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MODEL OF INVENTORY REPLENISHMENT IN PERIODIC REVIEW ACCOUNTING FOR THE OCCURRENCE OF SHORTAGES

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ABSTRACT. Background: Despite the development of alternative concepts of goods flow management, the inventory management under conditions of random variations of demand is still an important issue, both from the point of view of inventory keeping and replenishment costs and the service level measured as the level of inventory availability. There is a number of inventory replenishment systems used in these conditions, but they are mostly developments of two basic systems: reorder point-based and periodic review-based. The paper deals with the latter system. Numerous researches indicate the need to improve the classical models describing that system, the reason being mainly the necessity to adapt the model better to the actual conditions. This allows a correct selection of parameters that control the used inventory replenishment system and - as a result - to obtain expected economic effects.

Methods: This research aimed at building a model of the periodic review system to reflect the relations (observed during simulation tests) between the volume of inventory shortages and the degree of accounting for so-called deferred demand, and the service level expressed as the probability of satisfying the demand in the review and the inventory replenishment cycle. The following model building and testing method has been applied: numerical simulation of inventory replenishment - detailed analysis of simulation results - construction of the model taking into account the regularities observed during the simulations - determination of principles of solving the system of relations creating the model - verification of the results obtained from the model using the results from simulation.

Results: Presented are selected results of calculations based on classical formulas and using the developed model, which describe the relations between the service level and the parameters controlling the discussed inventory replenishment system. The results are compared to the simulation results which are treated as reference. Determined are the relative errors of calculations based on formulas and the model. It is determined that the results obtained from the model have a significantly better fit.

Conclusions: The model presented in the paper should be a starting point for further works with the purpose to account for other phenomena observed during the simulation of inventory replenishment. This will allow a more accurate determination of the controlling parameters of the tested system, and also using the results to build similar models for other inventory replenishment systems used in practice.

Key words: inventory management, periodic review, inventory shortages, modelling, simulation.

INTRODUCTION

Apart from the reorder point-based system, the periodic review system is one of two basic inventory replenishment systems. It is based on inventory review at a regular time interval and ordering varying quantities of goods, depending on the level available during the review. Terminology in this paper is based on the terminology of European Logistics Associations [ELA, 1994], where this system is designated as ST (ST system - an ordering system with variable order quantities and fixed order moments "T". If the economic stock is smaller than "S", procurement order is placed

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for a quantity such that the economic stock becomes equal to the level "S").

The ST system in its classic form is used in practice, although its modifications are also widely used - e.g. the sS system [Krzyżaniak, Fechner 2013]. Similarly to other inventory replenishment systems, the ST system is still the subject of much research aiming at optimized adaptation of the ST system model solutions to the real conditions where they are applied. One of the most important issues is optimal defining of the random variability of demand, and also of the random changes of the system time parameters, particularly the replenishment lead time [e.g. Diane, Bischak, Silver, Blackburn. 2013]. Very often the description of the demand distribution by means of one of theoretical distributions (e.g. normal distribution, the most popular is case of FMCG) is not sufficiently accurate. There are other approaches in the literature, e.g. description of the random variability of demand based on the fuzzy set theory [Dey, Chakrabotry, 2009].

Correct evaluation of random changes of demand and of the consequences of random delivery delays has a key importance for estimating the expected frequency and volume of shortages which directly affects the service level. Determination of the shortage volume is also the subject of a lot of papers, both empirical and theoretical [e.g. Lavin 2012, Johansen, Hill, 2000]. The research is based on building and using mathematical models, and also on simulation [e.g. Drake, Marley, 2010].

The research, the results of which are presented in this paper, was based on a complex mathematical model, verified on the basis of results of simulation of inventory replenishment in the ST periodic review system. The main purpose of the research was to determine and describe the model interaction between the expected shortage volume and service level understood as the probability that the whole demand is satisfied in a given cycle, taking into account the deferred demand (backorders).

FEATURES OF THE ST SYSTEM

Determining the controlling parameters:

- determination of the required service level (POP),
- calculation of the demand distribution in a unit of time (only random changes),
- determination of the replenishment lead time LT
- determination of the review cycle time T (it can depend on the volume of an economic order or result from the arrangements with the supplier),
- calculation of the S level, according to the formulas (3) or (6).

Stock replenishment procedure according to the determined parameters - at a specific moment in time determined by the used cycle:

- the available stock (economic stock) S_e is calculated

$$S_e = S_w + S_o + S_{er} - S_b \qquad (1)$$

where:
S_w stock physically available in the warehouse (on-hand),
S_o orders placed, but not yet implemented,
S_{er} stock en route,
S_b stock already booked.

- A procurement order is placed for the volume:

$$q = S - S_e \qquad (2)$$

These ST system rules are shown in figure 1.

In the classical approach, the relation between the parameter S (also called the maximum stock level) and the service level is as follows:

$$S = D * (LT + T) + SS \qquad (3)$$

where:
D - mean demand in a unit of time used (e.g. day, week)

T - review interval (time between two successive reviews (orders)),
LT - replenishment cycle time - time between the review and delivery of goods.

SS - safety stock, expressed as:

$$SS = \omega * \sigma_{(D\text{-}LT,T)} \qquad (4)$$

where:
ω - safety factor, which depends on the applied service level and the type of the demand frequency occurrence distribution,

$\sigma_{(D\text{-}LT,T)}$ - standard deviation of demand in the time equal to the sum of review interval and inventory replenishment time.

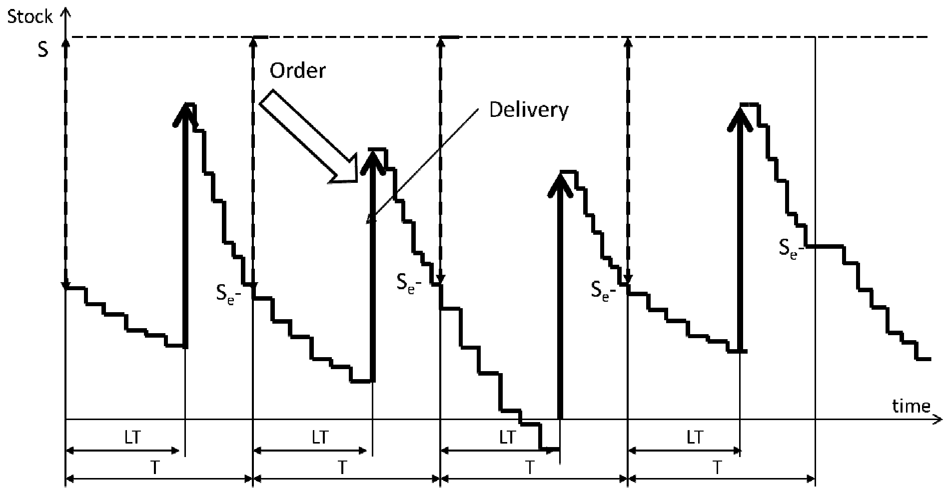

Fig. 1. Inventory replenishment in the periodic review (ST system)
Rys. 1. Ilustracja zasady realizacji odnawiania zapasu w przeglądzie okresowym (system ST)

In a general case (random variation of demand and inventory replenishment time), the following formula applies:

$$SS = \omega \cdot \sqrt{\sigma_D^2 \cdot (LT + T) + \sigma_{LT}^2 \cdot D^2} \qquad (5)$$

where:
σ_D – standard deviation of demand in a unit of time used (the same as for D)
σ_{LT} – standard deviation of replenishment lead time.

Obviously, the calculations of both deviations must concern the exclusively random changes. It is assumed that the review interval T does not change. In this paper it is also assumed that the replenishment lead time LT is constant (i.e. it is assumed that $\sigma_{LT} \approx 0$). With these assumptions, the relation (1) will be expressed as:

$$S = D \cdot (LT + T) + \omega \cdot \sigma_D \sqrt{LT + T} \qquad (6)$$

An additional assumption has been made for the type of distribution of demand D – a normal distribution has been used, typical for fast moving goods.

Another important issue affecting the practical use of relation (4) is correct definition of the service level. A classical probabilistic definition has been used here which defines the service level as a probability that no shortage in the inventory will occur in the review interval time and inventory replenishment time (LT + T). This probability will be represented by αSL [Tempelmeier H. 2000].

In case of normal distribution the relation between the probability of demand satisfaction and the safety factor is as follows:

$$\alpha SL = \int_{-\infty}^{\omega} \frac{1}{\sqrt{2 \cdot \pi}} \cdot e^{-\frac{z^2}{2}} dz = \Phi(\omega) \qquad (7)$$

Normal distribution is a good indicator of the demand variation for fast moving goods and that is why is has been used here. In reality, the lower limit of integration in the formula (7) should equal 0 (negative demand is excluded), but for fast moving goods with relatively high mean demand it can be assumed that:

$$\int_0^{\omega} \frac{1}{\sqrt{2\cdot\pi}} \cdot e^{-\frac{z^2}{2}} dz \approx \int_{-\infty}^{\omega} \frac{1}{\sqrt{2\cdot\pi}} \cdot e^{-\frac{z^2}{2}} dz \qquad (8)$$

The formula (4) can be rearranged in order to calculate the expected service level depending on the assumed maximum stock level S:

$$\alpha SL = \Phi[\omega] = \Phi\left[\frac{S - D\cdot(LT+T)}{\sigma_D \cdot \sqrt{LT+T}}\right] \qquad (9)$$

This relation is shown in figure 2.

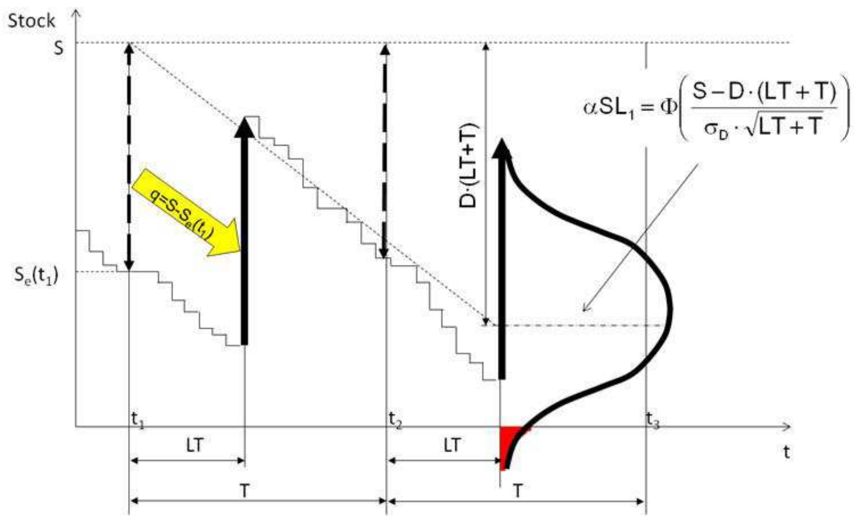

Fig. 2. Determination of service level in the ST system
Rys. 2. Ilustracja zasady wyznaczania poziomu obsługi w systemie ST

The formulas (6) and (9) usually work well in practice, but conformity of actual results to calculations largely depends on to what extent the distribution of frequency of actual demand conforms to the type of distribution used. The discrepancies are very often significant, which is a result of not only eliminating the "non-random" demand from the analysed data (the effects of promotions, seasonality, or other causes of periodic variations), but also - simply - of a complex nature of real phenomena.

The simulation tests based on the model distribution of demand have shown some discrepancies between the obtained service levels and the results calculated according to the formula (9). The discrepancies concern particularly the cases where the service level is lower. One can say that from the practical point of view this issue is not significant. On the other hand, building a correct model which results conform to the simulation in the entire tested range is important also from the point of view of building correct analytical models of other inventory replenishment systems (e.g. the Ss system - Fechner, Krzyżaniak 2013).

SCOPE OF SIMULATION TESTS USED TO BUILD AND VERIFY THE MODEL

The simulation tests used a proprietary tool developed as an Excel application which allows to simulate the most important inventory replenishment systems for chosen distributions of demand occurrence frequency.

The main source of data for the inventory replenishment simulation is generating the random demand variations for a given unit of time (here 1 day has been used). The normal distribution has been used, with the following parameters: mean D = 50.2 units, standard deviation σ_D=7.25 units. Typical variation of generated demand and corresponding distribution are shown in figure 3.

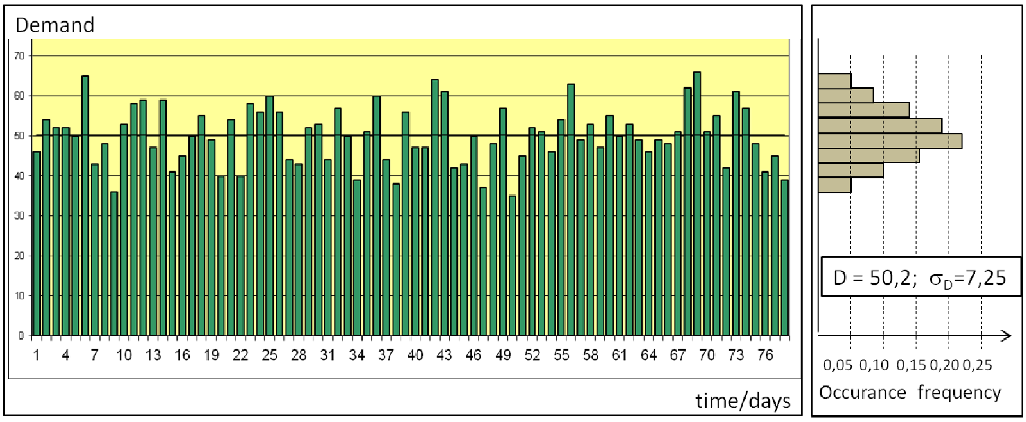

Fig. 3. An example of demand variation generated to be used in the inventory replenishment simulation
Rys. 3. Przykładowy przebieg zmian popytu generowany do wykorzystania do symulacji odnawiania zapasu

The conformity of the distribution of the generated demand with normal distribution was checked using the Kolmogorov-Smirnov test (e.g. Benjamin J. R, Cornell C. A., 1977) which is usually applied to test the null hypothesis that the distribution of a variable (empirical data) is close to the normal distribution. In this case the Kolmogorov-Smirnov test was applied to the data from the generator. For the selected sample of 78 days the conformity to the normal distribution at the significance level of α=0.05 was received.

Detailed analyses of the simulation results leading to the construction of the model have been performed for the parameter sets presented in table 1. The Smax - Smin ranges have been selected to ensure approximately comparable intervals of achieved service level.

A simulation result example is presented in figure 4.

Table 1. Range of data used in the model simulation and verification
Tabela 1. Zakres danych wykorzystanych w symulacji i weryfikacji modelu

Variant		1	2	3	4	5	6
Review interval T		8	7	6	5	6	6
Replenishment lead time LT		1	2	3	4	1	5
Variation range of parameter S	S max	505	505	505	505	400	615
	S min	410	410	410	410	305	520

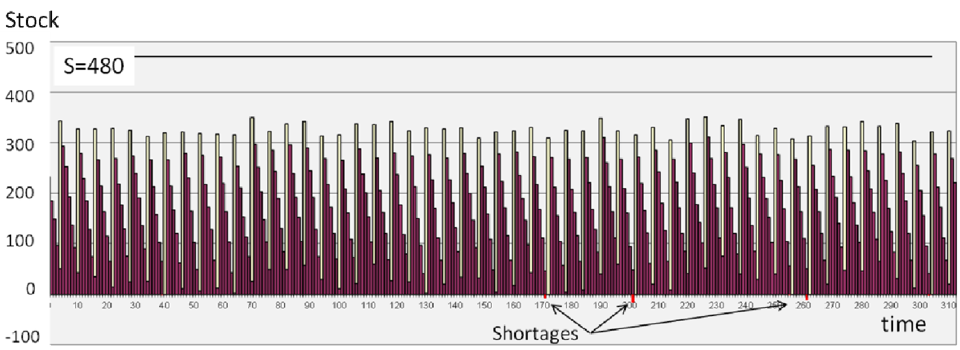

Fig. 4. Graphical representation of simulation results
Rys. 4. Przykład graficznej ilustracji wyników otrzymywanych drogą symulacji

During the analysis the following values were distinguished:

- Number (per cent) of cycles with shortages,
- Number (per cent) of cycles with shortages occurring after the cycles without shortages,
- Number (per cent) of cycles with shortages occurring after the cycles with shortages,
- Mean demand in the (LT+T) cycle for cycles with shortages,
- Mean demand in the (LT+T) cycle for cycles without shortages,
- Mean shortage volume per one cycle (sh),
- Mean shortage volume per one cycle with shortages (sh').

ST SYSTEM MODEL ACCOUNTING FOR INVENTORY SHORTAGES AND LOST SALES

The analyses of the above-mentioned values have indicated the need to include in the analytical model the phenomenon of reduced shortage risk in the cycle occurring after the cycle with shortages. This is a consequence of two phenomena:

1. Virtual shift of the S level in case of lost unsatisfied demand, that is when the unsatisfied demand in cycle "i" (as a result of shortage) is not "deferred" and does not increase the demand in cycle "i+1".
2. Variation of the actual demand in the (LT + T) cycle, depending on whether the observed cycle occurs after the cycle with shortages or after the cycle without shortages.

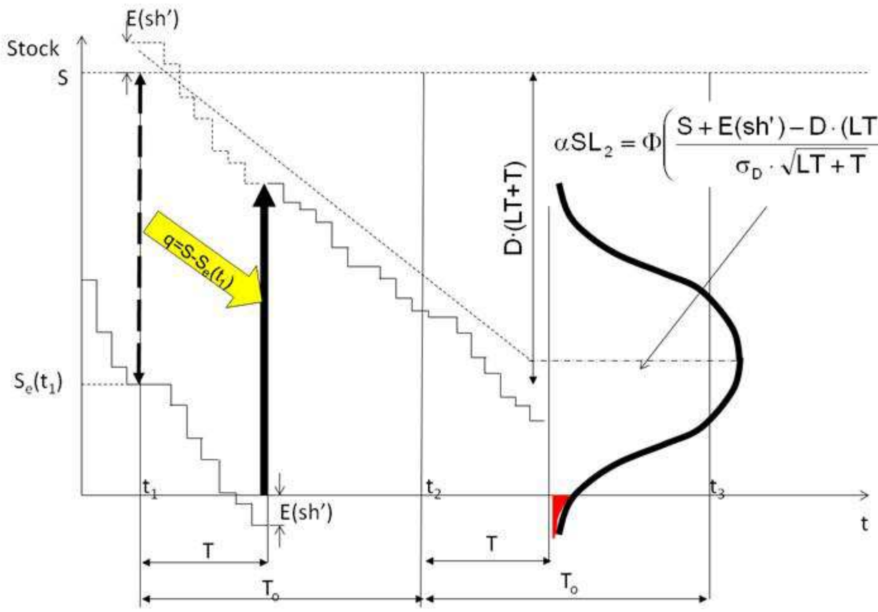

Fig. 5. Impact of the lost demand effect on the probability of shortage occurrence in the next cycle - formula (9), assuming r=0
Rys. 5. Wpływ efektu popytu traconego na prawdopodobieństwo wystąpienia braku w następnym cyklu - formuła (9), z przyjęciem r=0

This paper focuses on the first case. The following discussion concerns its impact on reduced risk of shortage occurrence in the next cycle.

1. If no shortage occurred in the previous cycle, the expected service level is:

$$\propto SL_1 = \Phi[\omega_1] = \Phi\left[\frac{S - D \cdot (LT + T)}{\sigma_D \cdot \sqrt{LT + T}}\right]$$

(10)

which conforms to the formula (9), as shown in figure 2.

2. If shortage occurred in the previous cycle, the expected service level is:

$$\propto SL_2 = \Phi[\omega_2] = \Phi\left[\frac{S + E(sh') \cdot (1 - r) - D \cdot (LT + T)}{\sigma_D \cdot \sqrt{LT + T}}\right]$$

(11)

where E(sh') is an expected shortage volume in case of absence of shortage, and r is the degree to which the unsatisfied demand manifests itself in the next cycles (deferred demand). Assumption that r=0 means the total loss of unsatisfied demand in cycle "i", whereas assumption that r=1 means that the unsatisfied demand is fully shifted to the cycle "i+1".

Both these cases are shown in figures 5 and 6, where figure 5 illustrates the total loss of unsatisfied demand (r=0), and the figure 6 illustrates the total shift of unsatisfied demand to the later cycles (r=1). It can be seen that the second case corresponds the situation shown in figure 2. However, one should keep in mind that the loss of unsatisfied demand happens very often, particularly in the retail trade. Thus, accounting for this phenomenon should be considered important.

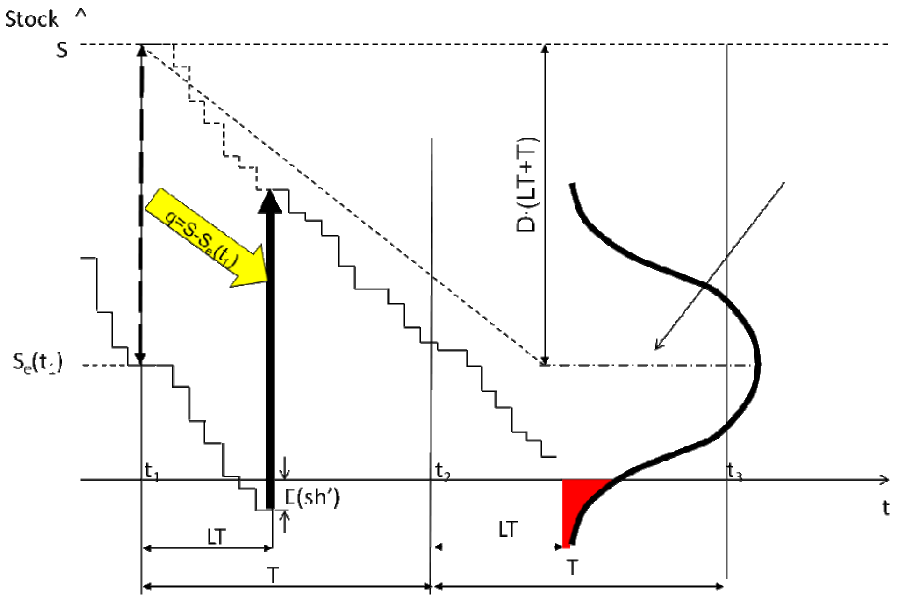

Fig. 6. Impact of the effect of lost demand shift to the next cycle on the probability of shortage occurrence in the next cycle - formula (9), assuming r=1

Rys. 6. Wpływ efektu przenoszenia straconego popytu na kolejny cykl, na prawdopodobieństwo wystąpienia braku w następnym cyklu - formuła (9), z przyjęciem r=1

Generally, the following formula is suggested to calculate the expected shortage volume in the cycle with shortage:

$$E(sh') = \propto SL \cdot E(sh'_1) + (1 - \propto SL) \cdot E(sh'_2)$$

(12)

where:

$$E(sh'_1) = \frac{E(sh_1)}{1-\alpha SL_1}; \qquad E(sh'_2) = \frac{E(sh_2)}{1-\alpha SL_2}$$
(13)

and $E(sh_1)$ and $E(sh_2)$ are expected numbers of shortages referenced to any cycle, respectively for case 1 (cycle after the cycle without shortages) and case 2 (cycle after the cycle with shortages). They are calculated according to the following formulas:

$$E(sh_1) = I(\omega_1) \cdot \sigma_D \cdot \sqrt{LT+T};$$
$$E(sh_2) = I(\omega_2) \cdot \sigma_D \cdot \sqrt{LT+T} \qquad (14)$$

where:

$I(\omega)$ - standardized number of units of shortage: $I(\omega) = \int_{z=\omega}^{\infty} (z-\omega) \cdot f(z) dz$

$\sigma_D \cdot \sqrt{LT+T}$ - standard deviation of demand in the review interval and inventory replenishment cycle.

Taking all above-mentioned formulas (10) - (14), the expected service level αSL is calculated as follows:

$$\alpha SL = \alpha SL \cdot \alpha SL_1 + (1-\alpha SL) \cdot \alpha SL_2$$
(15)

The formulas (10) - (15) are interdependent, as shown in figure 7. Hence, the solution of this system of equations requires an iterative approach.

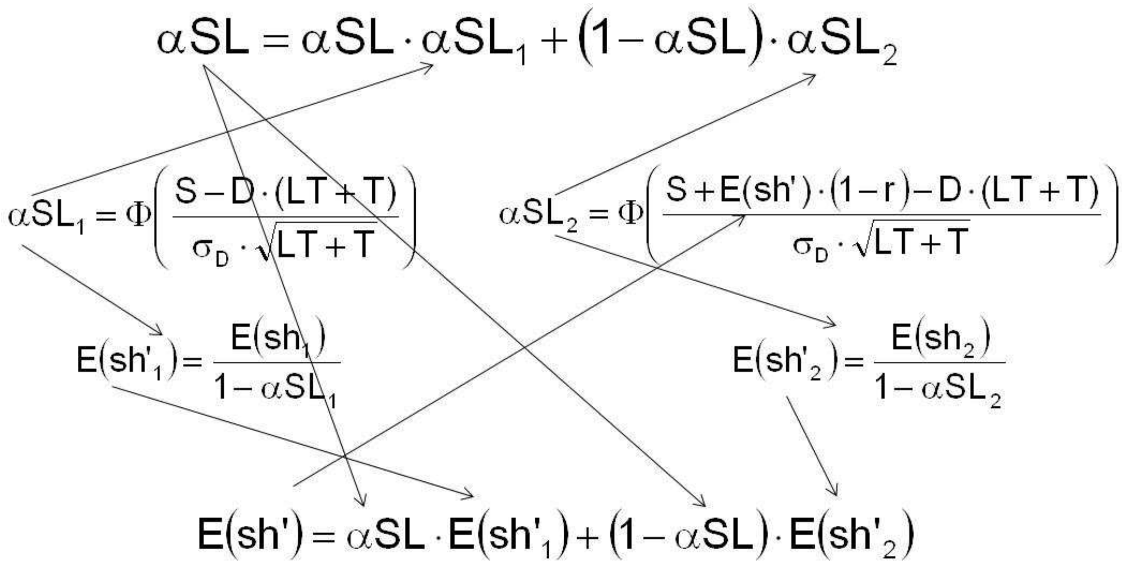

Fig. 7. Interdependencies between the equations included in the model
Rys. 7. Ilustracja wzajemnych zależności pomiędzy równaniami wchodzącymi w skład opracowanego modelu

RESULTS OF MODEL QUALITY TESTS

The presentation of the model quality test results has been limited to the comparison of the αSL obtained from the simulation (as a reference curve) to the values obtained from the classical formula (9) and from the model.

Figure 8 shows the αSL =f(S) curve for variant 3 (table 1). It can be seen that at the 80-85% level the differences between the simulation results and the calculations based on the classical formula (9) become significant.

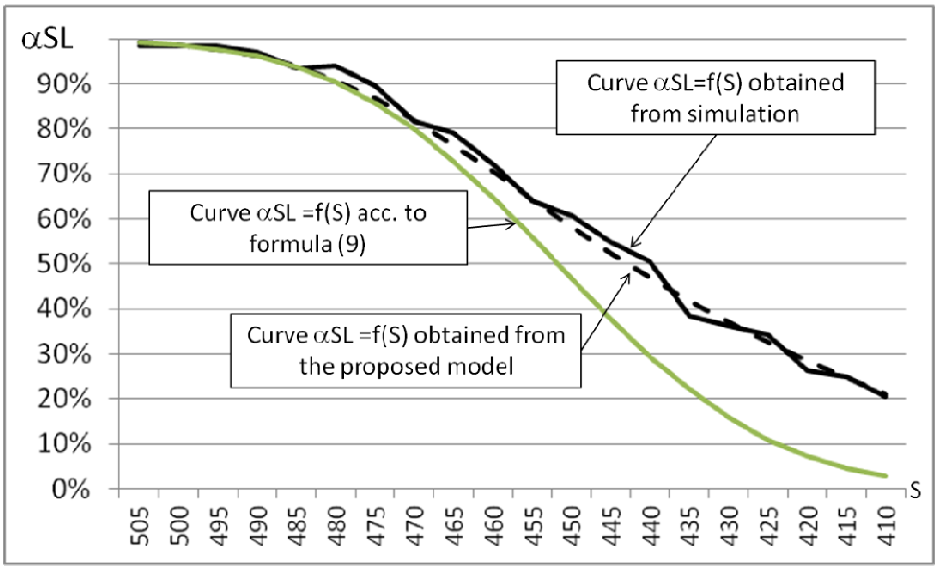

Fig. 8. Comparison of SL=f(S) curves obtained from simulation (reference), from classical formula (9), and from the presented model. The curves are determined for T = 6 days, LT = 3 days

Rys. 8. Porównanie przebiegu zależności SL =f(S) otrzymanych drogą symulacji (jako przebieg odniesienia), otrzymany w oparciu o klasyczny wzór (9) oraz w wyniku zastosowania przedstawionego modelu. Przebiegi wyznaczono dla T = 6 dni, LT = 3 dni.

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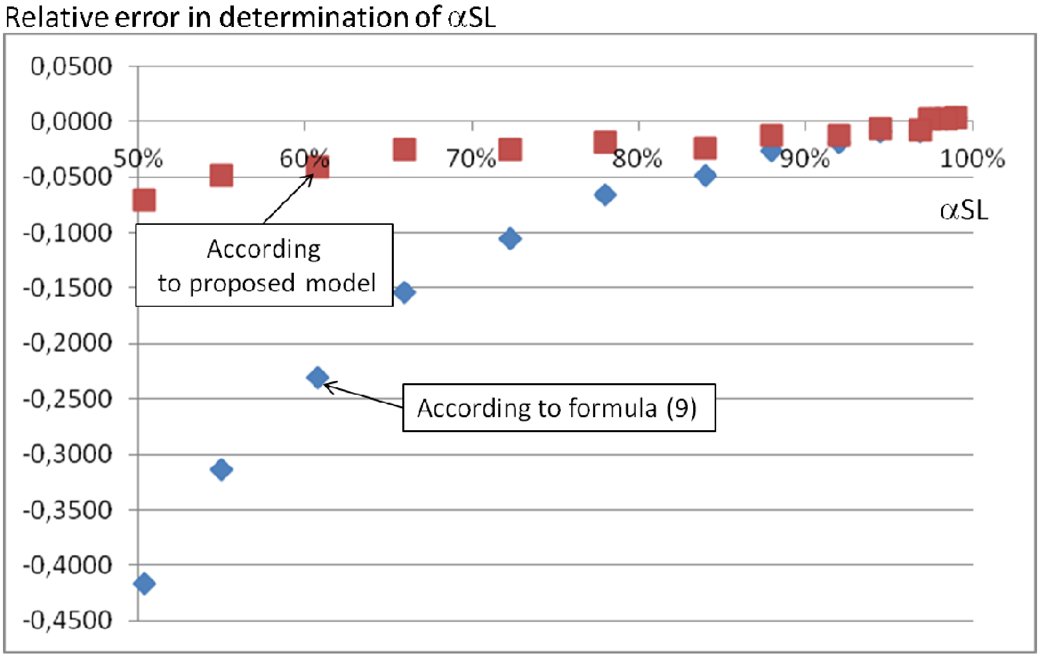

Fig. 9. Relative error in determination of the service level SL obtained from simulation (reference), from classical formula (9), and from the proposed model. The curves are determined for T = 6 days, LT = 3 days.
Rys. 9. Błąd względny wyników obliczenia poziomu obsługi SL otrzymanych drogą symulacji (przebieg odniesienia), otrzymany w oparciu o klasyczny wzór (9) oraz w wyniku zastosowania proponowanego modelu. Przebiegi wyznaczono dla T = 6 dni, LT = 3 dni

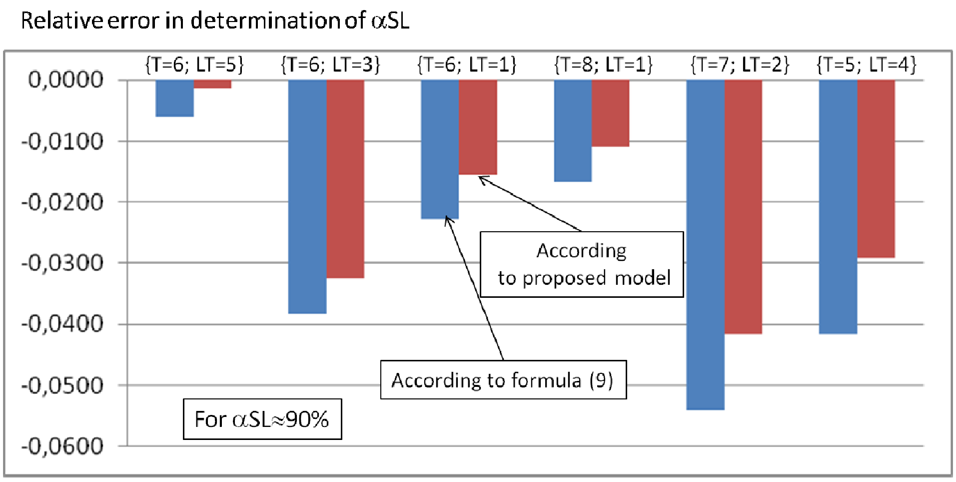

Fig. 10. Relative error in determination of the service level SL obtained from classical formula (9) and from the proposed model in comparison to the simulation results, determined for the chosen variants (table 1), at the simulation-obtained service level SL equal to about 90%.
Rys. 10. Błąd względny wyników obliczenia poziomu obsługi SL otrzymanych w oparciu o klasyczny wzór (9) oraz w wyniku zastosowania proponowanego modelu, w odniesieniu do wyników otrzymanych drogą symulacji, wyznaczony dla przyjętych wariantów (tabela 1), przy poziomie obsługi SL otrzymanym drogą symulacji równym ok. 90%

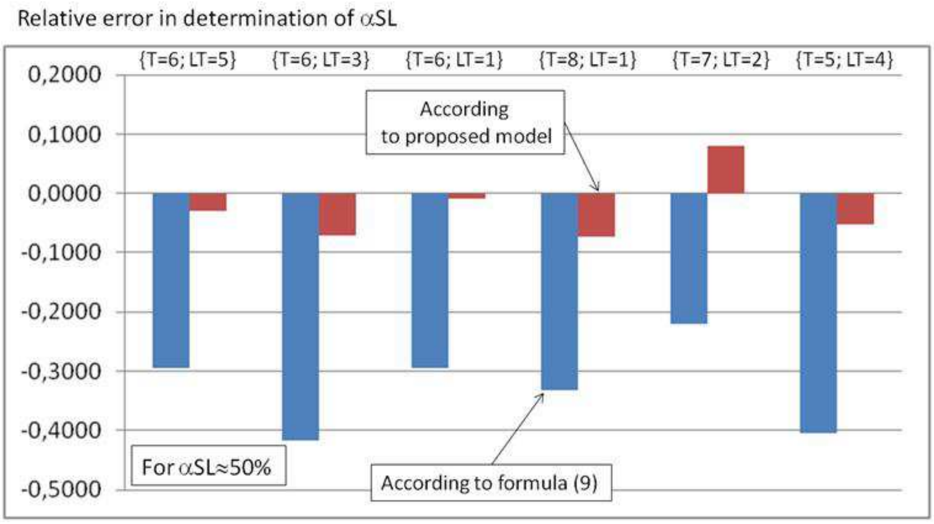

Fig. 11. Relative error in determination of the service level SL obtained from classical formula (9) and from the proposed model in comparison to the simulation results, determined for the chosen variant (table 1), at the simulation-obtained service level SL equal to about 50%

Rys. 11. Błąd względny wyników obliczenia poziomu obsługi SL otrzymanych w oparciu o klasyczny wzór (9) oraz w wyniku zastosowania proponowanego modelu, w odniesieniu do wyników otrzymanych drogą symulacji, wyznaczony dla przyjętych wariantów (tabela 1), przy poziomie obsługi SL otrzymanym drogą symulacji równym ok. 50%

Figure 9 presents relative errors in estimating the service level using formula (9) and the model in comparison to the values obtained from simulation. It can be seen that even for the 50% service level (not used in practice) the relative error for the results obtained from the model is small, which indicates its significantly better fit than of classical formula (9).

Figures 10 and 11 present on the other hand the identically defined errors for all six tested variants shown in table 1, at two chosen service levels: αSL = 90% and αSL = 50%. Here we can see (fig. 10), more clearly than in fig. 8 and 9, the better conformity of the presented model to the simulation results (reference), also at αSL =90%. We can also see that for the tested cases the value of errors does not depend on the interrelations between LT and T.

CONCLUSIONS

The presented model is a much more accurate tool to describe the relations (observed during the simulation) between the service level and the parameters controlling the periodic review- based inventory replenishment system. Although in case of the service levels used in practice (above 90%) the differences in accuracy are not significant, yet the possibility of describing the relations between the used service level and the system parameters is important also from the point of view of improved modelling of other inventory replenishment systems.

Other phenomena observed during the simulations which can affect the model accuracy (particularly the variation of actual demand depending on whether the observed cycle occurs after the cycle with shortages or after the cycle without shortages) require further development of the model.

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MODEL ODNAWIANIA ZAPASÓW W PRZEGLĄDZIE OKRESOWYM UWZGLĘDNIAJĄCY WYSTĘPOWANIE BRAKÓW

STRESZCZENIE. **Wstęp**: Zarządzanie zapasami w warunkach losowych zmian popytu jest wciąż - mimo rozwoju alternatywnych koncepcji zarządzania przepływem dóbr - ważnym zagadnieniem zarówno z punktu widzenia kosztów utrzymania i uzupełniania zapasów, jak i poziomu obsługi mierzonego poziomem dostępności zapasu. Istnieje szereg systemów uzupełniania zapasu w takich warunkach, przy czym stanowią one najczęściej rozwinięcie dwóch podstawowych: systemu opartego na punkcie ponownego zamówienia oraz opartego na przeglądzie okresowym. Artykuł odnosi się do drugiego z nich. Liczne badania wskazują konieczność udoskonalania klasycznych modeli opisujących ten system. Wynika to przede wszystkim z potrzeby lepszego dopasowania modelu do warunków rzeczywistych. To pozwala na poprawny dobór parametrów sterujących przyjętym systemem odnawiania zapasu i - tym samym - osiągania oczekiwanych efektów ekonomicznych.

Metody: Przedmiotem prezentowanych badań było stworzenie modelu systemu przeglądu okresowego odzwierciedlającego obserwowane w trakcie badań symulacyjnych zależności pomiędzy wielkością występujących braków w zapasie i stopnia uwzględnienia tzw. popytu odłożonego, a poziomem obsługi przyjętym jako prawdopodobieństwo obsłużenia popytu w cyklu przeglądu i uzupełnienia zapasu. Przyjęto następującą metodę budowy i weryfikacji modelu: symulacja numeryczna odnawiania zapasu - szczegółowa analiza wyników symulacji - budowa modelu uwzględniającego prawidłowości zaobserwowane podczas symulacji - określenie zasad rozwiązania układu zależności tworzących model - weryfikacja wyników uzyskiwanych na podstawie modelu z wynikami symulacji.

Wyniki: Przedstawiono wybrane wyniki obliczeń opartych na klasycznych formułach i przy wykorzystaniu opracowanego modelu, opisujących zależności pomiędzy poziomem obsługi a parametrami sterującymi odnawianiem zapasu w omawianym systemie. Porównano je z wynikami symulacji traktowanych jako referencyjne. Wyznaczono

błędy względne obliczeń opartych na formułach i modelu. Stwierdzono znacząco lepsze dopasowanie wyników uzyskiwanych przy zastosowaniu modelu.
Wnioski: Przedstawiony w artykule model powinien stanowić punkt wyjścia do dalszych prac mających na celu uwzględnienie innych zjawisk obserwowanych w trakcie symulacji odnawiania zapasu. Pozwoli to na bardziej dokładne wyznaczanie parametrów sterujących badanego systemu, ale także na wykorzystanie wyników prac do budowy podobnych modeli dla innych, stosowanych w praktyce, systemów odnawiania zapasów..

Słowa kluczowe: zarządzanie zapasami, przegląd okresowy, braki w zapasie, modelowanie, symulacja

MODELL ZUR ERNEUERUNG DER VORRÄTE BEI PERIODISCHER ÜBERPRÜFUNG UND BERÜCKSICHTIGUNG DES VORKOMMENS VON VORRATSMÄNGELN

ZUSAMMENFASSUNG. Einleitung: Das Vorratsmanagement bei zufälligen Änderungen der Nachfrage ist immer noch - trotz der Entwicklung alternativer Konzepte zum Management des Güterflusses - eine Frage, die sowohl im Hinblick auf die Kosten für die Vorratshaltung und -ergänzung als auch das Bedienungsniveau, das durch das Niveau der Verfügbarkeit der Vorräte gemessen wird, sehr wichtig. Es besteht eine Reihe von Systemen zur Ergänzung der Vorräte unter derartigen Bedingungen, wobei sie meistens eine Entwicklung der zwei grundlegenden Systeme sind: ein System, das auf dem Nachbestellpunkt basiert, und ein System, das auf der periodischen Überprüfung basiert. Der Artikel betrifft das zweite System. Zahlreiche Untersuchungen weisen auf die Notwendigkeit hin, die klassischen Modelle, die dieses System beschreiben, weiter zu entwickeln. Dies ergibt sich vor allem aus dem Bedürfnis, das Modell an die tatsächlichen Bedingungen besser anzupassen. Es ermöglicht eine richtige Auswahl der Parameter, die das angenommene System zur Erneuerung des Vorrats steuern, und somit die gewünschten wirtschaftlichen Effekte zu erzielen.
Methoden: Gegenstand der präsentierten Untersuchungen war die Erarbeitung eines Modells für ein System zur periodischen Überprüfung, das die während der Simulationsuntersuchungen beobachteten Wechselbeziehungen zwischen der Größe der Vorratsmängel und dem Grad der Berücksichtigung der sog. aufgeschobenen Nachfrage einerseits und dem Bedienungsniveau andererseits, das als Wahrscheinlichkeit der Bedienung der Nachfrage im Zyklus der Überprüfung und Ergänzung der Vorräte angenommen wird, widerspiegelt. Man hat folgende Methode zum Aufbau und zur Prüfung des Modells angenommen: nummerische Simulation der Erneuerung der Vorräte - detaillierte Analyse der Ergebnisse der Simulation - Aufbau eines Modells, das die Regelmäßigkeiten berücksichtigt, die während der Simulation beobachtet wurden - Bestimmung der Grundsätze für die Auflösung des Systems der Regelmäßigkeiten, die das Modell bilden - Vergleich der aufgrund des Modells erzielten Ergebnisse mit den Ergebnissen der Simulation.
Ergebnisse: Es wurden ausgewählte Ergebnisse der auf den klassischen Formeln basierenden Kalkulationen sowie unter Anwendung des entwickelten Modells dargestellt, die die Wechselbeziehungen zwischen dem Bedienungsniveau und den Parametern, die die Erneuerung der Vorräte in dem zur Analyse stehenden System steuern, beschreiben. Sie wurden mit den Ergebnissen der Simulation verglichen, die als Referenzergebnisse gelten. Es wurden die relativen Fehler der Kalkulationen bestimmt, die auf den Formeln und dem Modell basieren. Es wurde eine wesentlich bessere Anpassung der Ergebnisse festgestellt, die unter Anwendung des Modells erzielt werden.
Fazit: Das in dem Artikel präsentierte Modell soll als Ausgangspunkt für weitere Arbeiten gelten, deren Ziel es ist, andere Erscheinungen zu berücksichtigen, die während der Simulation der Erneuerung der Vorräte beobachtet wurden. Dies ermöglicht, die steuernden Parameter des zur Analyse stehenden Systems genau zu bestimmen und die Ergebnisse der Arbeiten zum Aufbau ähnlicher Modelle für andere, in der Praxis anwendbare Systeme zur Erneuerung der Vorräte zu verwenden.

Codewörter: Vorratsmanagement, periodische Überprüfung, Vorratsmängel, Modellierung, Simulation

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