Using Systems Modelling to Understand the Dynamics of Supply Chains

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Abstract

Supply chain management remains a significant challenge for business today. Management decisions regarding pricing, stock levels, discounting policies, and merchandising all contribute to this challenge. External factors such as buyer behaviour and competitors also add complexity. Using the tools of systems modelling, the authors explore the dynamics of supply chain management and the impact of various policy decisions relating to discounting. Using a liquor retailer and a commodity product – beer, to illustrate the dynamics, the paper presents a practical application of systems modelling and the insights that can be gained from this approach. The results of the simulations suggest that discounting can lead to inventory fluctuations, that contribute to higher inventory costs, sales fluctuations, profit losses and undermined buyer confidence. These results ultimately lead the authors to question the policy of discounting and suggest that consistent pricing may be the best approach for supply chain management and maximum return on investment.

Purpose

The purpose of this research was to explore the dynamics of supply chain management and to consider the impact that strategic decisions such as price discounting, had on the management of inventory and financial performance. The research aimed to demonstrate the extent to which inventory fluctuations and the associated costs were generated, not by attempts to deal with the external competitive environment, but by management decisions designed to compensate for previous poor pricing and inventory decisions. The intention of the authors was to be able to use the simulation results to make recommendations about the most effective and efficient means for inventory management and profit maximisation and to enable the supply chain managers to price, whilst understanding the full impacts of their typical pricing policy decisions.

Scope

In order to demonstrate the dynamics of systems modelling and highlight the advantages of a systems modelling approach, the authors chose to focus on a fast moving commodity product – beer. The selection of beer was based on the predominant consumer behaviours associated with this commodity product, such as switching and variety seeking behaviour (Kotler, 2000). The industry noted impact of competition and price sensitivity on market share and profitability were also significant factors in the selection decision. It was decided that beer would provide an excellent illustration of system dynamics and the use of modelling tools as fluctuations in the supply chain were predicted to be significant with moderate variations in price.

Specifically the model developed by the authors focused on the relationship between the price of beer and inventory stability. In order to gain an in-depth insight into this relationship, the authors chose Tooheys Red Cans as their focus product. Tooheys Red Cans were chosen because they were seen as a commodity product in beer purchasing and hence provided the greatest illustration of price sensitivity and buyer behaviour. VB cans were included in the model as a comparison product, which enabled the authors to model the impact of switching behaviour and its relationship with price.

Important to note is that beer is a unique product and that the system dynamics illustrated in this model do not necessarily represent that of other commodity products. What the model does however, is alert businesses to the dynamic relationships that need to be considered in supply chain management.

Literature Review

The dynamics of supply chains are characterised by bottlenecks and delays. Otto and Kotzab (2003) examined the needs for sets of metrics for supply chain measurement and identified Systems Dynamics as one of the six disciplines that made the greatest contribution to this field. The early contribution of Systems Dynamics to this field is seen in the work around the well-known “Beer Game” (Senge, 1990). Sterman (2000) outlines the Beer Game dynamics, which involved the oscillations of a short supply chain. Earlier work by Morecroft (1983) demonstrated how production and ordering policies converted into supply chain volatility, long delivery times and loss of market share. Paich and Sterman (1993) and Sterman (1989) also discuss the difficulties that managers have in understanding the complex dynamics of supply chains and in assimilating the feedback information generated in such situations. Wikner, Towill and Naim (1991) demonstrated how the Forrester model, derived

Forrester's Industrial Dynamics (1961), and provided a benchmark for improving dynamic performance of supply chains.

The highly interactive nature of the relationships both physical and interpersonal in supply chains makes the use of Group Modelling Techniques, (Vennix & Richardson, 1997) highly appropriate. Akkermans (1995) documents a participative business modelling method, used to deal with the complexities of both technical and organisational issues in strategic decision-making in supply chains. The advantages of such an approach is that it unearths the mental models of a range of decision makers, all whose decisions can influence the dynamics of the supply chain. The importance of such decision-makers was demonstrated by Haslett and Osbourne (2000).

Methodology

To ensure the systems model produced by the authors was of a reliable and recoverable calibre, the authors partnered with one of Australia's large liquor retailers. This partnership gained the authors access to important information about, historical sales and price data, buying and ordering practices, sales inventory, inventory management systems, organisational culture and structure, discounting techniques and market research about buyer behaviour, competition and price sensitivity.

The authors utilised a process of group modelling as the methodology behind their research. Group modelling has numerous advantages, such as uncovering mental models, creating commitment and ownership and realising the synergistic effects of group collaboration (Vennix, 1994).

Group modelling is the favoured approach for modelling in the 'real-world' of business, as it most closely reflects the environment of organisations. Organisations are a complex web of relationships among individuals existing in the same system. Organisations are not just the sum of their parts, but rather a whole that is far greater than the individual components (Morecroft & Sterman, 1994).

The group modelling process focuses not just on the static components of the system, but rather the behaviour that interacts between these components. This behaviour is often the most revealing component of the systems overall performance, and therefore crucial to capture in any system model. The behaviour of a system can only be isolated and therefore modelled by exploring the interaction between the entities of the system and this relies on individuals uncovering their mental models and behaviour within the system.

The knowledge of the organisational members and their understanding of the system was crucial in enabling the authors to gain an accurate insight into the dynamics of the systems model and the impact that one variable had on another.

The authors adopted the systems dynamics model building process described by Richardson & Pugh (1981) in Vennix (1994). This approach outlines seven stages to successful model building:

1. Problem identification and model purpose
2. System conceptualisation
3. Model formulation
4. Analysis of model behaviour
5. Model evaluation
6. Policy analysis
7. Model use or implementation

Incorporating the above process the authors were able to develop their systems model by moving through a series of stages, which progressively built and developed the model. The stages being:

- Understanding and researching the system
- Developing a casual loop of the system
- Developing a stock, flow, rate diagram of the system
- Developing the systems model
- Testing the assumptions of the model
- Running the simulations
- Presenting the policy recommendations

Boundary Issues

As with any model building exercise, the scope of the model must be defined. This means the authors must make a conscious decision as to where to limit the scope of the model. Without this discipline, developing a system model could ultimately continue ad-infinitum.

Accompanying this is the realisation that in some instances the model mechanics will be based on assumptions rather than hard data. The decision to use assumptions, rather than data in some cases, relates to a range of impediments, such as time, money and knowledge. Sometimes the data is just not known and therefore model builders must rely on assumptions to capture the behaviour in the model.

The authors have done their utmost to limit the use of assumptions in this model and wherever possible incorporated factual data, to accurately capture the dynamics of the model. Where assumptions have been used, the authors incorporated the knowledge of the organisation to provide a realistic assumption of the behaviour.

While the responses of competitors is a significant factor in reality, this model made a set of simple assumption about the nature of competition: the competitor's price for both beers varied between \$26- \$28 dollars during the simulation. Figure 1 shows the competitor's Tooheys beer price on the left and the VB price on the right.

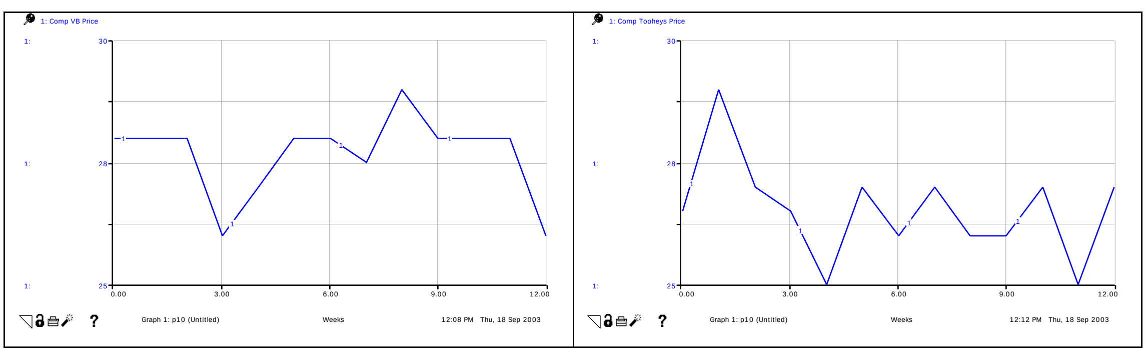

Figure 1: Competitor's beer prices

This approach provides the dynamics associated with fluctuation in competitor pricing but sought to minimise it, so as to isolate the internally generated dynamics arising from internal discounting policy which was often linked to stock levels.

Nature of the Problem

Historically, beer retailing has been typified by a policy of discounting. The discounting was based on planned campaigns, as a reaction to competitors pricing policies, and a reaction to over stock situations. The difficulty with this approach is that it makes the job of managing supply chains very difficult and unpredictable. The result often being wide fluctuations in inventory levels throughout the supply chain, thus ultimately impacting on profit and market share.

The supply chain of a traditional FMCG organisation is made up of a complex and dynamic interaction between suppliers, warehouses, retailers, customers and competitors. The problem for supply chain managers was how best to manage the supply chain in an environment of erratic discounting and fragmented inventory management systems. The evidence obtained by the authors suggested that there were frequent episodes of both stock outs and overstocks and that the communication between the entities of the system, that is suppliers, warehouses and stores, was haphazard at best.

In order to illustrate the supply chain management and the impact of discounting policies the authors set about developing a systems model which would capture all of the elements impacting on the supply chain of the liquor retailer.

The ultimate aim of the authors was to develop a systems model, to enable the users to visualise the impact of their policy decisions. Systems modelling enables organisations to shift their thinking from a problem solution framework to an organic systems approach, which highlights how the behaviour of those within the system contributes to the results they achieve. This is a significant mindshift for many and relies on an approach such as modelling to provide the catalyst for this shift.

Developing the Model

After investigating the nature of the problem, the authors were able to identify the key factors that impact supply chain stability. These factors are best illustrated through a casual loop diagram. Causal loop diagrams aid in understanding the nature of the problem, by demonstrating the causal relationship between the elements and the contribution they make to the behaviour of the system.

Causal Loop Diagram

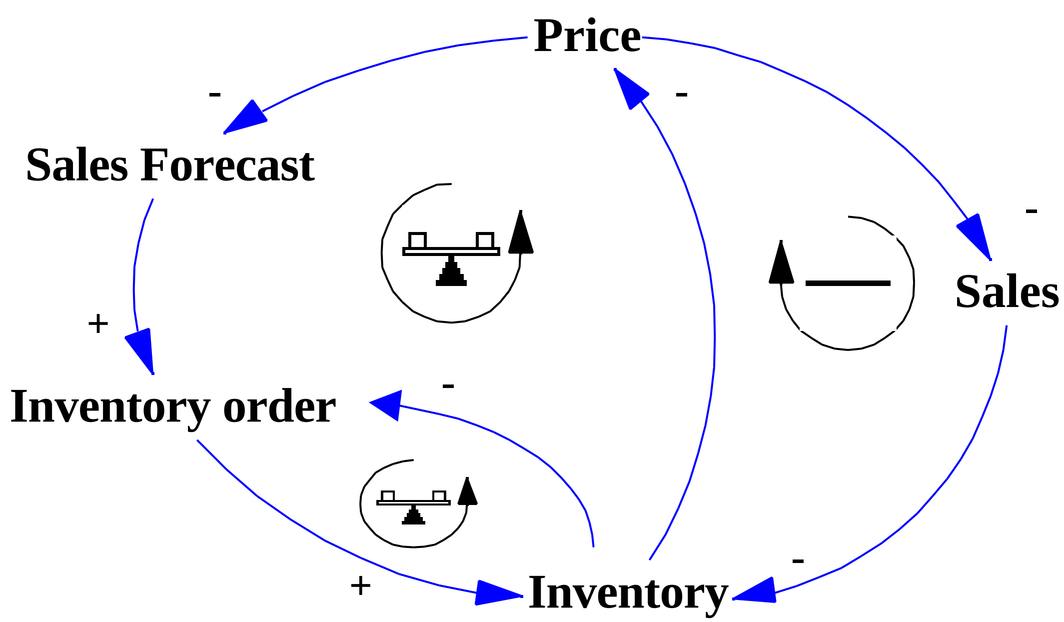

Figure 2: Causal Loop Diagram

An explanation of the above cause and effect relationships is best described in the following way:

Price to Sales: The relationship between price and sales is a negative relationship, which means that as the price increases, sales will decrease. Conversely, if the price decreases, sales will increase.

Sales to Inventory: The relationship between sales and inventory is also a negative relationship, which means that as sales increase, inventory decreases, and conversely, if sales decrease, inventory levels will increase as the supply chain continues to deliver product.

Inventory to Price: Again another negative relationship. If inventory levels increase, the greater the pressure to decrease price in order to reduce the inventory levels. On the other hand if inventory levels are low, the lower the pressure to reduce price. With some products, the lower the inventory, the greater the pressure to increase price – the law of supply and demand.

Price to Sales Forecast: The lower the price, the greater the sales unit forecast. That is there is an expectation that more beer will be sold. If the price is higher, forecasters will expect beer sales to be reduced. Worth noting is that the price to sales forecast and the price to sales relationships are partially independent of each other. Sales forecast refers to predicted sales, whereas sales equals the actual sales. In addition, other factors are usually considered when forecasting sales.

Sales Forecast to Inventory Order: Obviously, the greater the estimated sales forecast the greater the inventory required hence the need to increase the inventory order. The lower the estimated forecast of sales, the lower the inventory requirements.

Inventory Order to Inventory: The relationship between these two entities is a positive relationship, which means that as the inventory order increases the inventory levels increase. Conversely, any decrease in inventory orders will reduce the amount of inventory.

Inventory to Inventory Order: Conversely this relationship is negative. A high inventory leads to a lower inventory order and vice versa. Usually there is a notional "optimal" inventory level. The difference between actual inventory and the optimal inventory drives inventory orders.

Establishing these relationships is important, as they form the foundation of the ensuing model. Building a systems model is a step process which requires the modeller to progress move through the phases of causal loop diagram, rate/flow diagram and then building the structures of the model. Having established the fundamental causal relationship of the systems model, the authors were now able to consider the flows and rates of the model.

General Flow/Rate Diagram

The flow rate diagram is another important component of any model building exercise. A flow refers to the direction of the relationship between the entities and the rate refers to the volume of stock running through the model. Various components act as controls of the rates of flow in the system. The iconography of the simulation model is shown in Figure 1

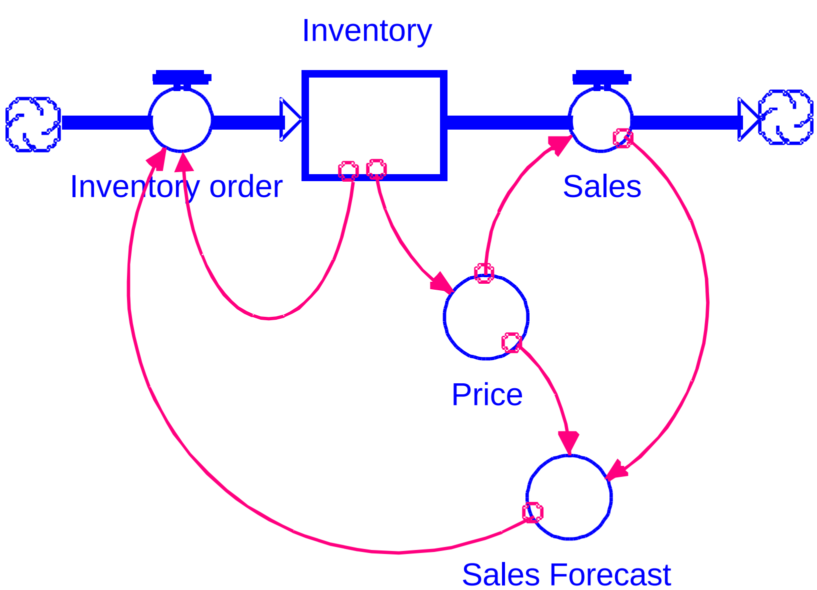

Figure 3: Rate/Flow Diagram

Figure 3 shows the relationships between Inventory Orders, Inventory, Sales, Price and Sales Forecast. Inventory Orders are an inflow into Inventory. The level of inventory also drives inventory orders. Sales are an outflow from Inventory. Inventory levels drive Price which is the rate at which Sales are made. The Price drives the Sales forecast which closes the loop by driving Inventory orders. The equations used for the inventory stocks of the model were:

STORE_INVENTORY (t) = STORE_INVENTORY (t - DT) + (into_store - TOOHEYS_SALES) * dt

INIT STORE_INVENTORY = 2500

INFLOWS: into_store = store_orders + DELAY (WH_overs_to_store, 1) + Promo_order_store

OUTFLOWS: TOOHEYS_SALES = Tooheys_Buyers

Having developed the high level structure of the model through the Rate/Flow diagram, the authors now needed to consider the behaviour behinds those rates and flows. Based on the data that the authors obtained about the supply chain the authors were able to integrate mathematical formulas into the model, which would simulate the behaviour of the supply chain.

The model was broken down into three major sections, supplier, warehouse and store. The three sections consider both the key elements, as well as the entire flow path that wrapped around the core diagram. The following diagrams provide a clear illustration of these three sections.

Supply Level

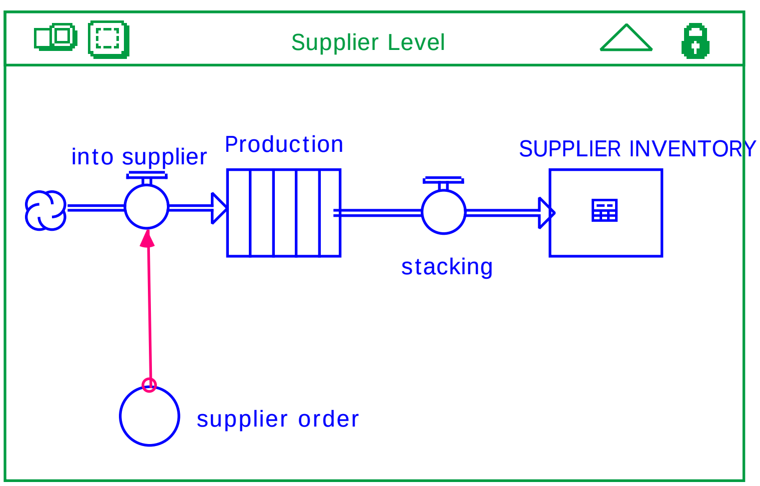

Figure 4: Supplier Level of the Systems Model

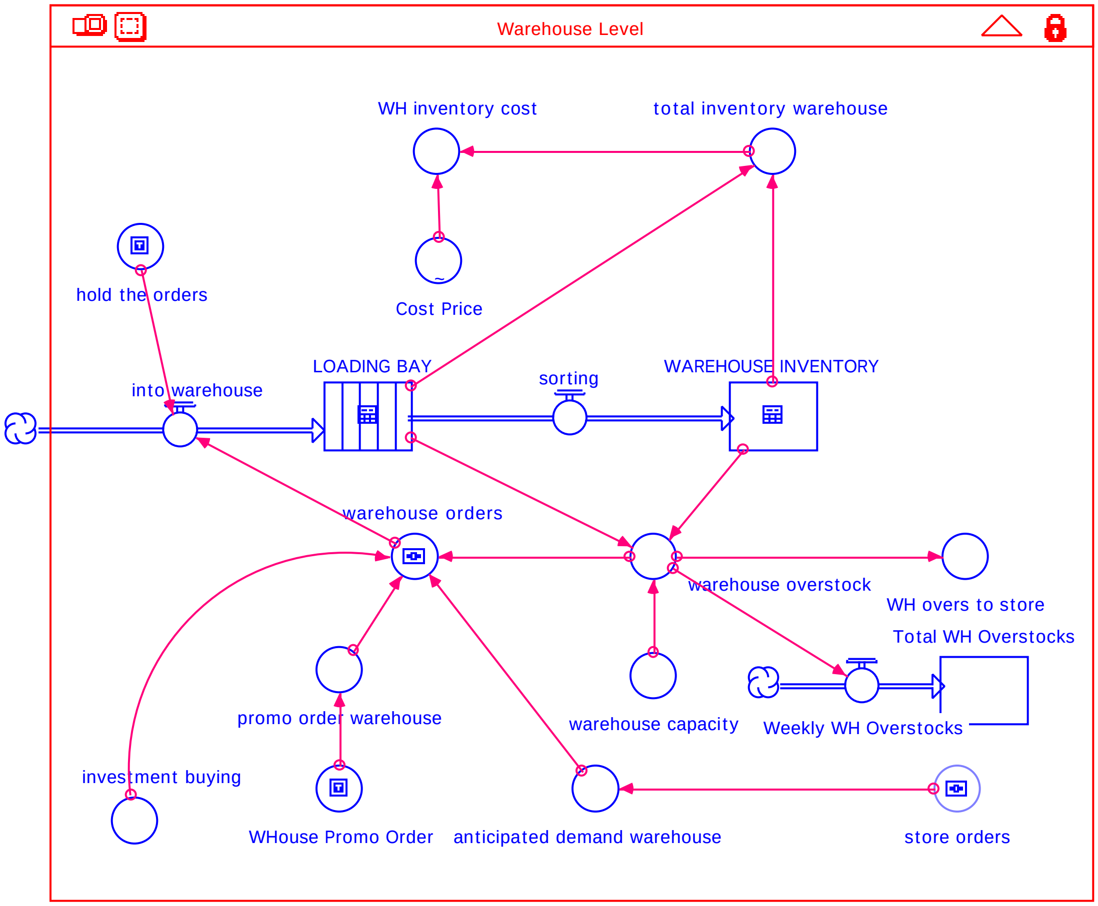

Figure 5: Warehouse level of system model

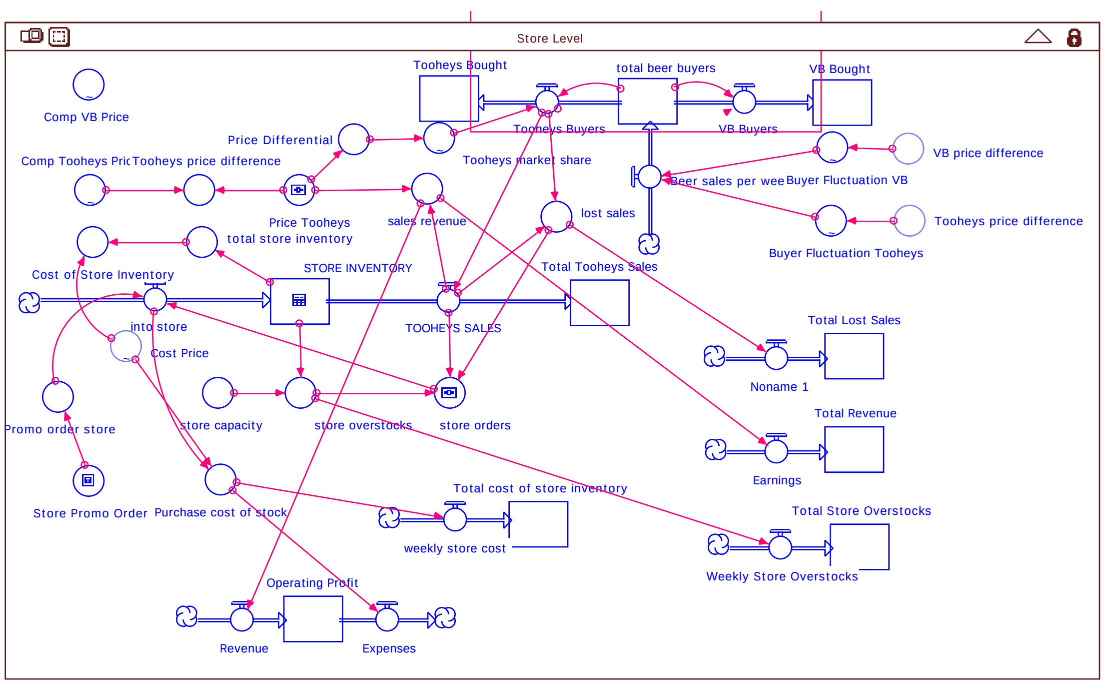

Figure 6: Store Level of system model

Running the Simulations

With the model built and the behaviour of the entities calculated and tested throughout the model, the authors were now in a position to run simulations of various scenarios and to assess the impact that this had on the supply chain and business performance according to the indicators.

After testing numerous scenarios, the authors identified three pricing policy decisions which provide the clearest illustration as to the impact of discounting on supply chain stability. In testing these scenarios, the authors' objective was to achieve the greatest degree of inventory stability while maximising the profit for the company. In addition, highlighting the cause and effect relationships between pricing policy options and system behaviour.

The three policies tested were as follows:

- Policy 1: Periodic discounting with no promotional order
- Policy 2: Periodic discounting with promotional order
- Policy 3: Low everyday price

The policies were tested over a period of twelve weeks. A twelve week period was chosen as it was long enough to demonstrated the effect of policy decision whilst not being tool long as to lose the interest of the model user.

Pricing Policy 1 and 2 is to discount the price of Tooheys once every four weeks. Every other week Tooheys is at its full retail price. Pricing Policy 3 is to average this discount and price Tooheys at the same discounted price each week, albeit a lesser discount than with Policy 1 and 2. Therefore, as in the following example where Policy 1 and 2 sees Tooheys discounted by $2.00 once every four weeks then Policy 3 would be to discount Tooheys 50cents every week.

The model interface allows the user to determine the quantities of beer to be ordered each week or to rely on the 'automated' ordering system built into the model. This ordering equation is designed to realise optimum inventory levels where quantities ordered are based on the previous week's sales taking into account current overstocks or out of stocks. The automated ordering is designed to mimic the mental models of the supply chain managers within the partner company. For the purposes of testing the three policies, the ordering equations for the warehouse and store are switched on.

Policy 1 and 2, for a commodity beer such as Tooheys Red, has shown to be successful at generating significant increases in sales. For this purpose the model incorporates a "promotional order" for Policy 2 which allows for increased inventory levels at the time of the promotion to meet the anticipated increase in demand. This is designed to capture ordering behaviour when prior knowledge of a product promotion is available. Policy 1 is similar to policy 2 however it does not incorporate the "promotional order" and as such tests the system's response to discounting where no allowance is made to increase inventory to meet potentially significant and temporary increases in demand.

Policy 1

- Price of Tooheys is discounted to $24.00 at weeks 3,7 & 11 and remains at $26.00 every other week.
- The price of VB is set to $28.00.
- Promotional orders for the warehouse and store are switched off
- Ordering equations for the warehouse and store are switched on.

Results of Policy 1

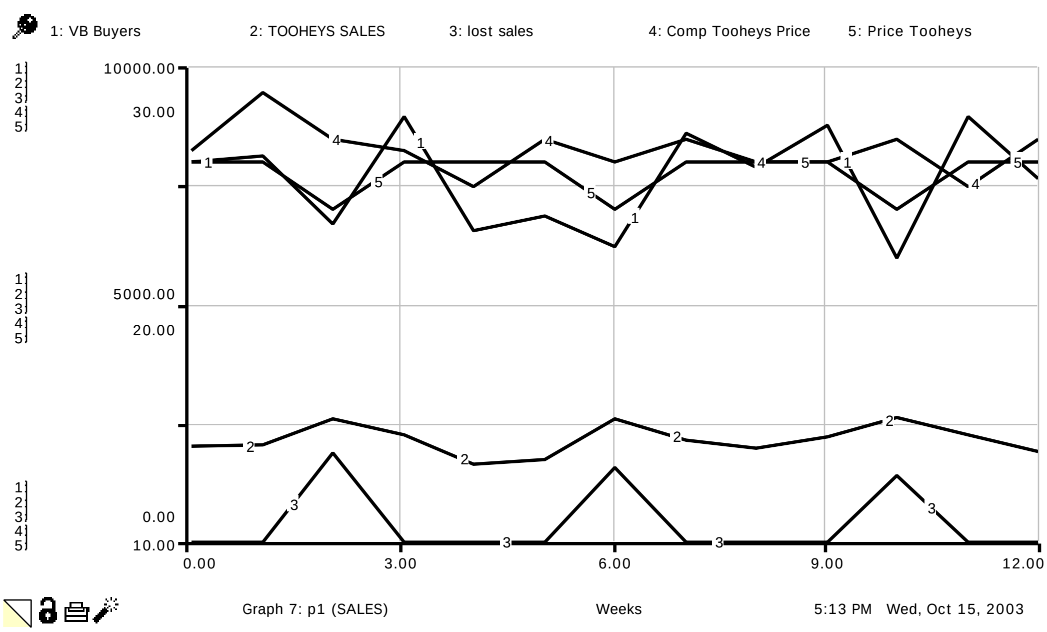

Figure 7: Policy 1 Sales Results

Figure 7 reveals sales of Tooheys increase as expected when the beer is discounted. The stores have inadequate stock to meet the increased demand of the promotion and lost sales are experienced. During the promotional weeks VB sales fall indicating that the discounted price of Tooheys attracted some portion of beer consumers who would otherwise purchase VB. Figure 8 details significant swings in ordering patterns as the system attempts to reduce overstocks and compensate for lost sales. Store inventory fluctuates dramatically, with instances of almost twice capacity.

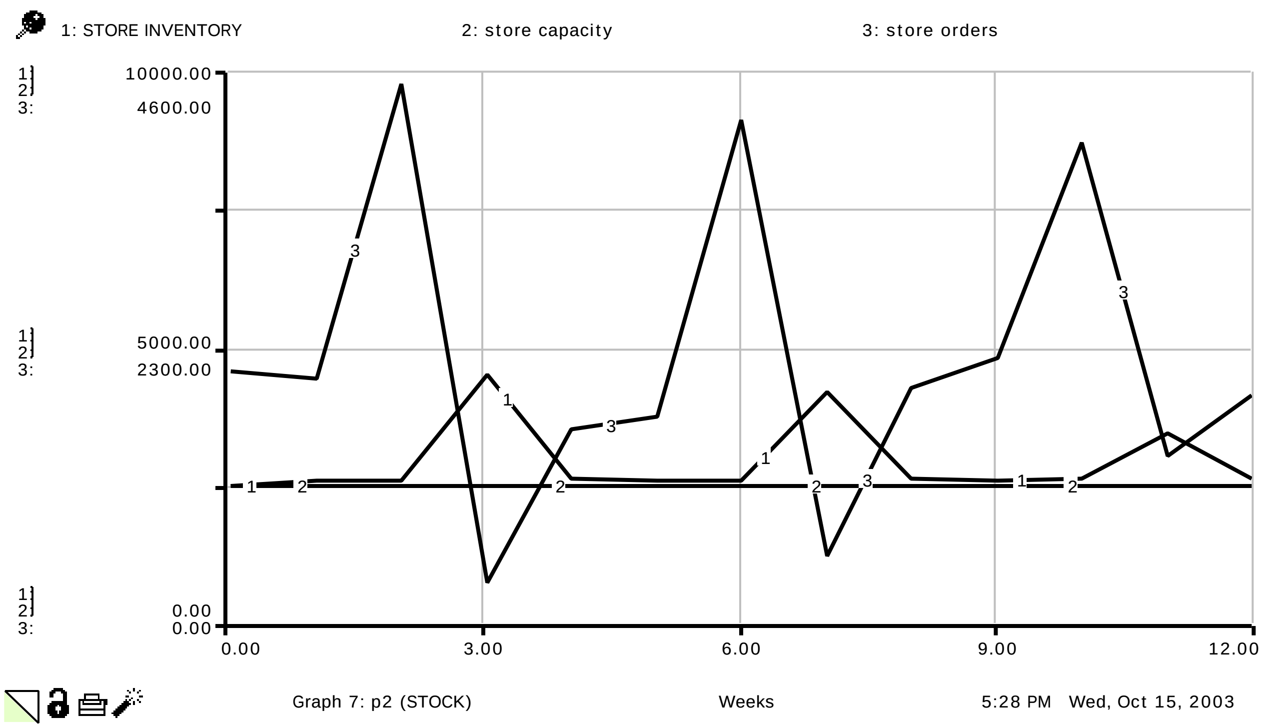

Figure 8: Policy 1, Inventory Levels and Ordering Patterns

Policy 2

- Price of Tooheys is discounted to $24.00 at weeks 3,7 & 11 and $26.00 every other week.
- The price of VB is set at its full retail of $28.00 so as to isolate the impact of discounting Tooheys.
- Promotional orders for the warehouse and store are switched on and timed to coincide with the above mentioned discounted weeks.
- Ordering equations for the warehouse and store are switched on.

Results of Policy 2

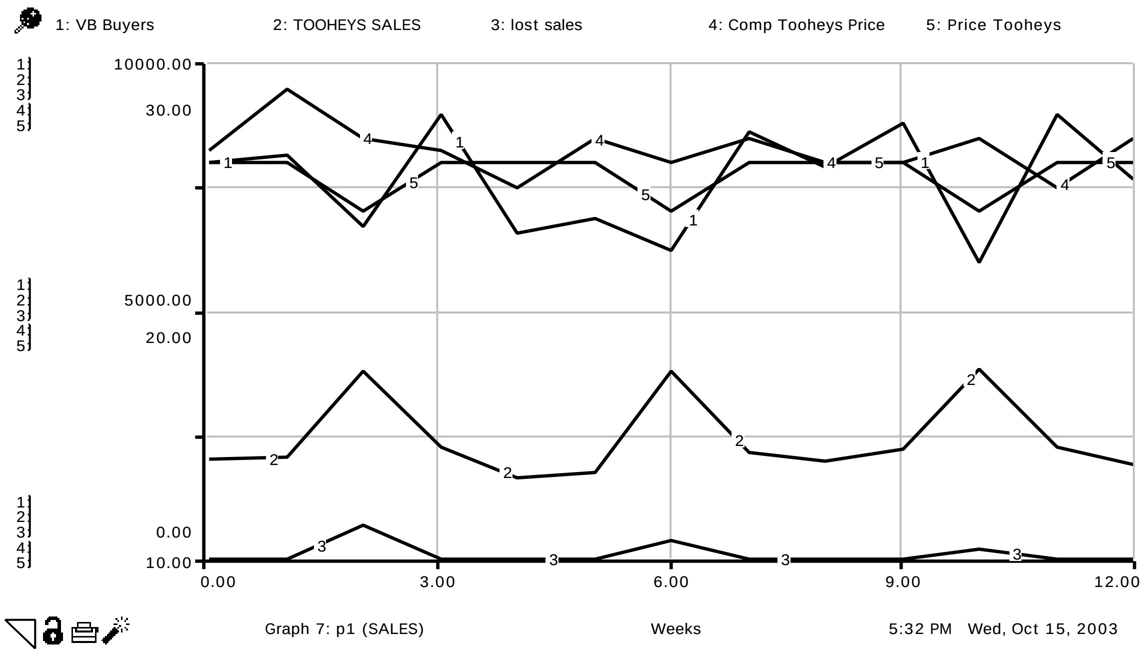

Figure 9: Policy 2, Sales Results

Figure 9 indicates that units of Tooheys sold during the non-promotional weeks vary between 1,640 and 2,200. During the promotional weeks sales increase as expected peaking at 3,800 representing a 100% increase compared to the lowest non-promotional weeks. Sale patterns for VB are identical to that of policy 1. The stores have inadequate stock to meet the increased demand of the promotion and lost sales are experienced albeit to a lesser extent than that of policy 1. Lost sales occur despite the preparation made for the promotions and the stores inventory increases significantly (at times up to 70% more than capacity) during the promotional weeks. This policy of planned periodic discounting generates significant variance in inventory levels and ordering patterns as represented in Figure 10.

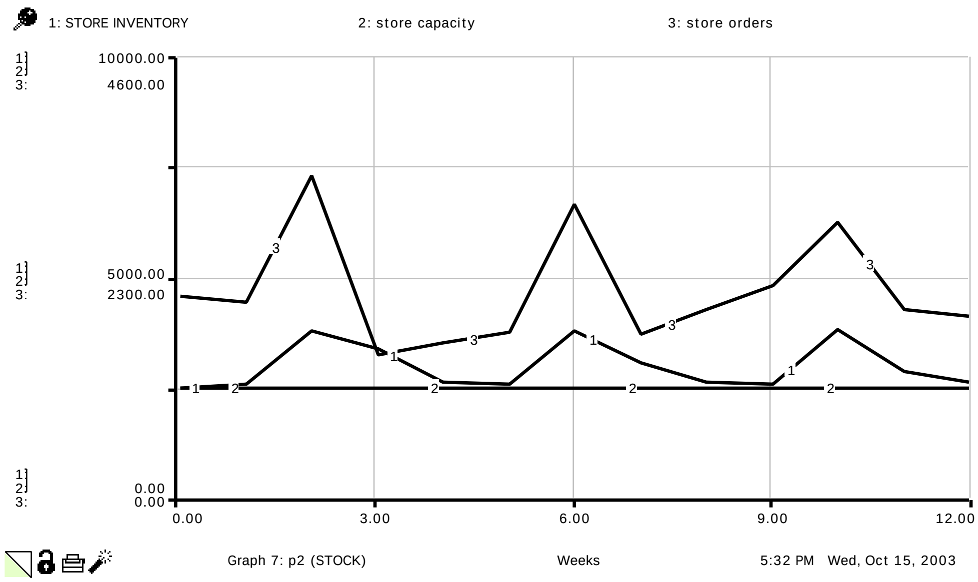

Figure 10: Policy 2, Inventory Levels and Ordering Patterns

Policy 3

- Price of Tooheys is $25.50 each week, effectively ‘spreading’ the $2.00 discount of policy 1.
- The price of VB is set to $28.00
- Promotional orders for the warehouse and store are switched off
- Ordering equations are switched on.

Results of Policy 3

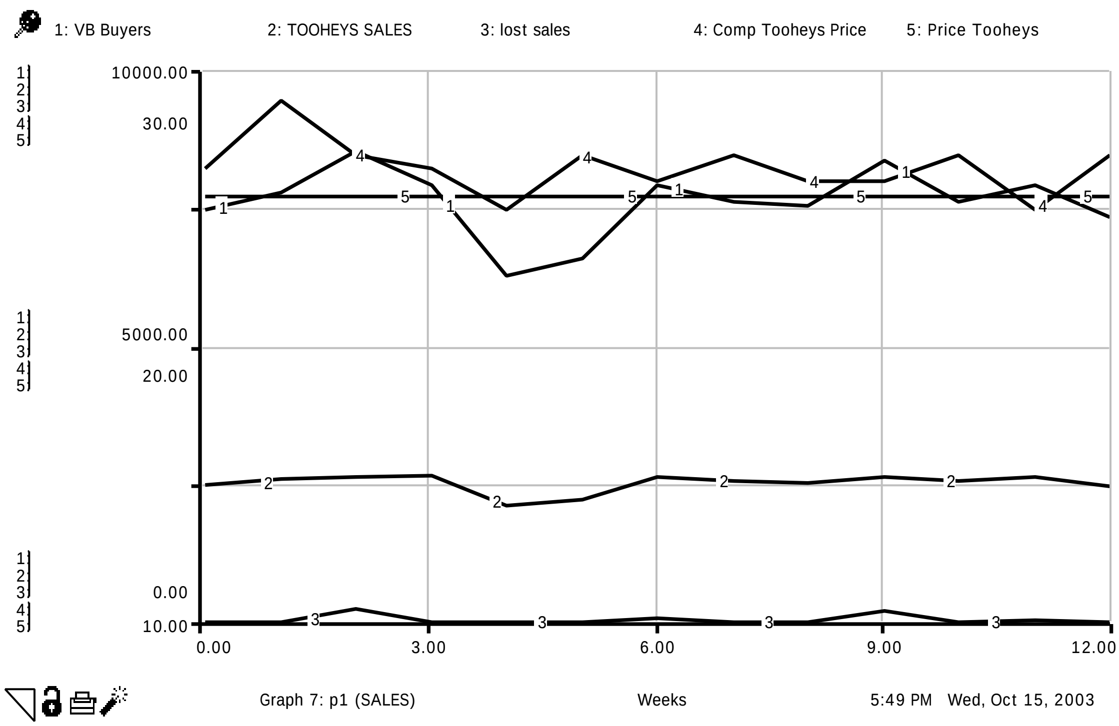

Figure 11: Policy 3, Sales Results

Figure 11 reveals sales are relatively steady throughout, with a marginal fall experienced in week 4 where competitors discount their price of Tooheys to $25.00. Similarly VB sales vary significantly less than in Policy 1 and 2 and modest changes are dependent on the competitors' pricing. After 12 weeks total Tooheys and VB sales are marginally higher than with policy 1. Stockouts or lost sales are up to 50% less than Policy 1.

Figure 12 revels that for Policy 3 ordering patterns are similar each week with only minor corrections required to return inventory to its capacity level and overstocks are notably lower than Policy 1 and 2.

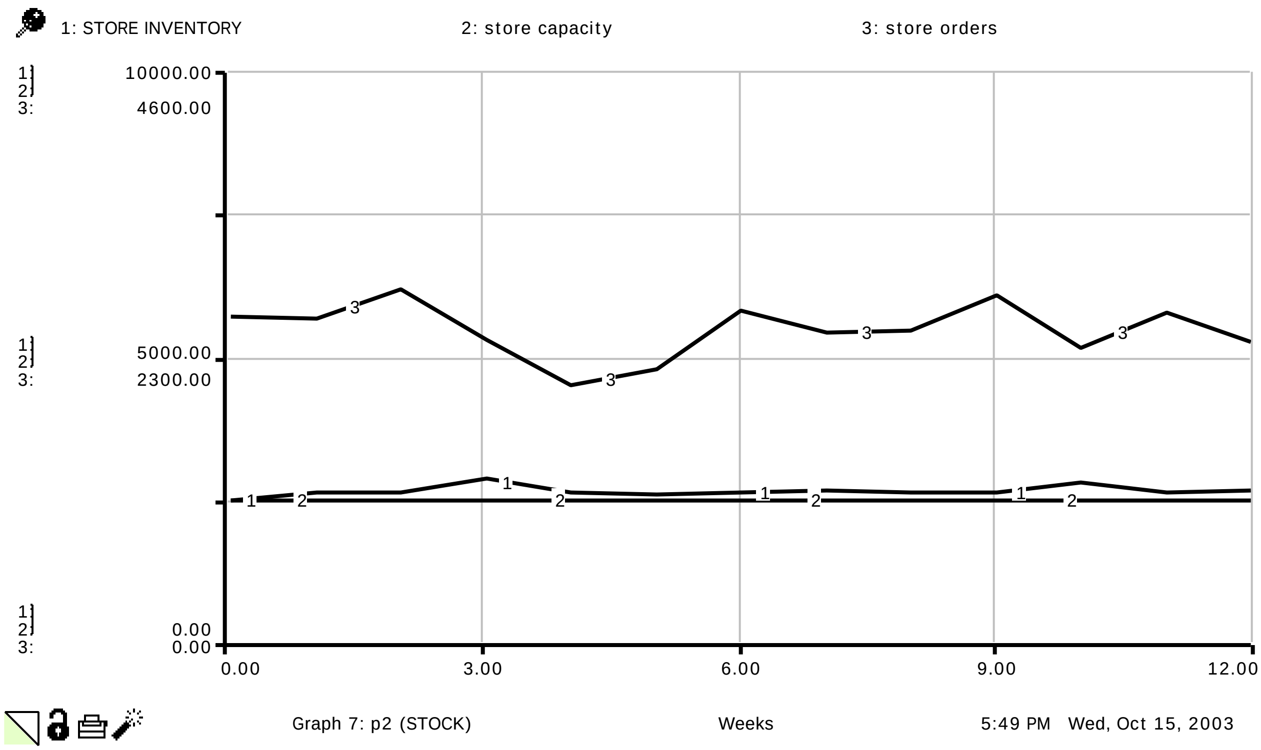

Figure 12 : Policy 3, Inventory Levels and Ordering Patterns

Summary of Results

The results of the pricing policies are summarised in table 1 below.

Item	**Policy 1**	**Policy 2**	**Policy 3**
Units Sold -Tooheys	26,018	29,618	30,169
Average Inventory – Tooheys	2964	3026	2663
Lost Sales(Stockouts) - Tooheys	4,842	1,242	456
Store Overstocks – Tooheys	5,459	6,211	1,811
Units Sold –VB	91,840	91,840	91,875
Sales Revenue – Tooheys	$660,872	$747,272	$769,303
Average Sale Price	$25.40	$25.23	$25.50
Total Gross Profit – Tooheys	$64,445	$73,170	$85,889
Gross Profit per Unit Sold	$2.48	$2.47	$2.84

Table 1: Summary of Simulation Results.

Units Sold- Tooheys

Policies 2 and 3 generate sales at least 12% more than that of policy 1 and work to maintain the retailer’s market share.

Average Inventory- Tooheys

For policy 3 the average weekly inventory held is 10% less than policy 1 and 12% less than policy 2. This lower inventory cost contributes to the greater profitability per unit sold for policy 3.

Lost Sales

Lost sales are minimised with policy 3 and are significantly less than policies 1 and 2. The lost sales experienced with policy 1 are nearly three times that of policy 2 revealing that without the promotional order that is incorporated in policy 2, the retailer had inadequate inventory to meet the increase in temporary demand stimulated by the discount.

Store Overstocks

Policy 3 store overstocks are approximately 70% less than policies 1 and 2. In policy 3,the store requires less space to store excess inventory. This impacts the number of product lines able to be stocked or alternatively the size of the retail outlet required to achieve the sales.

Units Sold – VB

This variable is similar under all policies, however as indicated in the graphs above, policy 3 generates less variance in sales levels of VB.

Sales Revenue, Average Sale Price – Tooheys

Although policy 2 and 3 result in similar units sold, nearly 40% of policy 2 sales result from when the price is discounted. With an average sale price 27 cents lower than policy 3, policy 2 results in overall lower sales revenue. The comparatively low sales revenue of policy 1 can be attributed to the number of units sold.

Total Gross Profit, Gross Profit per Unit Sold – Tooheys

With a higher average sale price the gross profit of policy 3 is 17% higher than that of policy 2. For policy 1 although the gross profit per unit sold is marginally higher than policy 2 the significantly lower unit sales result compromises the retailer's market share. The lower total inventory cost and the higher average sale price drive the higher gross profit per unit for policy 3.

Conclusions and Recommendations

The simulations conducted by the authors illustrated the impact of discounting on sales, inventory levels and profit. The simulations indicated that a policy of everyday lower pricing were more likely than periodic discounting, to result in stable sales patterns and overall lower inventory levels whilst maximising sales and gross profit and minimising lost sales.

Significant sale and inventory fluctuations are experienced with a pricing policy of periodic discounting. The most notable fluctuations are a direct result of the retailer's own pricing. By comparison, with a policy of low everyday prices the major drivers of sales are the price point and the ability to supply. Sales and inventory levels are relatively stable and fluctuations experienced are minor and tend to occur where the competitor discounts rather than the actions of the retailer. This therefore dramatically reduces one of the complexities of supply chain management.

Whilst the competitors' pricing cannot be ignored it is likely that with a policy of low everyday price the ability to contain the impact of competitors' actions is improved. Rather than reacting to the competitors' discounting (for example by matching aggressive discounting), where the retailer maintains low everyday prices, inventory and sales quickly resume to optimal levels when the competitors' price increases. By not responding to aggressive discounting, commodity minded and variey seeking consumers may begin to change to habitual buyers (Kotler, 2000).

The everyday discount of policy 3 indicates it is an amount sufficient to attract substantial sales of Tooheys but is not so low as to 'cannibalise' sales of VB or stimulate a response from the competitors. There are no great changes in consumer buying from week to week that may otherwise gain the competitors' attention. With policy 3 this retailer may become know for "low everyday prices" potentially increasing its market share in the long run, as it attracts commodity minded buyers. This policy may be complimented by one or two well timed promotions throughout the year that are co-ordinated with the supplier in terms of delivery of product, confidentially, price and exclusivity to that price point during the promotional period. Where the retailer is maintaining substantial and stable beer orders its bargaining power with the supplier is likely to be enhanced.

Based on the results provided by the simulations, the authors would advocate a policy of low everyday pricing. The authors found that this policy provided the greatest supply chain stability and overall business performance.

Understanding this, the authors propose the following recommendations:

- Knowledge of your product and its buyer's behaviour is key to building a systems model which will produce reliable results
- Test your market and understand the behaviour of your customers, to determine their degree of price sensitivity, variety seeking behaviour and brand/retailer loyalty
- Discounting policies need to be introduced alongside sophisticated inventory management systems, which allow for the timely and accurate transfer of information between suppliers, warehouses and stores. This

will assist in the ability to manage the inventory requirements within an environment of fluctuating sales and maximise the gross profit.

Interestingly the partner company in this exercise has decided to increase their investment in systems modelling to build management decision-making tools. Systems modelling enables the continuous testing of strategies and the building of knowledge about the consequences of potential actions. Not all complex cause and effect relationships are intuitively obvious. Whilst some actions may produce desired outcomes, there is always the possibility of undesired consequences elsewhere in the system. Systems modelling helps understanding of these complex relationships and enables the discovery of overall system optimisation. It is a valuable business tool, which can enhance a business manager’s understanding of the dynamics of their environment and the behaviours that can ultimately contribute to success or failure.

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