**International Journal of Information Systems and Supply Chain Management**
Volume 13 • Issue 2 • April-June 2020

# Determining Safety Stock for an Omni-Channel Environment

Thi Ngan Pham, Faculty of Business Administration,Ton Duc Thang University, VietNam

Albert Tan, Malaysia Institute for Supply Chain Innovation, Malaysia

Alvin Ang, National University of Singapore, Singapore

## ABSTRACT

The purpose of this article is to determine the safety stock for an omni-channel environment. The "Square Root Law" (for centralization of storage facilities) was proposed to combine the safety stock for both online and offline channels. A simulation study was conducted using a spreadsheet program and three scenarios were created based on review time, lead time and safety factor. This was based on the mean demand and standard deviation of the product's demand distribution. The study found that the sum of lead time and review time are significant in determining the amount of safety stock, and demand variability is a crucial determinant for safety stock. Recommendations are provided as guidelines for lowering the amount of safety stock in omni-channel environment.

## KEYWORDS

*Excel Simulation*, *Lead-Time*, *Multi-Channel*, *Omni-Channel*, *Safety Stock*, *Single-Channel*

## INTRODUCTION

Safety stock is always held to buffer against the supply of an item and its demand. The higher the safety stock level, the better organization is able to respond to uncertainty, and to achieve their target service levels. However, with a high safety stock level, the carrying cost also increases. It includes the opportunity cost of investments and obsolescence cost. Thus, it can be seen that inventory management has a major role to play for the cost savings of a company.

In the single-channel past, if a consumer wanted to buy a television, he will have to go down to the brick-and-mortar store, to pick out his selection and pay for it. With multi-channel, a consumer is able to browse online catalogues, compare choices, make his selection and get it delivered to his home. With the advent of the digital age together with mobile devices like smart phones, laptops and tablets, consumers are now able to make purchases anytime, anywhere and on any device, with options to collect in-store or get home delivery. In addition, the wider adoption of tablets and smartphones in the 2010s, is allowing and encouraging more people to make their purchases online. Omni-channel is seen as the next step in evolution for multi-channel, in which all the information regarding customers, inventory, operations and logistics are all captured and integrated in one unified platform. However, this produces a problem for any supply chain as there is a need to understand how much to stock to accommodate the consumers' demand. Therefore, this paper has proposed an equation that will be tested in various scenarios, to identify ideal usage situations. The proposed equation is based on the common safety stock equation, which considers factors like lead time, demand and review time, but has included considerations for both online and offline demand and review time. The purpose of this

DOI: 10.4018/IJISSCM.2020040104

equation is to determine how much safety stock is to be carried by any organization, yet keeping a balance by not overstocking which will incur a hefty penalty in the form of carrying cost.

This paper is structured as follows: the following section introduces the related literature on inventory management and the development of the concept of safety stock, the growth of the Omni-channel from single-channel; then, the proposed safety stock equation for Omni-channel will be presented, together with the various scenarios it will be tested in; this will be followed by the results analysis and findings.

## LITERATURE REVIEW

Single-channel means utilizing only a single mean of reaching potential customers. This includes being exclusively brick-and-mortar retail stores, or having purely an online e-commerce business (Hübner, Wollenburg, & Holzapfel, 2016). Figure 1 shows how a single-channel works.

Multi-channel are channels working side-by-side without interacting, similar to "working in silos" (Kourimsky & Berk, 2014; Verhoef et al., 2015). There is no logistics or operational interface between the channels. There are no common or shared objectives for the channels but individualized goals, like sales target for each channel (Hübner et al., 2016; Kourimsky & Berk, 2014). The end result for the company is competition, which might create more friction and misunderstanding, than overall better performance. Customers are not able to make purchases across the different channels, as information is not shared across the different channels.

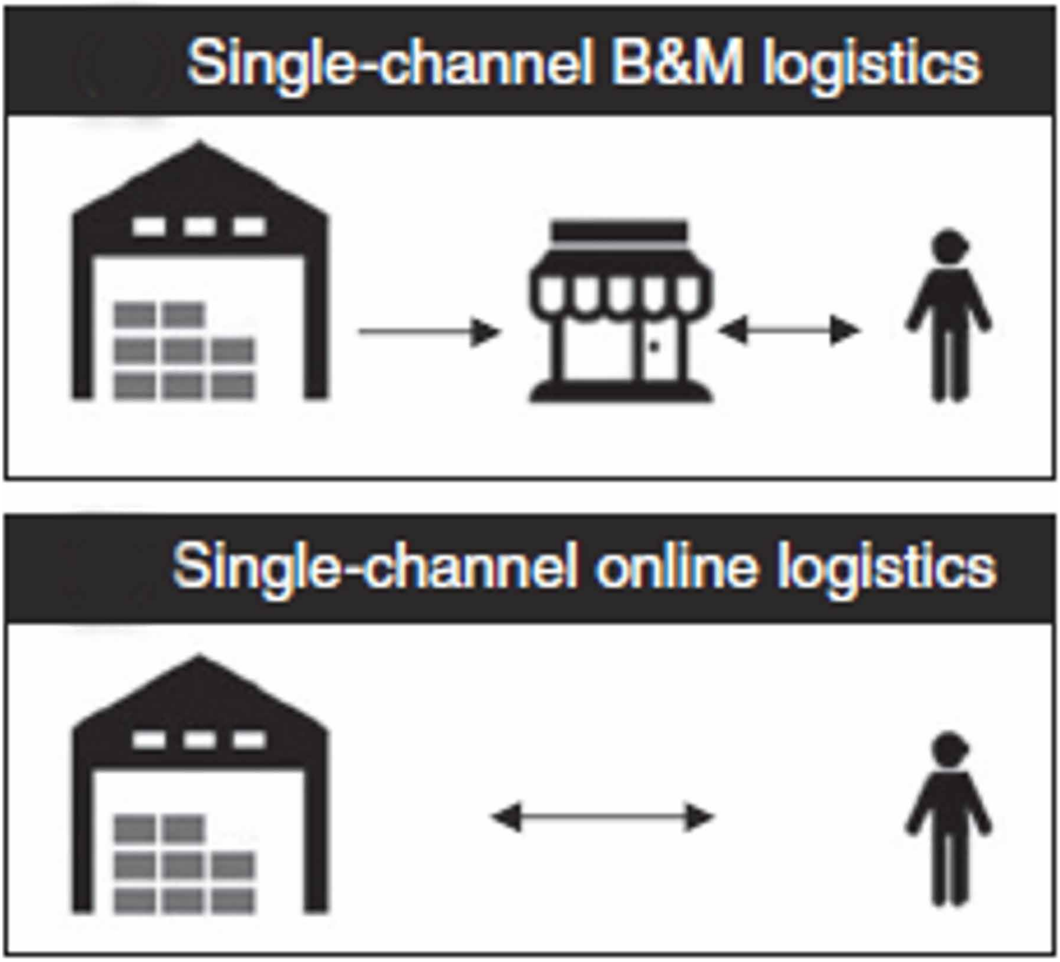
Omni-channel is seen as the advancement of the multi-channel (Figure 2). The word Omni, as defined by Oxford dictionary, means "all; of all things" and "in all ways or places." Where there is a clear divide between the online and physical stores in multi-channel, in Omni-channel the customers move seamlessly between the two domains, as the channels are integrated together. The customer who is connected online via his smartphone, can access information anytime and anywhere. This allows him to make his purchases at any time of the day, with real time information available on all the channels (Piotrowicz & Cuthbertson, 2014). The modern consumer's shopping journey cuts across all channels including social media. Omni-channel (Figure 3) supply chains are rather immature, as significant investments are required to create cross-channel visibility, with adaptation of business rules. It is a huge challenge, which requires a radical and all-encompassing transformation of the organizational structure and its metrics to boost the performance of the various departments across channels (Yee et al., 2015).

Currently, huge advancements have already been made in the area of safety stock and warehouse location decisions. Inderfurth and Minner (1998) tested various service levels and compared them against the safety stock quantity. Graves, Willems, and Zipkin (2000) simplified the placement of safety stock by reducing stochasticity. This was done by modelling the supply chain as a network with each stage in the supply chain operating with a periodic review replenishment policy, together with a bounded demand and guaranteed service time between the stages. Evers (1999) showed that transshipment could reduce inventory, by fulfilling demands from other areas as the primary facility is unable to cope with the demand.

Maister (1976) discovered the Square Root Law. This law stated that the ratio of a decentralized inventory network to a centralized inventory network will be equal to the square root of the number of original field locations (or number of warehouses). Namely, $\frac{\text{Decentralized Inventory}}{\text{Centralized Inventory}} = \sqrt{n}$, where n represents the initial number of warehouses. Basically, the idea is that total inventory could be reduced if all stock was centralized and consolidated at smaller number of facilities, rather than large number of facilities. The effects of the Square Root Law can be seen in Figure 4.

Several researchers have agreed that the Square Root Law can be applied to different conditions under certain assumptions but there is still no agreement on what part of inventory can the Square

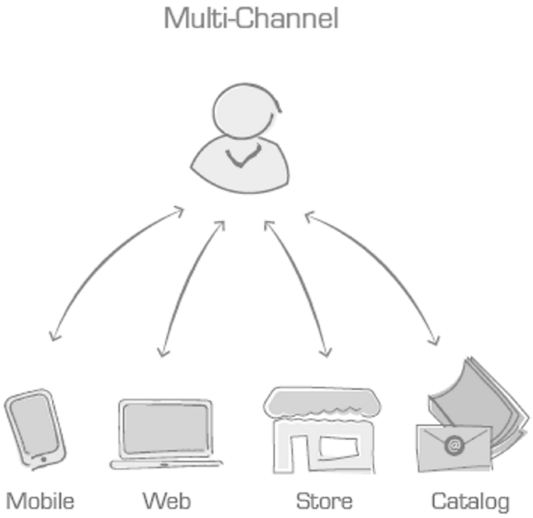
**Figure 1. Single-channel. Source: (Hübner et al., 2016).**



Root Law be applied to (e.g. safety stock, cycle stock and/or total stock)? Originally the Square Root Law has been mostly applied to safety stock, maybe because for this part of stock a reduction by consolidation is readily explained by the risk-pooling effect (Schwarz, 1981; Zinn, Levy, & Bowersox, 1989; Evers, 1995). The Square Root Law might not have been applied to cycle stock as much, because total cost savings from centralising cycle stock may be smaller than from safety-stock centralisation due to higher extra transportation costs (Maister, 1976; McKinnon, 1989; Evers, 1995).

While there has also been discussion on the importance of inventory management in Omni-channel, however, there has not been much research done on Safety Stock determination in Omni-channel logistics (Tan & Gligor, 2019). Safety Stock is known to contribute to inventory costs and with the advent of Omni-channel, a company's costs would increase if there was no effective method of calculating an optimum level of safety stock (to cater for the company's demand variability). The objective of this research is to apply Square Root Law in determining the safety stock for omni-channel businesses since some researchers claim that the Square Root Law provides good estimates of real savings (Sussams, 1986). Sussams (1986) maintains that in 25 examples the inventory savings predicted with the Square Root Law closely reflected the practical ones.

**Figure 2. Multi-channel. Source: (Kourimsky & Berk, 2014).**



## RESEARCH MODEL

Equation (1) represents a general Safety Stock equation proposed by Yamazaki, Shida, and Kanazawa (2016).

$$sS = z\sigma_t \sqrt{T + L} \tag{1}$$

Where $sS$ : Safety Stock, $z$ : Safety factor, $\sigma_t$ : Standard deviation of demand per unit time, $T$ : Review period, $L$ : Lead time. We took this equation and further developed it to take into account Safety Stock that is required for both online and offline channels. All variables have both an online and an offline portion except for the lead time, $L$ which is assumed to be similar for both channels. The Square Root Law was applied because we are centralizing the two channels (handled by two separate storage facilities, one for physical store and one for online sales). Thus, the modified equation becomes

$$sS_{OM} = \sqrt{\frac{\text{No. of Future Facilities}}{\text{No. of Current Facilities}}} \text{ x } \left[\text{Offline Safety Stock} + \text{Online Safety Stock}\right] \tag{2}$$

$$sS_{OM} = \sqrt{\frac{1}{2}} \; x \; \left[z_{offline}\sigma_{t(offline)}\sqrt{T_{offline} + L} + z_{online}\sigma_{t(online)}\sqrt{T_{online} + L}\right] \tag{3}$$

Where:

$sS_{OM}$ : Safety stock for Omni-channel, $z_{offline}$ : Safety factor for offline, $z_{online}$ : Safety factor for online, $\sigma_{t(offline)}$ : Standard deviation of demand per unit time for offline, $\sigma_{t(online)}$ : Standard deviation

**Figure 3. Omni-channel. Source: (Kourimsky & Berk, 2014).**

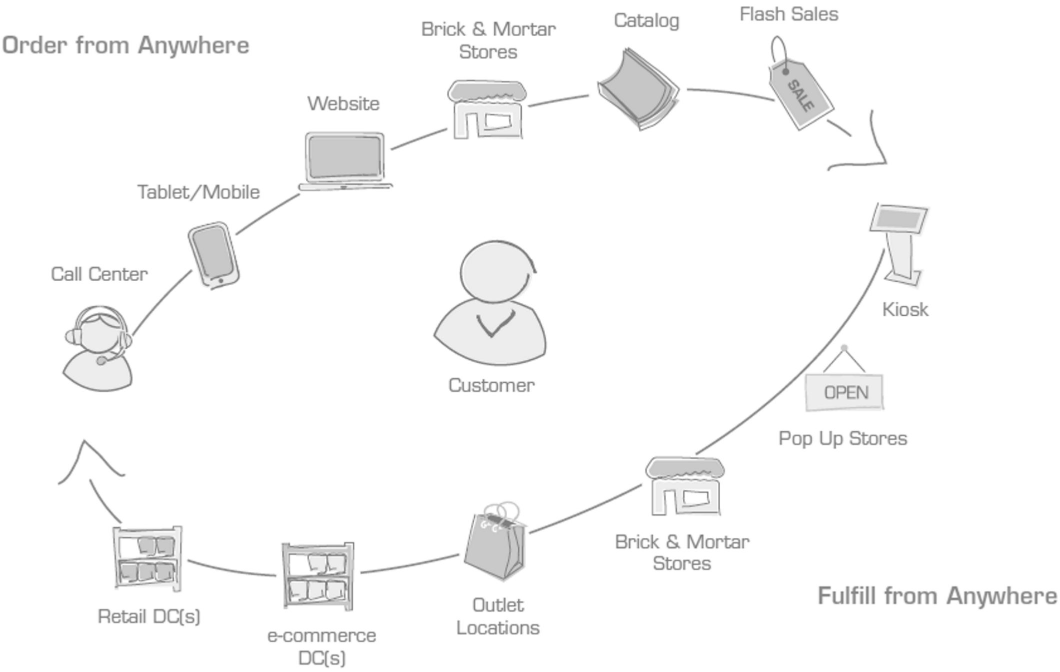
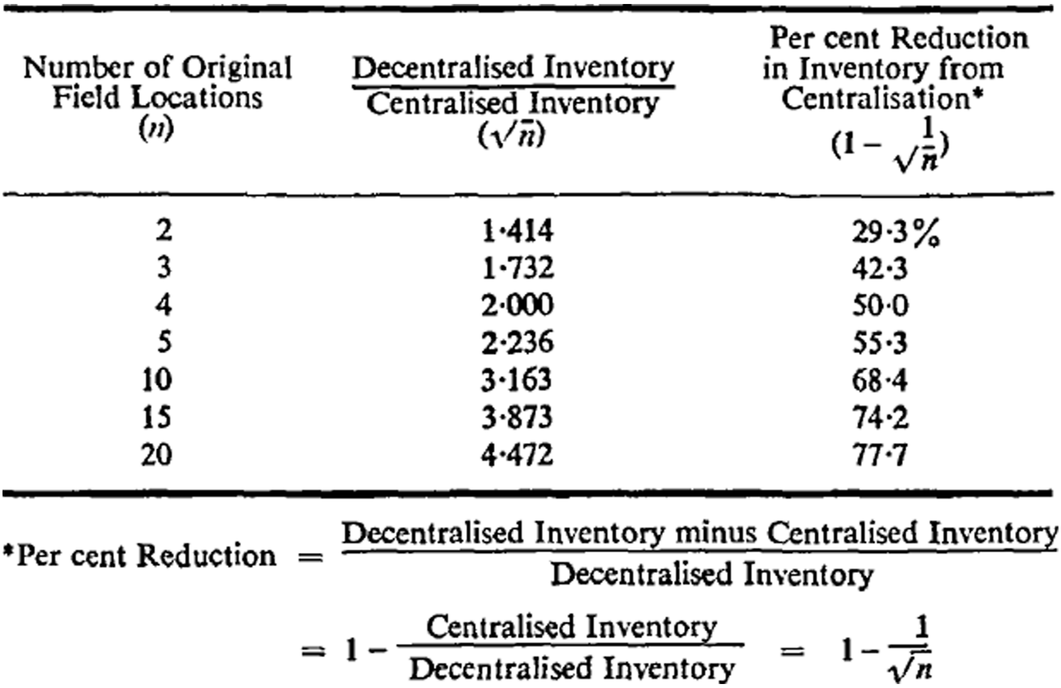


**Figure 4. Percentage reduction in inventory from centralization of warehouse (Maister, 1976).**



| Number of Original Field Locations ($n$) | $\frac{\text{Decentralised Inventory}}{\text{Centralised Inventory}}$ ($\sqrt{n}$) | Per cent Reduction in Inventory from Centralisation* ($1 - \frac{1}{\sqrt{n}}$) |
|---|---|---|
| 2 | 1·414 | 29·3% |
| 3 | 1·732 | 42·3 |
| 4 | 2·000 | 50·0 |
| 5 | 2·236 | 55·3 |
| 10 | 3·163 | 68·4 |
| 15 | 3·873 | 74·2 |
| 20 | 4·472 | 77·7 |

$$\text{*Per cent Reduction} = \frac{\text{Decentralised Inventory minus Centralised Inventory}}{\text{Decentralised Inventory}}$$

$$= 1 - \frac{\text{Centralised Inventory}}{\text{Decentralised Inventory}} = 1 - \frac{1}{\sqrt{n}}$$

of demand per unit time for online, $T_{offline}$ : Review period for offline, $T_{online}$ : Review period for online, $T$ : Lead time (same delivery lead time for both channels). Equation (3) is our proposed model and will be used in our simulation studies for the next few sections.

## SIMULATION SCENARIOS AND PARAMETERS

Excel was used for simulating Equation (3), or also known as the research model. We simulate the safety stock required for Online, Offline, Multi as well as Omni-channels. The scenarios for simulation are created based on these three factors:

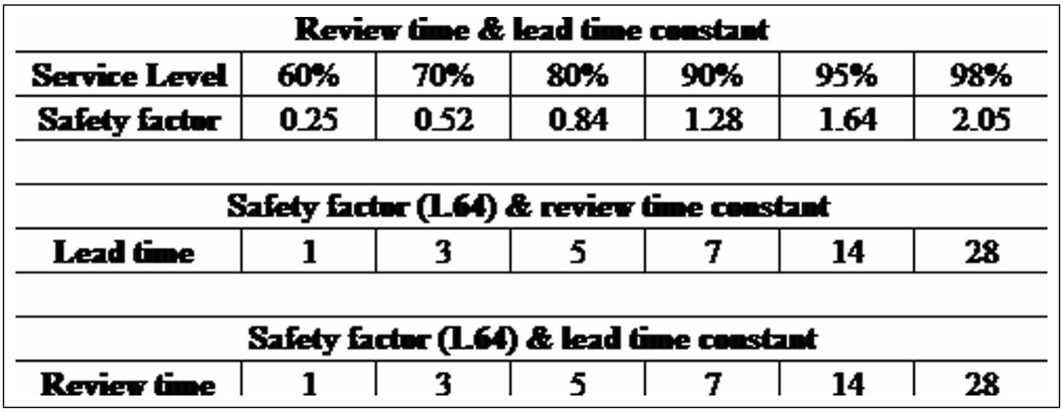
- Changes in the lead time
- Changes in the review time
- Changes in the safety factor

Six levels of lead time and review time, from 1, 3, 5, 7, 14, 28 time-units are introduced into the model. The products are also further classified according to their average demands ( $\mu = 20,100,350,600$ ) and standard deviations ( $\sigma = 1/10\mu, 3/10\mu, 5/10\mu, 7/10\mu$ ). The different average demand represents whether the product is a slow-moving or fast-moving item, whereas the different levels for standard deviation represents the demand variability of the product. For example, a product with ( $\mu = 20, \sigma = 7/10\mu = 14$ ), is a slow-moving item with a high degree of demand variability. In comparison, a product with average demand ( $\mu = 600, \sigma = 1/10\mu = 60$ ), is a fast-moving item but with stable demand. The objective for choosing such parameters was to align with similar parameters used in previous studies of inventory modelling and simulation (Banerjee, Burton, & Banerjee, 2003; Sezen, 2006). With six different review periods, four levels of average demand, four levels of standard deviation, four different results for safety stock, there is a total of 384 different situations in the all scenarios, where one variable is changed while the rest are being held constant. In the first scenario, lead time is kept constant at 1 time unit, whereas safety factor is varied six times, from 0.25 to 2.05, which corresponds to their respective service level of 60% to 98%. For the second scenario, lead time is varied, while the review time and safety factor are kept constant. The safety factor used corresponds to a 95% service level. For the third scenario, review time is varied, while the lead time and safety factor are kept constant. The safety factor used corresponds to a 95% service level. The values of the variables are as per Table 1 for design of experiment below. The results from the simulation study are tabulated in Table 4 and Table 5 in the Appendix.

The simulation assumptions are:

- Review time for offline is 7 unit time as it is periodic review, while the review time for online is 1 unit time as it is continuous review
- Demand is normally distributed and their standard deviations and means are deterministic and there is no seasonal or cyclic demand.
- Products are delivered when requested and there is no backorder.
- Two different storage facilities are currently handling the safety stock for offline and online.
- There is no transshipment happening between the facilities, both before and after consolidation
- All facilities use the same safety factor, both before and after consolidation
- There is zero variance of lead time for all facilities, both before and after consolidation.
- Demand at decentralized facilities are not linked and all have the same demand variance.
- Demands and lead times are independent and normal distributed random variables.
- Average total system demand remains constant after the consolidation

Table 1. The six different simulation scenarios



| Review time & lead time constant | | | | | | |
|---|---|---|---|---|---|---|
| **Service Level** | 60% | 70% | 80% | 90% | 95% | 98% |
| **Safety factor** | 0.25 | 0.52 | 0.84 | 1.28 | 1.64 | 2.05 |
| **Safety factor (1.64) & review time constant** | | | | | | |
| **Lead time** | 1 | 3 | 5 | 7 | 14 | 28 |
| **Safety factor (1.64) & lead time constant** | | | | | | |
| **Review time** | 1 | 3 | 5 | 7 | 14 | 28 |

## ANALYSIS OF RESULTS

For the first scenario, it can be observed that as safety factor increases, the amount of safety stock required increases (Figure 5). The difference between the safety stock required for safety factor of 0.25 (60% service level) and safety factor of 1.64 (95% service level), increases as the mean increases. Therefore, a faster moving stock compared to a slow-moving stock, requires more safety stock, even for an item with a standard deviation of 10% which represents a stable demand as there is lower deviation from the mean.

For the second scenario, it can be observed that as lead time increases, the amount of safety stock required increases (Figure 6). The difference between the safety stocks required for lead time of 1 time unit and lead time of 28 time unit, increases as the mean increases. Therefore, with delays of delivery, it can be observed that more safety stock is required to cater to faster moving products.

For the third scenario, it can be observed that as review time increases, the amount of safety stock required increases. The difference between the safety stocks required for review time of 1 time unit and review time of 28 time unit, increases as the mean increases. Therefore, with more infrequent inventory reviews, it can be seen that more safety stock is required to cater to increases in demand, like in the case of periodic reviews where an unexpected surge in demand might cause shortages or stockout. Therefore, we can conclude that if review time is continuous, it would help to reduce the amount of review time to a minimum.

There is a general observable trend that safety stock would increase, when the individual determinants like safety factor, lead time and review time are increased (Figure 7). Further models were subsequently tested to find out how standard deviation would affect the service level, what would happen when lead time and review time were combined together, and whether demand variance or lead time would play a more important role in determining the amount of safety stock (Figure 8).

This chart is based on product mean $\mu = 100$, with standard deviation $\sigma = 1/10\mu, 3/10\mu, 5/10\mu, 7/10\mu$, with variation in service level from 55% to 99%. A comparison of the results showed that with an increase in service level, there is an increase in safety stock. However, the curve would taper off, as the service level increases from 90% onwards. This shows that the impact of more safety stock on the service level is lessening. In other words, the investment on higher service levels might not pay off and there is diminishing returns. Further investment in safety stock would only end up tying up capital, which the company can utilise for other forms of investments. In addition, with greater deviation from the product mean, more investment in safety stock is required for the same service level.

**Figure 5. Safety factor vs omni-channel safety stock**

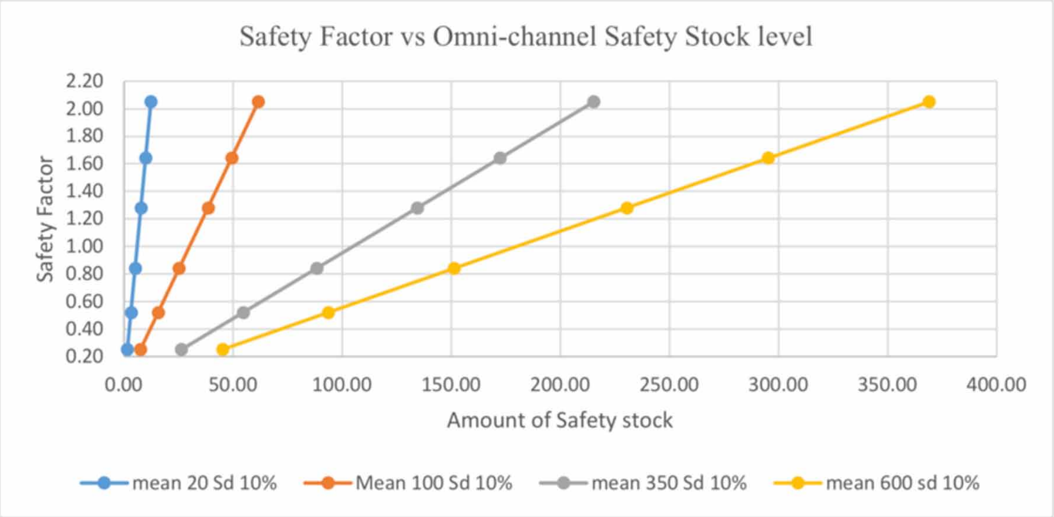
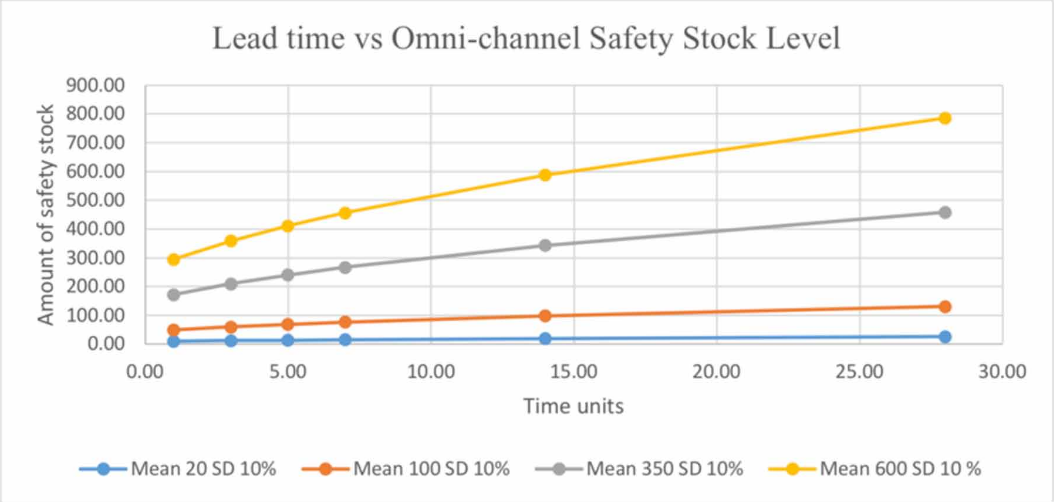


**Figure 6. Lead time vs omni-channel safety stock**



From the analysis of the results, there was an understanding that the individual lead time and review time did not matter as much as the sum total of these two times. Thus, a further model was developed to see what is the effect of the sum total of the time versus the safety stock level. With a constant service level of 90%, the sum total of the time was varied from 1 to 90 time units. The mean of the product was 100 and the standard deviation was 10% of the mean or $\sigma = 1/10\mu$. The results showed that with 4 time units total of review time and lead time, the safety stock required would be 100% of that required for 1 time unit total of review time and lead time (Table 2 and Figure 9).

The results showed that with 4 time units total of review time and lead time, the safety stock required would be 100% of that required for 1 time unit. If that time was increased to 14 time units, it would be 274% more than for 1 time unit. Thus, to reduce safety stock, the lead time and review time

**Figure 7. Review time vs omni-channel safety stock**

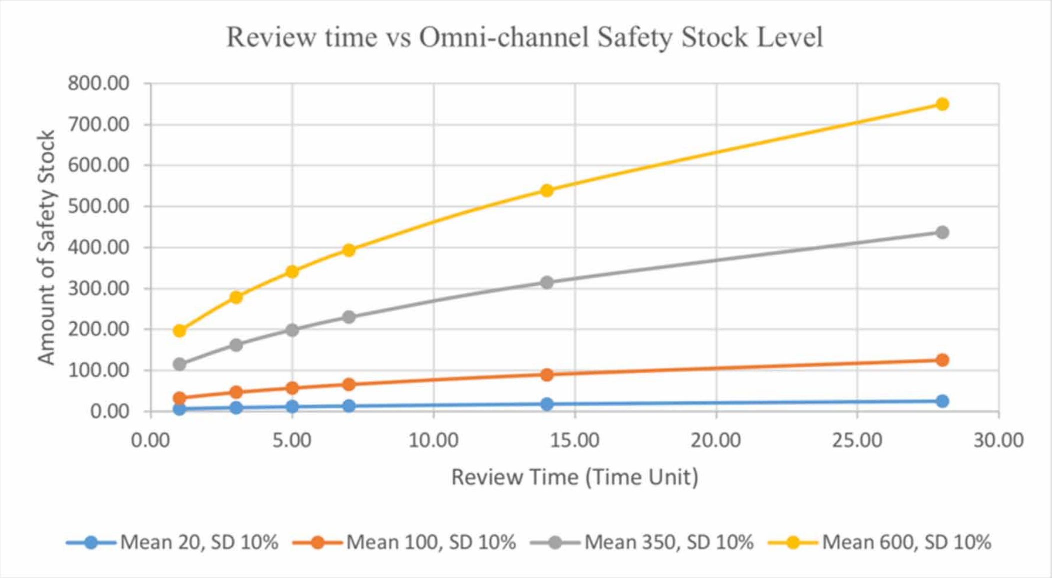
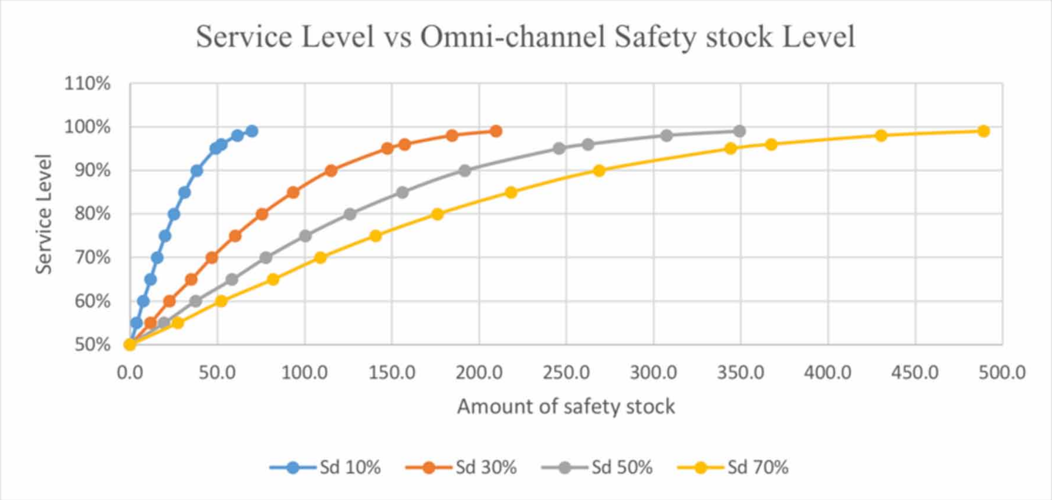


**Figure 8.**



need to be shortened to ensure that safety stock is kept at a low level. This concurs with the research done by Evers (1999) on the influence of lead time on safety stocks. In his research, he found that it was more effective when the average lead times are reduced for slow-moving items with unstable demand, and when the standard deviation of lead times are reduced for fast moving items with stable demand (Evers, 1999). This aspect of lead time and review time reduction is possible to be controlled by the company, by negotiating for reduced lead time and ensuring the inventory is continuously reviewed (Farhad et al., 2012). The objective is so that the company is able to achieve an optimum level of safety stock without affecting inventory availability and service level. As the equation was

**Figure 9. Safety stock level vs sum of lead and review time**

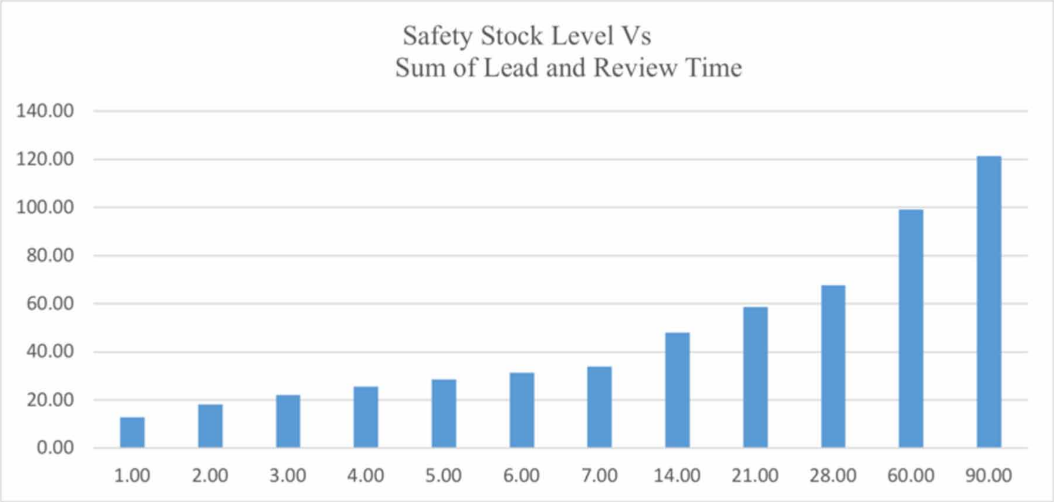


**Table 2. Total of lead and review time compared with safety stock required**

| **Total Time units** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **14** | **21** | **28** | **60** | **90** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Safety Stock Required | 12.80 | 18.10 | 22.17 | 25.60 | 28.62 | 31.35 | 33.87 | 47.89 | 58.66 | 67.73 | 99.15 | 121.43 |
| % Difference from Day 1 | 0.0% | 41.4% | 73.2% | 100.0% | 123.6% | 144.9% | 164.6% | 274.2% | 358.3% | 429.2% | 674.6% | 848.7% |

Source: own work.

using the "square root law" for centralization of warehouses, a 2 × 2 matrix was created to show the difference between safety stock required for centralized (Omni-channel) and decentralized (multi-channel) based on fast and slow moving products.

In the first matrix (Figure 10), it is based on the third scenario in which only review time is varied. The size of circles represents the amount of inventory required for the different product mean, with standard deviation at 10% and 70%, and review time at 1 and 28 time units.

As can be observed in the matrix in Figure 10, products that are stored in decentralised warehouses (multi-channel) would require more safety stock compared to those in the centralised warehouses (Omni-channel), due to the "Square Root Law" which is used for consolidation of stock. With increase in variance, which is represented by the higher standard deviation of 70%, the amount of safety stock increases. For slow moving products which are represented with their low mean $\mu$ 20 and 50, they require lower safety stock compared with the fast-moving products. Slow moving products can be considered to be stored at decentralised warehouses for faster response to consumers, if they are of low cost.

For the bar chart shown below (Figure 11), it is also based on the scenario in which only review time is varied, however only two sets of data are used where review time = 1 time unit and review time = 28 time units. The average demand is 100 with a standard deviation of 10%.

As can be observed in the chart above, there are only two colors of which one represents a centralized facility while the other represents decentralized facilities. As observed, those categorized under the centralized warehouse (Omni-channel), required a lesser amount of safety stock compared to those categorized under the decentralized warehouses (multi-channel). This is because the "Square

Figure 10. Warehouse type vs product velocity

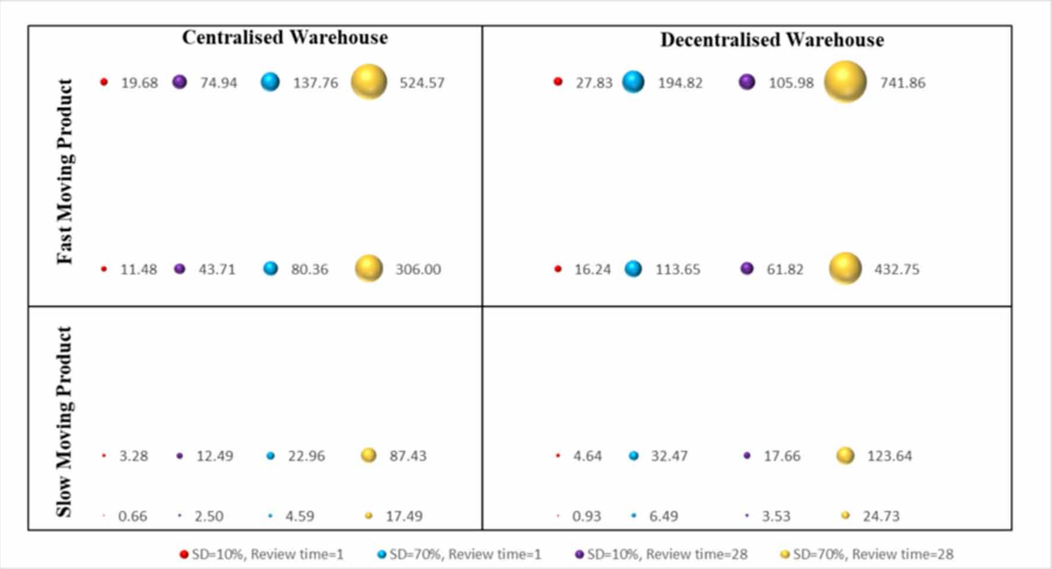
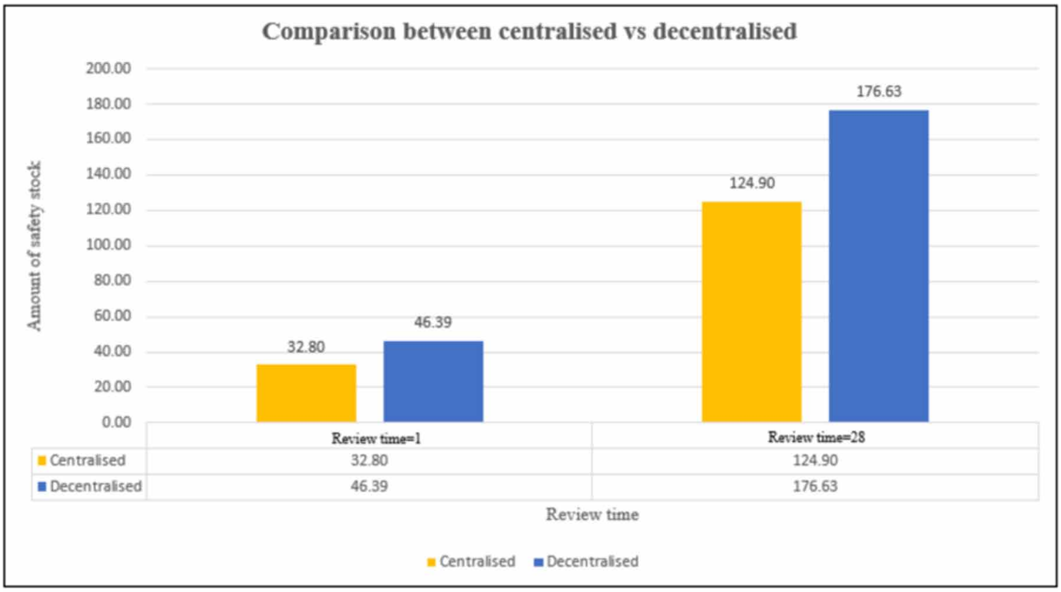


Figure 11. Comparison between centralized and decentralized facilities



Root Law" was applied to them. There is an increase of 438.5% of the amount of safety stock if the inventory was decentralized and review time = 28 time units, compared to an inventory which is centralized and only review time = 1 time unit. Therefore, with an increase in the review time needed to review the inventory such as in periodic replenishment policies, the amount of safety stock subsequently increased. This increase is further intensified if the facility is not centralized, as shown in the chart (Figure 11).

As there were increases in safety stock for both demand variation and lead time increase, Figure 12 is plotted to compare which determinant would cause a higher increase in the amount of safety stock. The graph shows that as demand variation causes a higher increase in the amount of safety stock required. Figure 12 also shows that as lead time increase of 60 time units requires less safety stock (185.49) than a demand variation of 40% (196.8). Thus, this shows that demand variability requires more stock than an increase in lead time, and thus, this is a more crucial determinant than lead time.

## RECOMMENDATIONS

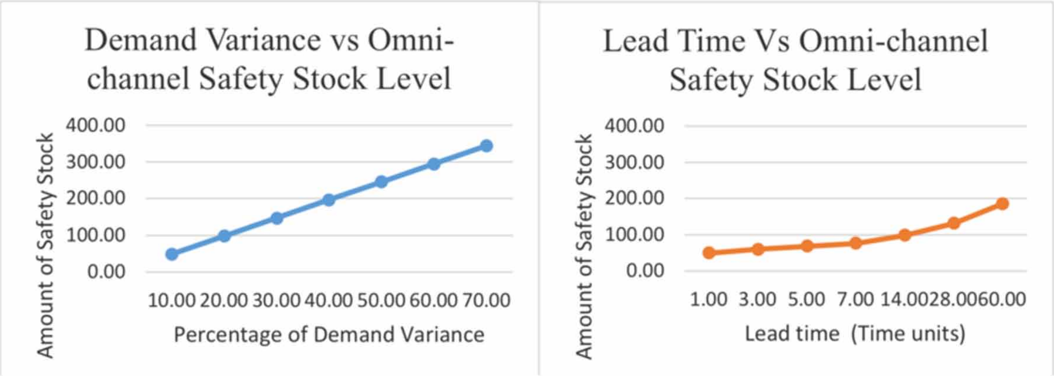
From this simulation, it has found out that the sum of lead time and review time is more significant than each individual lead time and review time. As these two factors can be influenced and controlled by the company, they should be reduced as much as possible. The savings for the reduction in these two factors, can be seen in the increase in the amount of safety stock compared with the increased sum of lead time and review time. This finding has also shown the importance of buyer-supplier relationship and the implementation of a continuous review policy. With a collaborative or alliance type of buyer-supplier relationship, the company will be able to negotiate for a reduced lead time for their purchase items and thus, be able to reduce the amount of safety stock it holds. In addition, with a continuous review policy, the review time can be effectively reduced to a minimum, such that the equation will have only a lead time component and no review time component. Demand variation has also shown to be more crucial in determining the amount of safety stock required, compared to lead time. As demand variation is dependent on consumers' behavior, a way to reduce the demand variation is by risk pooling.

Therefore the contribution by this paper towards the existing literature is the recommendations that will be put forth. The fundamental idea is that safety stock will increase as the standard deviation of demand, lead time or review time increases, and companies should pool their items together to reduce the demand variation and also to reduce the amount of safety stock that they carry (Chen 2009). The results of the modelling concurs with the vast amount of existing literature done on inventory management. The effects of centralization of warehouses, lead time on safety stock and the research done for the various methods of determining safety stock are well documented.

From Equation (3),

$$sS_{OM} = \sqrt{\frac{1}{2} \text{ x } \left[ z_{offline}\sigma_{t(offline)}\sqrt{T_{offline} + L} + z_{online}\sigma_{t(online)}\sqrt{T_{online} + L} \right]} \tag{3}$$

**Figure 12. Demand variation and lead time variation vs omni-channel safety stock**



We can adjust the Safety factor for offline $z_{offline}$ with a higher value as compared to the Safety factor for online $z_{online}$ since consumers expect the stock to be available in store while they are shopping as compared to online shopping where the stock can be backordered. Therefore, more safety stock should be allocated more to the store than for online sales.

Next, ABC classification can be performed to classify the items, according to their price and whether they are fast or slow moving in order to determine if they should be centralized or decentralized. For centralization, the main motivation should be to lower cost as the items are expensive and slow moving. For decentralization, the motivation should be faster response to consumers, and the items should be low value and fast moving. This will help to ensure that consumers receive their items quickly. Pooling is good for operations when the uncertainty is minimal and not beneficial when the uncertainty is too high. We would recommend products with the following certain characteristics to store either in a centralized facility or decentralized facilities as listed in Table 3.

Another recommendation is to further pool and share inventory with companies in the same industry or companies retailing similar standard items. Grocery stores and stores which sell electrical appliances are some of the companies that might benefit if they could come together and share their safety stock. This is because they carry items which can be standardized such as television sets, laptops, cooking oil and canned foods. Besides cost savings from pooling their inventories, the individual company will also save on obsolescence cost as the products that they are retailing, do have a shelf life. Although the terms “consolidation” and “pooling”, would give the idea of locating all the products at one single location, the idea instead would be to share the information of how much safety stock each company is keeping. This way, the companies need not share a physical location but instead keep their safety stock at their own facilities.

## CONCLUSION

Safety stock is a part of inventory, and it is usually held to buffer against demand variations and supply uncertainty. However, in carrying too much safety stock, companies run the risk of obsolescence, increase in carrying costs, missed investment opportunities and lower profits. With the Omni-channel retailing, which is the next step in evolution for the multi-channel retailing, there is a greater need to ensure that customers are able to get their purchases as they are now able to purchase anytime, anywhere and on any of their devices. This research question is to look into this relatively unexplored area of safety stock in an Omni-channel environment, and the significance of the question is so that the cost of safety stock can be reduced, and to increase the profitability of a company. The main contribution for this paper is finding out that the sum of lead time and review time is more significant than the individual lead time and review time, and showing that the demand variation is a more crucial determinant in the safety stock equation than lead time increase, as it would require more safety stock to cater to a 40% demand variation than a 60 time units lead time. Furthermore, the safety factors for both online and offline sales should be adjusted separately since offline sales expect higher stock availability as compared to online sales which allow backorder if stock is not available.

**Table 3. Characteristics of products to be centralized or decentralized**

| Centralized facility | Decentralized facilities |
|---|---|
| • Slow Moving Stock<br>• Bulky items like fridges, washing machines<br>• High value items<br>• Items with limited shelf life<br>• Items with long lead time<br>• Items with high demand variability | • Fast Moving Stock<br>• Small items like thumb drives, laptops<br>• Low value items<br>• Items without shelf life<br>• Items with short lead time<br>• Items with low demand variability |

## Limitations and Future Work

Several assumptions were made in refining the equation. These include review time being one week for offline channels and daily for online channels, which in reality might not be the case, as most major retail companies have some form of an ERP software like SAP installed, which tracks the inventory all the time. Another limitation is the assumptions is that the orders are immediately filled and no backorder is allowed. For online sales that are delivered to the consumer's home, it is not expected to be immediate and if the delivery is delayed by a few days, the consumer would still be satisfied with the company's service. Due to the usage of the "square root law", the safety factor and demand have to be the same for both online and offline which in practice is not likely. Due to the stochastic demand for online sales, in practice, lower levels of inventory and safety stock are typically kept which results in lower service levels. Demand for online and offline sales are also different, thus in reality the proposed equation might have limited usage.

An area for future research can be to further improve the equation such that safety factor, standard deviation of demand and mean demand can be varied for both the online and offline channels. In this way, the calculations will be more accurate and the variables will be more likely to those used in practice. Another area is that a better simulation program can be used for modelling the simulation, such that instead of just the facilities level, the program is able to come up with the detailed safety stock for the retail store level. In this way, the results will be more accurate as the information from the individual stores will be used to calculate the average demand and standard deviation. This simulation program can be partnered with a standard ERP program, such that the daily demand can be gathered for its utilization.

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# APPENDIX

## Table 4. Ranges of parameters used in computational experiments

**Safety Factor scenario**

| Average Demand | Standard Dev. | Safety factor, corresponding Service level in [ ], constant review time and lead time | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.25 [60%] | | | | 0.52 [70%] | | | | 0.84 [80%] | | | | 1.28 [90%] | | | | 1.64 [95%] | | | | 2.05 [98%] | | | |
| | | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel |
| μ=20 | σ=2 | 1.41 | 0.71 | 2.12 | 1.50 | 2.94 | 1.47 | 4.41 | 3.12 | 4.75 | 2.38 | 7.13 | 5.04 | 7.24 | 3.62 | 10.86 | 7.68 | 9.28 | 4.64 | 13.92 | 9.84 | 11.60 | 5.80 | 17.39 | 12.3 |
| | σ=6 | 4.24 | 2.12 | 6.36 | 4.50 | 8.82 | 4.41 | 13.24 | 9.36 | 14.26 | 7.13 | 21.38 | 15.12 | 21.72 | 10.86 | 32.58 | 23.04 | 27.83 | 13.92 | 41.75 | 29.52 | 34.79 | 17.39 | 52.18 | 36.9 |
| | σ=10 | 7.07 | 3.54 | 10.61 | 7.50 | 14.71 | 7.35 | 22.06 | 15.60 | 23.76 | 11.88 | 35.64 | 25.20 | 36.20 | 18.10 | 54.31 | 38.40 | 46.39 | 23.19 | 69.58 | 49.20 | 57.98 | 28.99 | 86.97 | 61.5 |
| | σ=14 | 9.90 | 4.95 | 14.85 | 10.50 | 20.59 | 10.30 | 30.89 | 21.84 | 33.26 | 16.63 | 49.89 | 35.28 | 50.69 | 25.34 | 76.03 | 53.76 | 64.94 | 32.47 | 97.41 | 68.88 | 81.18 | 40.59 | 121.76 | 86.1 |
| μ=100 | σ=10 | 7.07 | 3.54 | 10.61 | 7.50 | 14.71 | 7.35 | 22.06 | 15.60 | 23.76 | 11.88 | 35.64 | 25.20 | 36.20 | 18.10 | 54.31 | 38.40 | 46.39 | 23.19 | 69.58 | 49.20 | 57.98 | 28.99 | 86.97 | 61.5 |
| | σ=30 | 21.21 | 10.61 | 31.82 | 22.50 | 44.12 | 22.06 | 66.19 | 46.80 | 71.28 | 35.64 | 106.91 | 75.60 | 108.61 | 54.31 | 162.92 | 115.20 | 139.16 | 69.58 | 208.74 | 147.60 | 173.95 | 86.97 | 260.92 | 184.5 |
| | σ=50 | 35.36 | 17.68 | 53.03 | 37.50 | 73.54 | 36.77 | 110.31 | 78.00 | 118.79 | 59.40 | 178.19 | 126.00 | 181.02 | 90.51 | 271.53 | 192.00 | 231.93 | 115.97 | 347.90 | 246.00 | 289.91 | 144.96 | 434.87 | 307.5 |
| | σ=70 | 49.50 | 24.75 | 74.25 | 52.50 | 102.95 | 51.48 | 154.43 | 109.20 | 166.31 | 83.16 | 249.47 | 176.40 | 253.43 | 126.71 | 380.14 | 268.80 | 324.70 | 162.35 | 487.06 | 344.40 | 405.88 | 202.94 | 608.82 | 430.5 |
| μ=350 | σ=35 | 24.75 | 12.37 | 37.12 | 26.25 | 51.48 | 25.74 | 77.22 | 54.60 | 83.16 | 41.58 | 124.73 | 88.20 | 126.71 | 63.36 | 190.07 | 134.40 | 162.35 | 81.18 | 243.53 | 172.20 | 202.94 | 101.47 | 304.41 | 215.25 |
| | σ=105 | 74.25 | 37.12 | 111.37 | 78.75 | 154.43 | 77.22 | 231.65 | 163.80 | 249.47 | 124.73 | 374.20 | 264.60 | 380.14 | 190.07 | 570.21 | 403.20 | 487.06 | 243.53 | 730.58 | 516.60 | 608.82 | 304.41 | 913.23 | 645.75 |
| | σ=175 | 123.74 | 61.87 | 185.62 | 131.25 | 257.39 | 128.69 | 386.08 | 273.00 | 415.78 | 207.89 | 623.67 | 441.00 | 633.57 | 316.78 | 950.35 | 672.00 | 811.76 | 405.88 | 1217.64 | 861.00 | 1014.70 | 507.35 | 1522.05 | 1076.25 |
| | σ=245 | 173.24 | 86.62 | 259.86 | 183.75 | 360.34 | 180.17 | 540.51 | 382.20 | 582.09 | 291.05 | 873.14 | 617.40 | 886.99 | 443.50 | 1330.49 | 940.80 | 1136.46 | 568.23 | 1704.69 | 1205.40 | 1420.58 | 710.29 | 2130.87 | 1506.75 |
| μ=600 | σ=60 | 42.43 | 21.21 | 63.64 | 45.00 | 88.25 | 44.12 | 132.37 | 93.60 | 142.55 | 71.28 | 213.83 | 151.20 | 217.22 | 108.61 | 325.83 | 230.40 | 278.32 | 139.16 | 417.48 | 295.20 | 347.90 | 173.95 | 521.84 | 369 |
| | σ=180 | 127.28 | 63.64 | 190.92 | 135.00 | 264.74 | 132.37 | 397.11 | 280.80 | 427.66 | 213.83 | 641.49 | 453.60 | 651.67 | 325.83 | 977.50 | 691.20 | 834.95 | 417.48 | 1252.43 | 885.60 | 1043.69 | 521.84 | 1565.53 | 1107 |
| | σ=300 | 212.13 | 106.07 | 318.20 | 225.00 | 441.23 | 220.62 | 661.85 | 468.00 | 712.76 | 356.38 | 1069.15 | 756.00 | 1086.12 | 543.06 | 1629.17 | 1152.00 | 1391.59 | 695.79 | 2087.38 | 1476.00 | 1739.48 | 869.74 | 2609.22 | 1845 |
| | σ=420 | 296.98 | 148.49 | 445.48 | 315.00 | 617.73 | 308.86 | 926.59 | 655.20 | 997.87 | 498.93 | 1496.80 | 1058.40 | 1520.56 | 760.28 | 2280.84 | 1612.80 | 1948.22 | 974.11 | 2922.33 | 2066.40 | 2435.28 | 1217.64 | 3652.91 | 2583 |

## Table 5. Time review scenario

**Review time scenario**

| Average Demand | Standard Dev. | Number of time units in the review time, constant safety factor (z) =1.64 corresponding to 95% service level | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | | | 3 | | | | 5 | | | | 7 | | | | 14 | | | | 28 | | | |
| | | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel | SS offline | SS online | Multi-Channel | Omni-Channel |
| μ=20 | σ=2 | 4.64 | 4.64 | 9.28 | 6.56 | 6.56 | 6.56 | 13.12 | 9.28 | 8.03 | 8.03 | 16.07 | 11.36 | 9.28 | 9.28 | 18.55 | 13.12 | 12.70 | 12.70 | 25.41 | 17.97 | 17.66 | 17.66 | 35.33 | 24.9797 |
| | σ=6 | 13.92 | 13.92 | 27.83 | 19.68 | 19.68 | 19.68 | 39.36 | 27.83 | 24.10 | 24.10 | 48.21 | 34.09 | 27.83 | 27.83 | 55.66 | 39.36 | 38.11 | 38.11 | 76.22 | 53.90 | 52.99 | 52.99 | 105.98 | 74.9392 |
| | σ=10 | 23.19 | 23.19 | 46.39 | 32.80 | 32.80 | 32.80 | 65.60 | 46.39 | 40.17 | 40.17 | 80.34 | 56.81 | 46.39 | 46.39 | 92.77 | 65.60 | 63.52 | 63.52 | 127.03 | 89.83 | 88.32 | 88.32 | 176.63 | 124.899 |
| | σ=14 | 32.47 | 32.47 | 64.94 | 45.92 | 45.92 | 45.92 | 91.84 | 64.94 | 56.24 | 56.24 | 112.48 | 79.54 | 64.94 | 64.94 | 129.88 | 91.84 | 88.92 | 88.92 | 177.85 | 125.76 | 123.64 | 123.64 | 247.29 | 174.858 |
| μ=100 | σ=10 | 23.19 | 23.19 | 46.39 | 32.80 | 32.80 | 32.80 | 65.60 | 46.39 | 40.17 | 40.17 | 80.34 | 56.81 | 46.39 | 46.39 | 92.77 | 65.60 | 63.52 | 63.52 | 127.03 | 89.83 | 88.32 | 88.32 | 176.63 | 124.899 |
| | σ=30 | 69.58 | 69.58 | 139.16 | 98.40 | 98.40 | 98.40 | 196.80 | 139.16 | 120.51 | 120.51 | 241.03 | 170.43 | 139.16 | 139.16 | 278.32 | 196.80 | 190.55 | 190.55 | 381.10 | 269.48 | 264.95 | 264.95 | 529.90 | 374.696 |
| | σ=50 | 115.97 | 115.97 | 231.93 | 164.00 | 164.00 | 164.00 | 328.00 | 231.93 | 200.86 | 200.86 | 401.72 | 284.06 | 231.93 | 231.93 | 463.86 | 328.00 | 317.58 | 317.58 | 635.17 | 449.13 | 441.58 | 441.58 | 883.17 | 624.493 |
| | σ=70 | 162.35 | 162.35 | 324.70 | 229.60 | 229.60 | 229.60 | 459.20 | 324.70 | 281.20 | 281.20 | 562.40 | 397.68 | 324.70 | 324.70 | 649.41 | 459.20 | 444.62 | 444.62 | 889.24 | 628.79 | 618.22 | 618.22 | 1236.43 | 874.291 |
| μ=350 | σ=35 | 81.18 | 81.18 | 162.35 | 114.80 | 114.80 | 114.80 | 229.60 | 162.35 | 140.60 | 140.60 | 281.20 | 198.84 | 162.35 | 162.35 | 324.70 | 229.60 | 222.31 | 222.31 | 444.62 | 314.39 | 309.11 | 309.11 | 618.22 | 437.145 |
| | σ=105 | 243.53 | 243.53 | 487.06 | 344.40 | 344.40 | 344.40 | 688.80 | 487.06 | 421.80 | 421.80 | 843.60 | 596.52 | 487.06 | 487.06 | 974.11 | 688.80 | 666.93 | 666.93 | 1333.86 | 943.18 | 927.33 | 927.33 | 1854.65 | 1311.44 |
| | σ=175 | 405.88 | 405.88 | 811.76 | 574.00 | 574.00 | 574.00 | 1148.00 | 811.76 | 703.00 | 703.00 | 1406.01 | 994.20 | 811.76 | 811.76 | 1623.52 | 1148.00 | 1111.55 | 1111.55 | 2223.09 | 1571.96 | 1545.54 | 1545.54 | 3091.08 | 2185.73 |
| | σ=245 | 568.23 | 568.23 | 1136.46 | 803.60 | 803.60 | 803.60 | 1607.20 | 1136.46 | 984.20 | 984.20 | 1968.41 | 1391.88 | 1136.46 | 1136.46 | 2272.92 | 1607.20 | 1556.16 | 1556.16 | 3112.33 | 2200.75 | 2163.76 | 2163.76 | 4327.52 | 3060.02 |
| μ=600 | σ=60 | 139.16 | 139.16 | 278.32 | 196.80 | 196.80 | 196.80 | 393.60 | 278.32 | 241.03 | 241.03 | 482.06 | 340.87 | 278.32 | 278.32 | 556.63 | 393.60 | 381.10 | 381.10 | 762.20 | 538.96 | 529.90 | 529.90 | 1059.80 | 749.392 |
| | σ=180 | 417.48 | 417.48 | 834.95 | 590.40 | 590.40 | 590.40 | 1180.80 | 834.95 | 723.09 | 723.09 | 1446.18 | 1022.60 | 834.95 | 834.95 | 1669.90 | 1180.80 | 1143.30 | 1143.30 | 2286.61 | 1616.88 | 1589.70 | 1589.70 | 3179.40 | 2248.18 |
| | σ=300 | 695.79 | 695.79 | 1391.59 | 984.00 | 984.00 | 984.00 | 1968.00 | 1391.59 | 1205.15 | 1205.15 | 2410.30 | 1704.34 | 1391.59 | 1391.59 | 2783.17 | 1968.00 | 1905.51 | 1905.51 | 3811.02 | 2694.79 | 2649.50 | 2649.50 | 5299.00 | 3746.96 |
| | σ=420 | 974.11 | 974.11 | 1948.22 | 1377.60 | 1377.60 | 1377.60 | 2755.20 | 1948.22 | 1687.21 | 1687.21 | 3374.42 | 2386.07 | 1948.22 | 1948.22 | 3896.44 | 2755.20 | 2667.71 | 2667.71 | 5335.42 | 3772.71 | 3709.30 | 3709.30 | 7418.60 | 5245.74 |

*Thi Ngan Pham joins the business administration department of Ton Duc Thang university in Vietnam, as a lecturer upon PhD graduation and became the head of International Business major after 5 years. Her current role includes teaching and leading the development of International business program for her school. Her current research interests include the role of supply chain on international trading beside its operation on firm' cost and efficiency. Furthermore, she is also investigating the interaction between finance and supply chain especially in developing countries where cash flow is always a challenge for upstream suppliers. She has Bachelor degree in International business from Tianjin Nankai University in China and a Master degree from Tianjin University of Finance and Economics in China. She completed her PhD in Sun Yat -Sen University in China.*

*Albert Tan has worked as a consultant for the Center for Corporate Learning at the Singapore Manufacturers' Federation (SMa) and as Director in a government agency at Singapore. He has also held position as the Associate Director at The Logistics Institute – Asia Pacific, NUS; managing the Double Master program in Supply Chain Management and Logistics Management. He has held teaching positions in the college of graduate studies at the University of Wollongong in Dubai, National University Singapore and Singapore Institute of Management. Dr. Tan holds an MBS from the National University of Ireland and a PhD in Supply Chain Management from the Nanyang Technological University. He is a Research Affiliate with the Massachusetts Institute of Technology (MIT). He is also a Certified Fellow in Production and Inventory Management from APICS.*

*Alvin Ang is currently a Research Fellow with the Department of Industrial Systems Engineering & Management (ISEM) at National University of Singapore (NUS). He was also previously a Research Fellow with The Logistics Institute Asia Pacific (TLIAP) at NUS, Singapore. He did his Ph. D (Operations Management Research), Masters (Logistics) and Bachelors (Mechatronics) in Nanyang Technological University (NTU), Singapore. His current research interests are into optimizing the safety stock for retailers in an omni-channel environment, and interfaces between operations research and operations management. His area of expertise also lie with Kanban Controlled Systems (KCS).*