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Simulation as a way of optimizing a delivery size: Impact on the profitability of an enterprise

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Abstract

The paper examines the classical problem of optimization of the size of a delivery to a warehouse. Using a model developed by the author, simulations were conducted using data obtained from companies in Poland. The results revealed that the impact of this optimization on the economic efficiency of an enterprise can be considerable in some cases. It is difficult, however, to develop an appropriate mathematical formula for solving such a problem. The use of a simulation seems to be more appropriate for solving this problem than optimization models.

Introduction

The problem of optimizing deliveries to a warehouse has been the topic of many publications and scientific research in the field of logistics for many years. To solve this problem, an EOQ (Economic Order Quantity) formula was developed, which takes into account the trade-off between the costs of maintaining inventories and ordering costs. The next problem involves determining a re-order point and safety stocks. The level of safety stocks is one of the factors affecting the level of logistics customer service. If too much inventory is present, it is expensive, but if it is too low, lost sales may occur. According to the authors, in the case of the variable and difficult-to-predict demand for stored goods, both of these optimization problems should be (at least in some cases) considered together. A logistics customer service level is affected not only by the safety stock level but also by the size of an order, and this relation should be included in a model.

EOQ is a manifestation of the use of the system approach because it takes into account different factors. In the author's opinion, however, the formula does not take into account all of the important relations between logistics processes. Thus, it is probably necessary to modify it, and maybe even use a new method to identify optimal solutions in this field, which may require the use of other methods – not optimization, but rather simulation.

The problem can become more complicated if transport costs are included, which in practice can occur when a receiver (not the supplier) is responsible for transport.

Such assumptions make it difficult to develop an optimization model, which would need to take into account the complex relations between the different processes in a company. However, a question arises here – whether the development of these methods and models is worth the effort being expended. Can they significantly reduce the broadly understood logistics costs and, consequently, improve the economic efficiency of an enterprise?

The hypothesis here is that this impact will be significant when the share of logistics costs of general costs are high with respect to sales. However, will this impact be greater in the case of low- or high-value goods? In the case of cheap goods, the capital costs of maintaining inventories and lost sales are low. However, if a profit margin is low, even small changes in costs can have a significant impact on profits.

The goal of this article is to answer the above questions.

Literature review

In 1916, H. Ford developed a model of the economic order quantity, which takes into account ordering costs (placing an order) and holding costs (Harris, 1913; Erlenkotter, 1989). Most models are based on this classic model, which has undergone many modifications over the years, taking into account different types of decision situations (Witkowski, 2002; Hamdy, 2007) and costs – e.g., transport costs (Birbil et al., 2015). According to some authors, these models are highly useful for solving decision problems (Agarwal, 2014).

Carter and Ferrin (Carter & Ferrin, 1996) postulated that transport costs should be included in the models. The authors of various publications usually assume in their models that the transport costs are borne by the supplier. In practice, a situation often occurs when a supplier consolidates shipments to their customers or can negotiate favorable rates with a logistics operator. However, there are also situations in which the receiver of the goods has the responsibility for transport, which is the case in commercial companies, especially smaller ones. According to research conducted in Poland, in small and medium manufacturing and service enterprises, 47.7% of transport costs are covered by suppliers, and the rest by their customers. In the distribution of finished goods, 54.8% of transport costs are paid by the receivers of the goods (Ślusarczyk & Kot, 2013).

Carter (Carter & Ferrin, 1996) stated that few authors have attempted to include transport costs in the classic model (Lee, 1986; Carter & Ferrin, 1996) or in the costs of order fulfillment as a fixed amount. Such a situation can happen if a company utilizes its own vehicle to transport different goods in multiple batches. However, this would be uneconomical if a vehicle with the same load capacity were always utilized, regardless of the size of the deliveries. Because of this, the capacity should be adjusted to the volume of goods being transported, which means that the costs of fulfilling an order from a supplier are not fixed. The unit transportation costs decrease as the size of a delivery increases. Changes to these costs are affected by the structure of the fixed and variable costs, and this structure should be included in a model, as Wasiak points out (Wasiak, 2016).

The problem of transport cost degression in the EOQ model has also been discussed by the author of this article (Milewski, 1997; 2007a; 2007b). The decrease in transport costs, however, is a more complex phenomenon that requires accounting for not only the transport costs resulting from the vehicle's payload, but also prices obtained from carriers, for example (Li et al., 2017).

Models of an optimal level of safety stock and re-order point are also being developed. Here, there is also a trade-off, but it is between inventory costs and the costs of lost sales. Very rarely in the logistics literature are these two optimization problems considered together. The author of this article has investigated this problem for years, especially from the perspective of the system approach (Milewski, 1998; 2006) by taking into account various logistics processes and their costs (Li et l., 2017) not only in one place, but in a whole logistics channel and even a supply chain (Milewski, 1999; 2007a; 2007b; 2011). There is a relationship between an order quantity and the inventory available for customers. The larger the batch of a delivery, the lower the risk of stock shortages. As a result, a given level of customer service can be achieved at a lower level of safety stock (Milewski, 2007b).

Generally, the importance of optimization of an inventory level from the point of view of the efficiency of economic processes is recognized. For example, the value of inventories in the USA was estimated at approx. 14% of GDP, while the costs of transport and storage were approx. 9% (Wilson, 2005).

Quite often in the scientific literature and in industry studies, it is stated that the main cost item is transport costs (Ballou, 2007). According to The Establish Davis Logistics Cost and Service Database, transport costs account for the largest share (3-4%) of revenues, and total logistics costs account for 8–9% of sales (Establish, 2019). It is worth comparing these data with the costs of production and production logistics, which in relation to turnover may amount to 7.50% to 17.08% (Hovi & Hansen, 2010; Karri & Ojala, 2012; Solakivi, 2012; Ślusarczyk & Kot, 2013). However, this depends of course on the industry and country.

Similar research results have also been obtained in Poland in which transport costs dominate the distribution of goods – from 40% to 77% (Harris, 1913; Januszewski, 2016). The share of total logistics costs presented in the literature ranges from 20% to 40%

of total costs and from 7.50% to 16.0% of turnover (Wajszczuk & Cieszkowski, 2005).

The above data, although interesting, have some drawbacks. First of all, these are aggregated data. Secondly, they are probably only estimates. Thirdly, the so-called "alternative costs" (capital costs related to inventory and lost sales) are economic categories that are not considered in traditional accounting systems. Logistics, on the other hand, affects economic efficiency not only through costs, but also through good logistics customer service and, consequently, higher sales. In fact, logistics customer service may be more important for the company's profitability than cost optimization.

The level of logistics customer service measured by the availability of goods at the points of sale is high and amounts to 90–99% (IGD, 2019). Determining the relation between sales volume and service level is very difficult due to multiple factors affecting sales (Witkowski, 2002). However, it seems that a high level of service leads to higher profits. For example, in 2005, Procter & Gamble carried out research which showed that reducing the time to move a product from an entry zone to a sales zone has a significant impact on the level of profits in a store (Fechner, 2007).

Taking into account so many consequences of determining an order quantity (not only on costs but a level of logistics customer service), means that using an optimization formula may not be the best optimization method, but rather a simulation. The need for a simulation increases with the increasing complexity of a logistics problem. For example Li et al. developed a simulation model for a complex supply chain (Li et al., 2017) and also used profits as the optimization criteria, which increased the complexity of the optimization problem.

Simulation as a method for optimizing a level of inventories has also been proposed by other authors (see Gocken, Dosdogru & Boru, 2017). In the opinion of the author of this paper, in many cases this is the only method for solving real, practical optimization problems in the logistics field.

Model of deliveries to a distribution warehouse

In order to assess how important the problem of optimization of deliveries is, an electronic model in the Excel application has been developed in which logistic processes and the resulting costs and sales are simulated in detail, day-by-day for a whole year. As a subject of optimization, the market of FMCG (Fast Moving Consumer Goods) was chosen. Due to the specificity of these goods, a normal distribution of demand, characteristic for consumer goods, was assumed in the model.

Deliveries are made to a warehouse from which customers are directly served, so the level of inventories impact the customer service level measured by the availability of stocks. When this level is too low, the company cannot fulfill sales (costs of lost sales).

It was also assumed that the transport costs are taken into consideration. Such a situation can occur when the warehouse is supplied from:

1. The company's factory or a central or regional warehouse, or distribution center;
2. An external supplier, but it is the receiver that is responsible for transport (EXW or FCA formula of INCOTERMS).

In this paper, option 2 was assumed.

The next assumption, which affects the structure and cost levels, is that the company uses storage and transportation services from external service providers, which currently is a common practice.

The term "total logistics costs" is used which covers the "lost sales costs" and "costs of logistics processes". The "lost sales costs" are not included in the profit calculation of companies. However, they are indirectly reflected in sales volumes, and so ultimately also impact profits. The "costs of logistics processes" are used to calculate the profits, and these costs cover the costs of transport, maintaining inventories (capital costs), warehouse inventory storage, and ordering inventory from a supplier.

As the optimization criterion, the lowest "total logistics costs" were applied and compared to the profits corresponding to respective delivery sizes. If the "total logistics costs" below and above an optimal delivery amount are higher and profits are lower, the criterion of "minimum of total logistics costs" can be used interchangeably with the "highest profits" criterion. This is important because it is easier to calculate the costs of logistics than profit.

In this paper, instead of the term "order quantity", "delivery Size" is used, which in the author's opinion is more proper, because the costs of the logistics processes are affected not by the number of units ordered, but by the size of the actual deliveries.

The basic data for the calculation are based on the financial results of listed companies (Table 1), data on products and processes of IV.

The cost structure and profit margins of companies are diverse (Table 1). "Costs of goods sold" are purchase costs, and the costs of logistics processes (transport, storage, inventory maintenance, placing orders) are the components of "Selling costs". The highest margins are in the clothing and footwear industry. In the clothing industry, the share of logistics costs is not large, and margins are relatively high, so one would expect that changes in logistics costs due to a change in the size of a batch of supplies will not significantly impact profits. However, this hypothesis must be confirmed by the simulations.

Table 1. Average net profits of companies listed on the Warsaw Stock Exchange (Financial Reports of companies)

Branch	Garment	Shoes	Food and FMCG	Electronic
Margin netto	6.3%	3.8%	1.4%	2.6%
Costs of goods sold	44.4%	60.9%	80.0%	80.6%
Selling costs	20.6%	31.8%	13.0%	5.6%
Overall costs	2.3%	1.2%	2.1%	1.3%
Other operating costs	0.8%	0.9%	1.3%	0.2%
Sum	23.7%	33.9%	35.6%	1.5%

Table 2. Input data for simulation (author's analyses)

Commodity	Weight	Average daily sales	Standard deviation	Purchase price	Sales price
	[kg/pellet]	[kg/day]	[kg/day]	[PLN/kg]	[PLN/kg]
Food	700	1540	462	2.4	3
	700	1540	1386	2.4	3
Garments	200	440	132	79.92	180
	200	440	396	79.92	180
Consumer Electronics	240	1000	300	2000	0.12
	240	1000	900	2000	0.12

Table 3. Typical freight rates of road carriers in Poland in 2018 (gross prices) (data obtained from the Polish road transport market)

Loading capacity [pallets/vehicle]	1	8	10	16	24	34	38
Loading capacity [tons/vehicle]	3.5	6	8	10	15	24	22
Freight rates [PLN/km]	1.2	2.2	2.7	3.1	3.7	4.0	4.8

Table 4. Costs of inventories and warehousing in Poland in 2018 (data from the logistics market in Poland in 2018)

Capital costs	Warehousing services	
	[PLN/pallet/day]	[PLN/pellet]
20%	0.73	6.1

Simulations were carried out for three products (food, clothing, consumer electronics), which are characterized by different purchase and sales prices as well as the weights and volumes of the products. For each of the products, there were also two variants of the standard deviation of demand (SD) – low (10% of the average daily sales) and high (90%) – and of the delivery time – 1 day from placing an order and 4 days. There were no changes to the delivery times (deliveries are performed on time).

According to GUS data (GUS, 2018), the average distance of transport by Polish road haulers is 200 km, so this distance was used in the model.

For each combination of these variants, 10 simulations were carried out, and the average results was used as the final results.

Simulations were also carried out for delivery batches which were lower and higher than the optimal one by only 1 palette, to examine how important it is to precisely determine an optimal delivery size.

It can be expected that logistics processes will have various impacts on profit because it is shaped by various factors (different cost structures and profit margins).

Results of simulations

First, it should be verified if the logistics costs alone (apart from the impact on profits) significantly change with changes in the size of a delivery batch.

Figure 1 presents changes in the "total logistics costs" (including lost sales) for food products, in the basic variant – delivery time 1 day, small standard deviation.

It may seem that changes of costs near the optimal delivery volume are small, which raises doubts as to the need for precisely determining delivery sizes. Large changes in logistics costs correspond with the delivery sizes that are well below the optimal. The conclusion that arises here is that perhaps it is better to order too large a batch than too small, but the final conclusions can only be made after calculating profits.

Interestingly, the results of the simulation of the impact of delivery sizes on the level of logistics customer service (LCS) confirms the views presented earlier in this paper. As can be seen in Figure 2, the service level increases with the size of a delivery batch. However, after reaching a high level, the quality of the service stabilizes.

The simulation results for this problem are also interesting because they show that the standard deviation for demand also has a certain impact on the level of LCS because it is difficult to achieve a higher level with larger sales fluctuations. However, delivery time is still a significant factor.

The simulation results are presented in Tables 5 to 9. Table 5 contains the optimal delivery frequencies calculated as a result of the simulation (the

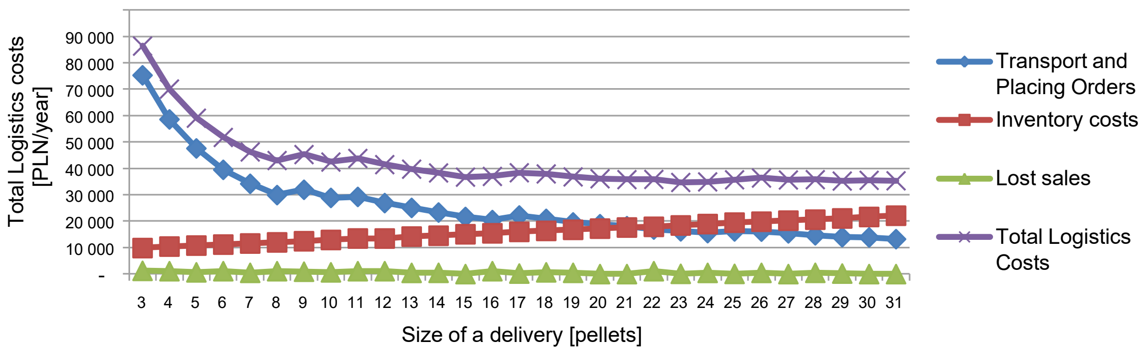

Figure 1. Influence of the size of a delivery to a warehouse on total logistics costs (Food) (Purchase price 2.4 PLN/kg; Weight 700 kg/pallet, Lead Time = 1 day, SD = 10% average demand)

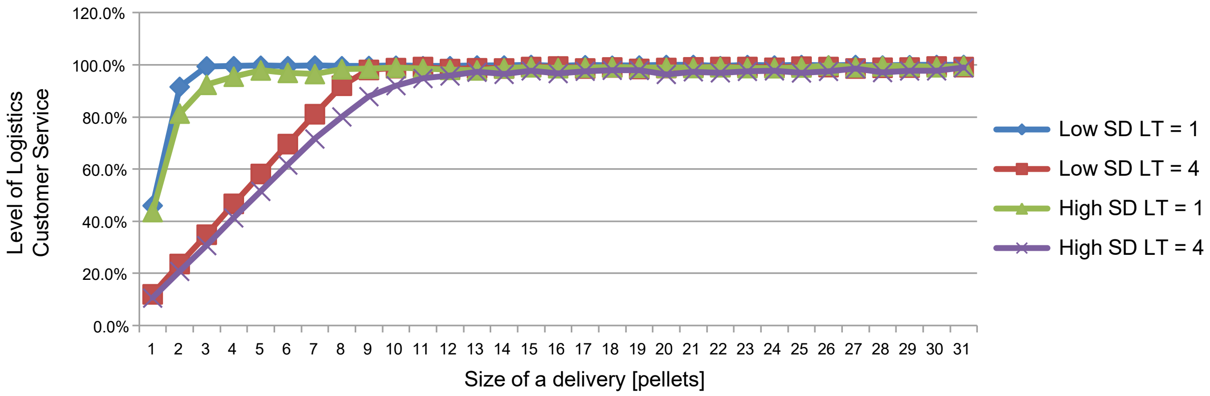

Figure 2. Influence of the size of a delivery to a warehouse on logistics customer service (Food) (Purchase price 2.4 zł/kg; Weight 700 kg/pallet)

Table 5. Results of simulation: optimal frequencies of deliveries and levels of logistics customer service (author's analyses)

Variants of standard deviations	Lead time [days]	Food		Garments		Consumer Electronics	
		Freq.	LCS	Freq.	LCS	Freq.	LCS
Lower SD	1	17	99.79%	41	100.00%	184	100.00%
	4	19	98.93%	32	99.16%	53	99.41%
Higher SD	1	20	99.70%	37	100.00%	89	100.00%
	4	19	98.94%	39	99.04%	45	99.24%

smaller a delivery batch, the higher the frequency of deliveries) and customer service levels corresponding to those optimal delivery batches. A certain trend is visible here – the higher the value of the goods, the higher the frequency of deliveries, which can be explained by the higher costs of maintaining stocks of more expensive goods. The LCS level for these goods is also higher.

The model "reacts" to larger changes in sales and longer delivery times not only by increasing the

Table 6. Results of simulation: differences of the total costs of logistics (author's analyses)

Variants of standard deviations	Lead time [days]	Variants of Delivery quantities					
		Food		Garments		Consumer Electronics	
		Lower DQ	Higher DQ	Lower DQ	Higher DQ	Lower DQ	Higher DQ
Lower SD	1	7.7%	8.3%	34.8%	36.4%	136.6%	4.7%
	4	1.5%	3.6%	4.0%	21.1%	10.4%	6.6%
Higher SD	1	7.7%	11.2%	39.3%	50.2%	86.2%	39.4%
	4	7.6%	8.6%	28.2%	16.7%	25.4%	10.7%
Average changes		7.0%		28.8%		40.0%	

Table 7. Average structure of the costs logistics processes (author's analyses)

Commodity	Transport	Warehousing	Inventories	Ordering	Lost sales
Food	37.74%	40.11%	14.71%	3.65%	3.79%
Garments	22.79%	11.64%	35.59%	2.75%	27.23%
Consumer Electronics	4.00%	1.32%	81.09%	0.56%	13.04%

level of safety stocks, but also by increasing delivery batches. Therefore, the hypothesis is confirmed that there is actually a relationship between the size of a delivery and the level of logistic customer service. This means that these two parameters should be considered together. Another effect is a lower level of LCS for longer lead times and higher SD, which can be explained by the fact that maintaining its high level becomes increasingly expensive.

Analyzing the data in Table 6 reveals that, in fact, the total logistics costs below and above an optimal batch size can be significantly higher, although the changes in the size of the delivery are only ±1 pallet. The size of changes in logistics costs depends on the type of goods, however.

If these results are combined with the logistics costs structure (Table 7), then interesting regularities are noticed:

(1) For the "food" and "clothing" categories, the logistics costs are higher when a delivery batch is larger than an EOQ, but for the "electronics" category, the contrary is true. The probable explanation is that for relatively more expensive products, lowering the delivery batches results in higher costs of lost sales.
(2) In the vast majority of cases, extending a delivery time results in smaller differences of cost. Perhaps with longer delivery times, logistics costs may already be very high for every delivery option. However, it then becomes difficult to explain why an increase in deviations of sales results in an increase of differences between costs. This requires more in-depth analyses.

As it can be seen from Table VIII, the profits are always lower if a delivery batch does not equal an optimal one. That means that both criteria – the "lowest total logistics costs" and "the highest profits" – can be used interchangeably. However, the magnitude of changes in costs are reflected to a small extent in changes of profits. The biggest cost savings are observed in "electronics" (40%) and the smallest in "food" (7.0%). The biggest declines in profits are observed in "food" (average – 21%) and the smallest in "clothes" (–2.6%). It is even more difficult to explain why, in most cases, changes in profits are lower when the standard deviations are higher and delivery times longer.

It is no surprise that more expensive goods have higher levels of LCS and are more profitable. However, for all products, a very high LCS is the most advantageous option. This confirms the results of the studies cited earlier, that the level of LCS is and should be high.

Changes in the logistics costs and the relationship between them and the value of goods are important, but this is not the only factor. We can ask why the changes in the profits of "electronics" are higher (–4.6%) than the profits of cheaper "clothes". In order to find the answer to this question, another relation was analyzed – the ratio of the costs of logistics processes to profit margins, and the results are presented in Table 9.

Changes in the profits of food products were the largest because these products have the highest relation of logistics process costs to profits (between 284.8% and 559.0%). Electronic products are the second highest, and the smallest cost-benefit ratio was observed in the clothing industry (from 5.9% to 8.7%). The impact of the variation in demand measured by the standard deviation (SD) and delivery time was also very clear here – the more unstable the demand and the longer the delivery times, the higher the ratio of logistics processes costs/profits. However, an optimal delivery size is the result of various factors, and the model used to optimize deliveries must be adequately expanded and structured to reflect these complex links.

Perhaps unsophisticated mathematical formulas should be used, but these may be an econometric model based on the results of simulations such as those presented in this paper. For example, if we look at the results of the simulations in Table 5, a certain

Table 8. Results of simulations: differences in profits in case of a lower and higher delivery quantities (by 1 pallet) (author's analyses)

Variants of standard deviations	Lead time [days]	Variants of Delivery quantities					
		Food		Garments		Consumer Electronics	
		Lower DQ	Higher DQ	Lower DQ	Higher DQ	Lower DQ	Higher DQ
Lower SD	1	–17.9%	–19.2%	–2.0%	–2.1%	–8.5%	–0.7%
	4	–4.5%	–10.5%	–0.6%	–3.1%	–0.5%	–2.0%
Higher SD	1	–22.4%	–32.3%	–2.4%	–3.1%	–8.9%	–5.2%
	4	–29.0%	–33.2%	–4.9%	–2.9%	–6.9%	–4.0%
Average changes		–21.1%		–2.6%		–4.6%	
Average LCS		99.3%		99.5%		99.7%	

Table 9. Results of simulation: costs of logistics processes in relation to profits (author's analyses)

Variants of standard deviations	Lead time [days]	Variants of Delivery quantities					
		Food		Garments		Consumer Electronics	
		Lower DQ	Higher DQ	Lower DQ	Higher DQ	Lower DQ	Higher DQ
Lower SD	1	284.8%	293.3%	5.9%	5.9%	13.2%	15.0%
	4	297.6%	317.7%	6.7%	6.9%	27.0%	32.2%
Higher SD	1	377.1%	449.3%	7.0%	7.2%	25.1%	27.3%
	4	524.2%	559.0%	8.7%	8.6%	49.7%	51.1%
Average		387.9%		7.1%		30.1%	

Table 10. Results of two methods of simulation: Aggregate vs. Detailed Simulation (author's analyses)

Variants of standard deviations	Lead time [days]	Parameters of deliveries	Variants of Delivery quantities					
			Food		Garments		Consumer Electronics	
			Agg.	Detail.	Agg.	Detail.	Agg.	Detail.
Lower SD	1	EOQ [pallets]	31	33	16	13	4	6
	1	ROP [tons]	2,60	2,77	0,74	1,11	1,69	2,97
	4	EOQ [pallets]	31	29	16	17	4	20
	4	ROP [tons]	8,29	8,33	2,37	2,62	5,38	7,03
Higher SD	1	EOQ [pallets]	31	27	16	15	4	12
	1	ROP [tons]	4,73	4,22	1,35	1,70	3,07	4,25
	4	EOQ [pallets]	31	28	16	14	4	23
	4	ROP [tons]	12,54	9,99	3,58	3,71	8,14	9,14

trend can be seen: the higher the value of the goods, the higher the frequency of deliveries. This means that when the value increases, the EOQ decreases. How these identified relations should be used could be the subject of a future study.

Conclusions

The model and the simulations carried out using it largely confirmed the stated assumptions, but were also somewhat surprising. It turns out that delivery optimization can be an important factor in the economic efficiency of a company, even in the case of cheap goods. The great surprise was the profitability of a very high level of logistic customer service, even for cheap goods.

The impact of changes of the delivery batches on profits, although varied, was significant in almost all cases. Therefore, it can be concluded that the problem of optimizing the size of a delivery batch is important and that precisely determining it significantly affects a company's financial results.

An open matter is a method that can be used to optimize and solve this problem. Undoubtedly, the inclusion of such complex relations in the form of mathematical optimization formulas is very difficult. The model developed in this paper takes into account the real relations of economic processes and reflects processes in a very detailed way. A compromise solution may also be a simulation based not on the detailed data, but on the aggregate data (average demand, average level of inventories, deliveries etc.). These two simulation results are presented in Table 10 and in some cases have significant differences. Additionally, it is difficult to see any trends here. In some cases, the EOQ and ROP levels are higher in the "detailed simulation" than in "the aggregated", and lower in others. There are also various differences between these parameters – the EOQ and ROP of food and garments are relatively similar, but are rather large in case of "consumer electronics".

Therefore, caution should be taken in excessive simplification of optimization models. It seems that the only possible methods for solving such problems is a simulation method that uses detailed models which simulate real processes.

Limitations of the model and further suggestions

The model, although developed based on real processes, data, and relations of these processes, concerns a specific (although often encountered) situation. It was assumed that these are fast-moving consumer goods whose demand has a normal distribution. In the case of a different demand distribution, the costs of maintaining a high stock level are likely to be significantly higher, and therefore an optimal level of logistic customer service would be lower.

The model assumes that the costs of lost sales directly depends on the level of logistical customer service measured by only one parameter – the availability of inventories. The model does not take into account the situation in which a customer completely terminates cooperation with a supplier because it is dissatisfied with the service.

The model takes into account transport and storage costs as the costs of services provided by external companies, which is quite a common situation nowadays. In the case of a company using its own transport and storage resources, the structure of these costs would be different. As a result, they would show different changes with the size of a delivery batch and the level of stocks. However, this would likely have little effect on the interrelations between the processes presented in this article.

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