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Introduction

The term Hybrid Simulation (HS) was in use since the early beginnings of Simulation as a discipline. The initial definitions were based on combining discrete variables models with continuous variables models, or even models that combine simulation with analytical methods such as optimization (Shanthikumar and Sargent, 1983). Most of the earlier attempts of HS were based on pragmatic interests from computer programming or analytical perspectives. In the last 10 years, however, there was a sharp rise in the interest on HS. This is mainly driven by the rising need to cope with the heightened complexity of modern problems. HS is the combined use of two or more simulation models from three major paradigms in simulation modelling: system dynamic (SD), discrete event simulation (DES) and agent-based simulation (ABS) (Jahangirian *et al.*, 2010). Among these three methods, SD is a macro level technique dealing with aggregates which are at highest abstraction level; DES is appropriate for meso and micro level abstract; ABS is relatively new compared with other two methods, which could be used in all abstraction levels (Lättilä *et al.,* 2010). The three methods are applied in many areas, such as healthcare, supply chain, transportation, manufacturing, business and management but there are no applications in strategic management.

Strategic management is an essential process for companies to deal with an unknown future, which requires decision-making under uncertainty (Kunc and Morecroft, 2007). Strategic management helps companies to form their vision, analyse its internal and external environment, and select strategies to create value for shareholders and customers (Ireland *et al.*, 2008). However, the business system is complex and operates in a dynamic environment. Consequently, how to effectively manage and develop strategies for companies is challenging for managers (Rahmandad and Repenning, 2016; Kunc and Morecroft, 2009). Under this circumstance, HS can be another tool to support managers to make complex and dynamically challenging decisions, since HS could provide analysis comprising both macro and micro analysis of business issues.

Although HS is widely used modelling technique in business, after reviewing the literature, the application of HS in strategic management has not been discussed widely (Mustafee *et al.*, 2017; Brailsford *et al*., 2018). Therefore, the motivation of this paper is to propose a modelling development process that could be used in business to support strategic decisions. This study aims to explore the applicability and strengths of proposing the three-paradigm HS approach on developing and analysing strategies and build a bridge between strategic management with the OR Community by introducing the TOWS matric. Specifically, we build a hypothetical HS model loosely based on a largest chain of supermarkets in the United Kingdom for developing the model and testing strategies.

To achieve this target, the first objective is to build a hybrid model which combine SD, DES and ABS. More specifically, the model is to simulate the current situation in terms of SD for the financial operations and R&D development; DES to model the company's operational process and the supermarket's supply chain system; and ABS to simulate the market sector and how the individual customer behaves and interacts to make purchase decisions. The second objective is to generate a collection of potential strategic options for the company using the TOWS matrix considering the company's current strengths and weaknesses in terms of resources and competencies against future opportunities and threats (Weihrich, 1982). After selecting the strategy, the HS model will test its robustness and select the best option for the company's development.

Literature Review

The literature review covers the intersection of the areas employed in our study: the use of simulation in business, hybrid modelling and strategic management methods to develop strategies.

Simulation in Business

System Dynamics for Strategic Planning. SD model represents the real-world systems in terms of variables, stocks, and flows that are inter-connected (Sterman, 2000). Stocks, which could be money, people and material, are the core of the model and change at each time step because of the feedback loops that drive the flow rates in and out the stock (Goh and Ali, 2016). To understand a business problem in SD, it is essential to identify the system behaviour considering the interacting feedback process (Sterman, 2000). Generally, the SD model is a macroscopic view of a system and may be used to explore how the system structure generates the system behaviour (Morgan *et al.*, 2017, p.908) so SD is typically used in long-term, strategic models. It is based on its ability to capture the whole system rather than focusing on short-term goals and single measures of performance which helps managers to improve the performance of their businesses (Taylor and Dangerfield, 2005).

In the business context, SD offers a methodology to support strategic management and policy analysis (Sweetser, 1999; Kunc, Morecroft and Brailsford, 2018; Kunc, Mortenson and Vidgen, 2018). Dierickx and Cool (1989) first pointed out that SD could assist strategic planning since the company's strategic assets are accumulated over time. By using SD, managers understand whether the current strategy provides benefits over time and take actions to mitigate problems (Kunc and Morecroft, 2007). To further evaluate the functionality of SD in strategic development, Torres *et al.* (2017) divided the use of SD in strategy development into three areas: testing strategy theories, learning and developing strategic thinking and assisting strategic planning within companies.

Moreover, SD can combine with the scenario theory, which considers the external environment dynamic of the company, to better assist managers to formulate and understand the strategies adopted in the firms (Torres *et al.,* 2017). Kunc and O'Brien (2017) suggest a methodology that integrates the scenarios with the resource map to rehearse a firm's strategic performance using SD technique. Carlisle *et al.* (2016) evaluated and analysed strategic planning in a complex coastal urban leisure space, using the SD model to test the robustness of the strategy.

One of the critiques to SD models is the treatment of systems mechanistically, so it is not an appropriate paradigm for modelling systems where individuals within the system are highly differentiated, or when behaviour is best defined by people (and other entities) rather than the state variables themselves. SD is a "top-down" modelling approach, and thus requires extensive knowledge about how the state variables of the system interact with one another manner (Dooley, 2002, p.10).

Discrete Event Simulation use in Logistic and Production. DES emerged in the late 1950s (Hollocks, 2006). The basic factors in DES include events, entities, activities, attributes, and queues (Hoad and Kunc, 2016). Modellers use DES to simulate the individual events together with the entities that operated in the system at discrete steps and explore whether the system can meet its target in different situations (Pidd, 1988).

DES has been applied in different areas such as manufacturing, business processes, supply chain, logistics and manufacturing. Particularly, DES has been mostly used to plan and schedule activities, because it can evaluate the operational performance of the system before the actual implementation in the real world (Lin *et al*., 2001; Rabelo *et al*., 2005). Hence, DES supports decision-making with useful information about how operating systems can be modified (Sweetser, 1999) and considers the impact of stochastic processes to demonstrate system performance under specific values and policies (Hoad and Kunc, 2016).

DES is also commonly applied to simulate the supply chain system and the production processes. Using DES to model production of the company has been seen as the best practice in the industrial engineering for a long period since DES provides a realistic view of the system with detailed individual variables of the system (Banks and Gibson,1998; Hoad and Kunc, 2016). Many service facilities, production systems, maintenance and recycling facilities, and transportation and material handling systems are best described and simulated via DES (Wang *et al*., 2014, p.78).

However, DES has some limitations. DES models the micro variables of the system so when dealing with business strategic level decisions, strategic data is difficult to acquire and often unavailable (Zülch *et al.*, 2002). Peña-Mora *et al*. (2008, p.703) point out that due to the narrow focus on detailed information, DES models sometimes fail to provide realistic estimations because missing data or unrealistic rules can significantly affect process performance. They also mention that since the DES model uses an event-oriented view to analyse processes, it cannot integrate feedback structures between process performance and project contexts. Furthermore, DES is not appropriate when state variables interact with each other and change continuously, and when entities and their internal mechanisms are the elements of the simulation that more important than the event itself (Dooley, 2002, p9). DES is therefore used to complement SD models: to explore the same system but to focus on the part of the system behaviour which is not fully captured by SD model (Morgan *et al.*, 2017, p.910).

Agent-based Simulation in Customers' Behaviours and Market. ABS models simulate the system as a collection of agents that are discrete entities designed to mimic the behaviour of the real-world counterparts (Siebers *et al*., 2010, p.8). Bradshaw (1997) and Siebers *et al*. (2010, p.8) noted that unlike DES objects, agents are "objects with attitudes" and they can make autonomous independent decisions and show proactive behaviour based on a set of rules. Agents follow their internal logic and interact with each other (Bonabeau, 2002; Railsback and Grimm, 2011), their behaviours are influenced by the environment and agents learn from the environment to meet their objective in the dynamic system (Swinerd and McNaught, 2012, p.119,). Macal and North (2010, p.151) further explained how agents relate to each other. It is often referred to as topology or connectedness. Typical topologies consist of a spatial grid or network of nodes (agents) and links (relationships), describing how and with whom agents interact.

ABS helps managers understand the effect of unexpected factors and guide them to improve predictability (Nilsson and Darley, 2006). Thus, the model has been applied in several areas, human social, customer behavioural, physical and biological systems (Macal and North, 2014). The research considering issues such as understanding and modelling consumer behaviour and decision-making focuses on agent behaviour in the supply chains (Hilletofth and Lättilä, 2012), consumer motivations (Zhang and Zhang, 2007) and firms' environmental behaviour (Liu and Ye, 2012).

ABS also performs well in the analysis of business competitive environment, e.g. ABS models can simulate individual actions and interactions of agents in a complex adaptive market environment (North and Macal, 2007), especially when considering customers, retailers and competitors (Macal and North, 2010, p.151; Wang *et al.*, 2014, p.78). Modelling issues related to Diffusion of Innovation theory using ABS models is popular among scholars. Garcia (2005) points out that ABS can elicit the diffusion innovation theory because ABS is useful when the population is heterogeneous. Scholars have used ABS to demonstrate the changes between adopters and potential adopters in the business context (Dekimpe *et al*., 1998) and applied ABS to manage customer relationship by figuring out the key drivers of customer behaviours (Baxter *et al.*, 2003). Moreover, ABS is useful to explore the individual customers' decision of certain products (North *et al*., 2010) and provide the performance of the whole system with sufficient details.

Macal and North (2010, p.151) suggest that emphasizing the heterogeneity of agents in the population and the emergence of self-organization are two distinguishing features of ABS compared to other simulation techniques (such as DES and SD). Compared with SD models which are "computationally more efficient and analytically tractable", ABS models are more powerful in terms of structural realism and spatial dimensions to be represented where they might affect system behaviour (Swinerd and McNaught, 2012, p.119; Wallentin and Neuwirth, 2017, p.166). However, ABS cannot offer a systematic view of the company that SD can provide. ABS is not a useful tool for modelling some critical features such as material flows, transportation, inventory staging, and queueing for resources which DES models are good at (Siebers *et al*., 2010). Besides, human agents with different behaviours are the soft factors that hard to quantify and justify (Bonabeau, 2002).

Hybrid Modelling

In real-world situations, problems and systems are often highly complex, so it is possible to use different methods to focus on different aspects of a situation. Mixing methods may be referred to in various ways using different descriptors, while 'Hybrid' modelling was the most popular term used. This term was first proposed in the context of mixing OR/MS methods by Shanthikumar and Sargent (1983) to describe several mixed simulations and analytic model designs (Morgan *et al.*, 2017, p.909).

Jackson and Keys (1984) suggested that the OR/MS community is motivated to mix multiple methods into one model by a desire to improve modelling capabilities and increase the effectiveness of modelling projects. All methods have their benefits but also have aspects that are captured less sufficiently. Mixing methods, therefore, hold the promise of an overall better approach (Morgan *et al.*, 2017, p.909). Morgan *et al.* (2017, p.908) indicated that this combination of individual methods provides an additional methodology to cope with different problems and systems, enabling the symbiotic realization of the strengths of individual methods, while offering the potential to overcome some shortfalls and reduce limitations. Howick and Ackermann's (2011) review of papers, which describes mixing OR/MS methods in practice, reveals several reasons for combining including to deal with a complex problem system, to support stages of a project, to obtain specific benefits from specific methods and to overcome method shortfalls.

From the frameworks for describing how different simulation methods are combined in a hybrid model, there are four main modes of hybridisation.

1) Sequential: two or more distinct single method models that are executed sequentially once, (Brailsford *et al.*, 2018, p.5). One module runs first, and its output then fed to the next (Swinerd and McNaught, 2012, p.124)

2) Enriching: one dominant method, with limited use of other method, that is when SD is dominant while DES and/or ABS are used to model subsystems contained within it (Brailsford *et al.,*2018, p.5).

3) Interfaced: modules may be run in parallel with their outputs combined as required to represent the desired output as a function of time (Swinerd and McNaught, 2012, p.124)

4) Integrated: one seamless model in which it is impossible to tell where one method ends, and another begin. It is the highest level of hybridisation (Brailsford *et al.*, 2018, p.5 and p.20).

With the development of hybrid models, Mustafee and Powell (2018) identified these three types of HS model.

Type 1: Models that contain both discrete and continuous elements, e.g. a model combining DES and SD.

Type 2: A hybrid simulation model composed of elements that are either continuous or discrete, but not both, e.g. a model combining ABS and DES.

Type 3: Type 1 joined with Type 2, e.g. a model combining ABS, SD, and DES.

These three types of HS models can be further divided into four types of combinations.

Type 1-Hybrid Model of SD and DES. According to Brailsford *et al* (2018), the combination of SD and DES is most commonly used in hybrid modelling, which provides a top-down perspective for managers to understand the system. The two methods cope with the problem in different ways, SD simulates continuous variables, and DES evaluates the discrete entities (Brailsford and Hilton 2001). Specifically, SD treats the system as a whole, in which the elements are dynamically influenced, while DES pays more attention to the details, looking at the variation of each individual entity (Heath *et al.*, 2011). Hence, this type of hybrid model looks the system holistically by using the discrete components to represent the operations and the continuous elements to simulate the environment (Moradi *et al.*, 2015). The applications area of hybrid system of SD and DES include healthcare. (Zulkepli *et al.*, 2012; Viana *et al*, 2014), construction system (Rabelo *et al.*, 2005) and production and manufacturing enterprise (Venkateswaran *et al.*, 2004; Alvanchi and AbouRizk, 2011).

Type 2-Hybrid Model of SD and ABS. ABS and SD are often applied to simulate the complex dynamic system (Garcia, 2005). The two methods both have been used in various socio-economic problems include supply chains, healthcare and technology adoption (Guerrero *et al.*, 2016). Since SD is not designed for network and spatial diffusion problems, the combination of the two methods can improve SD models to solve problems in the network structure (Guerrero *et al.*, 2016). Osgood (2007) demonstrated that, based on different modelling goal, some sectors of the system can be modelled in an aggregated way and others can be disaggregated if needed when using the integrated model of SD and ABS. In the business context, a hybrid model of SD and ABS is useful in dealing with the innovation diffusion phenomenon (Swinerd and McNaught, 2015) and product strategy (Kieckhäfer *et al*, 2009)

Type 3-Hybrid Model of DES and ABS. DES and ABS are similar to some extent. The two methods are at low-level aggregation and they are designed to simulate stochastic entities (Heath *et al.*, 2011). Thus, the combination of the two modelling approach gives a bottom-up view to simulate the reactions among entities (Brailsford *et al,* 2018). The differences between the two methods lie in two aspects. Firstly, the agents in ABS has their individual rules which decide their own behaviours, in contrast, DES is passive since those rules are at the system-level that guide the entities move and transit. Secondly, queue is a basic element in DES, which could model the efficiency and capacity of the system, but ABS does not contain this concept (Maidstone, 2012). Researchers have used ABS-DES hybrid model in analysing supply chain (Krejci, 2015; Mittal and Krejci, 2015), healthcare (Fakhimi *et al.*, 2014 ; 2015 Liravias *et al.*, 2015), transportation (Wang *et al.*, 2014) and production (Barra Montevechi *et al.*, 2015).

Type 4-Hybrid Model of SD, DES and ABS. This type of hybrid model is not as widely discussed as the other three methods, and rare paper introduces the technical details, for example, how to design and hybridise the model (Brailsford *et al.*, 2018). Healthcare is one area that used this type of hybrid model. Mackay *et al.* (2013) create a precise patient flow from emergency department to the general wards. Similarly, Viana *et al.* (2012) use SD to simulate the progression of disease, DES models the appointment scheduling process and ABS as the individual patients. In the business area, Wang *et al.*, (2014) use the hybrid model to study the lifecycles of the beverage products under different environmental conditions. The SD model was built in the Vensim, but the ABS model was simulated in the AnyLogic. The paper did not explain how the two models combine and integrate. Another application is proposed by Elia *et al.* (2016), they built a model to simulate the waste of electrical and electronic equipment.

TOWS Metric—A Tool for Strategic Planning

Strategic planning (SP) was developed in the mid-1960s. Weihrich (1982) suggests that SP is used to evaluate the current and the future scenarios, find the correct direction for companies and prepare the appropriate method to realise its mission. Different from strategic thinking, SP is an analysis process of programming and experimenting strategies (Mintzberg, 1994) that provides insights into the company and its operational environment (Ward, 1988) while defining the actions to achieve its goals.

After putting forward the concept of corporate strategy in the 1960s, various studies began to apply SP in the business field (Cosenz and Noto, 2016). Researchers tried to explore the relationship between internal capabilities and external environment of a firm (Mintzberg, 1987). Hence, SWOT analysis, a tool that could consider both external and internal factors has been widely used in evaluating strategies (Ravanava and Charantimath, 2012). However, SWOT method only list the current and the future trend, it cannot tell the company how to use its strength to take advantage of the opportunity and how to address its weakness under different contexts. Thus, TOWS matrix, which is a new situation analysis dimension stems from the SWOT approach, could provide a conceptual framework for evaluating the present situation and developing strategies to cope with future scenarios (Weihrich ,1982).

According to Weihrich (1982)'s framework of using TOWS matrix to assist SP, the process of evaluation could be summarised as followed. Firstly, it is significate to identify various organisational inputs and prepare for the enterprise profile. The next step is to understand the current external environment and forecast the future environment. After that, list the internal weakness and strength for the company. Then, build a TOWS matrix to develop alternative strategies and evaluate the choice of strategies. The next step is to experiment and analyse the strategies generated from the table. Lastly, complete the consistency test and prepare for the contingency plans.

There are four types of strategies in the TOWS matrix originated from combining the components in a pairwise way (Wickramasinghe & Takano, 2009). A Strength-Opportunity (SO) strategy maximises the internal strength by taking advantage of external opportunities. A Weakness- Opportunity (WO) strategy minimises the internal weakness in order to exploit external opportunities. A Strength-Threats (ST) strategy aims at protecting the strengths from external threats. A Weakness-Threats (WT) strategy is a defensive strategy to reduce the weakness to face the threats. Table 1 illustrates how the strategies generated using the TOWS matrix.

Particularly, SD is frequently used to experiment the strategies under different scenarios (Cosenz and Noto, 2016). SD was also first used in strategic planning in the field of strategic management (Craig, 1980). Some previous studies have integrated the SD modelling with the TWOS metric in order to test the robustness of the potential strategies (O'Brien and Dyson, 2007; Kunc and O'Brien, 2017). Hence, in this paper, because SD is interacted with other two models, the strategies would be experimented and anlaysed in the HS model.

Modelling Methodology

Case Selection

According to the UK Institute of Grocery Distribution (IGD), the UK supermarket industry is the country's largest private sector employer, around 3.9 million employers are working in this area, which created 14% of the employment for the country. In 2018, there are about 59,897 stores in the UK, with supermarkets and convenience stores valued at £89.1 billion and £40.1 billion respectively. IGD predicts that the overall UK food and grocery market would keep growing, increase by 14.8% in 2023.

As an essential industry contributing to the economy, retail managers need to make appropriate decisions. Previous studies using simulation methods in the supermarket industry have focused on layout design and location selection. For example, Sainsbury's partnered with SimWorld to create an ABS model to simulate customer behaviour in the store and help the company design the best store layout to generate more sales (CASTI, 1999). Kohara and Sekigawa (2014) use an ABS model to forecast the sales of the store at four different locations. These works mainly use the ABS model, focusing on the micro aspects of the supermarket, without providing a comprehensive and long-term view. However, the customer's shopping habits and the UK retail landscape continue to change rapidly, it is essential for decision-makers to think about how to develop the supermarket retail in the future. Thus, a specific HS model is built for an UK supermarket to test a collection of possible strategies.

Hybrid Model Development

The steps for developing a hybrid model include four stages: conceptual modelling, model development, model verification and validation, and experimentation using the model. In the last stage, the model is employed for testing the strategies generated from a TOWS matrix.

Conceptual Model

Robinson (2008) states that, “Conceptual modelling is the abstraction of a model from a real or proposed system and is independent of the model code or software”. The conceptual model for our HS is based on the resource map method proposed by Kunc and Morecroft (2009). The essence of this approach is that the performance of the company is determined by the resources of the firm since whether the organization could survive in the competition is depend on its ability to acquire and maintain resources in the dynamic environment (Kunc, 2018). There are seven resources (Table 2) representing tangible and intangible components of a supermarket.

Particularly, when modelling a complete company, there are four different dimensions to be considered, finance resources, R&D technology, operational resources, and the market sector. These four parts are integrated and interact with each other to influence the company’s profit and market share. To be more specific, the hybrid model of this supermarket is using SD principles to simulate the finance and R&D technology, ABS principles to model the market and customers, and DES principles to simulate the operational sector.

Figure 1 illustrates broadly how the components of the hybrid model link and interact. In SD model, the financial resource is used in investing R&D technology; thus, the company has the ability to produce own-brand product and improve customers’ shopping experience, which increases the company’s reputation in the market. Particularly, reputation is a bridge linking the ABS market model and the SD model, since potential customers, which are agents in ABS model, become interested according to the reputation attract rate in SD model. However, those agents who are interested and willing to shop in the supermarket are not real customers because they haven’t purchased any products. Only those agents who purchase products will transform to adopters in ABS model. Thus, a transaction between ABS and DES is required. Agents who are interested and want to purchase stay at ‘Wants to Purchase ’state in ABS model, they will be sent to DES model, simulating their shopping behaviours. If agents purchase products through DES model, they will become ‘Adopters’ in ABS model. Otherwise, they will continue to stay at the ‘Wants to Purchase’ state.

Model Development

After the completion of the conceptual model, the simulation model is developed in the Software AnyLogic, which is a hybrid/multi-paradigm simulator using a single platform.

SD Model of the Financial Sector.

The basic SD model is divided into two parts, the financial dynamic and the R&D technology dynamic (Figure 2).

In the financial sector, there is one flow: money transfer from income to investment. The model assumes that the income is calculated by cost of sales and total sales, which are the revenue from online sales and physical sales. As for the investment, the model focuses on the investment on human and technology resources. The model also includes other investments (i.e. ‘investment allocate to other resources’).

As for the R&D technology dynamic, there are three main flows. The first one is human resources (skills) increase, which is affected by investment allocated to human resource. This resource influences customer experience and labour efficiency. The second represents the changes in product technology such as own brand products. It impacts product quality and price. The last one is related with logistic technology to improve inventory management and transportation efficiency.

In the base SD model, there are four positive feedback loops (Figure 3). Firstly, the increase in total sales leads to larger investment in human resource, which enhances the company's service and customer experience. Reputation increases and helps to attract potential adopter and make more profits. Secondly, the company invests in product technology development when sales increase, which improves production quality with better pricing. Reputation can be promoted simultaneously to enlarge market and earn more for investment. Thirdly, the increase in income reinforces the investment in logistics technology, which enhances transportation and attracts more customers using the online shopping channel increasing sales. Lastly, more income leads to more investment in inventory management, which decreases cost of sales and increases income.

A negative feedback loop (Figure 4) starts from the total sales, which includes online sales and physical sales. When the income is increasing, the company invests more on logistics technology to improve online shopping experience since transportation is more efficient. However, if online shopping becomes more popular among customers, physical sales will decrease as a result.

Sub-model Interaction (SD and ABS). ABS model represents the customer and market sector, which is closely connected with SD model through two links. On the one hand, the ABS model is highly related to the R&D technology in SD model. If the company has excellent service, quality product with adequate price and superior shopping experience, its reputation will increase. Thus, the company will be more competitive and attract more potential customer in the ABS model. On the other hand, when agents move from potential customers to customers, these new customers flow into the stock of customers in the SD model to increase the total sales as a positive feedback loop. The interaction is summarised in the following table 3.

ABS Model of Market Sector

The ABS model is built based on the Bass adoption model (1969). Bass (1969) defined the initial purchase adopters as innovators who influence later adopters. Bass pointed out the diffusion process is contagious because potential adopters are 'infected' by word-of-mouth and mass media (Bohlmann et al., 2010). To build the ABS model for the market and customer, the first step is establishing a new agent type 'Customer' and set an initial number of agents equal to the number of potential customers who are willing to shop in supermarket.

The main components in the ABS model are states and transitions. Since the object in this model is to simulate whether the company has the capability to attract new customers (adopters) from the pool of potential customers and maintain their current customers, four states have built, which are 'Potential Adopter', 'Want to Purchase', 'Adopter' and 'Churn Customer'. Besides, five external transitions and one internal transition are developed to place the agent within different states. Figure 5 illustrates how the ABS model is designed.

Specifically, Potential customers move to 'Want to Purchase' state influenced by the company's image (i.e. 'Brand Attraction') so the attraction rate stems from the reputation level in SD (i.e. 'Increase

Attraction Rate'). The second transition is triggered by 'Word of Mouth' effect, which is the internal influence among agents. Word of mouth originates from company's current customers when they are speaking to their friends or families who are potential adopters. To simulate this effect, two transitions are built. Firstly, there is a cyclic internal transition contact in 'Adopter' state. The model assumes that the contact rate is 10 agent per month. When the transition takes place, the action code will lead the agents who are customers send a text message 'Buy'. If agents who receive the message are not customers and are in the 'Potential Customer' state, they will be influenced by word of mouth and move to 'Want to Purchase' state. Moreover, since not every contact is successful, potential agents may not be persuaded, 'Adoption Rate' is set to 0.5 so only 50 percent of contacts will succeed. When agents move to 'Want to Purchase' state, they become customers if they actually purchase products in the supermarket. The purchasing process is managed by the DES model, which includes a shopping process and a supply chain model.

Agents who are at 'Adopter' state can abandon the company because of the price war, product quality and other factors. Thus, the last state is 'Churn Customer', which is triggered by the 'Competition Rate' in this model. The rate is currently set to 0.01 per year, but it will change based on the competitive market. Furthermore, once the agents become competitors' adopters, they will move back to the 'Potential Adopter' state and may become adopters again.

Sub-model Interaction (ABS and DES). Since agents who are interested in the supermarket are not actual customers, they will become customers and move into 'Adopter' state only when they purchase in a shop. Thus, there are two interactions between ABS and DES model, agents who are at 'Want to Purchase' state are sent to the DES model and agents who purchase products in the DES model return to the ABS model and transform into 'Adopter' state. The interaction is summarised in the following table 4.

DES Model of Operational Sector.

The DES model simulates the operational process of the company, which includes two aspects: customers' shopping process and the supply chain of the supermarket. The first part is connected with the ABS model, affecting whether the agents transform into customers, and the second part influences the purchase decision of agents when they are in the supermarket.

In the shopping process model (Figure 6), agents who are at the 'Want to Purchase' state in ABS model will arrive at the start point Customer Arrival. When agents arrive at the supermarket, customers will start their purchasing activity ('Hanging Around' variable) in the supermarket. Then, agents will 'Move to Destination' situation according to their shopping list. The next step is to 'Check Shopping List' and make decisions, agents will decide whether to purchase products or leave the supermarket, which depends on whether the product is in stock. If the supermarket cannot provide the product, agents will select the second route 'Not Purchase Leave', leaving the store without purchasing. In this situation, agents will not transform into adopters in the ABS model. If the product is in stock, agents will move to 'Purchase Product', where they will queue for checking out. The delay time for checking out is followed the triangular distribution. After this step, the agent goes to 'Purchase and Leave', where agents are sent back to the ABS model as an 'adopter' and the supermarket will update its stock immediately using the DES supply chain model.

The supply chain model is built to simulate how the supermarket replenishes its stock timely to ensure that products are all in stock. If products are out of stock, customers leave without purchasing, which means that the supermarket loses money. Figure 7 shows how the supply chain model built. Firstly, the supply chain model is triggered based on the specific condition, the event 'Inventory Management'. Once the supermarket stock is smaller than the record point, the supermarket needs to order products from the distribution centre using the inject function in the start point 'Nearest Distribution Centre', where the supply chain model will be triggered to provide a fixed number of products.

Since the model assumes that the supermarket orders products from the nearest distribution centre, the nearby distribution centre checks its stock first using the 'Check Warehouse Stock' routine, which leads to the next decision point 'select Output'. If the products are not in stock or the stock is not enough to offer, the supermarket needs to order products in 'Other Distribution Centre', which is farther and requires much time for delivery. When the supermarket decides which warehouse to order, the distribution centre will 'Load Product' after a process called 'Pack Product' to represent the delay in the process. After packaging, the last step is to 'Transport' them to the supermarket's warehouse. The delivery time is different in distribution centres. The nearest centre is faster than other. After delivery, the supermarket updates its inventory in 'Supermarket Stock', which influences the agent decision during the customer shopping process in the DES model.

Model Verification and Validation.

Since our model is a hypothetical model based on a supermarket company, the objective of our modelling effort is to conceptually illustrate its use in strategic planning without any specific implication for the real company. Most of our tests were related with the conceptual model so the validation of the results is not performed in detail only the model is following relevant trends as observed in the real data. However, a formal verification and validation test is an essential process for a real modelling project, which could help build confidence in models. Although a variety of test could be used to test the model, there is no established model validation and verification tests for HS yet (Brailsford et al, 2018). Qudrat-Ullah (2012, p.3) stated that the key to the modelling process is to identify how structure and decision policies help generate the observable patterns of behaviour of a system. Therefore, the first step in establishing the validity of a model is evaluating the quality of the structure, which contains two tests for the conceptual model and algebraic model. Design is an essential attribute of the conceptual model, which have boundary adequacy and structure verification tests, but for the algebraic model, quality is the main property, where equation formulation tests build further confidence, demonstrating the consistency among equations, parameters and data. This step contains three tests: dimensional consistency, parameter verification and extreme conditions (Morecroft, 2007, p.392). Once the structural validity is sufficiently established, behaviour validity will be assessed to achieve the overall validity of the model or to build confidence in the model, including visual fit and statistical fit (Morecroft, 2007, p.410). Morecroft concluded the final phase comprises tests of learning from simulation that depicts the interaction between the formal model and people's mental model through a wide range of experiments to better interpret past behaviour, to learn about future behaviours, to explain surprise behaviour and to correct faulty expectations (Morecroft 2007, p.405 & p.412).

Experimenting with Strategies

Since the objective of this model is to test strategies for the company to gain larger market share and attract more customers, it is essential to use the HS model to test a collection of different strategies that may help the company achieve its goal. Thus, four strategies, which are selected based on the TOWS matrix, are tested in order to visualise the future performance of the business. Table 5 is the TOWS matrix for the company of our case study.

S-O Strategy. It involves developing an online shopping channel for the company to comply with the trend of the digital world. Since the company has ample disposable income for investment and it has stable suppliers to provide appropriate products, it is suitable to develop online shopping under the background that online facilities are continually improving in the UK.

W-O Strategy. It suggest investing more money in advertising, which is an important promotion method which the company currently does not use appropriately. If the company wants to promote its own brand products, simply rely on the word of mouth effect is not enough. Advertising could provide direct information on the characteristics and advantages of the company, which is more efficient and effective. Thus, the WO strategy will focus on this promotion tactic.

S-T Strategy. It focuses on developing the company's own brand products, which are more competitive on price. Since the company has good relationships with their suppliers, both in the UK and overseas, it is easier for the company to develop its products by working with its partners. Thus, to implement the S-T strategy, which requires much money to invest in the product area, the money needs to be re-allocated between the product and logistics technology.

W-T Strategy. It aims at reducing the high employee cost and to cope with the insufficient labour force problem in the future. The strategy focuses on using the self-check machine to replace the staff in the store and reduce the labour cost while enhancing the efficiency of serving the queues in stores. The new model is modified in both the SD model, which reduces money on human resource and adds a new investment on equipment, and the DES model, which improve checking-out efficiency. In the shopping process DES model, the delay time in 'Purchase Product' decreases since checking out is more efficient compared with the traditional method.

Comparison. Since the focal issue of the model is to increase the market share by spending money in the appropriate place. The first KPI for comparing different strategies is the market share. The bar chart (Figure 8) below shows that except the W-T strategy, the other three strategies enlarge the market share after 10 years. S-O strategy, which will improve the online shopping channel, is most significant.

The next indicator for comparing the performance of the model is sales, which include physical and online channels. Figure 9 illustrates the total sales for the four strategies. SO strategy reaches the highest sales, since its online income is much greater than others, but the physical sales do not change. W-O strategy also performs quite well in both physical and online aspect, which means that advertising is a good choice to directly attract adopters if the company have sufficient money. Particularly, the S-T strategy gets the highest physical sales but the lowest online sales, since the model assumes the total investment remains at the same level. Thus, increasing money in product technology leads to a decrease in logistic efficiency, which influences the online shopping delivery and customers' choice.

As for the W-T strategy, the performance of using self-check machine to replace the labour force is not significantly different than others because it is more useful to reduce costs.

Discussion

The Value of Hybrid Modelling in Strategic Planning

Firstly, previous studies have illustrated that the hybrid modelling can enhance the strengths of each individual methods and the ability of simulating the complex system (Jackson and Keys, 1984; Howick and Ackermann's, 2011; Morgan et al., 2017). However, few papers provide a theoretical framework for designing a three-paradigm hybrid model. This study introduces the general process of developing HS models for strategic management (table 6), which contributes to hybrid modelling from a practical and technical perspective.

Furthermore, this study is the first application integrating three major simulation methods to analyse a complex business issue. The hybrid solution combining SD, DES and ABS to evaluate a complete company according to the concepts of strategic management, supply chain management and marketing is demonstrated step by step, which can be used for further research and application. This study verifies the capability of hybrid modelling in a real-world system application and shows its practical significance in addressing business problems.

Besides, the study explored the capacities of the modelling platform AnyLogic, which supports all three methods, and provides the environment to build and implement the hybrid model. The study also examines the software's functionality and abilities when using multi-paradigm technique to simulate a complete system.

Limitations

The limitations of this study lie in three aspects. Firstly, some modelling assumptions might not reflect the reality of the system, which are used to simplify the simulation process but leads to the deviation from the real world. For example, based on the company's resource and capability, the model assumes that the company's technology investment is divided into logistic and product technology. However, in reality, technology investment may include IT facilities, mobility network, e-payments and other fields, which are not considered in this model. Besides, to model the online sales and the physical sales, the model assumes that customers will either choose online or offline channel, which is not true in the real world since customers chooses both shopping channel in different situations. Thus, some assumptions should be re-considered to capture the actual operations of the system. Secondly, although the validation of the model has been tested, the real data collected for this research is not sufficient. Unfortunately, some parameters and table functions do not have a reliable reference to support. Hence, more deep data collection works should be conducted to ensure the truth of the result. Thirdly, the model is built in the personal learning edition of the software, which is not a comprehensive edition and has some limitations, such as the number of agents so it limits the size of the market.

Future research

To address the limitations that mentioned in the previous session and improve the practicability of the model, some future work can be considered. For example, to better represent the system, real data collection is necessary. The recent development in big data and business analytics provide an excellent platform for HS modelling as a tool to complement business analytics (Kunc and O'Brien, 2018). In this model, some parameters and table functions should be re-calculated by doing surveys or contact with the company for primary data. For example, in the DES model, when modelling the stores capacity and the average checking out time, using the CCTV camera in store or the detective sensor to monitor the actual data for the store could be a better choice. As for the company's supply chain system, the delay time of transportation among different distribution centres could be acquired by interviewing the employees or managers working at the supermarket. Also, questionnaires could be taken for understanding the customer's shopping experience and satisfaction. By using different methods, the reality and practicability of the model could be improved.

Conclusion

The application of the HS techniques in modelling strategic business problems has not been widely discussed in academic literature. However, it possesses important advantages for this area of modelling in management since it can deal with all levels of the organisation simultaneously. This study focusses on the process of developing the hypothetical HS model and exploring the functionality of the HS in assisting the company's decision-making. Particularly, a hypothetical model which combined SD, DES and ABS paradigm is designed based on a UK supermarket in a multi-method simulation software. In this HS model, SD is used to simulate the company's financial dynamic and technology development, ABS experiments the customer and market sector, and DES simulates customers' shopping experience and the supermarket's supply chain system. Since the inputs and outputs of the three models are correlated, the model is intertwined and coherent. The entire model simulates different levels of the enterprise, demonstrating a more comprehensive and unified perspective to cope with the complex real-world problem compared with the single simulation method.

To support the strategic management, TOWS is also proposed for generating a collection of possible options for companies. By using this strategic planning tool, managers can understand how to maximize the internal strength or minimise the internal weakness to address the external challenges and opportunities. After modifying the basic HS model according to each strategy, the study shows that HS models has the ability to experiment strategies, and to estimate and compare the result over a long period of time, 10 years or more. Therefore, managers can not only understand the company's current performance, but also predict the future development through the simulation model. Moreover, the study elaborates the framework of developing the HS model for strategic management and the process of building and combining the three parts of the model in detail, which could be future used and applied in other business and industry. Due to the flexibility and comprehensiveness of the HS model, we are confident that this study will open the doors for more work in this promising area of modelling in management.

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Figure 1 Conceptual Model of the Hybrid Model

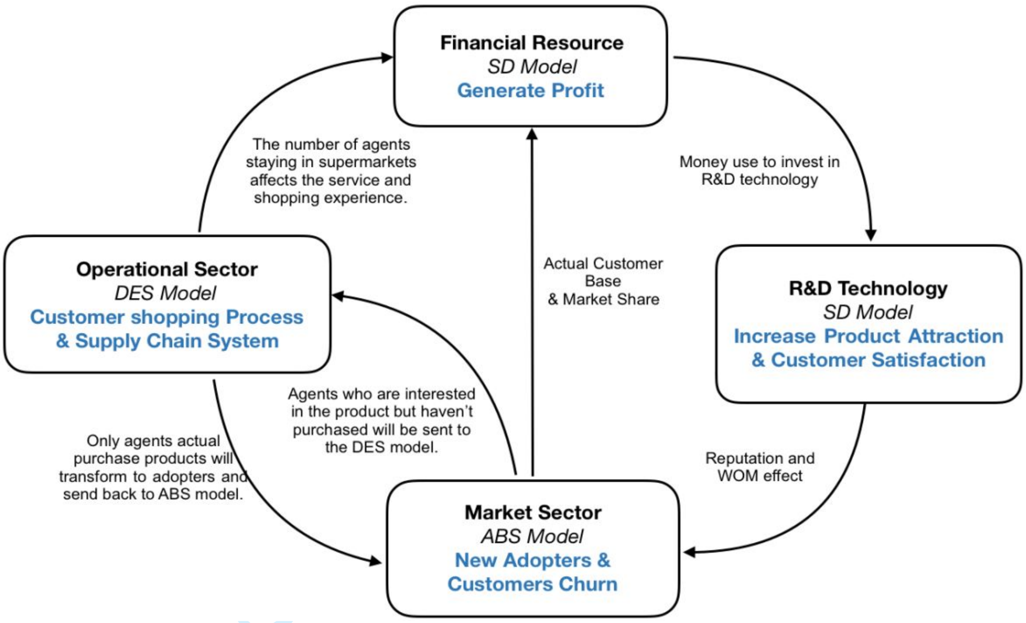

Figure 2 SD Model of Finance and R&D Technology

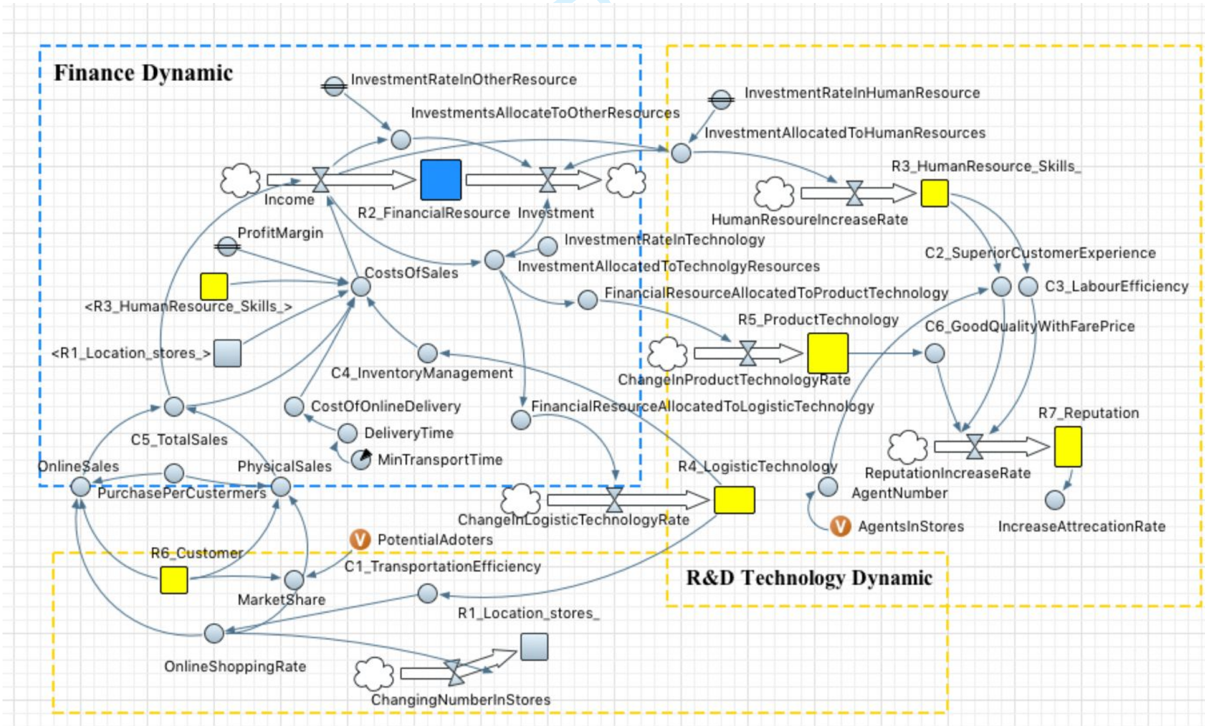

Figure 3 Reinforce Feedback Loops

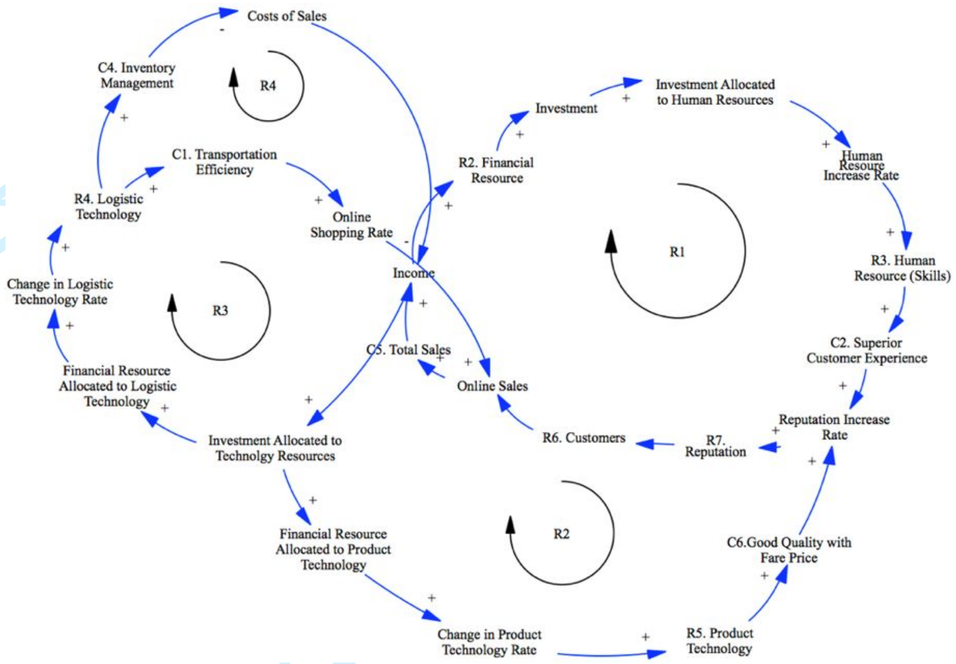

Figure 4 Balancing Feedback Loop

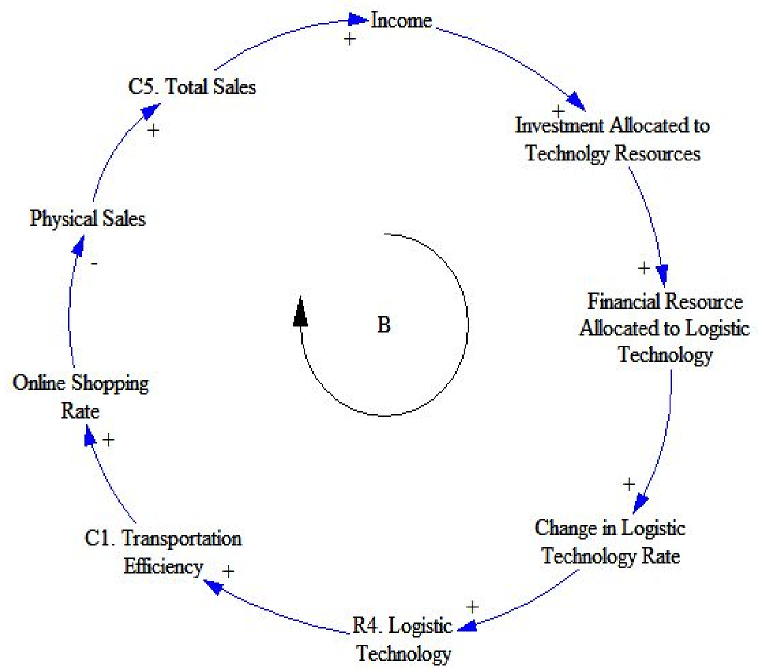

Figure 5 ABS Model of Market Sector

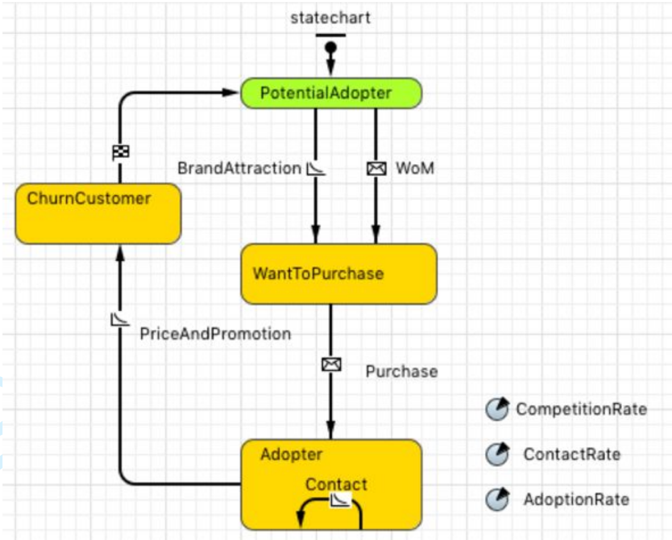

Figure 6 DES Shopping Process Model

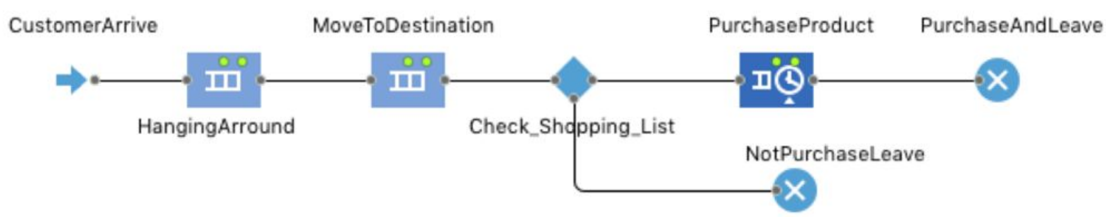

Figure 7 DES Supply Chain Model

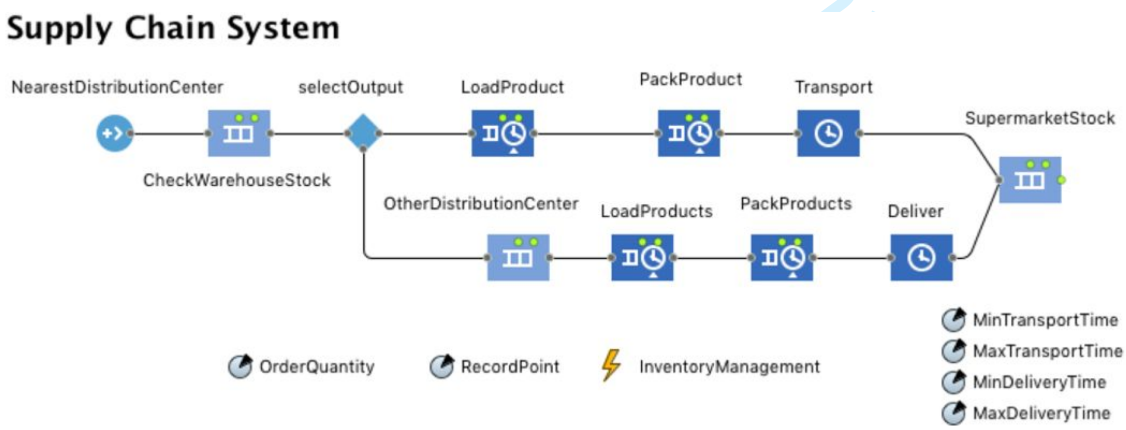

Figure 8 Market Share Comparison

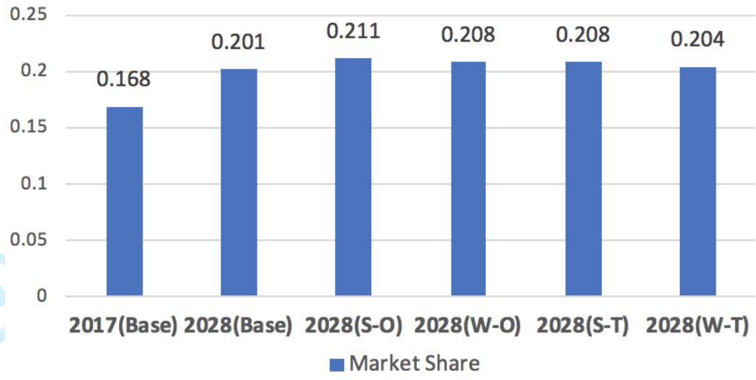

Figure 9 Sales Comparison

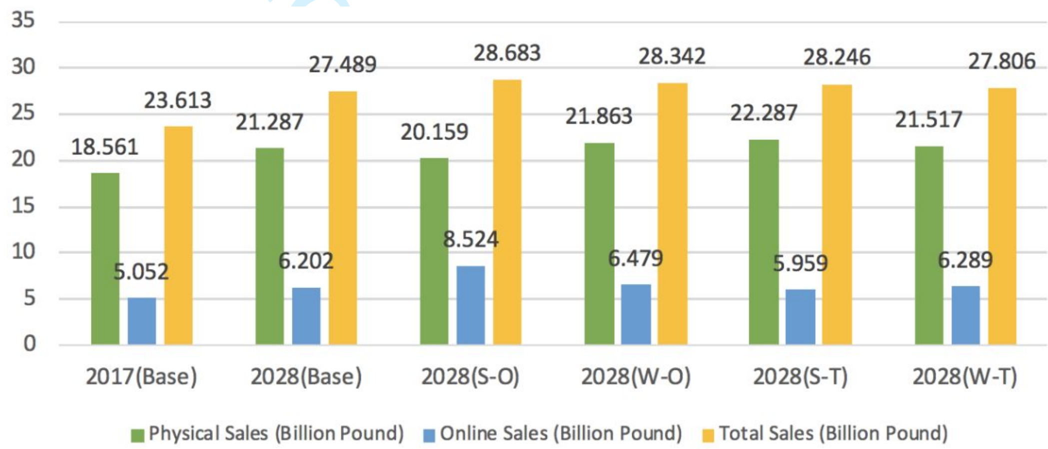

Table 1 TOWS Matrix (adopted from Weihrich,1982)

Internal Factors / External Factors	List Internal Strengths (S): 1. 2. 3…	List Internal Weaknesses (W): 1. 2. 3…
List External Opportunities (O): 1. 2. 3…	S-O strategies (Max-Max):	W-O strategies (Min-Max):
List External Threats (T): 1. 2. 3…	S-T strategies (Max -Min):	W-T strategies (Min-Min):

Table 2 List of Resources and Capabilities

Resource	Capability	Strength & Weakness
R1. Location stores	Physical Sales	Ample of stores in good location (S). Only focus on UK market (W). Revenue reliant on in store sales (W).
R2. Financial Position R3. Human Resource (Employee Skills)	Labour Efficiency	Ample disposable income (S). Sufficient investment (S). Quality employees (S). High employee training costs (W).
R4. Logistic Technology	Online Sales Transportation Efficiency Inventory Management	Online delivery efficiency (S). Ability to control food waste (W).
R5. Product technology	Good Quality with Fare Price	Long-standing relationships with suppliers (S). Competitive on product quality (S). Less competitive on price (W).
R6. Customers R7. Reputation	Superior Customer Experience	High brand identification (S). Lack of advertising (W). Strong corporate social responsibility (S)

Table 3. Process of Interacting SD and ABS

Process of interacting two models	Explanations
Step 1. Set the Rate of 'Brand Attraction' transition in the ABS model to the 'Increase Attraction Rate' in the SD model	By doing this, when reputation increases in the SD model, attraction rate in the ABS model improves simultaneously to attract potential adopter who become interested and moving into 'Want to Purchase' state.
Step 2. Send the agents of the 'Adopter' state in the ABS model into the stock 'R6_Customer in the SD model'.	When agents move into the 'Adopter' state in the ABS model, an entry action is triggered to send these agents into the stock 'R6_Customer in the SD model'. If the customers leave for another company, an 'exit' action will remove the agent from 'R6_Customer' stock.

Table 4. Process of Interacting ABS and DES.

Process of interacting two models	Explanations
Step 1. Write JAVA codes in 'Brand Attraction' transition and 'WoM' transition of the ABS model to send the agents to the DES model.	This step will send agents who are interested in the supermarket to the starting point 'Customer Arrive' of the DES shopping process model.
Step 2. Set the transition 'Purchase' of the ABS model triggered by the text message 'Purchase'. Step 3. Write the java code: agent.customer.recieve('Purchase') at the endpoint 'Purchase and Leave' of the DES model.	These two steps ensure that agents who have actual purchased products in the DES model will come back to the ABS model and transformed to the 'Adopter' states by triggering the 'Purchase' transition in the ABS model.

Table 5 Strategies Generate using the TOWS Matrix

Internal Factors / **External Factors**	**Strength** 1. Ample of stores in good location 2. Ample disposable income and sufficient investment. 3.Good reputation. 4. Long-standing relationships with suppliers. 5.Competitive on product quality.	**Weakness** 1. Only focus on UK mark. 2. High employee training costs. 3. Less competitive on price. 4. Lack of advertising.
Opportunities 1. Increase in demand of high quality and organic food. 2. An increase in the online shopping facility in the UK 3. Potential Industrial consolidation	**S-O Strategy** **Develop online shopping channel in the digital world (S2, S4, O2).**	**W-O Strategy** **Spend more money on advertising. (W4, O1, O3)**
Threats 1. Brexit leads to the storage of human resources. 2. Global increase in food price. 3. Competition becomes severe. 4. Government impose stricter regulations on food safety supervision.	**S-T Strategy** **Improve technology to develop great range of own-brand products with fair price. (S2, S4, S5, T2, T3)**	**W-T Strategy** **Using self-checkout machines to relieve the storage and the high cost of employee and help the company open stores for 24 hours. (W2, T1, T3)**

Table 6 General Process for Developing HS Models for Strategic Management

Stage	Observations/Recommendations
Description of Strategic Problem	• There direct relations between problem complexity and need for HS. • HS is used in addressing strategic issues in business areas where simulation methods have been extensively used.
Conceptual Model	• Overarching business system perspective based on the abstraction of the components of the company such as resources, customers, and operational processes. • Defining the rationale for the use of SD, ABS or DES according to the characteristics of the components of the company: macro, meso and micro level. • Defining the type of hybridization and linkages between models.
Computer Model	• The selection of HS tools selection is dictated by ease of linkages and equations to represent the components of the firm. • Single all-encompassing packages tend to be used more for HS as it reduces programming. • Non-uniformity of data sources is a significant challenge for HS model from financial to customer behaviour data.
Validation and Verification (VV)	• Intra-modular VV methods are similar to single paradigm models. • Inter-modular VV methods add extra dimensions to validation. • Non-existence of testing methods for HS requires more effort and skills.
Solution and Understanding	• Testing and experimenting need more development to meet complexity from a strategic perspective. • Trade-off between skills-mix and method selection is critical.

Appendix: Equations of the Hybrid Model

SD Model

Stocks and Flows

Name	Value and Equation	Data source
R1_Location_stores_	Initial Value: 601 d(R1_Location_stores_)/dt= Changing Number In Stores	https://www.about.sainsburys.co.uk/great-products-and-services/groceries
Changing Number In Stores	FunctionRentsOfComercialPropertiesEffectOnChangingNumberInStores (RentsOfComercialProperties) + FunctionOnline Shopping RateEffect OnChangingStoreNumber(Online ShoppingRate)	Authors assumptions
R2_FinancialResource (Unit: million_pound)	Initial Value: 3370 d(R2_FinancialResourcedt= Income-Investment,	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-financial-statements
Income (Unit: million_pound)	C5_TotalSales - CostsOfSales	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-financial-statements
Investment (Unit: million_pound)	InvestmentAllocatedToTechnolgyResources + InvestmentAllocatedToHumanResources + InvestmentsAllocateToOtherResources	Authors assumptions
R3_HumanResource_Skills_	Initial Value: 5 d(R3_HumanResource_Skills_)/dt= HumanResoureIncreaseRate	Authors assumptions
HumanResoureIncreaseRate	FunctionInvestmentAllocatedToHumanResourceEffectOnHumanResourceIncreaseRate(Investment AllocatedToHumanResources)	Authors assumptions
R4_LogisticTechnology	Initial Value: 5 d(R4_LogisticTechnology)/ dt= ChangeInLogisticTechnologyRate	Authors assumptions
ChangeInLogisticTechnologyRate	FunctionLogistiticTechnologyChangeRateDrivenByFinancialResourceAllocatedToLogisticTechnology(FinancialResourceAllocatedToLogisticTechnology)	Authors assumptions
R5_ProductTechnology	Initial Value: 0.003 d(R4_LogisticTechnology)/dt= ChangeInProductTechnology Rate	https://www.about.sainsburys.co.uk/investors/results-reports-and-presentations#2018

ChangeInProduct TechnologyRate (Unit: Product_per_year)	FunctionProductTechnologyChangeRateDrivenByFinancialResourceAllocatedToProductTechnology(FinancialResourceAllocatedToProductTechnology)	Authors assumptions
R6_Customer (Unit: tenth thound)	Initial Value: 954	https://www.about.sainsburys.co.uk/investors/results-reports-and-presentations#2018
R7_Reputation	Initial Value: 2 d(R7_Reputation)/ dt= ReputationIncreaseRate	Authors assumptions
ReputationIncreaseRate	C2_SuperiorCustomerExperience + C6_GoodQualityWithFarePrice + C3_LabourEfficiency	Authors assumptions

Dynamic Variables

Name	Value and Equation	Data source
C1_TransportationEfficiency	R4_LogisticTechnology	Authors assumptions
C2_SuperiorCustomerExperiece	(R3_HumanResource_Skills_ - 5 + FunctionAgentNumber EffectOnCustomerExperience(AgentNumber)) * 0.03	Authors assumptions
C3_LabourEfficiency	(R3_HumanResource_Skills_ - 5) * 0.03	Authors assumptions
C4_InventoryManagement	R4_LogisticTechnology	Authors assumptions
C5_TotalSales (Unit: million_pound)	OnlineSales + PhysicalSales	https://www.about.sainsburys.co.uk/investors/results-reports-and-presentations#2018
C6_GoodQualityWithFarePrice	FunctionProductTechnologyEffectOnGoodQualityWithFarePrice(R5_ProductTechnology)	Authors assumptions
PurchasePerCustermers (Unit: Pound / Year)	2366 * (1 + InflationRate)	https://www.statista.com/statistics/251728/weekly-number-of-us-grocery-shopping-trips-per-household/
InflationRate	0.03	http://www.bbc.co.uk/news/business-42702752
OnlineSales (Unit: million_pound)	OnlineShoppingRate * PurchasePerCustermers * R6_Customer/100	https://www.about.sainsburys.co.uk/investors/results-reports-and-presentations#2018

PhysicalSales (Unit: million_pound)	(1 - OnlineShoppingRate) * PurchasePerCustermers *R6_Customer/100	https://www.about.sainsburys.co.uk/investors/results-reports-and-presentations#2018
OnlineShoppingRate	0.2 * ChangeInShoppingChannels * FunctionFuelPrice EffectOnOnlineShoppingRate(FuelPrice) * FuntionTransportation EfficiencyEffectOnOnlineShopping Rate (C1_ Transportation Efficiency)	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-full-report
RentsOfComercialProperties (Unit: Pound / month)	770+step(+20, 2017)	https://www.theguardian.com/money/2015/oct/16/average-monthly-rent-hits-record-high-of-816-highlighting-housing-shortage
ChangeInShoppingChannels	1 physical=0.8 online=1.5 now=1	Authors assumptions
FuelPrice (Unit: Pound)	1.2	Authors assumptions
CostOfOnlineDelivery (Unit: million_pound)	80 + FunctionDeliveryTimeEffectOnCostOfSales(DeliveryTime)	Authors assumptions
ProfitMargin	0.071	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-full-report
CostsOfSales (Unit: million_pound)	TotalSales * (1 - ProfitMargin) + Function Inventory Management EffectOn CostsOf Sales (C4_Inventory Management) + FunctionHumanResource_Skills_ EffectOnCostsOfSales(R3_HumanResource_Skills_) + FunctionLocation_stores_ EffectOnCostsOfSales(R1_Location_stores_)+CostOfOnlineDelivery	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-full-report
InvestmentsAllocateToOther Resources (Unit: million_pound)	Income * InvestmentRateInOtherResource	Authors assumptions
InvestmentRateInOtherResource	0.68	Authors assumptions

InvestmentRateInTechnology	0.005 * EnviornmentalFriendlyRegulation * TechnologicalInnovation * LifestyleTrends	https://www2.deloitte.com/insights/us/en/focus/cio-insider-business-insights/technology-investments-value-creation.html http://sainsburys.work
TechnologicalInnovation	1 radical improvement=0.8 no change= 1.2 current=1	Authors assumptions
LifestyleTrends	1 healthy=1.2 unhealthy=0.8 current=1	Authors assumptions
EnviornmentalFriendlyRegulation	1 strict=1.1 loose=0.9 current=1	Authors assumptions
InvestmentAllocatedToTechnolgyResources (Unit: million_pound)	Income * InvestmentRateInTechnology	Authors assumptions
FinancialResourceAllocatedTo LogisticTechnology (Unit: million_pound)	InvestmentAllocatedToTechnolgyResources * 0.3	Authors assumptions
FinancialResourceAllocatedTo ProductTechnology (Unit: million_pound)	InvestmentAllocatedToTechnolgyResources * 0.7	Authors assumptions
InvestmentAllocatedTo HumanResources (Unit: million_pound)	Income * InvestmentRateInHumanResource	Authors assumptions
InvestmentRateInHumanResource	0.11	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-financial-statements
AgentNumber	AgentsInStores	Authors assumptions
IncreaseAttrecationRate	FunctionReputationEffectOnAttractionRate(R7_Reputation)	Authors assumptions

Table Functions

Name	Value and Equation	Data source
FunctionRentsOfComercialProperties EffectOnChangingNumberInStores	Function Changing Number in Stores (Rents of Commercial Properties) Function Changing Number in Stores ([(706,0) -	Authors assumptions

	(1006,20)],(706,0),(756,2),(806,4),(856,6),(906,8),(956,10),(1006,12))	
FunctionOnlineShoppingRateEffectOnChangingStoreNumber	Function Changing Store Number (Online Shopping Rate) Function Changing Store Number ([(0.1, -30) - (0.42,30)],(0.1,10),(0.13,5),(0.16,3),(0.19,1),(0.23,0),(0.28,-1),(0.31,-3),(0.34,-5),(0.37,-9),(0.4,-15),(0.42,-22))	Authors assumptions
FunctionInventoryManagementEffect OnCostsOfSales	Function Costs of Sales ([(0,-90)-(10,90)],(0,85),(1,50),(2,30),(3,15),(4,5),(5,0),(6,-30),(7,-50),(8,-70),(9,-85),(10,-90))	Authors assumptions
FunctionLocation_stores_EffectOn CostsOfSales	Function Costs of Sales (Location) Function Costs of Sales ([(530, -400) - (655,400)], (530, -375), (540,-325),(550,-275),(560,-225),(570,-175),(580,-125),(590,-75) , (605,0) , (615,50) , (625,100) , (635,150) , (645,200),(655,250))	http://www.about.sainsburys.co.uk/~/media/Files/S/Sainsburys/pdf-downloads/sainsburys-ar-2017-financial-statements
FunctionHumanResource_Skills_ EffectOnCostsOfSales	Function Costs of Sales (Human Resource (Skills)) Function Costs of Sales (Human Resource ([(0, -40)-(10,40)],(0,40),(1,25),(2,15),(3,8),(4,3),(5,0),(6,-13),(7,-22),(8,-30),(9,-35),(10,-40))	Authors assumptions
FuntionTransportationEfficiencyEffectOnOnlineShoppingRate	Function Online Shopping Rate (Transpiration Efficiency) Function Online Shopping Rate ([(0,0.8) - (10,2)],(0,0.85),(1,0.88),(2,0.91),(3,0.95),(4,0.98),(5,1),(6,1.03),(7,1.05),(8,1.09),(9,1.13),(10,1.2))	Authors assumptions
FunctionLogistiticTechnologyChange RateDrivenByFinancialResource	Function Logistics Technology Change Rate (Financial Resource Allocated to Logistic Technology)	Authors assumptions

AllocatedToLogisticTechnology	Function Logistics Technology Change Rate ([(1.2,-0.4)-(4,0.4)],(1.2,-0.3),(1.45688,-0.207018),(1.64526,-0.133333),(1.8,-0.08),(2.00489,-0.0280702),(2.20183,0.0350877),(2.4,0.15),(2.6,0.18),(2.8,0.21),(2.99817,0.245614),(3.2,0.26),(3.4,0.27),(3.6,0.275),(3.8,0.28),(4,0.3))	
FunctionFuelPriceEffectOn Online ShoppingRate	Function Online Shopping Rate (Fuel Price) Function Online Shopping Rate ([(1.17,0.8)-(1.37,2)],(1.17,1.09),(1.19,1.08),(1.21,1.05),(1.23,1.01),(1.25,1),(1.27,0.99),(1.29,0.98),(1.31,0.95),(1.33,0.93),(1.35,0.9),(1.37,0.88))	Authors assumptions
FunctionReputationEffectOnAttractionRate	Function Attraction Rate (Reputation) Function Attraction Rate ([(1,0) -(3.6,0.02)], (1,0),(1.87373,0.001),(2.20204,0.0012),(2.51446,0.002),(2.61507,0.00464455),(2.74216,0.00663507),(2.9275,0.00862559),(3.10754,0.00995261),(3.28758,0.0106161),(3.43055,0.0109005),(3.58411,0.0111848))	Authors assumptions
FunctionProductTechnologyChange RateDrivenByFinancialResourceAllocatedToProductTechnology	Function Product Technology Change Rate (Financial Resource Allocated to Product Technology) Function Product Technology Change Rate ([(5,0) - (200,0.002)], (5,0.0003), (10,0.00055),(15,0.00075),(20,0.00093),(25,0.001),(30,0.001195),(35,0.001315),(40,0.001415),(45,0.001467),(50,0.0015))	Authors assumptions
FunctionInvestmentAllocatedToHumanResourceEffectOnHumanResourceIncreaseRate	Function Human Resource Increase Rate(Investment Allocated to Human Resource) Function Human Resource Increase Rate([(77,-0.3)-(317,0.3)],(77,-0.2),(97,-0.189),(115,-0.198),(117,-0.177),(137,-0.154),(157,-0.129),(177,-0.1), (197,0) , (217,0.1) , (237,0.154)	Authors assumptions

	,(257,0.177),(277,0.199),(297,0.189),(317,0.2))	
FunctionProductTechnologyEffectOn GoodQualityWithFarePrice	Function Good Quality with Fare Price(Product Technology Effect) Function Good Quality with Fare Price([(0.003,0)-(0.017,0.06)],(0.003,0),(0.004,0.018),(0.005,0.028),(0.006,0.035),(0.007,0.041),(0.008,0.046),(0.009,0.0502),(0.01,0.0532),(0.011,0.0556),(0.012,0.0576),(0.013,0.058),(0.014,0.059),(0.015,0.0598),(0.016,0.06),(0.017,0.06))	Authors assumptions
FunctionDeliveryTimeEffectOn CostOfSales	Function CostOfSales (DeliveryTime) Function CostOfSales ([(0.5, -20) -(2,10)],(0.5,-20), (1,0), (2,10))	Authors assumptions
FunctionAgentNumberEffectOn CustomerExperience	Function CustomerExperience (AgentNumbe) Function CustomerExperience ([(0,0.2) -(250,-0.13)], (0,0.2), (50,0.15), (100,0.08),(150,-0.03),(200,-0.08), (250,-0.13)	Authors assumptions

DES Model

Shopping Process Model

Name	Settings	Data source
CustomerArrive (Enter)	Agent type: Agent	
HangingAround (Queue)	Capacity:10 Actions: On at exit: AgentsInStores++	Authors assumptions
MoveToDestination (Queue)	Agent type: Agent Maximum capacity	
Check_Shopping_List (SelectOutput)	Select True output= IF condition is true Condition: SupermarketStock.size()>=1	
NotPurchaseLeave (Sink)	Agent type: Agent	

PurchaseProduct (Service)	Queue capacity:1 Delay time: triangular (2, 10, 5) minutes	Authors assumptions
PurchaseAndLeave (Sink)	On enter: agent.customer.receive("Purchase"); SupermarketStock.removeFirst(). Agent type: PurchaseRequest	

Supply Chain System

Name	Settings	Data source
NearestDistributionCenter (Source)	Arrivals defined by: Calls of inject() function New agent: Agent	
CheckWarehouseStock (Queue)	Agent type: Agent Maximum capacity	
selectOutput (SelectOutput)	Select True output= IF condition is true Probability: 0.8	Authors assumptions
LoadProduct (Service)	Queue capacity:1 Delay time: triangular (1, 10, 5) minutes	Authors assumptions
PackProduct (Service)	Queue capacity:5 Delay time: triangular (0.5, 2, 1) hours	Authors assumptions
Transport (Delay)	Type: Specified time Delay time: triangular(MinTransportTime, MaxTransportTime, 1)days	Authors assumptions
Deliver (Delay)	Type: Specified time Delay time: triangular(MinDeliveryTime, MaxDeliveryTime, 2)days	Authors assumptions
OtherDistributionCenter (Queue)	Agent type: Agent Maximum capacity	
SupermarketStock (Queue)	Agent type: Agent Maximum capacity	
InventoryManagement (Event)	Trigger type: Timeout Mode: Cyclic Actions: **if** (SupermarketStock.size()<RecordPoint); NearestDistributionCenter.inject(OrderQua ntity);	
MinDeliveryTime (Parameter)	Type: double Default value:2	Authors assumptions

MaxDeliveryTime (Parameter)	Type: double Default value:3	Authors assumptions
MinTransportTime (Parameter)	Type: double Default value:1	Authors assumptions
MaxTransportTime (Parameter)	Type: double Default value:2	Authors assumptions

ABS Model

Name	Settings	Data source
PotentialAdopter (State)	Entry Action: main.PotentialAdoters++; Exit Action: main.PotentialAdoters--;	
BrandAttraction (Transition)	Trigger by: Rate Rate: main.IncreaseAttrecationRate (per year) Action: main.CustomerArrive.take(**new** PurchaseRequest (**this**));	
WoM (Transition)	Trigger by: Message Message type: String Fire transition: On particular message Message: "Buy!" Action: main.CustomerArrive.take(**new** PurchaseRequest (**this**)); Guard: randomTrue(AdoptionRate)	
WantToPurchase (State)	Entry Action: main.WantPurchase++	
Purchase (Transition)	Trigger by: Message Message type: Objective Fire transition: On particular message Message: "Purchase"	
Adopter (State)	Entry Action: main.Adopters++; main.R6_Customer++ Exit Action: main.Adopters--; main.R6_Customer--;	
Contact (Transition)	Trigger by: Rate Rate: ContactRate (per month) Action: sendToRandom("Buy");	
PriceAndPromotion (Transition)	Trigger by: Rate Rate: CompetitionRate (per year)	
ChurnCustomer (State)	Entry Action: main.ChurnedCustomer++;	

Churn (Transition)	Trigger by: Timeout Timeout: 1 year	Authors assumptions
ContactRate (Parameter)	Type: Rate Unit: per mouth Default value:10	Authors assumptions
AdoptionRate (Parameter)	Type: double Default value:0.5	Authors assumptions
CompetitionRate (Parameter)	Type: Rate Unit: per year Default value:0.01	Authors assumptions