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- [Papers](#)
- [About](#)

Table of contents

Page of 4
[Next](#)

1. Front Matter
Pages i-xxiv
[PDF](#) 
2. [An Optimal Ordering Policy of the Retailers Under Partial Trade Credit Financing and Restricted Cycle Time in Supply Chain](#)
Shin'ichi Yoshikawa
Pages 1-8
3. [An Immunized Ant Colony System Algorithm to Solve Unequal Area Facility Layout Problems Using Flexible Bay Structure](#)
Mei-Shiang Chang, Hsin-Yi Lin
Pages 9-17
4. [Characterizing the Trade-Off Between Queue Time and Utilization of a Manufacturing System](#)
Kan Wu
Pages 19-27

5. Using Latent Variable to Estimate Parameters of Inverse Gaussian Distribution Based on Time-Censored Wiener Degradation Data
Ming-Yung Lee, Cheng-Hung Hu
Pages 29-35
6. Interpolation Approximations for the Performance of Two Single Servers in Series
Kan Wu
Pages 37-44
7. On Reliability Evaluation of Flow Networks with Time-Variant Quality Components
Shin-Guang Chen
Pages 45-51
8. Defect Detection of Solar Cells Using EL Imaging and Fourier Image Reconstruction
Ya-Hui Tsai, Du-Ming Tsai, Wei-Chen Li, Shih-Chieh Wu
Pages 53-62
9. Teaching Industrial Engineering: Developing a Conjoint Support System Catered for Non-Majors
Yoshiki Nakamura
Pages 63-71
10. An Automatic Image Enhancement Framework for Industrial Products Inspection
Chien-Cheng Chu, Chien-Chih Wang, Bernard C. Jiang
Pages 73-78
11. Ant Colony Optimization Algorithms for Unrelated Parallel Machine Scheduling with Controllable Processing Times and Eligibility Constraints
Chinyao Low, Rong-Kwei Li, Guan-He Wu
Pages 79-87
12. General Model for Cross-Docking Distribution Planning Problem with Time Window Constraints
Parida Jewpanya, Voratas Kachitvichyanukul
Pages 89-102
13. A New Solution Representation for Solving Location Routing Problem via Particle Swarm Optimization
Jie Liu, Voratas Kachitvichyanukul
Pages 103-110
14. An Efficient Multiple Object Tracking Method with Mobile RFID Readers
Chieh-Yuan Tsai, Chen-Yi Huang
Pages 111-117
15. A New Bounded Intensity Function for Repairable Systems
Fu-Kwun Wang, Yi-Chen Lu
Pages 119-125
16. Value Creation Through 3PL for Automotive Logistical Excellence
Chin Lin Wen, Schnell Jeng, Danang Kisworo, Paul K. P. Wee, H. M. Wee
Pages 127-132
17. Dynamics of Food and Beverage Subsector Industry in East Java Province: The Effect of Investment on Total Labor Absorption
Putri Amelia, Budisantoso Wirjodirdjo, Niniet Indah Arvitrida
Pages 133-140
18. Solving Two-Sided Assembly Line Balancing Problems Using an Integrated Evolution and Swarm Intelligence
Hindriyanto Dwi Purnomo, Hui-Ming Wee, Yugowati Praharsi
Pages 141-148

19. Genetic Algorithm Approach for Multi-Objective Optimization of Closed-Loop Supply Chain Network
Li-Chih Wang, Tzu-Li Chen, Yin-Yann Chen, Hsin-Yuan Miao, Sheng-Chieh Lin, Shuo-Tsung Chen
Pages 149-156
20. Replacement Policies with a Random Threshold Number of Faults
Xufeng Zhao, Mingchih Chen, Kazunori Iwata, Syouji Nakamura, Toshio Nakagawa
Pages 157-164
21. A Multi-Agent Model of Consumer Behavior Considering Social Networks: Simulations for an Effective Movie Advertising Strategy
Yudai Arai, Tomoko Kajiyama, Noritomo Ouchi
Pages 165-172
22. Government Subsidy Impacts on a Decentralized Reverse Supply Chain Using a Multitiered Network Equilibrium Model
Pin-Chun Chen, I-Hsuan Hong
Pages 173-180
23. A Capacity Planning Method for the Demand-to-Supply Management in the Pharmaceutical Industry
Nobuaki Ishii, Tsunehiro Togashi
Pages 181-188
24. Storage Assignment Methods Based on Dependence of Items
Po-Hsun Kuo, Che-Wei Kuo
Pages 189-195
25. Selection of Approximation Model on Total Perceived Discomfort Function for the Upper Limb Based on Joint Moment
Takanori Chihara, Taiki Izumi, Akihiko Seo
Pages 197-204
26. Waiting as a Signal of Quality When Multiple Extrinsic Cues are Presented
Shi-Woei Lin, Hao-Yuan Chan
Pages 205-210
27. Effect of Relationship Types on the Behaviors of Health Care Professionals
Shi-Woei Lin, Yi-Tseng Lin
Pages 211-217
28. A Simulation with PSO Approach for Semiconductor Back-End Assembly
James T. Lin, Chien-Ming Chen, Chun-Chih Chiu
Pages 219-227
29. Effect of Grasp Conditions on Upper Limb Load During Visual Inspection of Objects in One Hand
Takuya Hida, Akihiko Seo
Pages 229-237
30. A Process-Oriented Mechanism Combining Fuzzy Decision Analysis for Supplier Selection in New Product Development
Jiun-Shiung Lin, Jen-Huei Chang, Min-Che Kao
Pages 239-247
31. Reliability-Based Performance Evaluation for a Stochastic Project Network Under Time and Budget Thresholds
Yi-Kuei Lin, Ping-Chen Chang, Shin-Ying Li
Pages 249-256
32. System Reliability and Decision Making for a Production System with Intersectional Lines
Yi-Kuei Lin, Ping-Chen Chang, Kai-Jen Hsueh

- Pages 257-264
33. Customer Perceptions of Bowing with Different Trunk Flexions
Yi-Lang Chen, Chiao-Ying Yu, Lan-Shin Huang, Ling-Wei Peng, Liang-Jie Shi
Pages 265-270
 34. A Pilot Study Determining Optimal Protruding Node Length of Bicycle Seats Using Subjective Ratings
Yi-Lang Chen, Yi-Nan Liu, Che-Feng Cheng
Pages 271-277
 35. Variable Neighborhood Search with Path-Relinking for the Capacitated Location Routing Problem
Meilinda F. N. Maghfiroh, A. A. N. Perwira Redi, Vincent F. Yu
Pages 279-286
 36. Improving Optimization of Tool Path Planning in 5-Axis Flank Milling by Integrating Statistical Techniques
Chih-Hsing Chu, Chi-Lung Kuo
Pages 287-294
 37. A Multiple Objectives Based DEA Model to Explore the Efficiency of Airports in Asia-Pacific
James J. H. Liou, Hsin-Yi Lee, Wen-Chein Yeh
Pages 295-302
 38. A Distributed Constraint Satisfaction Approach for Supply Chain Capable-to-Promise Coordination
Yeh-Chun Juan, Jyun-Rong Syu
Pages 303-310
 39. Design and Selection of Plant Layout by Mean of Analytic Hierarchy Process: A Case Study of Medical Device Producer
Arthit Chaklang, Arnon Srisom, Chirakiat Saithong
Pages 311-318
 40. Using Taguchi Method for Coffee Cup Sleeve Design
Yiyo Kuo, Hsin-Yu Lin, Ying Chen Wu, Po-Hsi Kuo, Zhi-He Liang, Si Yong Wen
Pages 319-325
 41. Utilizing QFD and TRIZ Techniques to Design a Helmet Combined with the Wireless Camcorder
Shu-Jen Hu, Ling-Huey Su, Jhih-Hao Laio
Pages 327-334
 42. South East Asia Work Measurement Practices Challenges and Case Study
Thong Sze Yee, Zuraidah Mohd Zain, Bhuvanesh Rajamony
Pages 335-344
 43. Decision Support System: Real-Time Dispatch of Manufacturing Processes
Chung-Wei Kan, An-Pin Chen
Pages 345-352
 44. The Application of MFCA Analysis in Process Improvement: A Case Study of Plastics Packaging Factory in Thailand
Chompoonoot Kasemset, Suchon Sasiopars, Sugun Suwiphat
Pages 353-361
 45. Discussion of Water Footprint in Industrial Applications
Chung Chia Chiu, Wei-Jung Shiang, Chiuhsiang Joe Lin
Pages 363-370
 46. Mitigating Uncertainty Risks Through Inventory Management: A Case Study for an Automobile Company
Amy Chen, H. M. Wee, Chih-Ying Hsieh, Paul Wee

Pages 371-379

47. Service Quality for the YouBike System in Taipei

Jung-Wei Chang, Xin-Yi Jiang, Xiu-Ru Chen, Chia-Chen Lin, Shih-Che Lo

Pages 381-388

48. Replenishment Strategies for the YouBike System in Taipei

Chia-Chen Lin, Xiu-Ru Chen, Jung-Wei Chang, Xin-Yi Jiang, Shih-Che Lo

Pages 389-396

49. A Tagging Mechanism for Solving the Capacitated Vehicle Routing Problem

Calvin K. Yu, Tsung-Chun Hsu

Pages 397-404

50. Two-Stage Multi-Project Scheduling with Minimum Makespan Under Limited Resource

Calvin K. Yu, Ching-Chin Liao

Pages 405-413

Page of 4

[Next](#)

About these proceedings

Introduction

This book is based on the research papers presented during The Institute of Industrial Engineers Asian Conference 2013 held at Taipei in July 2013. It presents information on the most recent and relevant research, theories and practices in industrial and systems engineering. Key topics include:

Engineering and Technology Management

Engineering Economy and Cost Analysis

Engineering Education and Training

Facilities Planning and Management

Global Manufacturing and Management

Human Factors

Industrial & Systems Engineering Education

Information Processing and Engineering

Intelligent Systems

Manufacturing Systems

Operations Research

Production Planning and Control

Project Management

Quality Control and Management

Reliability and Maintenance Engineering

Safety, Security and Risk Management

Supply Chain Management

Systems Modeling and Simulation

Large scale complex systems

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Engineering Economy Engineering Education Engineering and Technology Management

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Reliability and Maintenance Engineering Risk Management Supply Chain Management
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An EPQ with Shortage Backorders Model on Imperfect Production System Subject to Two Key Production Systems

Baju Bawono, The Jin Ai, Ririn Diar Astanti
and Thomas Indarto Wibowo

Abstract This paper is an extension of the work of Lin and Gong (2011) on Economic Production Quantity (EPQ) model on an imperfect production system over infinite planning horizon, where the production system is dictated by two unreliable key production subsystems (KPS). While any shortage on the inventory of product was not allowed in the model of Lin and Gong (2011), planned shortage backorders is considered in the model proposed in this paper. The mathematical model is developed in order to determine production run time (τ) and production time when backorder is replenished (T_1) that minimizes the expected total cost per unit time including setup, inventory carrying, shortage, and defective costs. Approaches to solve the model are also being proposed in this paper, altogether with some numerical examples.

Keywords Economic production quantity model • Shortage backorders • Imperfect production system • Optimization technique • Approximation method

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1 Introduction

Productivity is generally defined as the ratio between output and input. The input can be man, material, machine, money, and method. In manufacturing industry, where the output is tangible product, the productivity can be measured by how many or how much the output resulted. Productivity might be affected by one of the input mentioned above, such as machine. Machine is one element of the production subsystem. The machine is reliable if it can perform as good as the standard. However, in reality there is a condition where, the machine does not perform well or it is called imperfect condition. This condition might happen due to, for example, machine breakdown. As illustration, boiler breakdown in a Crude Palm Oil (CPO) industry will increase the concentration of ALB in the oil so that it will decrease the quality of CPO (Sulistyo et al. 2012). Therefore, the output of the CPO is also decreased. In other word, the productivity of the industry is decreased.

The economic production quantity (EPQ) model developed by many researchers in the past, such as Silver et al. (1998) under the assumption the production subsystem is perfect (no breakdown). However, this ideal condition is rarely happened in the real situation. If this model is applied in the real situation where the production subsystem is imperfect, then, the target production is never be reached. The EPQ model considering imperfect production subsystem have been proposed by some researchers, such as Rosenblatt and Lee (1986). They assumed that in the production system there may exist an imperfect condition where the in-control state changed to out-control state where the random time to change is assumed following exponential distribution. As the result, the system might produce defective product. Following this work, some models dealt with various additional system setting had been proposed, such as (Lee and Rosenblatt 1987, 1988, 1989; Lee and Park 1991; Lin et al. 1991; Ben-Daya and Hariga 2000; Hsieh and Lee 2005). In those previous models, the imperfectness of production system is assumed to be dictated by single key production subsystem (KPS) only. Lin and Gong (2011) recently extended the study by proposing an EPQ model where the production system is imperfect and dictated by two imperfect KPS's over an infinite planning horizon. Ai et al. (2012) continued this work by considering finite planning horizon.

While those above mentioned researches discussed on EPQ model without shortage, the research conducted by Chung and Hou (2003) extended the work of Rosenblatt and Lee (1986) by incorporating the shortage into their model. Shortage itself can be defined as the situation when the customer order arrive but the finished good are not yet available. When all customer during the stockout period are willing to wait until the finished goods are replenished then it is called as completely backorder case. Shortage is common in practical situation, when the producer is realized that its customers loyal to their product.

This paper is extending the work of Chung and Hou (2003) and Lin and Gong (2011) by combining both works into a new EPQ model that consider 2 (two) imperfect KPS and shortage. The organization of this paper is as follow: Sect. 2

describes the mathematical model development, Sect. 3 discusses the solution methodology of the proposed method, Sect. 4 presents the numerical example, followed by some concluding remarks in Sect. 5.

2 Mathematical Model

This paper considers a production lot sizing problem where a product is to be manufactured in batches on an imperfect production system over an infinite planning horizon, in which shortage of product is allowed at the end of each production cycle and all shortage is backordered. The demand rate is d , and the production rate is p . As defined in Lin and Gong (2011) and Ai et al. (2012), the imperfectness of the system is shown on two imperfect key production subsystems (KPS) that may shift from an in-control to an out-of-control state due to three independent sources of shocks: source 1's shock causes first KPS to shift, source 2's shock causes second KPS to shift, and source 3's shock causes both KPS to shift. Each shocks occur at random time U_1 , U_2 , and U_{12} that follows exponential distribution with mean $1/\lambda_1$, $1/\lambda_2$, and $1/\lambda_{12}$, respectively. When at least one KPS on out-of-control state, consequently, the production system will produced some defective items with fixed but different rates: α percentage when first KPS out-of-control, β percentage when the second KPS out-of-control, and δ percentage when the both KPS out-of-control. The cost incurred by producing defective items when the first KPS is shifted, the second KPS is shifted, and both KPS are shifted are π_1 , π_2 , and π_{12} , respectively.

The production cycle of this situation can be described as Fig. 1, in which the inventory level is increased during the production uptime (τ) at rate $(p - d)$ and decreased at rate $-d$ during the production downtime. It is shown in Fig. 1, the production cycle length T can be divided into four sections, each of them with length T_1 , T_2 , T_3 , and T_4 , respectively. The backorders are replenished in Sect. 1, in which the inventory level is increased from $-B_{max}$ to 0. The inventories are accumulated during Sect. 2, in which inventory level at the end of this section is I_{max} . After that, the inventory level is decreased to 0 during Sect. 3 and the shortage happened in Sect. 4.

The optimization problem is to determining optimal production run time τ and production time when backorder is replenished T_1 , that minimizes the expected total cost per unit time including setup, inventory carrying, shortage and defective costs.

In single production cycle, although shortages are exist, the number of product being produced ($p \cdot \tau$) is equal to the demand of product ($d \cdot T$) in that cycle. Therefore $T = p\tau/d$. If the setup cost is denoted as A , based on (1), the setup cost per unit time (C_1) can be defined as

$$C_1 = \frac{A}{T} = \frac{Ad}{p\tau} \quad (1)$$

The average inventory per production cycle as function of τ and T_1 can be expressed as

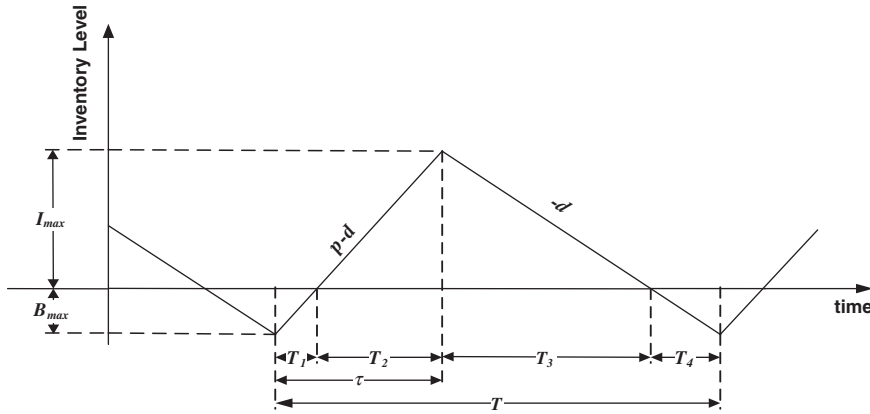


Fig. 1 Production cycle

$$\bar{I}(T_1, \tau) = \frac{(p-d)\tau}{2} - (p-d)T_1 + \frac{(p-d)T_1^2}{2\tau} \quad (2)$$

Therefore, if unit inventory holding cost per unit time is defined as h , the inventory carrying cost per unit time (C_2) can be defined as

$$C_2 = \frac{h(p-d)\tau}{2} - h(p-d)T_1 + \frac{h(p-d)T_1^2}{2\tau} \quad (3)$$

The average shortage per production cycle as function of τ and T_1 can be expressed as

$$\bar{B}(T_1, \tau) = \frac{(p-d)T_1^2}{2\tau} \quad (4)$$

Therefore, if unit shortage cost per unit time is defined as s , the shortage cost per unit time (C_3) can be defined as

$$C_3 = \frac{s(p-d)T_1^2}{2\tau} \quad (5)$$

The results from Lin and Gong (2011) are presented below to obtain the defective cost per unit time (C_4), in which the unit defective cost when the first KPS is shifted, the second KPS is shifted, and both KPS are shifted is defined as π_1 , π_2 , and π_{12} , respectively.

$$C_4 = \frac{d(\pi_1 E[N_1(\tau)] + \pi_2 E[N_2(\tau)] + \pi_{12} E[N_{12}(\tau)])}{p\tau} \quad (6)$$

$$E[N_1(\tau)] = p\alpha \left(\frac{1 - \exp[-(\lambda_2 + \lambda_{12})\tau]}{\lambda_2 + \lambda_{12}} - \frac{1 - \exp[-(\lambda_1 + \lambda_2 + \lambda_{12})\tau]}{\lambda_1 + \lambda_2 + \lambda_{12}} \right) \quad (7)$$

$$E[N_2(\tau)] = p\beta \left(\frac{1 - \exp[-(\lambda_1 + \lambda_{12})\tau]}{\lambda_1 + \lambda_{12}} - \frac{1 - \exp[-(\lambda_1 + \lambda_2 + \lambda_{12})\tau]}{\lambda_1 + \lambda_2 + \lambda_{12}} \right) \quad (8)$$

$$E[N_{12}(\tau)] = p\delta \left(\frac{\exp[-(\lambda_1 + \lambda_{12})\tau] + (\lambda_1 + \lambda_{12})\tau - 1}{\lambda_1 + \lambda_{12}} + \frac{\exp[-(\lambda_2 + \lambda_{12})\tau] + (\lambda_2 + \lambda_{12})\tau - 1}{\lambda_2 + \lambda_{12}} - \frac{\exp[-(\lambda_1 + \lambda_2 + \lambda_{12})\tau] + (\lambda_1 + \lambda_2 + \lambda_{12})\tau - 1}{\lambda_1 + \lambda_2 + \lambda_{12}} \right) \quad (9)$$

Therefore, the expected total cost per unit time can be stated as

$$Z[\tau, T_1] = C_1 + C_2 + C_3 + C_4$$

$$Z[\tau, T_1] = \frac{Ad}{p\tau} + \frac{h(p-d)\tau}{2} - h(p-d)T_1 + \frac{h(p-d)T_1^2}{2\tau} + \frac{s(p-d)T_1^2}{2\tau} + \frac{d(\pi_1 E[N_1(\tau)] + \pi_2 E[N_2(\tau)] + \pi_{12} E[N_{12}(\tau)])}{p\tau} \quad (10)$$

3 Solution Methodology

Following Lin and Gong (2011), all exponential terms in the total cost expression can be approximate by MacLaurin series:

$$\exp(-\lambda\tau) \approx 1 - \lambda\tau + \frac{1}{2!}(\lambda\tau)^2 - \frac{1}{3!}(\lambda\tau)^3 \quad (11)$$

Therefore the total cost expression can be rewritten as

$$Z[\tau, T_1] \approx \frac{Ad}{p\tau} + h(p-d) \left[\frac{\tau}{2} - T_1 \right] + \frac{(h+s)(p-d)T_1^2}{2\tau} + \frac{H\tau}{2} - \frac{K\tau^2}{6} \quad (12)$$

$$H = d(\pi_1\alpha\lambda_1 + \pi_2\beta\lambda_2 + \pi_{12}\delta\lambda_{12}) \quad (13)$$

$$K = d[\pi_1\alpha\lambda_1(\lambda_1 + 2\lambda_2 + 2\lambda_{12}) + \pi_2\beta\lambda_2(2\lambda_1 + \lambda_2 + 2\lambda_{12}) + \pi_{12}\delta(\lambda_{12}^2 - 2\lambda_1\lambda_2)] \quad (14)$$

It is well known from calculus optimization that the necessary condition for minimizing $Z[\tau, T_1]$ are the first partial derivatives equal to zero. Applying this condition for Eq. (12), it is found that

$$\frac{\partial}{\partial \tau} Z[\tau, T_1] = \frac{H}{2} + \frac{h(p-d)}{2} - \frac{K\tau}{3} - \frac{Ad}{p\tau^2} - \frac{(h+s)(p-d)T_1^2}{2\tau^2} = 0 \quad (15)$$

$$\frac{\partial}{\partial T_1} Z[\tau, T_1] = -h(p-d) + \frac{(h+s)(p-d)T_1}{\tau} = 0 \quad (16)$$

Solving Eq. (16) for T_1 , it is found that

$$T_1^* = \frac{h}{(h+s)} \tau^* \quad (17)$$

Substituting Eq. (17) to Eq. (15), it is obtained that

$$\frac{H}{2} + \frac{hs(p-d)}{2(h+s)} - \frac{K\tau}{3} - \frac{Ad}{p\tau^2} = 0 \quad (18)$$

If the term $K\tau/3$ is neglected or approximated as zero, it found after some algebra that

$$\tau^* = \sqrt{\frac{2Ad}{p\left[H + hs\left(\frac{p-d}{h+s}\right)\right]}} = \sqrt{\frac{2Ad}{p\left[d(\pi_1\alpha\lambda_1 + \pi_2\beta\lambda_2 + \pi_{12}\delta\lambda_{12}) + hs\left(\frac{p-d}{h+s}\right)\right]}} \quad (19)$$

The sufficient condition of this result can be easily proven, since the Hessian matrix is positive definite.

4 Numerical Examples

To illustrate the proposed model and solution methodology, the numerical example is conducted on 8 (eight) sample problems as it is shown in Table 1.

Table 1 Parameters and solutions of sample problems

Parameters	Prob 1	Prob 2	Prob 3	Prob 4	Prob 5	Prob 6	Prob 7	Prob 8
d	200	200	200	200	200	200	200	200
p	300	300	300	300	300	300	300	300
α	0.1	0.1	0.3	0.3	0.1	0.1	0.3	0.3
β	0.1	0.1	0.3	0.3	0.1	0.1	0.3	0.3
δ	0.16	0.16	0.48	0.48	0.16	0.16	0.48	0.48
λ_1	0.05	0.05	0.05	0.05	0.15	0.15	0.15	0.15
λ_2	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
λ_{12}	0.02	0.02	0.02	0.02	0.06	0.06	0.06	0.06
π_1	10	10	10	10	10	10	10	10
π_2	10	10	10	10	10	10	10	10
π_{12}	12	12	12	12	12	12	12	12
A	100	100	100	100	100	100	100	100
h	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
s	0.16	0.24	0.16	0.24	0.16	0.24	0.16	0.24
<i>Solutions</i>								
τ^*	1.761	1.747	1.061	1.058	1.061	1.058	0.622	0.622
T_1^*	0.587	0.437	0.354	0.265	0.354	0.265	0.207	0.155
$Z[\tau^*, T_1^*]$	75.73	76.32	125.6	126	125.6	126	214.3	214.5

5 Concluding Remarks

This paper extend the work of Chung and Hou (2003) and Lin and Gong (2011) by incorporating 2(two) imperfect KPS considering shortage on EPQ model. Based on the numerical example it can be shown that the proposed model and its solution methodology works on 8 (eight) sample problems. Further work will be conducted to find another solution methodology approaches and to do the sensitivity analysis on the proposed model. In addition, formulating an EPQ model with 2(two) imperfect KPS considering shortage can be further investigated for finite planning horizon.

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