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Removing bullwhip from the Tesco supply chain

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Abstract

We demonstrate how bullwhip reduction principles generated through generic supply chain modelling have been used to tackle the bullwhip problem within Tesco, the largest UK grocery retailer. In the context of bullwhip research, this bridging between theory and practice has not been extensively demonstrated previously. The research involved examining the automated store ordering system, through which seven replenishment algorithms were identified. We demonstrated that three of these algorithms (accounting for 65% of the sales value) were deemed to generate excessive bullwhip and could be altered to avoid such practice. Their essential structure also reflected an Order-Up-To policy. A simulation model of the system was developed and, based on experience from generic bullwhip research, order variability was reduced to approximately 75% of sales variability while maintaining customer service levels. The change was implemented by the retailer, producing significant economic benefits in line with the suggested model.

1. Introduction

Within the retail environment, inventory management within stores represents an essential element of a business' operations. The availability (or otherwise) of stock on the shelves has a significant impact on the experience of the shopper, and can influence their behaviour. Corsten and Gruen (2004) found that, in 31% of cases, consumers will visit an alternative store to purchase the missing item, representing lost sales for the retailer. Further, their survey found that, in 72% of cases, the root cause of the out-of-stock situation was related to the store ordering process. The management of inventory within a retail environment has been extensively studied, considering aspects such as perishability (Bitran et al., 1998, Blackburn and Scudder, 2009), information accuracy (Fleisch and Tellkamp, 2005, DeHoratius, 2008), product range (Ketzenberg et al., 2000) and demand substitution (Smith and Agrawal, 2000, Yücela et al., 2009). Throughout, there is a particular focus on maintaining product availability and/or profit, with a key element of this body of research being the determination of the optimal inventory control policy.

The last decade has seen a significant increase in the use of automated store ordering (ASO) systems to manage the replenishment process. Before this, in many retailers the process involved some human intervention in the decision making process, either centrally or at each individual store. However, the improved efficiency of automation along with the introduction of Electronic Point of Sale (EPOS) technology has led to changes in the replenishment process and the introduction of ASO.

Consequently, there have been a number of studies carried out to look at these systems. It has been noted that the underlying logic for ASO systems is based around a (R,s,nQ) ordering policy, with a review period R between orders, a dynamic reorder point s and orders the multiple n of a fixed case size Q (van Donselaar et al., 2006). Building on this, the same authors have compared the performance of the ASO against more traditional approaches (Gaur et al., 2009) as well as considering the suitability of the ordering policy for different types of products, and especially perishable items (van Donselaar et al., 2006).

Falck (2005) considers two further aspects relating to ASO systems. First, the ability of these systems to cope with the weekly variability in demand as well as different store delivery schedules. A comparison between static and dynamic reorder points shows that the latter is more effective at maintaining availability. Second, an alternative approach for dealing with promotional periods is proposed, to increase the responsiveness of the forecast.

One aspect that has received less attention is the bullwhip effect generated by ASO systems. The bullwhip effect sees the magnitude of order variability increased up a supply chain. Figure 1 shows the bullwhip effect generated by the replenishment systems within Tesco, the largest UK grocery retailer, for soft drinks; comparisons with other grocery products from other retailers show such behaviour is not uncommon (Taylor, 2006, Potter et al., 2009). It has been suggested that there is a need to reduce bullwhip in order to improve efficiency throughout the grocery supply chain (Taylor and Fearne, 2006). This paper demonstrates how bullwhip reduction principles generated through generic supply chain modelling have been used to tackle the bullwhip problem within the ASO system of Tesco, the largest UK grocery retailer. In the context of bullwhip research, this bridging between theory and practice has not been extensively demonstrated previously.

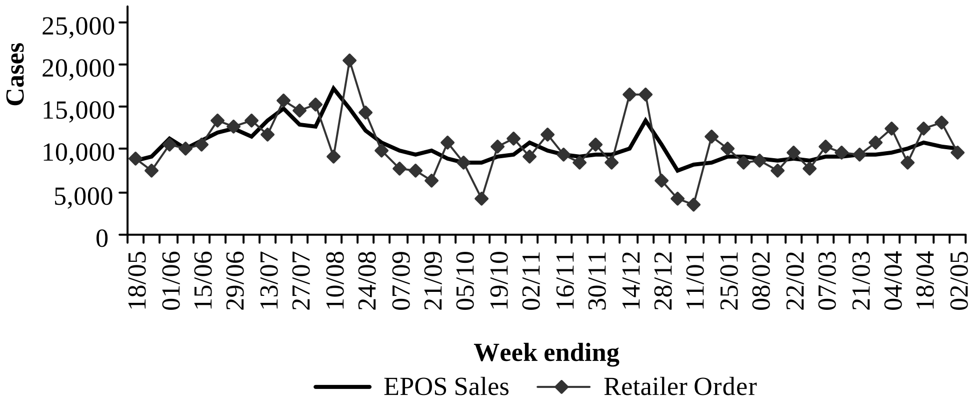

Figure 1. Demand amplification across 1 year for sales of Cherryade

2. Research context

In examining the ASO system within Tesco, it is important to place the research within the wider context of logistics operations in the UK grocery environment. The past 40 years has seen an extensive evolution within the sector, as the distribution channels have evolved from store-based control in the 1960s to increasing levels of centralisation today. The first stage in this evolution was the introduction of regional distribution centres (RDCs) during the late 1970s and 1980s. These enabled a reduction in inventory in the retail outlets and allowed centralisation of the ordering process to suppliers (Fernie et al., 2000). Increasing congestion at the RDCs during the 1990s has resulted in the introduction on consolidation centres for smaller suppliers, to increase the efficiency of transport operations (Smith and Sparks, 2004).

This timescale has also seen Tesco grow significantly to become the dominant player in the UK grocery industry. At the start of 2010, the company had a UK market share of 30.5%, well ahead of their rivals Asda, part of the Walmart family (16.9%) and J. Sainsbury's (16.3%) (UKPA, 2010). Although the market is effectively oligopolistic, there is strong competition between the retailers (Competition Commission, 2008). Among the factors that have contributed to the growth of Tesco has been a focus on supply chain excellence, recognising that it is essential to get this right in order to deliver value to the customers (Jones and Clark, 2002). In doing so, the operations have been underpinned by lean thinking – only carrying out activities which add value to the customer. In 2001, Tesco introduced Factory Gate Pricing (FGP) as their next stage in the evolution of grocery distribution. This saw the retailer take full control of the logistics into their RDCs, arranging transport from the supplier's factory (Potter et al., 2007). In doing so, this provided visibility of the operations upstream, and particularly the nature of orders being placed on suppliers.

The late 1990s and early 2000s also saw Tesco develop and introduce a new ASO system. The introduction of lean thinking saw lower levels of inventory held throughout their operations, supported by an increase in the frequency of stock reviews to twice daily. Consequently, there was a need for an ASO system that could cope with this increased complexity and maintain customer service levels. The aim was to increase availability to those that may be expected in, for example, Toyota. As Jones and Clark (2002) note, 98.5% availability for each product gives, across a basket of 40 products, a probability of complete fulfilment of only 55%.

As a company, Tesco was aware of the presence of bullwhip within their operations, both before and after the introduction of the ASO system. However, there was a perception that the new system was being too responsive to changes in demand and therefore increasing the amplification effect within the supply chain. Analysis revealed that the daily variability of workload at the RDCs was increased 185% by this system, creating pressures particularly in terms of increasing the level of resources required to service the orders. The visibility gained through FGP meant that Tesco could also see this additional amplification being transmitted up the supply chain and the implications of it in the inbound distribution network (for example, through short term, unexpected peaks in requirements for trucks). Therefore, it was identified that changes needed to be made to the system, leading to the research presented in this paper. The overall aim was to examine the ordering rules within the ASO system, evaluate their dynamic performance and suggest improvements to address the issues raised. It was not necessary to determine the optimum replenishment policy.

3. Research approach

In order to examine this problem, the approach taken was to develop a dynamic simulation model of the system, to analyse the causes of the dynamic behaviour in a structured manner and to test the dynamic impact of changes to the system. The model was developed using a proprietary spreadsheet package and represented the replenishment process for a single stock keeping unit (SKU) within a single retail outlet. To build the model, the approach suggested by Towill (1996) for modelling industrial systems was followed. As shown in Figure 2, this suggests the use of three types of information sources in developing the model.

3.1 People-based sources

A key part of the data collection process was a series of interviews between the research team and those involved in the development of the system within Tesco. In total, 20 hours of interviews were carried out over a 3 month period. The discussions provided detailed insights into the structure of the model and the rationale behind it, with each week building on the previous week's content. During the interviews, documentation relating to the system was also shared, to complement the verbal description. Between each interview, the research team would develop the simulation model to include the element(s) discussed. The updated model was then shown to the developers in Tesco each week, as part of the verification process as to the accuracy of the model.

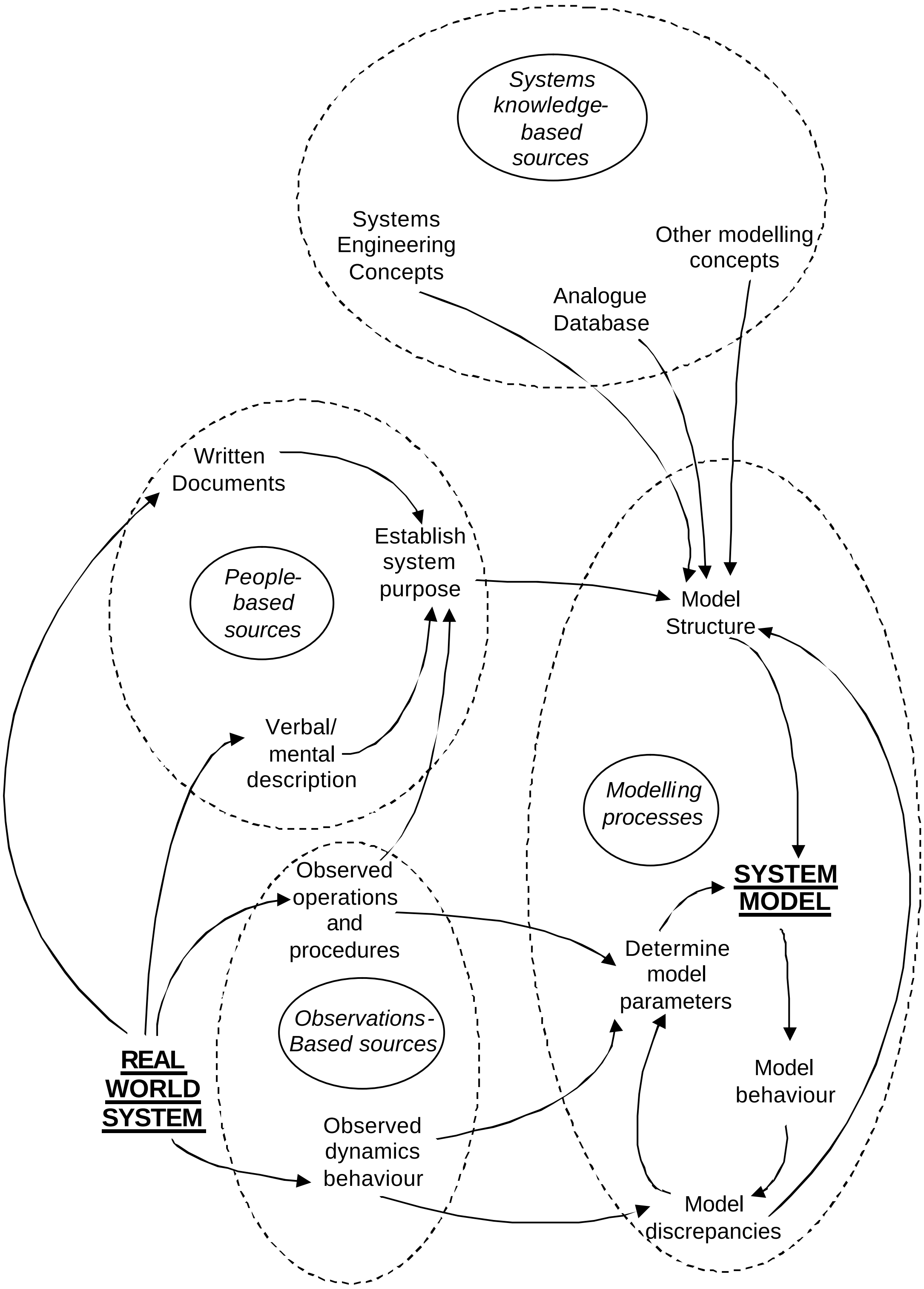

Figure 2. Summary of information sources utilised in the interactive industrial dynamics modelling of supply chains (Towill, 1996)

3.2 Observation-based sources

Here, the main source of data collected was in the form of time series information on demand for a range of products, including the output from the ASO system. This enabled the bullwhip effect to be clearly identified and quantified to facilitate both the parameter setting and validation of the model.

3.3 Systems knowledge-based sources

The research team had a strong grounding in system dynamics and control theory and could draw the knowledge gained through extensive analysis of generic inventory control systems through the Inventory and Order Based Production Control System (IOBPCS) family (Towill, 1982, John et al., 1994). This provided an in depth understanding of the various structural elements, how they can be adjusted (for example, through changes in parameter values) and the likely impact of these changes on the overall dynamic performance of the system. The knowledge obtained from these sources assisted in understanding the causes of dynamic behaviour within the system and the steps that Tesco could take to improve overall performance.

3.4 Modelling processes

As already mentioned, the model was built in a proprietary spreadsheet package. The verification of the structure of the model took place during the interviews with the developers within Tesco, while validation used the data from observation-based sources. This enabled a comparison between the dynamic performance of the model and that of the ASO system. As shown in Figure 2, there is a feedback loop in the process here, to ensure that where discrepancies arise, changes to either the model structure or parameters can be made. This approach was followed, with any changes being further verified with the development team.

4. Overview of ASO system

The purpose of this section is to provide an overview of the ASO system as originally designed, highlighting the information sources used to generate store orders and some of the main components of the replenishment decision. The information in this section was predominantly obtained through the interviews and archival data sources. Figure 3 provides an input-output diagram of the system, showing the main information sources used. As can be seen, two of the outputs provide feedback loops into the ordering decision – the forecast demand and orders placed but not yet received. Although not shown explicitly, an inventory feedback loop also exists as store orders will, after the delivery lead time, influence store stock levels. From these information sources, there are a number of different components to the replenishment decision.

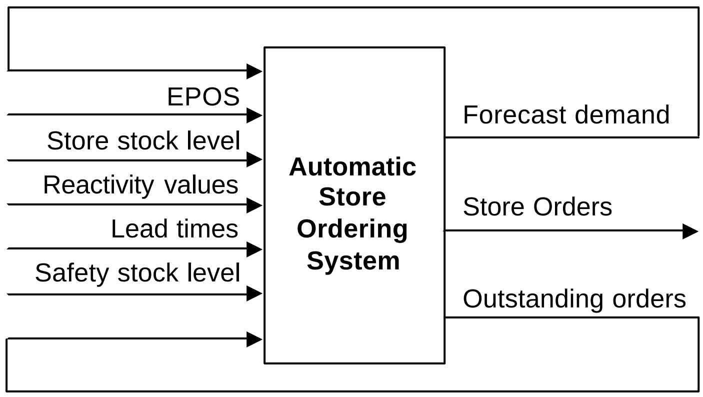

Figure 3. Input-output diagram of Tesco's ASO system

4.1 Components of the replenishment process.

Forecasts. Forecasts for each SKU are generated by the replenishment system based on a combination of three moving average forecasts over a period of 1 day, 3 days and 7 days. These are combined into a single forecast by using a weighted combination of these three moving average forecasts. The weights are set via a "co-efficient of reactivity" or COR value. The COR value is set to reflect product demand characteristics. Milk for example has a steady demand and is given a COR value such that more weight is given to the 7 day moving average. The demand for ice lollipops is highly dependent on the weather and has a high erratic demand profile, so is given a COR value that assigns more weight to the 1 day moving average.

Each product category is supervised by a category manager. Their main role is to review the COR values and the forecasts that are generated on a daily basis. Forecasts may be adjusted to account for the latest weather reports, seasonality, national holidays (for example, Christmas, New Year, Easter), special occasions (such as Mother's Day, Valentines Day or Chinese New Year) and events (particularly sporting events such as the Football World Cup or Olympics). All of these can change people's shopping habits in terms of the size of their purchase and/or the mix of products. The category manager also has access to information on promotions and marketing activities such as the moving of a product to the "gondola end", BOGOF (buy one get one free) promotions and media activity by the supplier. Finally the local store manager has the opportunity to indicate that a local event is likely to increase the demand for specific product categories. In Cardiff for example, a big sporting event at the national stadium will likely generate a huge increase in the amount of beer, wine and snacks being sold.

Expected lost sales. The EPOS data is interrogated and compared to the expected demand for each SKU. If the EPOS data shows a complete lack of sales for the SKU over any significant time, then an "out of stock" indicator is raised (even if the system predicts that there is stock in the store). The expected lost sales during the out of stock period is then calculated and added into the demand file and a message is sent to the store manager to investigate that SKU. Is the store really out of stock? Even though the computer system believes that there is stock available, pilferage, damages and code-life / stock rotation issues, failure of the EPOS system to correctly scan the product through the till or mis-picks in the DC could have reduced the available stock to zero, without the system knowing. Or is the stock actually in the store, but in the "back room" having been off-loaded from the delivery truck, but not transferred into the selling area. Lost sales due to these issues are predicted and added into the demand pattern so as to ensure that forecasts are made based on a "total consumer demand" rather than on an "actual consumer demand".

Batch sizes. Certain minimum order quantities are respected. These minimum quantities could reflect issues such as avoiding the need break-up a box / case (of, say, 12 bottles of balsamic vinegar) in the distribution system, or to ensure that there is a proper presentation of the product to the customer. The presentation of a product on the shelf is an important factor to stimulate sales. A customer is unlikely to find "singles" of a product and, even if the single item is found, may not be selected for purchase if it is the last one. The use of innovative shelving and box shapes (a technique Tesco has pioneered together with suppliers in the UK) has helped to reduce case sizes and allow a better presentation of products.

Transport lead-times. The orders generated between 00.01-05.00 on day 1 are to be delivered by 6.00 on day 3, 48 hours later. This order may be used to satisfy demand in the following 24 hours, or a second "top-up" delivery may be scheduled for later in day 3, depending on the demand in store on the delivery day. Therefore, the forecasts may be altered by trading hours of the store, local delivery restrictions (some stores are in residential areas and large trucks are not allowed to go there and/or delivery times may be restricted at certain periods of the day), number of deliveries per day (which may change during the week) and preferred delivery patterns.

Code-life. Certain products are highly perishable. Spinach and rocket for example have a code-life of about 2 days. Other products such as baked beans and washing powder have a much longer shelf-life. This has a big impact on both the physical replenishment process and how the replenishment order is generated. For very short shelf life products, typically fresh produce, the distribution is set up as a stockless flow-through system where replenishment quantities are set equal to the forecasted expected demand in selling period. At the end of that demand any left over stock is assumed to be waste, and thus there is not inventory feed-back loop. For products with a long shelf life and high demand volumes, an inventory of product may be kept in store. Because these products are not perishable then inventory information may be used in the replenishment process.

Smoothing and skimming. After a large individual stores' replenishment order (or group of smaller stores on the same delivery route) has been provisionally calculated it undergoes a "smoothing and skimming" exercise. This attempts to ensure that only full roll-cages and truckloads are dispatched to the stores in order to achieve high efficiencies in the transport system. If the total order for a product is higher than the available supply then some "fair share" allocation is generated between all of the stores. This aspect was not explicitly included within the model developed in this research.

Discontinued lines. Some products are to be discontinued and thus in the final 3 weeks the distribution system is set-up to run down the entire inventory in the supply chain. Again, this aspect is not explicitly modelled.

4.2 The different replenishment strategies

Based on the above elements, it was discovered that there were seven different algorithms used within the ASO, which can be categorised as depicted in Figure 4 according to the volume of demand and the code-life of the product. Those products with a short code-life (i.e. perishable items) are replenished using a 'one touch' policy. Orders are based on forecast demand and assume that, at the end of each day's sales, there will be no inventory left. In doing so, the aim is to minimise the volume of products that are marked down in price or wasted. In fact, the orders are simply aggregated at the RDC level before being communicated to suppliers. These deliveries from suppliers then arrive at the RDCs (which operate as cross-docking centres for these products), are sorted for each store and then despatched onwards. The only difference between high and low volume products are the frequency of deliveries, with stores receiving up to 3 deliveries each day of high volume products.

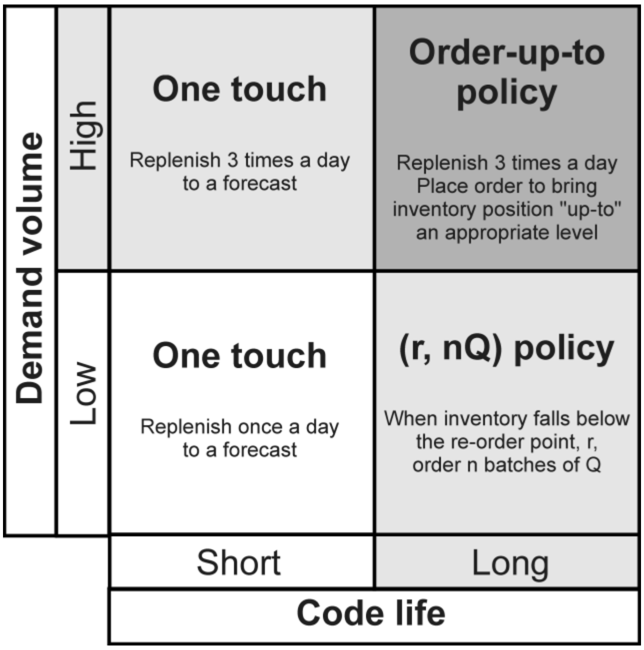

Figure 4. Replenishment strategies within Tesco

For long code life products, replenishment decisions are based on maintaining a set level of inventory at each store. This approach reflects the longer time afforded to sell this category of products. Where these products have a low demand volume, a *(r, nQ)* policy is adopted, where replenishment occurs once the re-order point is reached. As discussed earlier, Tesco uses 'cases' as the minimum sized unit in the physical flow of their supply chain, hence the ordering in multiples of a batch size. For high volume products, an order-up-to policy is adopted with replenishment up to 3 times a day. Each replenishment decision only considers forecast demand from the time the order is delivered until the next delivery is due. Consequently, many elements of the ASO system are based on hourly time increments. Having identified the main replenishment strategies, the next stage of the research was to investigate their dynamic properties.

5. Analysing the dynamic behaviour

In order to analyse the dynamic behaviour of the system, a simulation model of the system was built using a proprietary spreadsheet package. This was the most effective approach to analysing the dynamics due to the complexity and non-linear nature of the system. The spreadsheet was designed to take into account the volume of products and decide on whether a product was low or high volume (based on rules determined by Tesco). Performance measures included dynamic performance and the availability of products in the stores. The model was based around time increments of one hour. The total simulation length was 165 days, with the first 14 days excluded from performance calculations due to the transition period of the model.

From the analysis of this model, it was ascertained that for all short code life products and the low demand, long code life products, the dynamic performance of the current replenishment rules could not be significantly improved. As noted earlier, the objective was to improve, rather than optimise performance. However, it was determined that the dynamic performance of the order-up-to policy for high volume products could be improved. This accounts for 65% of the total sales value of products within Tesco. Here, experience with the IOBPCS family of inventory control models highlighted potential improvement opportunities.

As designed, the ASO system was designed to use the following order-up-to policy:

$$Orders_t = \mu_{demand} + (TNS - NS_t) + (TWIP - WIP_t)$$

where μ_{demand} is forecast demand, NS_t is the net stock position at time t (based on forecast demand and deliveries between the order calculation and delivery at t), TNS is the target stock level, WIP_t is the orders placed but not yet delivered and $TWIP$ the target level of WIP. This equation highlights the feedback loops illustrated in Figure 3. The structure of this ordering rule is similar to that found within the APIOBPCS model first proposed by John et al. (1994). Analysis of the APIOBPCS model, both through simulation and control theory (Mason-Jones et al., 1997; Disney and Towill, 2002), has highlighted the role that proportional controllers can play in changing the dynamic performance of such systems. Therefore, a proportional controller was added into the structure of the simulation model, so that the ordering rule became:

$$Orders_t = m_{demand} + \frac{1}{Ti}\left(TNS - NS_t\right) + \frac{1}{Ti}\left(TWIP - WIP_t\right)$$

where 1/Ti is the proportional controller. Having identified the opportunities offered by introducing a proportional controller, a range of different values of Ti were evaluated, the final value being determined jointly between the research team and Tesco.

6. Recommended improvements at Tesco

Based on the above analysis, the main recommendation was the introduction of a proportional controller into the ordering policy for high volume, long code life products. The impact of this change can be seen in Figure 5, which depicts orders, the weekly workload profile with the original ASO system design and the revised workload with the proportional controller. The variability in workload has been reduced to approximately 75% of the sales variability. In particular, there is a slight change in the delivery profile, with more products being delivered into the store early in the week ahead of peak sales on the weekend. While this does increase the inventory holding at the stores slightly, the additional cost of this is compensated by the improved efficiency in the RDC and transport network.

Although no changes to the ordering rules were proposed for the other categories of products, some other changes were proposed to improve dynamic performance, thus:

- Short code life, low volume – Careful forecasting will help to ensure that the amount of product closely matches demand levels. Equally, premium pricing for these items could be introduced, to reflect the additional costs these products impose on the supply chain, including the increased risk of waste at the end of code life.

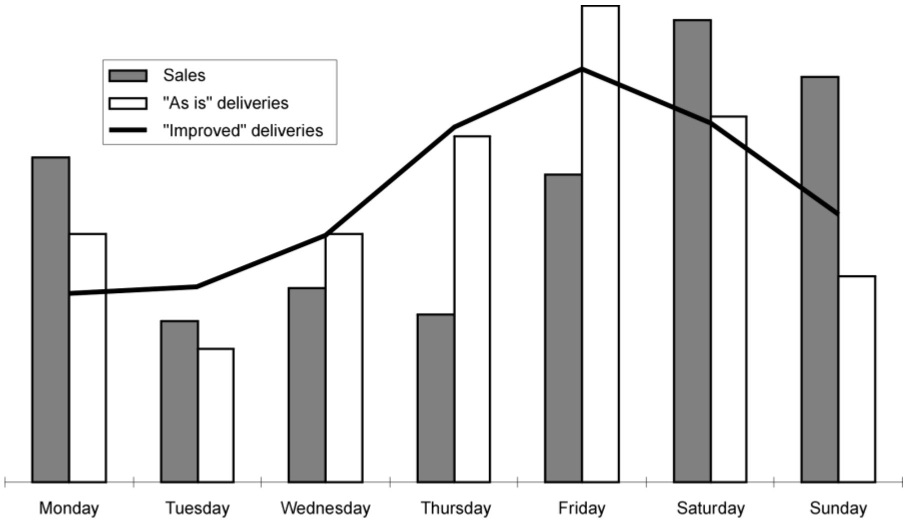

Figure 5. The weekly workload profile at Tesco: Before and after

- Short code life, high volume – the key here is to minimise the lead time so that the forecast can be as accurate as possible. Equally, reducing the amount of handling the product receives means that it reaches the shelf as quickly as possible to maximise selling time. The introduction of cross-docking facilities is one step towards this. Aligned with this is synchronising supply, so that the products can 'flow' from the supplier, through the RDC network at straight to the shelf in the store.
- Long code life, low volume – the key aspect here is to reduce the batch size. Rounding of orders has long been recognised as a cause of bullwhip (Lee et al., 1997) and is particularly a problem with this type of product where demand may be as low as one case per week. Reducing the case size will increase ordering frequency and allow closer alignment with demand. Another approach could be to adopt a 2 bin system, possibly aligned with novel shelving so that the products can quickly be positioned and the sales from a case be monitored. Developments in RFID in the future may enable this level of tracking to occur.

7. Conclusions

Retailers are becoming increasingly reliant on ASO systems to bring efficiency into their store replenishment process. This paper reports on a piece of research carried out jointly with Tesco following the introduction of a new ASO. Tesco's replenishment system was found to increase the daily variability of workload by 185% in the distribution centres. A small change to the replenishment algorithms was recommended that smoothed daily variability to approximately 75% of the sales variability. The solution was applied to one specific category of products – long code life, high volume. These products accounted for 65% of the total sales value of Tesco UK. The change created a stable working environment in the distribution system and reduced distribution and warehousing costs by an estimated £28m per year.

This research also highlighted the scope for transferring generic findings on the dynamics of inventory control systems into real life. Being able to translate a seemingly complex system into a simpler and well studied form made it easier to identify potential improvements. This is important within the context of research as industrial partners often require solutions on a short timescale. Generic applications speed the research process and provide a set of tools that can be easily applied. However, the improvements need to be tested on the reality rather than the generic model to ensure that both counter intuitive results are not produced and any scepticism by practitioners as to the applicability of generic solutions is overcome.

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