Full paper

Sustainable Warehouse Management Modelling

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Abstract

Sustainability is about addressing and balancing the economic, environmental and social aspects of businesses, their operations and outputs. Many businesses consider sustainability as one of their core strategic values but find it hard to implement in their existing business setting. Using system dynamics concepts, this paper explores the application of sustainability principles in the context of warehouse storage and distribution management. This paper also introduces the models of setting up of a warehouse or transformation of an existing warehouse that provides the storage and distribution services to customers using third party transportation systems. The concept of a sustainable warehouse is introduced and the models that enable us to understand and manage the business in a sustainable fashion are described. The implementation within a system dynamics modelling and application building environment is also discussed.

Keywords: sustainability, modelling, warehouse management, system dynamics.

1 Introduction

Sustainability is a concept and strategy for integrating and balancing economic, environmental and social dimensions (WBCSD, 2003), commonly termed as TBL or triple bottom line (GRI, 2002), into decision making (Elkington, 1997). Sustainable management of businesses is the roadmap to achieving the present needs of society without compromising the opportunities of future generations (Bruntland, 1987). Ministry for the Environment (2002) observes that New Zealand may not be able to look after its people and offer them a place they want to live in if businesses and society do not stop and reverse the damage to the environment. New Zealand's clean and green image is now becoming fragile (Parliamentary Commissioner for the Environment, 2002) and its sustainability status is declining in many aspects of its production and consumption of goods and services over the last ten years. Ministry for the Environment (2002) also stresses that New Zealand will struggle to provide an adequate standard of living for its citizen in the future if the current trends are not broken.

This quality assured paper appeared at the *21st Annual Conference of the National Advisory Committee on Computing Qualifications* (NACCQ 2008), Auckland, New Zealand. Samuel Mann and Mike Lopez (Eds).

Over the past 100 years, New Zealand's energy use has doubled every 22 years and its energy intensity is the highest among the Organisation for Economic Cooperation and Development (OECD) countries. Green Office (2002) observes that New Zealand is the seventh worst of 23 International Energy Agency countries in terms of energy use per dollar of GDP. Additionally, in the last 15 years, the amount of solid waste produced in the Auckland Region has almost doubled.

Ministry for the Environment (2004) emphasises on the performance of the three sustainability dimensions and the New Zealand Business Council for Sustainable Development stresses that sustainability is not just an option but a requirement for many businesses in New Zealand (NZBCSD, 2003). Sustainability is now becoming a necessity as stakeholders and society place higher expectations on companies, expecting them not only to be profitable businesses but also to be socially (Ansett, 2007) and environmentally responsible for their actions. While many companies have jumped onto the sustainability bandwagon, sustainability is still a relatively new concept to most businesses as far as strategy development, business process transformation and implementation are concerned.

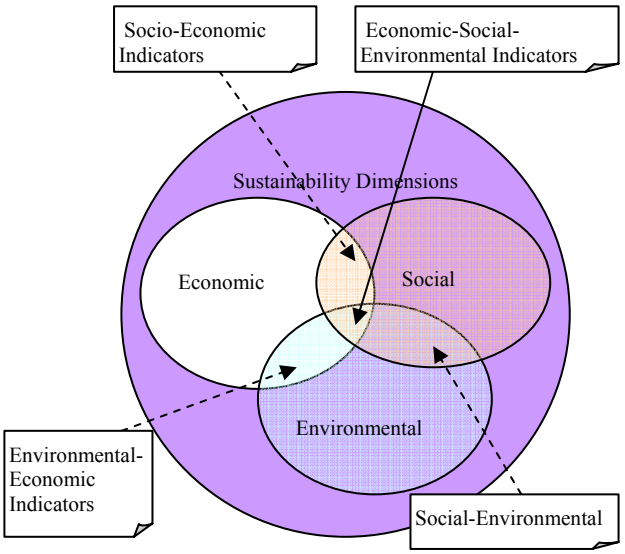


Figure 1. Inter-relationship among the sustainability dimensions of the businesses

Sustainability dimensions are inter-related (Figure 1) and any change in the objectives of a dimension greatly

influences the other two dimensions. Therefore, if the company had considered each of the sustainability dimensions independently and made decisions without considering all possible consequences of their decisions, any attempt to become a sustainable business would be unsuccessful. The first step in transforming a company into a sustainable business is to develop a sustainability vision and sustainability strategies that include sustainability objectives. In order for business strategies to be successful, they need to be derived from the organisational resources and experiences (Lynch, 2005). However, current sustainability visions and strategies are mostly a personal vision of top management which are not realistically supported by the organisation's resources, processes, and knowledge-base. This lack of consideration and poor execution is mainly due to the lack of frameworks and tools which can foster a real understanding that each of the three dimensions are inter-related and demonstrate the dynamic relationships the three sustainability dimensions have with each other.

This paper explores sustainable warehouse modelling in the context of an organisation that provides storage and transportation services (section 2). We model the sustainability issues of warehouses (sections 3 and 4) in general and then apply it in particular to the firm under study (sections 5 and 6). We close the paper with a brief description of the implementation of the models and the development of a system that enables us to monitor the triple bottom line scorecard (section 7).

2 Sustainable Warehouse Management

Most warehousing and transportation companies have little regard for the environmental impacts of their actions and do not understand the social consequences of their business activities. These companies consider factors such as cost effectiveness and customer satisfaction as the main performance indicators (Linton 2007; Quariguasi Frota Neto 2008). Linton (2007) and Quariguasi Frota Neto (2008) argue that being involved in the storage and transportation of goods, these companies have to recognise the importance of transforming their current business model into a sustainable one. An added impetus to the argument is that vehicle emissions are one of the major sources of pollution.

This research undertakes a real-life sustainable warehouse management project in Auckland for an ISO certified warehousing company. The company provides storage facilities for chemical and food items in Auckland and Christchurch for various customers and delivers the goods to various manufacturing and retail businesses all over New Zealand. Various small to large transportation companies are also working in collaboration with the company in the transportation and delivery process. The warehousing company is growing rapidly and thus wishes to increase capacity by establishing more warehouses. The company's operations management processes are well-defined but due to shortage of skilled workforce, recent developments in health and safety, and environmental regulations as well as pressures from the sustainability aware members of its supply-chain, clients and the end users, the company decided to redesign the business processes for the new warehouses that follow sustainability management approach and achieve competitive advantage within a short period. Major issues like employee retention, compliance and environmental footprints, and financial return are associated with the location of the warehouse. Therefore, the selection of warehouse location is an important strategic issue that would have a major impact on economic, environment and social dimensions of the entire management of the business. We highlight some of these issues in the remaining part of this section.

Due to the nature of the goods handled, the company has to meet a large variety and number of compliance regulations such as health and safety, hazardous goods storage and handling, food items storage and handling, environmental compliance to name a few. It is obligatory for all employees to be highly trained in the compliance processes. Thus it is hard to recruit skilled employees ranging from managers to warehouse operators who are needed to handle the chemical and food items. Ideally, the company would want zero employee turn over in order to minimise new staff training costs and achieve beyond the statutory compliance obligations to become a leader in the niche market.

Currently, the company's distribution system is entirely dependent on the road transportation network. Vehicle pollution is one of the biggest causes of environmental pollution in New Zealand, thus in the effort towards becoming a sustainable business, the warehouse should be located such that the pollution generated is minimal. This can be achieved by either locating closer to the end users or in a place that enables them to utilise alternative forms of environment friendly transportation. In the pursuance of providing maximum stakeholder satisfaction, the company also intends to invest a good proportion of their budget in information and decision support systems to aid effective decision making. The major stakeholders of the company are customers, retail/ manufacturing centres, end consumers, transportation companies, consultants, accountants, employees and government departments.

With the aim of helping the company become a leading sustainable warehouse management company, the authors undertook a research project to develop a sustainability systems model. While keeping the issues discussed earlier in mind, this model will be used to simulate and analyse sustainability key performance indicators determined from the critical success factors of a sustainable warehouse. The model will also support them in strategic decision making towards becoming a leading sustainable warehouse management company.

A sustainable warehousing company would not only have to consider the economic factors, such as rent and operations costs, but also balance the social and environmental effects that occur within the warehouse compound as well as its surrounding vicinity. This research places an emphasis on developing a balanced scorecard in conjunction with a sustainability model to help select a suitable location for a warehouse. The selection depends on the supply and delivery locations of the customers and the end users, transportation choices to and from the warehouse, and skilled staff availability and their job satisfaction.

3 Modelling the Sustainable Warehouse

The sustainable warehouse management system can easily be broken down into simpler and more manageable parts for modelling (van Es, 1998). However, modelling in isolation is not sufficient; it is the relationship and interaction between the parts that are important (Ahmed and Sundaram, 2007). Sustainability models can be developed using a systems thinking approach and this helps in shifting the focus from individual effects to interconnected systems (Ferguson, Dakers and Gunn, 2003) to shape organisations and their processes. Therefore, the sustainable warehouse management model needs to address the inter-relationships of economic objectives, employee welfare and minimisation of environmental impacts in an integrated fashion.

Maani and Cavana (2000) observe that the study and management of a complex feedback system can only be done using system dynamics/ systems thinking modelling methodologies. Only the study of the system as a whole will lead to effective solutions and establish a win-win-win proposition for the three dimensions. Therefore, iThink, a modelling tool that supports system dynamics, was chosen for the sustainable warehouse modelling. iThink is useful for modelling dynamic relationships such as social issues (e.g. health, safety, recruitment, retention, working hours, wage, job satisfaction, training, etc.); environmental issues (e.g. carbon minimisation, recycling, solid waste, air pollution, water pollution, etc); and economic issues (e.g. capital investment, warehouse rent, transportation cost, handling cost, packaging, information systems, hire cost, etc). Firstly, a cause-effect diagram was constructed to demonstrate the interdependence among the various issues and present an influence diagram. Then, the relationships among the factors were established.

Subsequently, an interactive game which demonstrates the interdependent relationships between the three sustainability dimensions was created. This allows users to gain a better understanding of how a decision will affect each of the three sustainability dimensions.

While the warehouse's location was the main decision problem, other decision parameters were required to design a sustainable model. Some of the major decision parameters include:

- Capital investment : to improve staff efficiency and reduce manual labour
- Number of employees : to ensure employees are not overworked
- Employee Training: to ensure high employee productivity and effectiveness and continuous up skilling
- Carbon minimisation: carbon credits, planting trees and air filtering
- Transportation decisions: various modes of transport have significant differences in carbon emissions

A sustainability scorecard was created to monitor the status of various key sustainability performance indicators. Some of the main tracking parameters include:

- Cash flow
- Warehouse utilisation
- Carbon emissions and minimisations
- Order processing time
- Employee job satisfaction
- Social and environmental impacts on surrounding areas (e.g. nearby residents)

4 High Level View of Sustainable Warehouse Management

Figure 2 represents a high level view of a sustainable

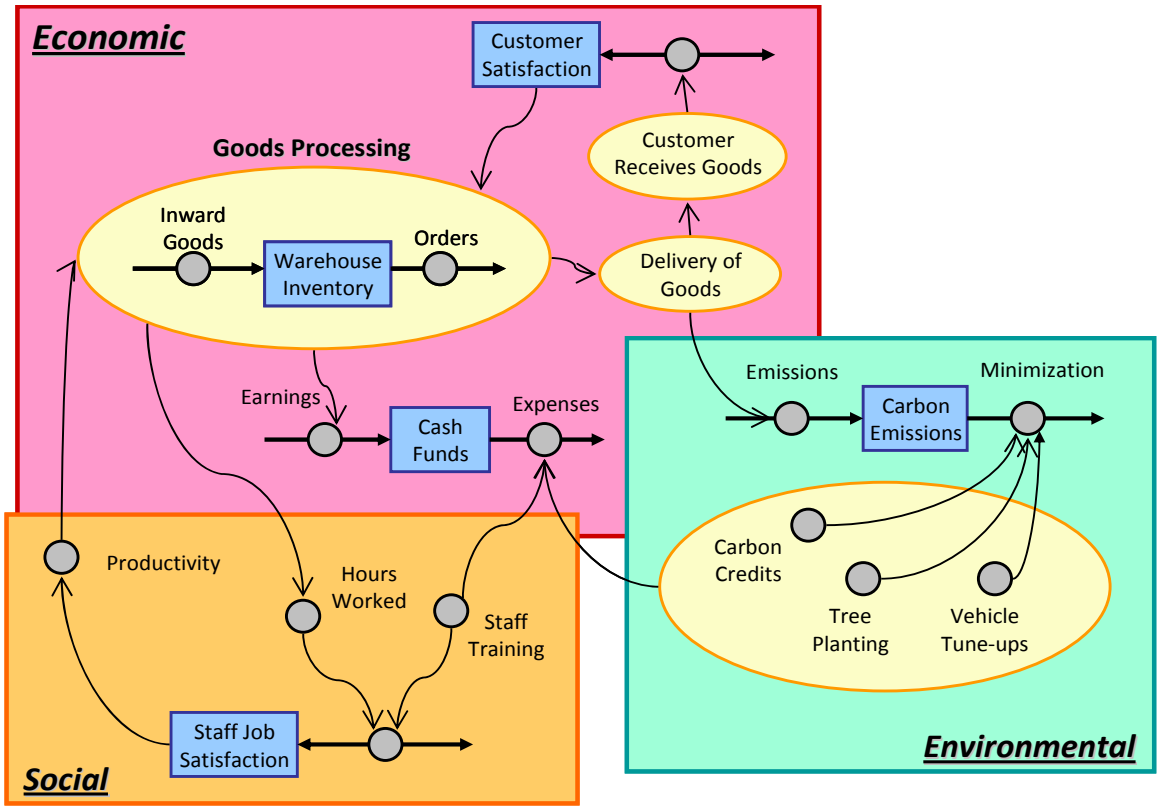


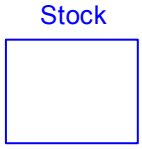
Figure 2. High level view of a sustainable warehouse model

warehouse model. The interdependencies of the three sustainability dimensions are depicted by arrows cutting across dimensions. The tradeoffs and interdependent relationships are further discussed in Section 6.

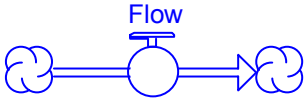
In a warehouse, *Goods processing* involves processing of inward goods and orders. The rate of processing is determined by the staff's level of job satisfaction and productivity. If the employees are not able to process the required orders, the customers' satisfaction decreases leading to poor business relationships. Once the orders have been processed, they are transported to the customer's clients. The process of delivering goods to their destinations results in large amounts of carbon emissions produced by the transportation fleet. In order to offset the carbon emissions, at least one of the *Carbon minimisation* activities will have to be performed, leading to an increase in costs.

5 System Dynamics Warehouse Management models

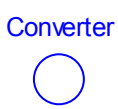
This section discusses the individual dimensions of the warehouse management model that was developed using system dynamics modelling concepts. Model attributes and sustainability indicators were selected based the user requirements and GRI (2002) guideline. Before discussing the dynamics of a sustainable warehouse model, the purpose of each element used in the model is defined. In this instance, a stock and flow model was used to represent the sustainable warehouse model. Elements of a stock and flow model consist of: Stocks, Flows, Converters and Connectors. Each of these elements is further described below.



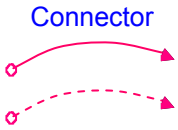
A stock represents the accumulation of either a physical or non-physical quantity e.g. number of orders, level of customer satisfaction.



A flow represents an activity which fills up or depletes a stock. The arrow indicates the direction of positive flow to or from a stock. For example, a customer sends a container of goods for storage in the warehouse (inflow), delivering goods from the warehouse to a client (outflow).



A converter has several functions. It can hold values for constants or serve as an external input (user input) to the model. It can also convert inputs into outputs through user defined algebraic relationships or graphical functions e.g. carbon dioxide emission rate for various categories of vehicles.



Connectors provide the links between model elements. The solid wire is an action connector while the dashed wire is an information connector.

5.1 The Economic Model

Figure 3 is a snapshot of the main economic model of a sustainable warehouse. The stock that is central to the economic model is *Warehouse inventory*. When a customer sends an order to the warehouse, it is added to the *Order backlog*. The number of staff *(i.e. Hours available for processing orders)* will determine the number of orders processed *(Orders filled)* and delivered. Any orders that cannot be processed, due to the shortage of either staff, will remain in the *Order backlog* until the next run. *Warehouse utilisation* which considers the effectiveness and efficiency of space usage is also an important economic factor to monitor in the warehousing business.

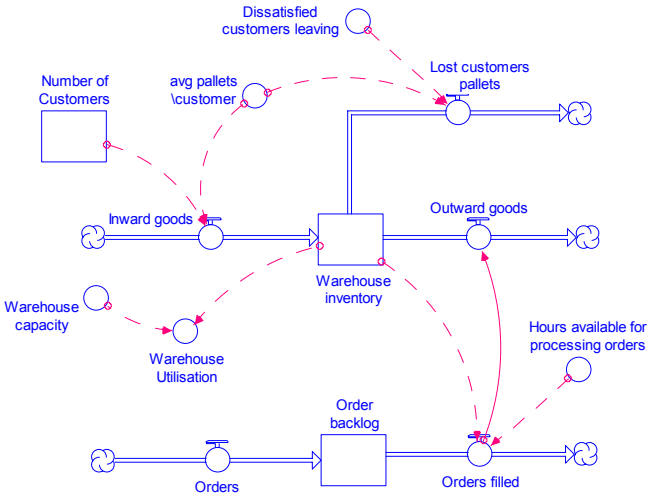


Figure 3: Economic model of a sustainable warehouse

The warehouse company wants to maintain a high capacity utilisation rate to ensure maximum profits. Thus if utilisation is consistently low, it is an indication that the company should seek to obtain new customers by means of promotions or advertising. On the other hand, if the warehouse is over utilised, the company will have to consider increasing their warehouse capacity or rent short-term storage facilities for excess inventory at a greater than average cost. The company should also try to maintain a high level of customer satisfaction by ensuring that goods are delivered on time or the company might run the risk of losing some of their customers.

5.2 The Environmental Model

A high level model showing a few factors that influences the environmental dimension is illustrated in Figure 4. This model shows the main inflows *(Emissions)* and

outflows (*Minimisations)* of the *Carbon emissions* stock. Carbon emissions *(Total transportation emissions)* are generated by the company's transportation fleet comprising of vans, small and large trucks. As the vehicles are highly utilised, their efficiency deteriorates over time thus producing higher levels of carbon emissions. The warehouse company can minimise this by regularly maintaining and upgrading their vehicles (*Transportation fleet upgraded*). The company may offset their carbon emissions by planting trees *(Carbon absorption by trees)* or purchasing *Carbon credits*.

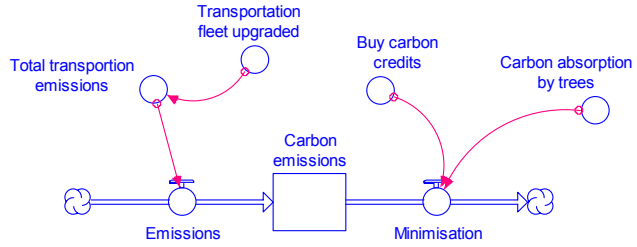


Figure 4: Environmental model of a sustainable warehouse

5.3 The Social Model

The social dimension of the sustainable warehouse is very complex and contains many elements. For the sake of simplicity, a simplified social dimension model is presented in Figure 5. This model represents the social effects of a warehousing company with respect to its employees. The main stock in this model is *Job Satisfaction*. It is an index which has a maximum value of 100. The job satisfaction of the warehouse employees is very important. This will be discussed further in Section 6. Factors such as hours per employee per week *(Work hours/person)*, the extent of *Staff training* and support provided and *Capital investments,* like new equipment and software to aid employees in their work, all have an impact on their level of job satisfaction. If employee *Job satisfaction* drops below a certain level, staff members start to leave the company, resulting in having to hire more staff, thus incurring recruiting and new staff training costs.

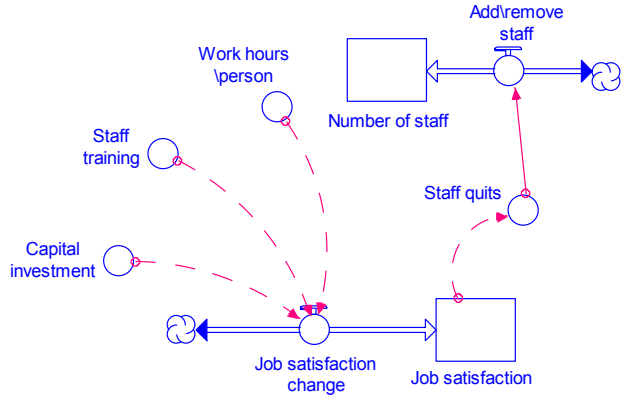


Figure 5: Social model of the sustainable warehouse

6 Interactions between the sustainability models/dimensions

Having briefly discussed the inter-relationships of the sustainability dimensions in Section 4 and Figure 2, this section is dedicated to demonstrating some of the relationships between the three sustainability dimensions in the sustainable warehouse model.

6.1 Environmental – Economic – Social

In order for the company to move towards sustainability, they have to consider and balance the tradeoffs between financial gain as well as being both environmentally and socially responsible. As previously shown in Figure 4, so as to offset their *Carbon emissions*, the company will have to purchase *Carbon credits*, plant trees or minimise the emissions from their transportation fleet. All three *Carbon minimisation* options will increase their expenses, which might lead to lesser funds being made available for *Staff training* and *Capital investments*. Inadequate staff training and capital investments will lead to poor job satisfaction and low productivity. This is further discussed in the Section 6.2.

Another factor the company needs to consider is that the trees will require several years before they are able to provide the full benefits of carbon absorption. Thus, they may wish to consider purchasing *Carbon credits* as a short term solution while planting trees as the long term but more cost effective solution. In either case, the company should minimise inevitable carbon emissions by maintaining vehicle efficiency as it is important to consider the effects of carbon emissions on society, especially in areas along delivery routes. The company must engage sustainably focussed transportation and distribution companies and shares carbon emission responsibilities with its supply chain network.

6.2 Social – Economic

Following on from Section 6.1, choosing not to hire more staff when required might result in short-term savings but will be detrimental to the company in the long run. This is because, the number of staff determines, on average, the number of *Hours available for processing orders.* Thus, a shortage of staff will result in employees having to work excessive hours over a long period of time to try reduce the *Order backlog*. This results in decreased *Job satisfaction* due to increased stress and tiredness. Poor job satisfaction will also lead to low morale and higher risks of making mistakes, therefore causing a drop in overall productivity. A drop in productivity means the average order processing time also rises, further increasing the *Order backlog*.

High levels of backlog will lead to poor customer satisfaction and retention. If a customer is lost, not only will the company have to spend more money finding new customers, the loss of reputation and increased negative word of mouth will have harmful long term effects.

7 Implementation of the Sustainable Warehouse Management models

To implement the models, the modelling software tool iThink 9.0.2, from iSee Systems, was used. iThink uses stock and flow diagrams to model and simulate processes and scenarios. It shows the outcomes of certain user-defined inputs and communicates the interdependencies between processes and problems. Outputs can be displayed in the form of graphs, tables and warning

gauges. In this instance, dynamic systems modelling techniques were used in the creation of this model. The process of creating the model in iThink was an iterative process. It started with a very simple warehouse inventory model (Figure 3) consisting of one stock *(Warehouse Inventory)*, one inflow *(Inward goods)* and one outflow *(Outward goods)*. This model was then tested to ensure that the relationships defined were correct. Once, this was verified, more elements such as *Order Backlog* and *Number of customers* were added. Again this was tested before adding new elements. The whole process of building the entire model was carried out in this manner to allow ease in identifying errors in the model.

while yellow indicates cautionary alert and red indicates high alert. An example of a warning gauge *(Average Cash Funds)* can be found in Figure 6. The *Map* layer is where the stock and flow diagrams are built. The *Model* layer is similar to the *Map* layer except in the *Model* layer, the user is able to define the relationships between the model elements. The *Equation* layer contains all the equations and relationships.

7.1.2 System Walkthrough

Figure 6 shows the main user interface of the simulation model. There are six main sections on this user interface; the *Sustainability Scorecard*, the *Economic* inputs, the *Social* inputs, the *Environmental* inputs, the *Location*

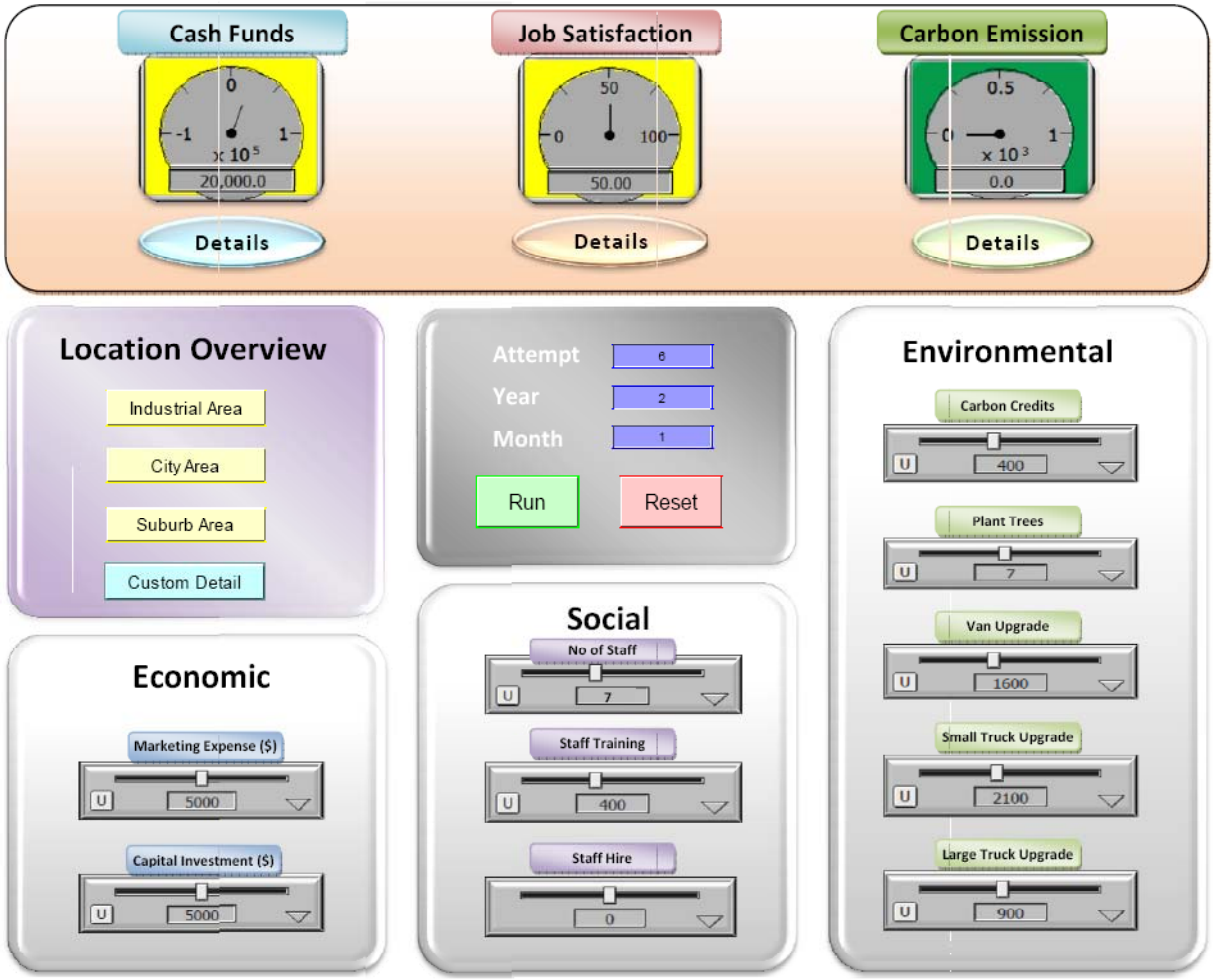


Figure 6: The Sustainable Warehouse Management Simulation Interface

7.1.1 The Development Platform

The iThink modelling tool consists of four different layers. They are the *Interface* layer, the *Map* layer, the *Model* layer and the *Equation* layer. The *Interface* layer allows users to create the end-user interface. This end-user interface is made up of input devices that can be adjusted by the end-user. This is also where outputs such as graphs, tables and warning gauges are displayed. Warning gauges display the value of a variable throughout the simulation. It is also able to automatically change from green to yellow to red depending on the status of the variable. Green indicates a normal status

Overview and the *Run* section.

The *Sustainability Scorecard* consists of three indicators; *Cash Funds*, *Job Satisfaction* and *Carbon Emissions*. *Cash Funds* is the average cash funds from all three locations. If the decision maker clicks on *Details*, the decision maker sees individual cash funds values of the three different locations in a detail level page. Thus if *Cash Funds* enters the "High Alert" (red) stage, the user can inspect the individual warehouse values to determine if all the warehouses are in the red or only a certain warehouse is in financial distress. The decision maker is then able to drill further down into the details to

determine which type of expenses was causing a drain in finances. For example, the warehouse may have been paying too many employees while there is little work to be carried out. This indicates that the decision maker might have to review the staffing for cost minimisation. The decision maker can carry out the same operations for the social indicator, *Job Satisfaction*, and the environmental indicator, *Carbon Emissions*.

The decision maker also has the option, at any time during the simulation, of reviewing the three main indicators for each location by choosing one of the choices in *Location Overview*. The *Custom Detail* button leads the decision maker to a page where they would be able to customise their own graphs or data tables.

The *Economic* input section allows the decision maker to determine the *Marketing Expenses* (to obtain new customers) and *Capital investment* for each period. These values are reset to zero after each period. The *Social* input section allows the decision maker to define the level of *Staff Training* available to improve job satisfaction and *Hire* or *Fire Staff* according to the volume of work available. In the *Environmental* section, the decision maker *Buys Carbon Credits, Plants Trees or Shares Responsibilities with Transportation Companies* to offset their carbon emissions. They are able to optimise the efficiency of their transportation fleet by choosing a transport mode to upgrade or enforce a new selection rule for the transportation company.

To begin the simulation, the user chooses all the values of the inputs that are desired, and then clicks the *Run* button. The simulation runs for one month and pauses to allow the user to review the effects of the decisions made. The user interface is similar to a game console; it is simple, self explanatory and easy to use. An experienced warehouse expert with a little computer knowledge will be able to use the system without training.

7.1.3 Support for Decision Makers

To aid the warehouse executives in making strategic decisions, the user interface of the sustainability model alerts the user with various notifications during the course of the simulation. For example, if the cash flow is low, a message pops up to notify the user that their cash flow is unsustainable. It also alerts the user if the employees are over worked; customer satisfaction level has decreased to a non-acceptable level; investment is required in employee training; warehouse location is not suitable considering the end user location or capital investment; monthly operational costs and overheads are too high; high customer turn over or employee resignation due to poor communication or handling etc.

8 Conclusion and Future Research

Sustainable business management and operations are a pre-requisite for the transformation of existing businesses into sustainable ones. This involves the development of sustainable policies, identifying the problems, assessing options for addressing the problems, considering inter-connected issues, and taking into account the long-term pros and cons. But to be able to explore such issues, an environment that enables us to simulate the complex interdependencies between the social, economic, and environmental dimensions is required. This paper has gone some distance in proving that it is possible to model the interconnectivity between disparate sustainability dimensions. The testing, validity, usefulness and entirety of the model in the context of a real warehouse for day-to-day decision making are still under progress.

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