Dynamic simulation of the supply chain for a short life cycle product—Lessons from the Tamagotchi case

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Abstract

Supply chain phenomena such as the bullwhip effect and boom and bust have been widely studied. However, their interaction with other factors has not been elaborated. We use scenario-based dynamic simulations to study the short product life cycle case, exemplified by Tamagotchi™, which was the first of the virtual pet toys. Our model has three components, market, retail and factory. To simulate the supply chain dynamics, all parts consist of scenarios based on the Tamagotchi™ case and are integrated into a dynamic model. Our model should be helpful to decision makers and planners faced with similar short life cycle product introductions. © 2003 Elsevier Ltd. All rights reserved.

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1. Introduction

Capricious market demand, severe competition and internal dynamics are major concerns for supply chain management. Advertisement through the mass media and the development of the Internet have speeded up the diffusion of new products. At the same time, technical innovation and severe competition in the market promote rapid obsolescence of existing products and technologies. When a company succeeds in developing a new product category, other competitors may soon emerge. The market originator must endure not only the substantial risk of whether the market would materialize or not, but also the difficulty of recovering major costs, such as research and development and advertisement. Increasingly, the supply chain becomes the mechanism for coping with these problems
because it is often inefficient for any single company to produce a whole product. Hence, modern business is essentially the competition of one supply chain with another [2]. Supply chain dynamics is the interaction processes of the participants from different departments and companies. A positive aspect of supply chain dynamics is effective collaboration, which may lead to higher performance. A negative aspect is independent decision making, which may create various delays and aggravate the forecasting error. Tompkins [3] introduced the concept, \textit{Supply Chain Synthesis}. It is a holistic, continuous improvement process of ensuring customer satisfaction and is all about using partnerships and communication to integrate the supply chain. Bowersox and Closs [4] observed that “coordination is the backbone of overall information system architecture among value chain participants.” Therefore, it is necessary to coordinate the activities appropriately within a supply chain to achieve better overall, i.e. system, performance.

This research stresses the interactions of the various supply chain phenomena. Our research interest is to clarify the critical factors for minimizing the negative effects of supply chain dynamics and to gain insight on how to effectively manage them. As a case study, we consider \textit{TamagotchiTM}. This was the first of the virtual pet games, introduced in 1996 by the Japanese toy manufacturer, Bandai Co. This case provides a good example illustrating the problems that can arise from the interactions between capricious demand, boom or bust, and capacity decisions in the very short product life cycle setting.

We developed a simulation model that incorporates feedback processes and demonstrates the impact of supply chain dynamics. Without simulation models, it is very difficult to grasp these dynamics [5,6]. Our model is designed to be a dynamic and multi-echelon model to better reflect real systems. The main feature of the model is that it considers the simultaneous influences of several phenomena, such as the bullwhip effect, boom and bust, and multi-echelon decisions. We believe that our model contributes to planning and forecasting the demand of new products.

2. Prior research

Sunil and Meindl [7] gave the definition “a supply chain is dynamic and involves the constant flow of information, products and funds between different stages. Each stage of the supply chain performs different processes and interacts with other stages of the supply chain.” Gopal and Cahill [8] discussed trade-offs within the supply chain. For instance, sales and marketing wish for a high degree of production flexibility and rapid turnaround. They want to catch up with recent trends. From the short-term view, they would increase the stock of goods rising in popularity, but reduce the stock of goods decreasing in popularity. On the other hand, manufacturing favors longer production runs, fewer setups, smooth schedules and a balanced line. These types of trade-offs have a great influence on the supply chain. Magee et al. [9] argued that “variations in production are far more severe than variations in demand, and the more levels and stages of production there are, the more violent production level changes become.” From the viewpoint of distribution, the main character of the supply chain is the multiple echelon(s) including suppliers, manufacturers, wholesalers, and retailers. Overall, performance is a result of the complex interactions among them.

Computer simulations are a widely used and effective method to grasp the impact of supply chain dynamics. Queuing theory plays a very important role and sets the framework of these simulations because capturing the interactions between demands and backlogs is a critical factor for any supply
chain. Ballou [6] indicated that, when more than two echelons are involved, managing the inventory throughout the entire chain becomes too complex for mathematical analysis and is usually carried out with the aid of computer simulation. Computer simulations are divided into two types, static and dynamic. Bowersox et al. [10] noted “the primary difference between them is the manner in which time-related events are treated. Whereas dynamic simulation evaluates system performance across time, in static simulation no attempt is made to structure time-period interplay. Dynamic simulation is performed across time so that operating dynamics may impact the planning solution.” Static simulations are the foundation of the dynamic ones. Nersesian and Swartz [11] systemized the use of simulation in logistics. With Visual Basic, they introduced the ways to decide the issues separately, such as the timing and quantity of orders, the level of inventory, the number of warehouses, and so on. Much research has been conducted on the effect of the lead-time on performance [12,13]. Schwarz and Weng [14] have built a model demonstrating the interactions between the variance of the lead-times in each link of the supply chain and system inventory holding costs. Static simulations help identify the key issues, elements and relations among them in the supply chain. However, it is very difficult for static simulations to analyze supply chain dynamics because of the lack of appropriate feedback loops.

From the viewpoint of information distortion, Gavirneni et al. [15] simulated an overall supply chain model. Their model emphasized the value of information and extended existing inventory theory. Chen [16] characterized optimal decision rules under the assumption that the division managers share a common goal to optimize overall performance of the supply chain. Lee et al. [17] discussed the relation between the bullwhip effect and information distortion. The bullwhip effect is the exaggerated order swings caused by the information distortion. They claimed that “the information transferred in the form of orders tends to be distorted and can misguide upstream members in their inventory and production decisions. In particular, the variance of orders may be larger than that of sales, and the distortion tends to increase as one moves upstream.” As a result, the information distortion can lead to tremendous inefficiencies: excessive inventory investment, poor customer services, lost revenues, misguided capacity plans and missed production schedules. They also regarded the “shortage game” as one of the major concrete causes of the bullwhip effect [18]. This can be explained as follows. When product demand greatly exceeds supply, customers might duplicate the orders with multiple retailers and buy from the first one that can deliver; and then cancel all other duplicate orders. Later, when supply exceeds real demand, backlogs will suddenly disappear. The manufacturer gets an inflated picture of the real demand for the product and puts larger amounts of capital into capacity expansion based on what may be called “phantom” demands [19]. Lee et al. [17,18] called this phenomenon the shortage game. Winker et al. [20] emphasized the concept of total system stocks and proposed remedies for improving the performance of the entire supply chain. That work clarified and analyzed the important phenomena, the information distortion, bullwhip effect, the shortage game for simulating supply chain dynamics in general terms.

Dynamic simulations are necessary to analyze the supply chain because it is interactive and incorporates hierarchical feedback processes [21]. Many supply chain models have been built by using system dynamics. Forrester [22] built a system dynamics model of the three-echelon production distribution system and demonstrated how market demands are amplified through the transactions in the supply chain. Senge and Sterman [23] called attention to the difference between local and global maximization and pointed out the risk of local decision-making. Paich and Sterman [24] simulated the diffusion process of a new product and analyzed the “boom and bust” process. This phenomenon
is caused by several influences. First, the cycle of the product may be very short. Second, there is a
long time lag for expanding or reducing the manufacturing facilities according to revealed demands.
Finally, retailers, wholesalers and manufacturers tend to overestimate the demand when the demand
is growing rapidly, while customers are unpredictable. Vennix [25] has demonstrated how group
model building creates a climate in which team learning can take place, fosters partnership and
helps to create acceptance of the ensuing decisions and commitments to the decision. Cheng [26]
proposed various integrated corporate models emphasizing information technology. System dynamics
has therefore already proven its worth in supply chain management. For future development of sup-
ply chain, many more dynamic simulation studies integrating the various aspects are required. In the
following sections, we conduct a dynamic simulation study, which combines the effects of several
phenomena, information distortion, bullwhip effect, boom and bust, and multi-echelon decisions by
modeling a simple but representative case. Our model was designed not to reproduce the real world
exactly, but rather to help decision makers in planning in situations similar to that experienced by
Bandai with the *Tamagotchi*™ product.

3. Case study

Bandai introduced *Tamagotchi*™ to the market at the end of November, 1996. Bandai also sells
products featuring popular characters, such as POWER RANGERS™, GUNDAM™ and
DIGIMON™. Table 1 is a breakdown of the sales percentages of each division. Bandai Co. classified
their products into 8 divisions: character goods for boys, vending machine products, video games
and general toys, models, toys for girls, apparel, snacks, and others. *Tamagotchi*™ is categorized
in the video games and general toys. It was an egg-shaped computer game and the first simulation
game of the virtual pet class. The goal of this game is to “raise” *Tamagotchi*™ and the way to
play is to take care of it by feeding, giving an injection, and so on. Although Bandai estimated
that this toy had the potential to be a big hit, they could not accurately forecast the shift of the
demand. At the beginning, they decided to place no advertisements for it in the mass media because
they expected customers to buy it by word of mouth. However, the effect of word of mouth was
much stronger than they had expected. Although initial target sales volume was 300 thousand by the
end of 1996 (for the first 6 weeks) in the domestic market, it became popular so rapidly that they
sold about 450 thousand by the end of the year and 4 million by the end of March, 1997. Bandai
started selling it in North America, Europe and Asia in May, 1997. The total overseas sales volume
exceeded 2.4 million by the end of October, 1997. This demand boom outpaced Bandai’s ability to
meet the demand.

The shortage caused a variety of problems including crimes, the shortage game and copy problems.
Hundreds of people formed long lines at toy stores that had much smaller inventories than the
demand. At the peak, Bandai received about 5000 complaints a day about the shortages by phone.
Further, many robberies and aggravated assaults to acquire the toy were reported to the police.
Finally, although Bandai understood that they had a high risk of overstocking and excess capacity,
they had to expand their manufacturing facilities to produce 2–3 million units per month in July,
1997. After Bandai expanded their manufacturing capability, they met a sharp decline of demand.
As a result, it was announced that they had 16 billion yen (US$123 million at US$1 = 130 yen) in
after-tax loses in fiscal 1998 ending March, 1999, mainly because huge numbers of the toy were left
unsold. This case illustrates that Bandai was overly influenced by the boom and the bullwhip effects. Thus, to illustrate what happened to Bandai and to demonstrate how they might have avoided these tremendously unfortunate effects, we built a simulation model.

4. Research methodology

Forrester founded the Systems Dynamics Group at MIT in the early 1960s. Much research using system dynamics has been conducted in various fields in the natural and social sciences. System dynamics is selected in this paper because it is one of the best methods for analyzing complex systems. According to Shapiro [27], “systems dynamics is a well-elaborated methodology for deterministic simulation.” We used the Systems Dynamics software, STELLA™ [1], as a tool to build our supply chain model. Its merits are the following. First, it has a function that analyzes the movements of dynamic systems. It can simulate the impacts of causal relationships that have feedback loops. Second, it has a function that permits consideration of various delays and queues. These are very important elements in analyzing supply chains as noted above. Finally, STELLA™ has strong
sensitivity analysis tools. Generally, sensitivity analysis is helpful in obtaining conclusions and general implications of models.

5. Scenarios for the market, retail and factory levels

Fig. 1 summarizes our model that is divided into three levels, the market, retail and factory. At the market level, the total demand is equal to the sum of demands for new customers, phantom demands (for example, from the shortage game), and sales for repeaters minus recycle sales in a period. We assume that the diffusion process of new products can be expressed by using the logistic curve. The logistics curve is an S-shaped curve and, usually, applied to the diffusion of diseases. It is given by the following differential equation, \( \frac{dx}{dt} = \alpha x_t (K - x_t) \), where \( x_t \) is the cumulative number of people who purchased by the end of time \( t \) and \( \frac{dx}{dt} \) is the derivative of \( x_t \). The parameter \( \alpha \) is a small number that controls the diffusion speed, where bigger values are associated with faster diffusion. \( K \) is the theoretical upper limit of the number of purchases. In our research, the logistics model is uniquely used to demonstrate the effect of shortages on the number of potential customers. If a

Fig. 1. Conceptual framework of the model.
shortage occurs, the company loses their potential customers and $K$ becomes smaller. At the market
level, we assumed that the diffusion speed of new products could be expressed by using the logistic
curve with $x = 0.00000015$ and we chose 25 million (about 15% of Japan’s population) as the
initial upper limit. To set the value of $x$ entails two technical difficulties. First, it is very difficult
to apply logistics regression to our model because the upper limit is not fixed. Second, we do not
have enough data on the weekly sales. Hence, we approximated the curve visually and chose the
value. We also assumed that 10% of the customers who could not purchase it because of shortages
would withdraw from the market. On the other hand, the shortages would create phantom demands
because of the shortage game and the rate chosen for this was 20%. In addition, 5% of customers
would repurchase one week later, but another 5% would resell four weeks after purchase due to loss
of interest.

At the retail and factory levels, demands would be reviewed every week and forecasted demands
are decided by using exponential smoothing. It is disputable which forecasting method fits best in
this case. Forecasting methods are classified into qualitative and quantitative methods. Qualitative
forecasting methods include subjective curve fitting techniques, the Delphi Method, and so on. In
qualitative methods, experts play an important role to predict the future event subjectively. Usually,
these methods are useful in the case of new products because there is no historical sales data
[28]. However, they are not of much use for forecasting sales with very limited information. Since
Tamagotchi™ was the first simulation game of the virtual pet class, there was no product, which
had an analogy to it. Thus, it was very difficult for even experts in the toy industry to provide
reliable forecasts.

Quantitative forecasting methods also have the same difficulty in forecasting a new product like
this. Gopal and Cahill [8] note that “forecasts depend not only upon the customer, but also on the
ability of the supply chain to project and respond to the product and service needs of the customer.”
Bandai Co. and retailers had very limited information and did not build an on-line information system
at that time. They did not have options without simple quantitative forecasting methods based on
the latest sales data and orders. Among the simple quantitative methods, moving average and simple
exponential smoothing are useful methods to avoid the variation inherent in the last-period technique
and the variability in the arithmetic average. Both techniques weaken the sharp fluctuations of the
demand but introduce a delay between changes in demand and their reflection in sales forecasts
[21]. The main difference between them is that exponential smoothing is more flexible and can place
greater emphasis on more recent data than does the moving average method [29]. Hence, we chose
exponential smoothing.

We assume that the plant reviews the appropriate production volume every week and the delay
to increase manufacturing capacity is three weeks. The life of the manufacturing facility, essentially
the machine for producing the toy, is 160 weeks, or about 3 years. In other words, the facility
can continue to produce for 160 weeks. If the manufacturing rate is doubled, then depreciation is
doubled and the period of depreciation decreases. It takes a week to ship to the customer from
the factory. The manufacturer would decrease the manufacturing capacity after recognizing that the
demand was declining. The initial manufacturing rate was expected to be $37,500 = 300,000/8$ per
week. The 300,000 comes from the initial target sales in the first 6 weeks; 8 comes from 6 (first
6 weeks) minus 1(delivery time) plus 3 (preparation weeks before launching). In addition, it was
assumed that they could double the production volume through overtime and temporary workers
without enlarging the facility. On the other hand, when the company has excess inventory, they can
reduce the work rate by up to 50%. Their initial maximum manufacturing rate was assumed to be $75,000 = 37,500 + (450,000 - 300,000)/(5 - 1)$. Here, 450,000 is the number of the actual sales in the first 6 weeks; $(5 - 1)$ represents our assumption that they had 5 weeks to make most of their facility assuming the decision to do so was made by the end of the first week. Table 1 summarizes the main variables in our model. (Table 2)

6. Results

Our model simulates the supply chain dynamics and confirms that both the boom and bust and the bullwhip exert profound influences. The typical boom and bust phenomenon is shown in Fig. 2, which relates the total demand and manufacturing capability. The latter had its peak enhanced by the overestimate of the demand with a delay just after the peak because of the phantom demand and construction lag [24]. Bandai maximized their manufacturing facilities (July, 1997) just before the sharp decline of the demand because there was a lag between identifying the peak demand enhanced by the phantom demand and enlarging the facility to this level. Finally, they suffered heavy damage by the overproduction of huge numbers of unsold toys. In our model, the bullwhip effect is combined with boom and bust. As a result, the factory level experiences a larger fluctuation in demand and much more inventory increase than does the retail level in daily operations [17]. Also, in this case, the situation becomes much worse after peak demand than before because of the accumulated information distortion and existence of the additional manufacturing facilities. This type of bullwhip effect is illustrated in Fig. 3, which shows the shifts of inventory at factory and retail levels.

We see that in the case of a product with a short life cycle, it is prudent to carry out more analysis and examine more potential scenarios. The demand grows faster and more capriciously. The company then faces more risk of shortages in the early stages. The shortages may create phantom demands and reduce the number of potential customers. As a result, companies may have huge inventories while still losing a certain degree of sales. The manufacturing facility might be outdated earlier than in the case of a long product life cycle. In addition, even though the repeat purchase rate is high, the company would not enjoy the usual advantages of repeat purchases. We, therefore, consider some additional scenarios that address different diffusion speeds and delay times in finding phantom demands, investment policies, and repeat rates. We performed sensitivity analyses on these parameters too and do what-if analysis on the information loop.

6.1. The impact of the diffusion speed

In this model, it is assumed that the diffusion of a new product is based on the logistic curve. The derivative of the logistic curve is $z \times \text{Diffusion Level} \times (\text{Upper Limit} - \text{Diffusion Level})$. Three sensitivity analyses were conducted on $z$, with values of 0.00000001, 0.000000015, and 0.00000002, respectively. Fig. 4 shows the shifts of the total and periodic demands according to the diffusion speeds. This figure suggests that, if the diffusion speed becomes faster, the total number of customers would be higher and the peak demand would be larger and sharper. Fig. 5 shows the shift of the level of manufacturing capability. Although the company may face rapid shrinkage of demand after
Table 2
Equations used in the model

Accumulated_{Order}(t) = Accumulated_{Order}(t - dt) + (Retail_{Order-Received}) dt
INITIAL = 0
INFLOW Retail_{Order} = MAX(Total_{Demand-Inventory_at_Retail}, 0)
OUTFLOW Received = OF_of_IF + DELAY(Retail_{Order-OF_of_IF}, 4)

Diffusion_{Level}(t) = Diffusion_{Level}(t - dt) + (Periodical_{Diffusion}) dt
INITIAL = 75,000
INFLOW Periodical_{Diffusion} = Periodical_Sales-Sales_for_Repeater

Expected_{Demand}(t) = Expected_{Demand}(t - dt) + (IF_of_ED-OF_of_ED) dt
INITIAL = 75,000
INFLOW IF_of_ED = (Retail_{Order}*1 + Information*0) alpha + Expected_{Demand} (1 - alpha)
OUTFLOW OF_of_ED = Expected_{Demand}

Inventory_{Factory}(t) = Inventory_{Factory}(t - dt) + (IF_of_IF-OF_of_IF) dt
INITIAL = 37,500
INFLOW IF_of_IF = Delay(Manufacturing_Ability*(2^Double)*((1/2)^Half)*(0^Stop), 1)
OUTFLOW OF_of_IF = MIN(Inventory_{Factory}, Accumulated_{Order})

Inventory_{Retail}(t) = Inventory_{Retail}(t - dt) + (OF_of_IF-Periodical_Sales) dt
INITIAL = 75,000
INFLOW OF_of_IF = MIN(Inventory_{Factory}, Accumulated_{Order})
OUTFLOW Periodical_Sales = MIN(Inventory_{Factory}, Total_Demand-Phantom_Demand)

Manufacturing_Ability_{t} = Manufacturing_Ability_{t} - dt + (Complete-OF_of_MA) dt
INITIAL = 37,500
INFLOW Complete = DELAY(IF_of_UC, 3)
OUTFLOW OF_of_MA = IF_of_IF/160

Phantom_{Demand}(t) = Phantom_{Demand}(t - dt) + (IF_of_PD-OF_of_PD) dt
INITIAL = 0
INFLOW IF_of_PD = Backlog 0.2
OUTFLOW OF_of_PD = DELAY(IF_of_PD, Finding_Delay)

Sales_for_Repeater_{t} = Sales_for_Repeater_{t} - dt + (IF_of_SR-OF_of_SR) dt
INITIAL = 0
INFLOW IF_of_SR = DELAY(Periodical_Sales*Repeat_Rate, 1)
OUTFLOW OF_of_SR = DELAY(IF_of_SR, 1)

Total_Sales_{t} = Total_Sales_{t} - dt + (Periodical_Sales) dt
INITIAL = 0
INFLOW Periodical_Sales = MIN(Inventory_{Retail}, Total_Demand-Phantom_Demand)

Under_{Construction}(t) = Under_{Construction}(t - dt) + (Expansion-Complete) dt
INITIAL = 0
INFLOW IF_of_UC = IF(Under_{Construction} = 0) then Expansion else 0
OUTFLOW Complete = DELAY(IF_of_UC, 3)

Upper_{Limit}(t) = Upper_{Limit}(t - dt) + (OF_of_UL) dt
INITIAL = 125,0000000 * 0.15
OUTFLOW OF_of_UL = IF(Upper_{Limit} > Diffusion_{Level}) then Backlog x 0.1 else 0

A = 0.000000015
Alpha = 0.2
Backlog = MAX(Total_{Demand-Periodical_Sales}, 0)
Double = IF(Working_Rate > 1) then 1 else 0
Expansion = IF(Upward = 1) then MAX((Expected_{Demand-Manufacturing_Ability-Under_{Construction}})/
Investment_Policy, 0) else 0
Finding_Delay = 2
Half = IF (Working_Rate < 0) then 1 else 0
Table 2 (continued)

<table>
<thead>
<tr>
<th>Information</th>
<th>Investment_Policy</th>
<th>Past_Max</th>
<th>Periodical_Demand</th>
<th>Repeat_Rate</th>
<th>Stop</th>
<th>Total_Demand</th>
<th>Upward</th>
<th>Working_Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>= MAX(Total_Demand-Phantom_Demand-Inventory_at_Retail, 0)</td>
<td>= 3</td>
<td>= MAX(DELAY(Expected_Demand, n)) $n = 1, 2, 3$</td>
<td>= a Diffusion_Level (Upper_Limit-Diffusion_Level)</td>
<td>= 0.05 Repeat_Rate</td>
<td>= IF(Working_Rate $&lt;-3$) then 1 else 0</td>
<td>= Periodical_Demand + Phantom_Demand + Sales_for_Repeater</td>
<td>= IF(Expected_Demand $&gt; Past_{Max}$) then 1 else 0</td>
<td>= (Expected_Demand-Inventory_at_Factory)/Manufacturing_Ability</td>
</tr>
</tbody>
</table>

Fig. 2. Total demand and manufacturing ability.

the peak with a fast diffusion speed, the maximum level of manufacturing capability would be larger. Therefore, products with short life cycles have bigger risks than those with long life cycles.

6.2. The effect of the delay in finding phantom demands

In this model, phantom demand amplifies the variation of the demand as noted above. If it takes a long time to identify the phantom demand, then such phantom demand creates still more phantom demand. Three sensitivity analyses have been conducted on the delay time for finding the phantom demand, with values 1, 2 and 3 weeks, respectively. Fig. 6 shows the shift in manufacturing capacity of these sensitivity analyses. This figure suggests not only that the longer the delay the bigger the maximum manufacturing capacity, but also that the phantom demand has unexpected benefits. Namely, it signals the popularity of the product quickly, which promotes capacity expansion earlier. However, the most difficult part is to identify the amount of phantom demand and estimate the turning point. As a result, overestimation of this demand might make the capacity level unnecessarily and...
inappropriately larger than desirable. This phenomenon was one of the main combined results of the bullwhip effect and boom and bust. Therefore, it is crucial to identify phantom demands as early and accurately as possible.

6.3. The effect of the investment policy

It might be argued that companies control the level of the manufacturing capacity because they set the investment policy. We note, however, that Fig. 7 is not consistent with this assertion. It
shows the shifts of phantom demands caused by investment policies, which are aggressive, neutral, and conservative. Under the aggressive investment policy, the capacity is expanded by the difference between expected demand and the current plus planned additional capacity. Although the company could double its capacity without expansion, they in effect prepare for double the demand. Under the conservative investment policy, the size of investment is one-third that of an aggressive investment policy. Ironically, at the beginning of the boom phase, the conservative investment policy creates phantom demand most quickly among all policies, and enlarges the effect of phantom demands. They
become a big driver to expand capacity to an inappropriate level. Hence, companies cannot always control the level of manufacturing capacity by investment policies alone.

6.4. The importance of repeaters

We assumed that 5% of customers in each period would repurchase the toy in the next period. It was inexpensive and simple enough to use for customers to own and handle more than two simultaneously. Kotler [30] proposed three total sales patterns from the viewpoint of repeat purchasers, one-time purchase, infrequently purchased and frequently purchased. Our result is similar to that of the frequently purchased case. Generally, repeaters serve as a buffer because whether the company can minimize the damage from shrinkage after the peak demand depends to a large degree on the repeat rate. However, from Fig. 8, which shows the shift of the total demand for the different repeat rates (0%, 5%, 10%), it is very difficult to conclude that repeat purchases always play a role as a buffer and help avoid busting. In our model, 5% of buyers would buy another in the next week. The toy was evidently so attractive that repeaters want to have another as people would want actual pets like dogs, but it is too simple for repeaters to keep interest in it for a long time. This type of higher repeat rate might not enhance the effect of the buffer, rather increase the level of the peak and sharpen it. As a result, even though the repeat rate is high, companies may be unable to avoid sharp demand shrinkage after the peak unless stable repeat purchases continue long term.

6.5. What-if analysis: value of information

As noted earlier, information distortion is known to be one of the biggest problems in supply chains. What-If analysis was conducted to contrast two different cases of whether the phantom demands are identified or not. Originally, in this model, investments in manufacturing capacity were
done based on orders from retail shops including the phantom demands. We also considered the case that expected demand at the factory is calculated by exponential smoothing of the market demand minus the sum of inventory at the retail level and the phantom demand. Fig. 9 shows the results of the change. This figure demonstrates that, in the case that the phantom demands can be identified, the variance and final unsold of inventory at the factory level would be much smaller. (Fig. 10)
7. Conclusions

This paper has focused on supply chain dynamics in the short product life cycle case. In that case, setting the product and supply chain specifications is more important than improving them later because the supply chain might not have enough time to improve them and enjoy the benefits under the short life cycle assumption. We believe that our model contributes to decision-making such as the levels of manufacturing capacity and advertisement, as well as the timing to foreign market. In conclusion, from our research, we may derive the following recommendations:
Control of diffusion speed: From the results of our simulations, it may be concluded that faster diffusion is not always beneficial. It is true that in the product introduction period fast diffusion is important. However, fast diffusion might sharpen and increase the peak demand. To stabilize the demand variation and minimize shortages and phantom demands, it is desirable to control the diffusion speed. Otherwise, due to acquisition lag, the supply chain might experience a large loss as Paich and Sterman [24] demonstrated. To slow the diffusion speed it is imperative not to advertise in the mass media and to entreat customers not to discuss the product on the Internet as Bandai did. In the real world, manufacturing and distribution capacity must continue to be the ultimate constraints in the supply chain. Therefore, not only the demand side but also the supply side should be involved with the decision processes related to diffusion strategy.

The importance of repeat purchasers as a buffer: The importance of repeat purchases is recognized in every business. Generally, after the peak, most products face shrinkage of demand. If the repeat rate is higher, the peak becomes flatter and the shrinkage after the peak becomes smaller. A high repeat rate, however, does not always play a significant role because certain types of repeat purchases enhance and sharpen the peak demand and offset the advantages of repeat purchases. For example, Tamagotchi™ was a very novel but simple game. Most repeaters bought another immediately after they had bought the first one. However, very few repeaters continued to buy it in the long term because they soon lost interest in it. Unlike high repeat rates under long product life cycles, those of short product life cycles may entail big risks and high peaks of demand.

Identifying phantom demand: Phantom demands amplify the peak of the demand. In addition, if it takes a long time to detect them, they re-amplify themselves. Therefore, even if companies control their diffusion speed and capacity effectively, they would suffer amplified peaks without early discovery of phantom demands. Further, the information distortion in supply chains is one of the main causes of the boom and bust and the bullwhip effects. If the information that was processed without recognizing the phantom demands at each stage is used for forecasting the demand, the expected demand has greater variance. Lowson et al. [31] assert that timely and accurate information flows enable quick and accurate response, and contribute to minimizing the inventories and make optimal use of contractors. Corbett et al. [32] concluded that, through the more open, frequent and accurate exchange of information, companies could eliminate the bullwhip effect and ensure ongoing improvement. Many researchers demonstrated the effect of information sharing by using simulation models [17,18,22,24].

A potential limitation of this research is that exact parameter values were not available from the Tamagotchi™ case. Thus, it was not possible to assess model validity with respect to the original situation. However, results followed the general patterns of that case very closely in the qualitative sense. Our scenarios covered the most likely parameter ranges and the results are likely to have bracketed the actual dynamics of the case. In reality, the value of a model of this kind will be to permit what-if analyses by planners who will be themselves uncertain of the most valid choices of parameter values to use. What-if analysis should be critically important in observing possible results from various choices of parameter settings. For example, it may be possible that conservative (large) estimates of phantom demand are generally advisable. However, such choices may not be appropriate if repeat purchases are high or capacity decisions are conservative at the same time. By observing a large number of scenarios, more informed decisions can be made based on the likely impacts of the interactions among the parameter choices. In addition, for simplicity, we have focused the model on logistics. The model might be expanded to include a financial component reflecting
costs and profitability. One avenue for future research is the development of modular components for simulation models of this kind. Such a modular system might usefully include flexible options for demand model and forecasting model choices.

References