the CO_2 emission as much as possible but rather reach an acceptable target. Therefore, for the third and fourth scenarios, in order to calculate the desired input parameters, we set a minimum constraints for the response time and a maximum target for the CO_2 emission reduction. In line with this, we calculated the input parameters using the following algorithm:

```
if sc1_RespTimeOut >=constraints
   param_CRU = (current_param_CRU * constraints) / sc1_RespTimeOut
   sc1_CO2Out = (param_CRU * sc1_CO2Out) / current_param_CRU
   param_LowEmission = [param_LowEmission * (CO2Target - sc1_CO2Out)] / sc2_CO2Out
endif
```

Using the above algorithm, we calculated the input parameters when the response time reduced by 1% and 2%. The CO_2 target is set to 10% reduction for both cases. For the third scenario, therefore, the constraints is set to 1% allowed increase of response time with a target of 10% reduction on CO_2. (scenario 3). The input parameters for achieving this target without violating this constraints are 7% of the incidents that do not need transfer to hospital attended by CRU and 24% fleet replacement with low emission vehicles. Finally, the fourth scenario is set to 2% allowed increase in response time and again a 10% target of reduction on CO_2, and uses 13% CRU responses and 19% low emission fleet replacement (scenario 4), as shown in Figure 6. The base case model involves none of the above, i.e., no incident is attended by CRU and there is none low-emission vehicle in the fleet.

The tested scenarios input is color-coded and the customized output graphs show the scenarios colors. This helps the analysts to easily identify the trends while the simulation is running. Further, the numerical results are displayed in the customized tables, but these are more difficult to follow during the simulation run.

Scenario configurations	
Scenario 1	100% of incidents that do not need transfer to hospital attended by CRU
Scenario 2	100% fleet replacement by low emission vehicles
Scenario 3	7% CRU - 24% Low Emission (1% increase in response time constrain)
Scenario 4	13% CRU - 19% Low Emission (2% increase in response time constrain)

Figure 6: Experimental scenarios configuration.

For illustration, we ran the simulation for 10,000 incidents (represents 10,000 simulation time units) and compared the results. The plotted graphs for the representative KPIs of the TBL framework in the system under study are shown in Figure 7. While the simulation is running, the graphs are plotted in a temporal manner. The analyst can observe that the first scenario, indicated in blue, causes a considerable increase in the response time (negative impact on the social aspect of TBL), however, it decreases the CO_2 emissions and the fuel consumption (positive impact on the environmental and economic aspect of TBL). The second scenario (green) performs rather well in all three aspects, however we should mention here that the initial cost of replacing all emergency ambulance with low emissions vehicles was not taken into consideration. It is therefore expected that there is a considerably negative impact on the actual economic bottom-line. The inputs for the third and fourth scenarios were generated using the aforementioned algorithm and the output from the first two scenarios. The third scenario, indicated in red, shows that the constraints of less than 1% increase in the response time is satisfied. In the same time, the target of 10% decrease of CO_2 emissions is almost reached. Finally, the results of the fourth scenario (yellow) show that the average response time agrees with the preset constraints of less than 2%, as well as, the target for CO_2 emission is again almost reached. In this scenario, however, we observe a further reduction in the fuel consumption in relation to scenario three.

Results Comparison			
%	Ave Response Time	CO2 Emission	Fuel Consumption
SC1	15.4122272080902	-28.8964727766492	-28.8964647102739
SC2	0.0271345026145431	-33.3696945904049	-0.0271846178122886
SC3	1.15391502272397	-7.82018966627708	-1.50183859461502
SC4	2.12585947589332	-7.68329689731984	-2.71372109850071

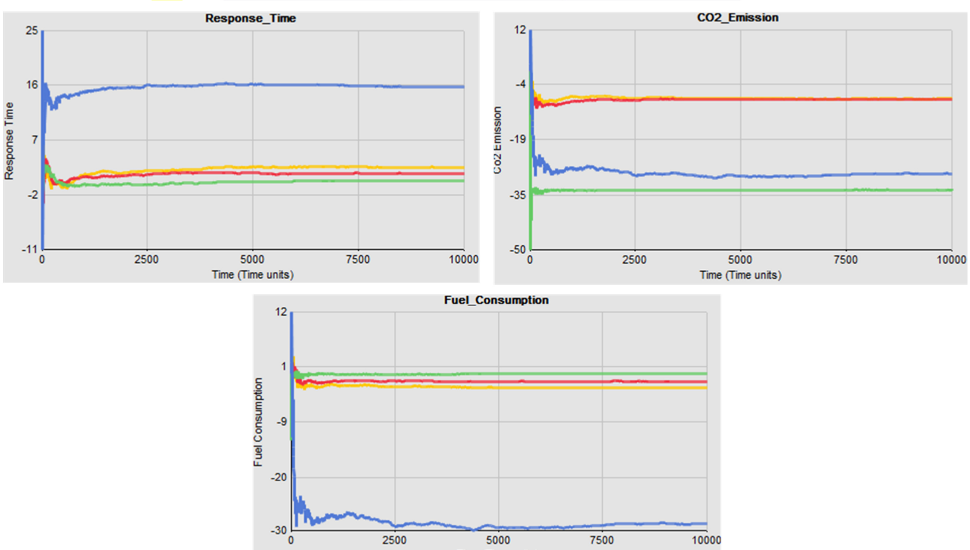

Figure 7: Sustainability analysis of the results based on TBL framework.

6 CONCLUSIONS

This paper presented a novel approach of hybrid ABMS-DES modeling for strategic planning and simulation analytics. The focus of the presented case study was on sustainable planning within the healthcare sector. London Ambulance Service was selected as a representative healthcare organization that faces the challenges of all three aspects of the Triple Bottom Line framework. The authors propose that the presented hybrid approach can be applied in various modes for sustainable development planning within the healthcare context.

The proposed approach of using hybrid modeling and simulation as a framework for analyzing large and complex systems using simulation can potentially have an enormous impact on the way we see and apply simulation analytics. More particularly, the emerging trend, which certainly will become prominent in the future, is to distribute large models, either as parallel simulation or distributed simulation, over networked resources (grids, clouds, etc.). When doing so, the outputs of the different resources can arrive at time intervals, or after the simulation completion, but as different sets of output data that need to be combined and analyzed. Using a DES model to do so seems an attractive solution. However, research needs to be conducted in the field of simulation analytics in order to establish concrete methodologies.

Sustainability has been among the fastest-growing areas of activity in research in recent decades. Despite this, Modeling & Simulation approaches for implementing and managing TBL of sustainability are still in their infancy. TBL-based systems are uncertain and complex systems dealing with different levels of abstractions. Therefore, the future research is expected to explore applications of M&S for such systems. Addressing such issues may entail employing System Dynamics approach in addition to the combination of ABMS-DES for further analysis of the TBL-based system.

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