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PROBABILISTIC PERIODIC REVIEW SYSTEM TO DETERMINE MINIMUM AND MAXIMUM INVENTORY REPLENISHMENT LEVELS IN ACME COMPANY

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ABSTRACT

The spare parts inventory management plays an important role of maintenance schedule and prevention of equipment failure. However, the difficulties are met, where there are events where some spare parts arrive late to the warehouse which will cause stock-outs. It is found that inventory control users applied a deterministic approach through rough approximation to determine the minimum and maximum amount for each part. Actually, spare parts are different than regular items in terms of its tendency to follow probabilistic model. The aim of this research is to propose an inventory management for fast-moving spare parts. Power Approximation and Brown's method in the periodic review inventory modelare employed to determine the best possible amount of the desired minimum and maximum parts in stock. The service level is also used in order to maintain the proper amount of safety stock needed to prevent further stock-outs. As a result, Brown's method generates a 66% lower stock out reduction than the power approximation method. It also can reduce the total cost for as much as 47.76% from the current total cost.

Keywords: spare parts, service level, stock-out reduction, minimum/maximum, periodic review, power approximation method, brown's method.

INTRODUCTION

Acme Company, located in Kangean Islands, Sumenep, a petroleum exploration and production company, has been operating in one of the many oil and gas fields in Indonesia since year 2000. Currently as a gas producer, Acme needs materials and services to support their sustainable daily operation, especially spare parts. Without the spare parts, the production process of petroleum and gas cannot run continuously. Thus, the availability of spare parts is important, especially for maintenance operation for avoiding the equipment failure.

The inventory management system used by Acme is the minimum/maximum system. Currently, the minimum/maximum level of inventory is set manually by the users. The minimum level is a point where a reorder should be made, and the maximum is the utmost amount of inventory desired to be kept. Because the minimum/maximum level of an item is adjusted manually to ensure its flexibility, using rough approximation of each part's usage, the shortage could occur. For example, during April 2014, there are three items of spare parts of fourteen fast-moving parts which amount has already reached zero, which are part no. 3757, 1337, and 4358. This becomes a problem when it is found out that each part has high number of demand, and without having any amount of parts kept as safety stocks, stock-outs already happened before the inventory control team realized it. Part no. 3757, for example, has an average monthly usage of 17.19 parts, with a minimum level of 50 items on stock; it is questionable how 50 items would last in a span of a 90-day lead time while in reality the part itself is still on order.

Another problem is that the monthly usage of each items vary. Spare parts are different than regular items in terms of its tendency to follow probabilistic model [1]. Sometimes, most spare parts have an intermittent demand that occurs at given moments followed by long and variable period. It is very difficult to predict the intermittent demands that may cause shortage and result in enormously high costs. Thus, it is difficult to determine the appropriate level of minimum and maximum amount of items desired if the level of the usage varies every month.

Currently, the management concerns about the current spare part inventory model. It is applied a deterministic inventory model, that minimum/maximum level of inventory is decided manually and ordered spare parts sometimes come late which will result in loss opportunities. As an avid gas producer, Acme operates in high hours and the consequence of disturbing the production process may lead to a further accumulated loss of opportunity cost. These problems caused by the faulty in the implementation of the minimum and maximum system are manually determination of minimum and maximum levels, which was not applicable to probabilistic lead time and usage or demand.

Thus, the main objective of this research is to improve the inventory system in Acme to manage the spare parts replenishment by implementing the probabilistic spare part inventory model into the minimum/maximum philosophy in order to create an adjustable inventory control, where usage and lead time are treatments to the minimum and maximum levels and each variable is integrated through various formulas and affects each other's value

LITERATURE STUDY

Spare parts classification

Parts classification is essential in order to determine the proper managerial attention and to allow choices of demand forecasting and inventory control models as mentioned in [2].

According to Acme inventory Control Team, stock items of spare parts are classified into five groups:

- Fast Moving: parts that have historical movement in the last one year.
- Slow Moving: parts that did not move for more than a year.
- Insurance parts: parts identified as high risk material having high impact to operational sustainability.
- Surplus parts: excess parts, including ex-project materials.
- Obsolete parts; supporting parts for obsolete main unit.

The classification is similar to the FSN analysis in common inventory practices that defines items as fast-moving (F), slow-moving (S), or non-moving (N) as stated in [3].

Spare parts can also be generally classified into non-repairable and repairable. Repairable parts are spare parts that could be sent to be repaired or reconditioned upon preventive replacement or a failure. Non-repairable parts are parts that have to be discarded once they are removed from operation. Non-repairable parts are also called as the consumable parts [4].

Spare parts characteristics

One of the reasons why spare parts has different model than other stock items is that spare parts have different usage distribution patterns than other stock items. During many researches, many scholars and inventory analysts took several assumptions in spare parts' demand distribution pattern when forecasting demands or generating probability distribution functions. The theoretical foundation is given by Palm's theorem in [5], where under mild assumptions; the distribution of total number of demands tends to be a Poisson distribution.

Another example, it is assumed that a demand of spare part follows a Poisson distribution for the demand of every unit apparently converges rapidly to a Poisson process following the convergence of time to failure distribution. If the failure distribution is exponential, the number of failures in an interval follows the Poisson process as well as the number of components [1].

It was investigated several theorems about spare parts' demand models through calculating p-values of empirical data. In general, many researchers have given the theorems that include normal, Poisson, and gamma distributions as references to the study as mentioned in [6]. It is also stated that assumptions of spare parts demand distribution is common in industrial practices. Poisson distribution is also proven to be acceptable while being treated with normal approximations and calculations, where the results of computations under the normal assumptions are similar [7]. The value of mean is same in both normal and Poisson distribution. The mean for Poisson distribution is similar to the normal distribution, where the mean of the distribution is equal to μ and the variance is also equal to μ

Probabilistic periodic review model

In periodic-review system, the inventory level is checked and reordering is done only at specified points in time. Inventory levels may be checked and orders placed on a weekly, biweekly, monthly, or some other periodic basis. This inventory system is also known as the (s,S) model. In this model, *s* is the minimum level during review period and *S* is the maximum replenishment level. If inventories are reviewed on a periodic basis, an order should be placed of quantity between *S* and the remaining items during review period.

As mentioned in [8], it was then developed an analytic approximation to compute (s, S) levels for single items under periodic review with a set-up cost, linear holding and shortage costs, and fixed replenishment lead time. The model is called the Power Approximation. It is an alternative to the Normal Approximation [9], where the normality specification is dropped and proven useful for non-stationary demands and stochastic lead-times [10].

The initial inventory values are set using Equation (1) until Equation (4) as follow:

$$\text{so} = \left(0.973 * \mu_{(\text{r+l})}\right) + \sigma_{(\text{r+l})}\left(\frac{0.183}{c} + 1.063 - 2.192 * c\right) \quad (1)$$

$$So = \mu_{(\text{r+l})} + \left(\frac{h*\frac{(12)}{r}}{h*\frac{(12)}{r}+p}\right)\sigma_{(\text{r+l})} \quad (2)$$

Where

$$Dp = 1.30 * \mu^{0.494} * \left(\frac{K}{h*u}\right)^{0.506} * \left(1 + \frac{\sigma^2{}_{(\text{r+l})}}{\mu^2\text{r}}\right)^{0.116} \quad (3)$$

$$\text{And } c = \sqrt{\frac{Dp*u}{(\sigma_{(\text{r+l})}*p)}} \quad (4)$$

The notations for the above equations are given below:

r = Review interval in a period
l = Lead time of the spare part in a period

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$\mu_{(r+l)}$ = Average demand during review interval and lead time
μ_r = Average demand during review interval
$\sigma_{(r+l)}$ = Standard deviation of the demand during review interval and lead time

K = Order cost
H = Holding cost per unit per period
P = Loss-of-goodwill cost
U = Unit Cost
c = Cost criticality function

Where Dp, so, and So are the dummy variables of the equations. The final approximate inventory values are then determined using Equation (5) and (6) as follows:

$$s = \begin{Bmatrix} so, if\ \frac{Dp}{\mu_r} > 1.5 \\ \min(so, So), if\ \frac{Dp}{\mu_r} \leq 1.5 \end{Bmatrix} \quad (5)$$

And

$$S = \begin{Bmatrix} (so + Dp), if\ \frac{Dp}{\mu_r} > 1.5 \\ \min(so + Dp, So), if\ \frac{Dp}{\mu_r} \leq 1.5 \end{Bmatrix} \quad (6)$$

Where s will be the minimum amount of parts that needs to be on hand during the review period, and S will be the maximum amount of parts that needs to be stocked. For example in a review period of every three months, with s = 100 and S = 150, when the parts reached a number below 100 after three months, an order is made to replenish the parts to the level of 150 parts.

Brown's individual unit shortages

The amount of safety stock is normally determined first to assurance that usage deviation can be countered with the right amount of safety stock by increasing the percentage of the service level. It is then possible to determine the service level of each part by using the formula in Equation (7) and (8):

$$ss = z * \sigma_l \quad (7)$$

$$\text{And}\ \sigma_l = \sqrt{(L * \sigma^2) + (\mu^2 * \sigma^2_L)} \quad (8)$$

where
μ = Average demand
L = Average lead time
σ_L = Average lead time deviation
σ = Average demand deviation
z = Desired service level
σ_l = Standard deviation of demand during lead time

To check the required service level is by using the table of individual unit shortages as stated in [11]. The table utilizes the value of Z to correspond with the shortage proportion (E(z)) as shown in Table-1 below.

Table-1. Expected unit shortages for standard deviation.

Z	E(z)	Z	E(z)	Z	E(z)	Z	E(z)
-4	4	-0,7	0,843	0,65	0,155	1,5	0,029
-3,5	3,5	-0,6	0,769	0,7	0,143	1,6	0,023
-3	3	-0,5	0,698	0,75	0,131	1,65	0,021
-2,5	2,502	-0,4	0,63	0,8	0,12	1,7	0,018
-2	2,008	-0,3	0,567	0,85	0,11	1,75	0,016
-1,9	1,911	-0,2	0,507	0,9	0,1	1,8	0,014
-1,8	1,814	-0,1	0,451	0,95	0,092	1,85	0,013
-1,7	1,718	0	0,399	1	0,083	1,9	0,011
-1,6	1,623	0,1	0,351	1,05	0,076	2	0,008
-1,5	1,529	0,2	0,307	1,1	0,069	2,1	0,006
-1,4	1,437	0,3	0,267	1,15	0,062	2,2	0,005
-1,3	1,346	0,35	0,248	1,2	0,056	2,3	0,004
-1,2	1,256	0,4	0,23	1,25	0,051	2,4	0,003
-1,1	1,169	0,45	0,214	1,3	0,046	2,5	0,002
-1	1,083	0,5	0,198	1,35	0,041	2,6	0,001
-0,9	1	0,55	0,183	1,4	0,037	2,8	0,001
-0,8	0,92	0,6	0,169	1,45	0,033	3	0

The values of shortages then can be computed through the following calculation in Equation (9) as follows:

$$E(n) = E(z) * \sigma_l \quad (9)$$

Where

E(n) = Amount of units short per replenishment cycle.
E(z) = Standardized number of units short.
σ_l = Standard deviation of demand during lead time.

The comparison of the probabilistic inventory model is shown as Table-2 below. For this research, the Power Approximation and Brown's Individual Unit Shortages are chosen.

Tabel-2. Probabilistic inventory model comparisons.

Inventory model	Fixed variables	Advantages	Disadvantages
Probabilistic Continuous Review	Order Quantities	Addresses systems with high demand	Responds poorly in high variability
Probabilistic Periodic Review (Normal Approximation)	Review Intervals	Responds well in high variability	Less suitable to calculate spare part distributions
Probabilistic Periodic Review (Power Approximation)	Review Intervals		May result higher average holding cost
Brown's Individual Unit Shortages	Either	Adjustable to both continuous or periodic review	Does not estimate the probability of stock-out occurrence

RESEARCH METHODOLOGY

The first step is to collect the list of consumable items and filter items into fast-moving spare parts. Firstly, consumable items need to be filtered into spare parts then the spare parts need to be filtered into fast-movers. According to the company's assumption, fast-moving items is a part that has demand for at least once a year.

Then, collect demand data of consumable fast-moving parts. The purpose is to ensure that the distribution found in the data could support the Poisson probabilistic distribution. The mean time and standard deviation of the lead time is also collected to support further computation. The lead time will follow the similar process taken to the parts demand.

The calculation of maximum and minimum level of inventory and total inventory cost using power approximation method is performed for all fast-moving parts by determining the value of parameters Dp, so, and So, s, and S. The value of s then will be treated as the minimum level or the reorder point, where S will be treated as the maximum level of the part. Power approximation would address well in managing spare parts inventory where the demand distribution follows Poisson process.

Another method that will be employed is Brown's individual unit shortages, on the other hand, is a complementary method that could fit well in both continuous and periodic review probabilistic systems. Since the periodic review model has the upper hand in calculating spare part models, Brown's method could be used to determine the appropriate service level of each item once the periodic review parameters are found.

Data analysis will also be performed. The new minimum and maximum values of inventory level using proposed method will be determined and compared with minimum and maximum value of current method. Then, it I needed to identify the causes of the differences for the minimum and maximum value. The result of the comparison will reveal several indications in inventory control processes using minimum/maximum and will answer why the regular deterministic minimum/maximum is not compatible to manage probabilistic inventory items.

It is also to analysed whether the service level generated satisfies the model to prevent stock-outs. Modify the service level using Brown's method to reduce the possibilities and create a graph to describe the trade-offs between service level and total inventory costs. Also, the stock out occurrences between Power Approximation and Brown's method is analyzed.

RESULT AND DISCUSSIONS

After filtering all items, there are fourteen items which have the criteria of fast-moving and consumable parts. The mean and standard deviation of the lead time and usage are then collected as shown in Table-3.

As explained in research methodology section, it is needed to calculate related costs such as unit cost, order cost, holding cost, and lost-of-good will cost.All the costs are needed for further computation. There are several steps to calculate each cost for one spare part. Given Part No. 6623 as the sample, the costs are as follows:

- Monthly holding cost for as much as $ 18,76
- Order cost for as much as $ 16,00

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- Loss-of-goodwill cost for as much as $ 94,00

Given the following variables known:
r = Quarterly (3 months).
L = 97, 22435847 days = 3, 2408 months.
σL = 10 days = 0,33 months.
μ = 71, 6944 parts/month.
μr = 71, 6944 * 3 = 215, 0832 parts.
μ(r+l) = 71, 6944 * (3 + 3, 2408) = 447, 43127 parts.
Σ(r+l)
: $\sqrt{((3 + 3{,}2408) * 8{,}4672^2) + (71{,}6944^2 * 0{,}33^2)}$ = 31,914 parts.

K = $ 16
h = $ 20,44
p = $ 94
u = $ 4,70

Using Eqn. (3), the value of Dp can be calculated as:

$$Dp = 1.30 * 71{,}6944^{0.494} * \left(\frac{16}{20{,}44 * 4{,}70}\right)^{0.506} * \left(1 + \frac{31{,}9147622^2}{215{,}0832^2}\right)^{0.116}$$

$$Dp = 20{,}793$$

And the value of c can also be calculated using Equation (4) as follow:

$$c = \sqrt{\frac{35{,}778 * 4{,}70}{31{,}914 * 94}}$$

$$c = 0{,}181$$

After the values of Dp and c are known, it is now possible to calculate the values of so and So:

$$so = (0.973 * 447{,}43127)31{,}914\left(\frac{0.183}{0{,}181} + 1.063 - 2.192 * 0{,}181\right) = \mathbf{490}$$

and

$$So = 447{,}43127 + \left(\frac{20{,}44 * \frac{12}{3}}{94 + 20{,}44 * \frac{12}{3}}\right)31{,}914 = \mathbf{462}$$

Table-3. Fast-moving consumable parts.

Part No.	**Lead time** (days) **(1)**	**Lead time tolerance** (days) **(2)**	**Avg. usage per month (3)**	**Dev. usage (4)**
6623	97,22435847	10	71,6944	8,467
5579	67,39905093	10	58,1111	7,623
1858	90,7025496	10	17,0556	4,130
4689	76,52114583	10	17,0556	4,130
3757	90,67638696	10	17,1944	4,147
5871	110,8806829	10	13,8889	3,727
1337	93,08767692	10	12,5556	3,543
4358	86,46296627	10	10,6389	3,262
6626	63,46464583	10	10,1111	3,180
1589	92,83041377	10	2,27778	1,509
2841	81,08694444	10	1,38889	1,179
1588	37,53734954	10	2,36111	1,537
6418	90,25157697	10	2,52778	1,590
3879	54,20932485	10	1,13889	1,067

Using decision criterion in equation (5) and (6), given that the value of $\frac{Dp}{\mu r} = 0{,}097$, it is decided that the value of *s* will be equal to So, which is 462. On the other hand, given that the value of $\frac{Dp}{\mu r} = 0{,}166$, it is decided that the value of *S* will be equal to either 490 or 462, and since 462 is smaller than 510, the value of S will be also 462. This means that both minimum and maximum level of part no. 6623 is 462. It has decided then for part no. 6623 that the minimum level is 462 and the maximum level is also 462. This means during the review period, if the quantity of parts on hand falls below 462 parts, than an order is placed to replace the amount of item into the level of 462.

Compared to the current minimum and maximum level of part 6623, which are 50 and 100 parts, the amount of parts in the proposed system exceeds the current system. This can be explained by looking at their amount of usages. The usage monthly usage average is approximately 71 parts. If the users set the maximum level

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of 100 parts for three months of review period plus additional three months of lead time, then the inventory will run out of parts even before the review period comes.

A comparison of total cost spent for one review period (three months) can be calculated to show the saving result given by the proposed system. The total cost consists of holding cost, order cost, and loss-of-goodwill cost.

In order to calculate the total holding cost, the amount of average inventory level needs to be found by using the following Eqn. (10):

$$q = \frac{\max - ending\ inventory}{2} \quad (10)$$

Where in the case of part no. 6623:

q Average inventory level
max Maximum amount of parts = 462
μr Ending inventory = Safety stock = 15

Input the variables into the equation, resulting in: $q = \frac{462 - 15}{2} = 224\ parts$

Then the average inventory level is multiplied by the holding cost of part no. 6623 ($ 18.76) that will result in $ 4, 202.24 for one month, and multiplied again with the total time needed for one replenishment cycle. One replenishment cycle consists of one review period and one lead time period. For part no. 6623, one replenishment cycle consists of 3 month-review period and 3.24 months of lead time. Holding cost for one replenishment cycle is $ 4,202.24 * (3+3.24) = $ 26,241.39. Thus, total cost for one period of part no. 6623 is $ 26,241.39 plus $ 16 of order cost at the beginning of the period, equals to $ 26.257,39 per period.

Using the similar process, the holding cost for the current system can also be found. However, looking at the amount of maximum level (100), there will be negative results in the computation. It is needed to know how long 100 items would last in the system. By dividing the maximum amount (100) with the average demand per month (71.6944), it is found that 100 units would last for 1.39 months. Then on average, the inventory level for the current system is: $q = \frac{100 - 0}{2} = 50\ parts$

By 50 parts on average, the average holding cost will be 50 parts times 1.39 months multiplied by $ 18.76, results in $ 1, 308.33 per period. However, there are lost-of-goodwill costs caused by shortages since 100 parts only last for 1.39 months. The remaining months (3 + 3.24 – 1.39 = 4.85) are uncovered. The formula to calculate the total LOG cost is shown as Eqn. (11).

*Uncovered parts * LOG cost* (11)

The uncovered parts can be determined by multiplying the monthly demand with the uncovered period, where it is 71,6944 * 4,85 = 348 parts and the total LOG cost for one replenishment cycle is 348 * $ 94,00 = $ 32,658.54. Thus, the costs accumulated for one review period is $ 1308,33+ $16+ $ 32.658,54 = **$ 33.982,87** per period

On average, the proposed periodic system managed to reduce the cost for 14 fast-moving parts as many as **48.69%** for one replenishment cycle.

To apply the Brown's method into the proposed Power Approximation model, the safety stock needs to be found first. Since every variable is known but the safety stock, the σl can be calculated first using Equation (7) and (8):

$$\sigma l = \sqrt{(3.241 * 8.467^2) + (71.694^2 * 0.33^2)} = 28.345$$ parts

Then the service level is: $z = \frac{15}{28.345} = 0.52918$

The function returns the value of normal cumulative distribution of the value z it is known as service level. Thus, the service level of part no. 6623is 70%.Taking an example for part no. 6623 which z-value is 0.52918 and z-value from the Table-1 is 0/198. Then $E(n) = 0.198 * 28.345 = 5.612 \approx 6\ units\ short$

This means that during one replenishment cycle, there is still a chance that at most the inventory of part no. 6623 will have a shortage of 6 units. To determine the optimum solution to reach a level of zero chance of shortage, while still results in the lowest cost, a comparison for each service level is made. The comparison is done with the current service level, 73% service, 76% service, 84% service, 90% service, and 98% service. The comparison is done to generate a linear regression of the trade-offs between the extra safety stock (SS) cost and the shortage (LOG) cost, where the optimum point can be calculated through linear equation. The result is shown as Table-4 below.

Table-4. Service level comparison for Part no. 6623.

SL (%)	Z	Max	Shortage	Ex. SS	SS cost ($)	exp. LOG cost ($)	Total cost ($)
70	0.52	463	6	0	0	564	564.00
73	0.6	466	5	3	56.28	470	526.28
76	0.7	468	4	5	93.80	376	469.80
84	0.99	477	3	14	262.64	282	544.64
90	1.28	485	2	22	412.72	188	600.72
98	2.05	507	1	44	825.44	94	919.44

Theoretically, an optimum point between two data sets can be found by its linear intersection. Through Ms. Excel, the intersection can be found by setting up a scatter chart that consists of two variables, that are the Safety Stock cost and the Loss-of-Goodwill cost. The result is shown as Figure-1 below.

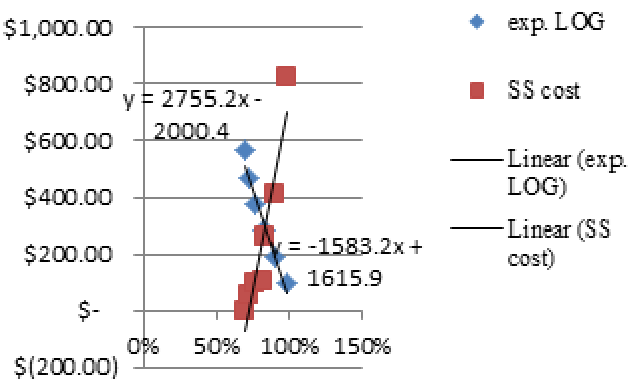

Figure-1. Part no. 6623 Tradeoffs chart.

From the Figure-1, it can be seen that the optimum service level is around 83%. By choosing 83% service level, the maximum amount of part no. 6623 is 476 units with an expected total cost of $ 406.79. When applied to all 14 parts using Equation (9), Brown's method manages to reduce the total cost of 14 parts for as much as 47.76% on average.

At first, the Brown's method may seem to result in a lower cost reduction rather than the power approximation method. However, Brown's method was calculated under the assumption that further stockouts may occur in the original power approximation method, and extra cost in the safety stock was generated due to the increasing service level. During calculations in Table-4, there are extra loss-of-goodwill cost generated in the original service level in the power approximation method, where for example, part no. 6623 has an extra loss of goodwill (LOG) cost for $ 564.00 excluding the total carrying cost of $ 26,241.39. The extra LOG cost needs to be added to the total cost. Therefore, the proposed power approximation methods with the LOG assumption results in a reduction for as much as 46.38%. The detail calculation using Brown's method can be seen as Table-5.

Tabel-5. Calculation of spare part inventory using Brown's Method.

Part No.	SL (%)	SS	Max level	Exp. Short	Additional SS	extra SS cost ($)	exp. LOG ($)	Total cost
6623	83	28	476	3	13	124.79	282.00	406.79
5579	86	25	330	2	15	143.99	133.34	277.33
1858	85	10	113	0	4	402.73	-	402.73
4689	85	9	104	0	3	51.26	-	51.26
3757	84	10	114	0	4	65.92	-	65.92
5871	84	10	104	0	5	47.06	-	47.06
1337	83	8	85	0	4	80.08	-	80.08
4358	85	7	70	0	2	52.66	-	52.66
6626	84	6	58	0	1	17.20	-	17.20
1589	87	3	16	0	0	-	-	-
2841	77	2	16	0	0	-	-	-
1588	79	2	12	0	1	56.82	-	324.56
6418	87	4	17	0	1	9.85	-	9.85
3879	84	2	7	0	0	-	-	48.67

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Table-6 and Table-7 show total cost calculation for power approximation method and Brown method compare with the current method.

It can be seen that the applied Brown's method managed to reduce the total cost generated from the power approximation method. The Brown's method manages to reduce the total cost from the current method for 47.76%on average, compared to the new power approximation cost calculation of 46.38%. It manages to give an extra 1.38% of cost reduction.

Table-6. Cost calculation using Power Approximation Method.

Part No.	**Current cost** ($)	**PA Method** ($)	**Cost reduction** (%)
6623	33,982.87	26,805.39	21.12
5579	10,312.32	8,222.52	20.27
1858	182,334.74	34,272.10	81.20
4689	23,977.76	4,923.18	79.47
3757	5,144.14	5,366.11	-4.31
5871	3,041.06	3,225.91	-6.08
1337	6,235.31	4,928.21	20.96
4358	18,401.95	5,205.14	71.71
6626	6,538.35	2,384.76	63.53
1589	13,363.45	6,659.47	50.17
2841	61,472.67	12,283.01	80.02
1588	3,635.02	1,612.37	55.64
6418	749.99	489.31	34.76
3879	757.12	144.80	80.88
			46.38

Table-7. Cost Calculation using Brown's Method.

Part No.	**Current cost** ($)	**Borwon's Method** ($)	**Cost Reduction** (%)
6623	33,982.87	26,648.18	21.5
5579	10,312.32	7,973.92	22.68
1858	182,334.74	1,650.83	82,64
4689	23,977.76	4,571.97	80.93
3757	5,144.14	5.243,03	-1.92
5871	3,041.06	3,025,10	0.52
1337	6,235.31	4,799,89	23.02
4358	18,401.95	4.947,40	73.11
6626	6,538.35	2,320.56	64.51
1589	13,363.45	6,659.47	50.17
2841	61,472.67	21,483.27	65.05
1588	3,635.02	1,548;41	57.40
6418	749.99	410.41	45.28
3879	757.12	123.33	83.71
			47.76

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Brown's method also managed to reduce stock out, which is the main objective of the study. The comparison is done between the expected individual item shortages in Brown's method and power approximation method. The shortages are taken from the calculation done in the service level analysis such as in Table-4. The reduction percentage can be seen in Table-8.

From Table-4, it can be seen that Brown's method offer 66% reduction of shortage per one replenishment cycle on average. This reduction can be achieved since Brown's method is originally developed to reduce any possible shortages that may occur.

Table-8. Parts shortage comparison.

Part No.	Brown's Exp. shortage	PA Exp. shortage	Reduction %
6623	3	6	50%
5579	2	6	67%
1858	0	6	100%
4689	0	5	100%
3757	0	2	100%
5871	0	3	100%
1337	0	2	100%
4358	0	2	100%
6626	0	1	100%
1589	0	0	0%
2841	0	0	0%
1588	0	1	100%
6418	0	0	0%
3879	0	0	0%
Average Shortage Reduction %		66%	

Furthermore, the calculation of minimum and maximum level of inventory can be seen in Table-9 below.

Table-9. Minimum/Maximum inventory level.

Part No.	Maximum level			Minimum level		
	Current	PA	Brown	Current	PA	Brown
6623	100	462	476	50	462	476
5579	200	320	330	100	320	330
1858	352	108	113	176	108	113
4689	300	100	104	200	100	104
3757	100	109	114	50	109	114
5871	100	100	104	50	100	104
1337	20	81	85	10	81	85
4358	150	67	70	75	67	70
6626	100	56	58	50	56	58
1589	20	16	16	10	16	16
2841	24	10	16	18	10	16
1588	20	12	12	10	12	12
6418	20	18	17	15	18	17
3879	20	8	7	10	8	

Most of minimum/maximum inventory levels of current system are higher than power approximation method or Brown's method, except for part no. 6623 and 5579. Currently, the maximum levels are being set too high in order to prevent unpredictable demand/usage. For part no. 6623 and 5579, however, the maximum level of the proposed system is set greater than the maximum level current system. This can be explained by looking at their amount of usages. For example, part no. 6623, the average monthly usage is approximately 78 units. If the users set the maximum level of 100 parts for three-month review period plus additional three months of lead time, then the inventory will run out of parts even before the review period comes.

CONCLUSIONS

Brown's individual unit shortages method managed to be the better method in determining the proper service level to avoid further stock-outs for each replenishment cycle, with a 66% reduction on average than the power approximation method. Although may add extra holding costs, Brown's trade-offs in preventing lost-of-goodwill cost offers the prevention of stock-outs. In addition, the reduction of the total inventory cost for as much as 47.76% from the current total inventory cost.

For further research, it is needed to propose the integrating of maintenance schedule and spare parts inventory control in order to reduce the downtime cost, shortage cost and total inventory cost.

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