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December 8th – 11th, 2015

Ho Chi Minh City, Vietnam

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PROCEEDINGS OF ABSTRACTS AND PAPERS OF THE 16th ASIA PACIFIC INDUSTRIAL ENGINEERING & MANAGEMENT SYSTEMS CONFERENCE (APIEMS 2015)	AUTHORS

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MESSAGE FROM THE GENERAL CHAIR

International University (IU), one of six member universities of Vietnam National University-HCMC was established on December 2003. The University is the first public international university in Vietnam that entirely uses English in all activities. IU-HCMC is considered a leading university in Vietnam National University system that excels in operations, teaching, and research aspects. This year, our university took great honor to hold the 16th Asia Pacific Industrial Engineering and Management Systems in Ho Chi Minh City, the largest city of Vietnam.

As an organizer of the APIEMS 2015, we are impressed with the number and quality of papers that we have received for the conference. On behalf of the APIEMS 2015 organizing committee, I would like to thank Prof. Hoang Pham and Prof. Chen-Fu Chien for their excellent keynote speeches, I would also like to express my gratitude to more than 300 participants and distinguished speakers for their enthusiastic supports. As the conference was first time held in Vietnam, we are very grateful for the help of the Honorary Chairs, Program Committee Co-Chairs, Reviewers, who have given us valuable counseling and assist in reviewing a huge number of abstracts and manuscripts. My sincere thanks to all faculties, staff and student volunteers of Industrial and Systems Engineering Department, staff of the Office of Research and Development Office, External and Public Relations, Facility Development in International University for their hard work to hold this event successfully. Thanks also to all of our sponsors who have generously support us for the Conference.

Finally, I would like to say a very warm welcome to all distinguished guests, speakers and participants of the APIEMS 2015. I wish you enjoy the conference, have many good presentations, fruitful discussions and meet new friends.

Dr. Ho Thanh Phong

Rector of International University

Head of Department of Industrial & Systems Engineering

APIEMS 2015 General Chair

MESSAGE FROM THE APIEMS PRESIDENT

On behalf of the Asia Pacific Industrial Engineering and Management Society, I would like to welcome the participants to this year APIEMS Conference. Started in 1998, APIEMS has grown to become the premier conference for industrial engineering and management systems in the Asia Pacific region with participants from all over the world.

I congratulate and thank to Dr. Ho Thanh Phong, Rector of International University, the Conference Chair and his colleagues who have made this conference a successful one. This is the first time the APIEMS held in Vietnam and hope we can come back again! We also welcome IEM professions join APIEMS activities and share their research results and applications.

Wish you had an enjoyable stay and have fruitful discussions at the conference!

Bernard C.Jiang, Ph.D, P.E.
Professor of Industrial Management Department and
Vice President of Taiwan National University of
Science and Technology (Taiwan Tech), TAIWAN
APIEMS President (2015-2016)

KEYNOTE SPEECHES

Keynote Speech I

Research Challenges and Opportunities in Reliability Computing

Hoang Pham

Distinguished Professor

Department of Industrial and Systems Engineering

Rutgers University, State University of New Jersey, NJ - USA

Abstract

Reliability computing, which consists of modeling and prediction, has become of great interest in recent years due to spacious arrays of complex systems and applications in our everyday safety, serviceability, security and economic welfare. Modeling is hard but predicting is much harder due to the uncertainties of the system's operating environments and human will when it come to the know-how to use the analysis of complex data and modeling results in order to make effective decisions.

This talk discusses some research challenges and opportunities in reliability computing that focus on the modeling of complex systems, both hardware and software, subject to the uncertainties of operating environments. Reliability computing results and model selections based on various criteria are also discussed.

Brief Bio

Dr. Hoang Pham is a Distinguished Professor and former Chairman (2007-2013) of the Department of Industrial and Systems Engineering at Rutgers University. Before joining Rutgers, he was a Senior Engineering Specialist with the Boeing Company and the Idaho National Engineering Laboratory. He has served as Editor-in-Chief, Editor, Associate Editor, Guest Editor, and board member of many journals. He is the Editor of Springer Book Series in Reliability Engineering, the Editor of World Scientific Book Series on Industrial and Systems Engineering, and has served as Conference Chair and Program Chair of over 30 international conferences.

He is the author or coauthor of 6 books and has published over 135 journal articles, and edited 10 books including Springer Handbook in Engineering Statistics and Handbook in Reliability Engineering. He has delivered over 35 invited keynote and plenary speeches at many international conferences. His numerous awards include the 2009 IEEE Reliability Society Engineer of the Year Award. He is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) and the Institute of Industrial Engineers (IIE).

Keynote Speech II

Big Data Analyticsto Empower Manufacturing Intelligence and Smart Production for Industry 3.5

Chen-Fu Chien

Tsinghua Chair Professor

NTHU-TSMC Center for Manufacturing Excellence

Department of Industrial Engineering & Engineering Management

National Tsing Hua University, Taiwan

Abstract

The leading nations including Germany and USA have reemphasized the importance of manufacturing in the corresponding national competitive strategies such as Industry 4.0 and AMP. The paradigm of production and manufacturing system is shifting, in which the increasing adoption of the multimode sensors, intelligent equipment and robotics, Internet of Things (IOT), and big data analytics have empowered an unprecedented level of manufacturing intelligence. Indeed, various companies are battling for dominant positions in this newly created arena via providing novel value-proposition solutions and/or employing new technologies to enhance smart production.On the basis of our empirical studies with various industries, this talk aims to address emergent issues and propose a strategy called Industry 3.5 as a hybrid strategy between the best practice of existing manufacturing for Industry 3.0 and to-be Industry 4.0 with a number of illustrations of disruptive innovations via data mining and big data analytics. This talk will use some case studies to foster more discussions for future industrial engineering by addressing the revolutionary industry as a whole.

Brief Bio

Chen-Fu Chienis a Tsinghua Chair Professor in National Tsing Hua University, Taiwan. He is PI for the Semiconductor Technologies Empowerment Partners (STEP) Consortium by Ministry of Science & Technology, Taiwan and the Director of the NTHU-TSMC Center for Manufacturing Excellence. From 2005 to 2008, he had been on-leave as the Deputy Director of Industrial Engineering Division in Taiwan Semiconductor Manufacturing Company (TSMC). Dr. Chien has received a number of invention patents, published two books, more than 120 journal papers, and a number of case studies in Harvard Business School.He received National Quality Award, the Distinguished Research Awards from MOST, Distinguished University–Industry Collaborative Research Award from MOEA, University Industrial Contribution Awards from Ministry of Education, and the 2011 Best Paper Award of IEEE TASE etc.

SPECIAL TALK

Why is Uncertainty Theory Useful in Industrial Engineering?

Baoding Liu

Professor

Department of Mathematical Sciences

Tsinghua University, China

Abstract

When no samples are available to estimate aprobability distribution, we have to invite some domain experts toevaluate the belief degree that each event will occur. Perhaps some people think that the belief degree issubjective probability orfuzzy concept. However, it is usuallyinappropriate because both probability theory and fuzzy set theorymay lead to counterintuitive results in this case. In order torationally deal with belief degrees, anuncertainty theory was founded in 2007 and subsequently studiedby many researchers. Nowadays, uncertainty theoryhas become a branch of mathematics for modelling belief degrees.

This talk will introduce some fundamental concepts of uncertainty theory and discuss why uncertainty theory is useful in industrial engineering and management Science. This presentation is based on the speaker’s book Uncertainty Theory published by Springer-Verlag, Berlin

Brief Bio

Baoding Liu received his B.S. degree in 1986 from Nankai University, and his M.S. degree in 1989 and Ph.D. degree in 1993 from Chinese Academy of Sciences. He joined Tsinghua University as Associate Professor in 1996, and was appointed Professor of Mathematics in 1998. Dr. Liu's research led to the development of *uncertainty theory* that is a branch of mathematics for modeling belief degrees.

TUTORIAL TALK

Recent Advances in Hybrid Metaheuristics for Manufacturing Scheduling

Mitsuo Gen

Professor

Fuzzy Logic Systems Institute

Research Institute for Science and Technology

Tokyo University of Science, Japan

Abstract

Many combinatorial optimization problems (COP) in the real world manufacturing systems impose on more complex issues, such as complex structure, nonlinear constraints, and multiple objectives to be handled simultaneously and make the problem intractable to the traditional approaches because of NP-hard COP. In order to develop an efficient solution algorithm for finding a best solution with the reasonable computational time for NP-hard combinatorial problems, we have to consider the following very important issues:*Quality of solution*, *Computational time*, and E*ffectiveness of the nondominated solutions for multiobjective optimization problem (MOP)*.

Evolutionary algorithm (EA) is a subset of metaheuristics, a generic population-based metaheuristic such as genetic algorithm (GA), particle swarm optimization (PSO), and estimation of distribution algorithm (EDA). EA is based on principles from evolution theory, and it is very powerful and broadly applicable stochastic search and combinatorial optimization technique which is effective for solving various NP hard COP models.

This tutorial talk will be firstly introduced a brief survey of several metaheuristics based on EA such as GA, hybrid GA (HGA), multiobjective GA (MoGA), PSO and EDA for applying to various combinatorial optimization problems in real world manufacturing systems. Secondly real applications based on hybrid metaheuristics will be introduced the recent manufacturing scheduling topics such as semiconductor devices final testing scheduling, hard-disc drive devices (HDD) manufacturing scheduling, thin-film transistor-liquid crystal display (TFT-LCD) module assembly scheduling.

Brief Bio

Dr. Mitsuo Gen is a senior research scientist at Fuzzy Logic Systems Institute (FLSI) and visiting professor at Research Institute for Science and Technology, Tokyo University of Science (TUS), Japan. PhD in Engineering: Kogakuin University in 1975 and PhD in Informatics: Kyoto University in 2006. Faculty: Ashikaga Institute of Technology for 1974-2003 and Waseda University for 2003-2010. Visiting Faculty: University of California at Berkeley, 1999-2000; Texas A&M University, 2000; Hanyang University, 2010-2012; and National Tsing Hua University, 2012-2014. Fuzzy Logic Systems Institute, 2009-currently and Tokyo University of Science, 2014-currently.

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CONFERENCE SCHEDULE

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<tr><th colspan="2">December 8th</th><th colspan="2">December 9th</th><th colspan="2">December 10th</th><th colspan="2">December 11th</th></tr>
<tr><td rowspan="12">09:00 - 17:00</td><td rowspan="7">Registration</td><td>07:00 - 09:00</td><td>APIEMS Fellow Meeting</td><td rowspan="2">8:00 - 9:30</td><td rowspan="2">IFPR-APR meeting</td><td rowspan="3">08:20 - 10:00</td><td rowspan="3">Technical Sessions</td></tr>
<tr><td>09:00 - 09:30</td><td>Opening Speech</td></tr>
<tr><td>09:30 - 10:30</td><td>Keynote Speech 1</td><td>09:30 - 10:30</td><td>Keynote Speech 2</td></tr>
<tr><td>10:30 - 11:00</td><td>Coffee Break</td><td>10:30 - 11:00</td><td>Coffee Break</td><td>10:00 - 10:20</td><td>Coffee Break</td></tr>
<tr><td rowspan="2">11:00 - 12:00</td><td>Technical Sessions</td><td rowspan="2">11:00 - 12:00</td><td rowspan="2">Technical Sessions</td><td rowspan="2">10:20 - 12:00</td><td rowspan="2">Technical Sessions</td></tr>
<tr><td>Special Talk</td></tr>
<tr><td>12:00 - 13:00</td><td>Lunch</td><td>12:00 - 13:00</td><td>Lunch</td><td>12:00 - 13:00</td><td>Lunch</td></tr>
<tr><td rowspan="5">Excursion</td><td rowspan="2">13:00 - 14:40</td><td>Technical Sessions</td><td rowspan="2">13:00 - 14:40</td><td rowspan="2">Technical Sessions</td><td rowspan="6">13:30 – 17 :30</td><td rowspan="6">IU + Saigon HTP Tours (Optional)</td></tr>
<tr><td>Tutorial Talk</td></tr>
<tr><td>14:40 - 15:00</td><td>Coffee Break</td><td>14:40 - 15:00</td><td>Coffee Break</td></tr>
<tr><td rowspan="2">15:00 - 17:00</td><td>Technical Sessions</td><td rowspan="2">15:00 - 17:00</td><td rowspan="2">Technical Sessions</td></tr>
<tr><td>APIEMS Board Meeting</td></tr>
<tr><td>18:00 - 20:30</td><td>Welcome Reception</td><td></td><td></td><td>19:00 - 21:30</td><td>Gala Dinner</td></tr>
</table>

TECHNICAL SESSION SCHEDULE

Dec 9th	Day 1								
11:00 - 11:20	WM1-1	WM2-1	WM3-1	WM4-1	WM5-1	WM6-1	WM7-1	WM8-1	WM9-1
11:20 - 11:40	WM1-2	WM2-2	WM3-2	WM4-2	WM5-2	WM6-2	WM7-2	WM8-2	WM9-2
11:40 - 12:00	WM1-3	WM2-3	WM3-3	WM4-3	WM5-3	WM6-3	WM7-3	WM8-3	WM9-3
12:00 - 13:00	Lunch								
13:00 - 13:20	WA1-1	WA2-1	WA3-1	WA4-1	WA5-1	WA6-1	WA7-1	WA8-1	WA9-1
13:20 - 13:40	WA1-2	WA2-2	WA3-2	WA4-2	WA5-2	WA6-2	WA7-2	WA8-2	WA9-2
13:40 - 14:00	WA1-3	WA2-3	WA3-3	WA4-3	WA5-3	WA6-3	WA7-3	WA8-3	WA9-3
14:00 - 14:20	WA1-4	WA2-4	WA3-4	WA4-4	WA5-4	WA6-4	WA7-4	WA8-4	WA9-4
14:20 - 14:40	WA1-5	WA2-5	WA3-5	WA4-5	WA5-5	WA6-5	WA7-5	WA8-5	WA9-5
14:40-15:00	Coffee Break								
15:00 - 15:20	WA1-6	WA2-6	WA3-6	WA4-6	WA5-6	WA6-6	WA7-6	WA8-6	WA9-6
15:20 - 15:40	WA1-7	WA2-7	WA3-7	WA4-7	WA5-7	WA6-7	WA7-7	WA8-7	WA9-7
15:40 - 16:00	WA1-8	WA2-8	WA3-8	WA4-8	WA5-8	WA6-8	WA7-8	WA8-8	WA9-8
16:00 - 16:20	WA1-9	WA2-9	WA3-9	WA4-9	WA5-9	WA6-9	WA7-9	WA8-9	WA9-9
16:20 - 16:40	WA1-10	WA2-10	WA3-10	WA4-10	WA5-10	WA6-10	WA7-10	WA8-10	WA9-10
16:40 - 17:00	WA1-11	WA2-11	WA3-11	WA4-11		WA6-11	WA7-11	WA8-11	WA9-11
17:00 - 17:20	WA1-12			WA4-12					WA9-12

- ✓ **W**: Wednesday **T**: Thursday **F**: Friday
- ✓ **M**: Morning **A**: Afternoon
- ✓ **1st number** : Session number
- ✓ **2nd number** : Presentation order
- ✓ **Example** : WM1-2 (**Second presentation** of **Session 1** on Wednesday morning)

Dec 10th	Day 2								
11:00 - 11:20	TM1-1	TM2-1	TM3-1	TM4-1	TM5-1	TM6-1	TM7-1	TM8-1	TM9-1
11:20 - 11:40	TM1-2	TM2-2	TM3-2	TM4-2	TM5-2	TM6-2	TM7-2	TM8-2	TM9-2
11:40 - 12:00	TM1-3	TM2-3		TM4-3	TM5-3	TM6-3	TM7-3	TM8-3	TM9-3
12:00 - 13:00	Lunch								
13:00 - 13:20	TA1-1	TA2-1	TA3-1	TA4-1	TA5-1	TA6-1	TA7-1	TA8-1	TA9-1
13:20 - 13:40	TA1-2	TA2-2	TA3-2	TA4-2	TA5-2	TA6-2	TA7-2	TA8-2	TA9-2
13:40 - 14:00	TA1-3	TA2-3	TA3-3	TA4-3	TA5-3	TA6-3	TA7-3	TA8-3	TA9-3
14:00 - 14:20	TA1-4	TA2-4	TA3-4	TA4-4	TA5-4	TA6-4	TA7-4	TA8-4	TA9-4
14:20 - 14:40	TA1-5	TA2-5	TA3-5	TA4-5	TA5-5	TA6-5	TA7-5	TA8-5	TA9-5
14:40-15:00	Coffee Break								
15:00 - 15:20	TA1-6	TA2-6	TA3-6	TA4-6	TA5-6	TA6-6	TA7-6	TA8-6	TA9-6
15:20 - 15:40	TA1-7	TA2-7	TA3-7	TA4-7	TA5-7	TA6-7	TA7-7	TA8-7	TA9-7
15:40 - 16:00	TA1-8	TA2-8	TA3-8	TA4-8	TA5-8	TA6-8	TA7-8	TA8-8	TA9-8
16:00 - 16:20	TA1-9	TA2-9	TA3-9	TA4-9	TA5-9	TA6-9	TA7-9	TA8-9	TA9-9
16:20 - 16:40	TA1-10		TA3-10	TA4-10	TA5-10		TA7-10	TA8-10	TA9-10

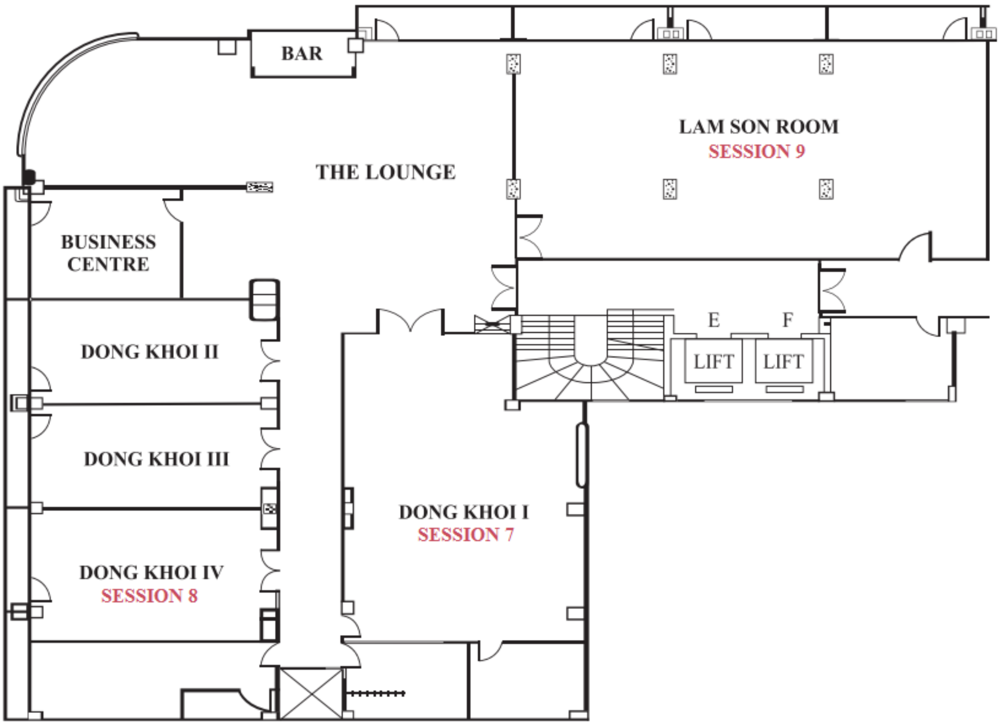
- ✓ **W**: Wednesday **T**: Thursday **F**: Friday
- ✓ **M**: Morning **A**: Afternoon
- ✓ **1st number** : Session number
- ✓ **2nd number** : Presentation order
- ✓ **Example** : WM1-2 (**Second presentation** of **Session 1** on Wednesday morning)

Dec 11th	Day 3								
08:20 - 08:40	FM1-1	FM2-1	FM3-1	FM4-1	FM5-1	FM6-1	FM7-1	FM8-1	FM9-1
08:40 - 09:00	FM1-2	FM2-2	FM3-2	FM4-2	FM5-2	FM6-2	FM7-2	FM8-2	FM9-2
09:00 - 09:20	FM1-3	FM2-3	FM3-3	FM4-3	FM5-3	FM6-3	FM7-3	FM8-3	FM9-3
09:20 - 09:40	FM1-4	FM2-4	FM3-4	FM4-4	FM5-4	FM6-4	FM7-4	FM8-4	FM9-4
09:40 - 10:00	FM1-5	FM2-5	FM3-5	FM4-5	FM5-5	FM6-5	FM7-5	FM8-5	FM9-5
10:00 - 10:20	Coffee Break								
10:20 - 10:40	FM1-6	FM2-6	FM3-6	FM4-6	FM5-6	FM6-6	FM7-6	FM8-6	FM9-6
10:40 - 11:00	FM1-7	FM2-7	FM3-7	FM4-7	FM5-7	FM6-7	FM7-7	FM8-7	FM9-7
11:00 - 11:20	FM1-8	FM2-8	FM3-8	FM4-8	FM5-8	FM6-8	FM7-8	FM8-8	FM9-8
11:20 - 11:40	FM1-9	FM2-9	FM3-9	FM4-9	FM5-9	FM6-9	FM7-9	FM8-9	FM9-9
11:40 - 12:00	FM1-10	FM2-10	FM3-10	FM4-10	FM5-10	FM6-10	FM7-10		FM9-10
12:00-13:00	Lunch								

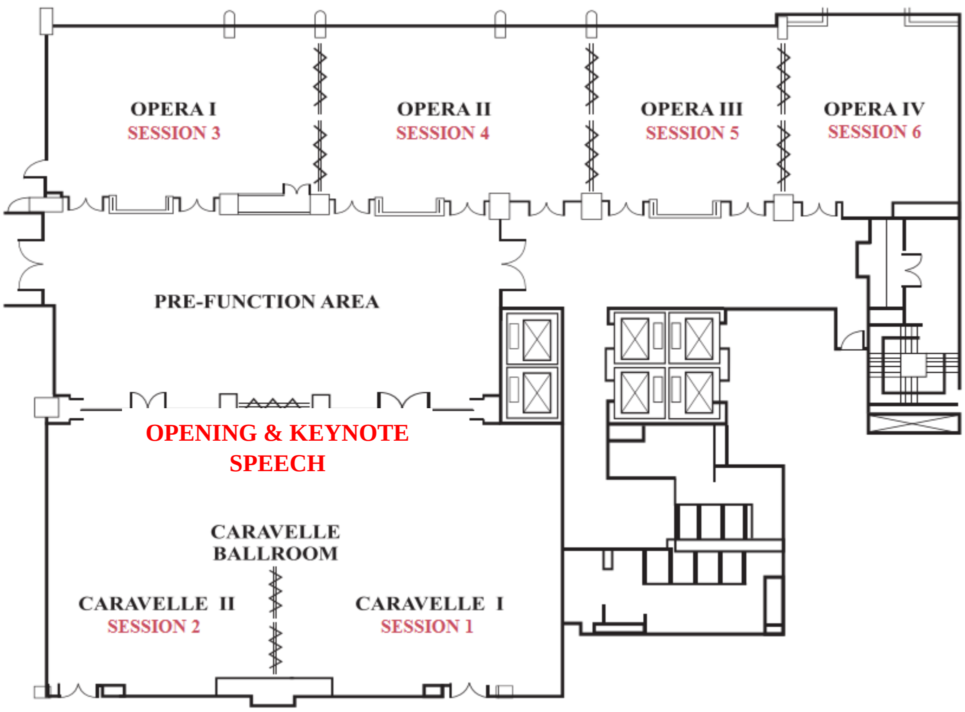
- ✓ **W**: Wednesday **T**: Thursday **F**: Friday
- ✓ **M**: Morning **A**: Afternoon
- ✓ **1st number** : Session number
- ✓ **2nd number** : Presentation order
- ✓ **Example** : WM1-2 (**Second presentation** of **Session 1** on Wednesday morning)

CONFERENCE VENUE LAYOUT

CARRAVELLE HOTEL



2nd Floor



3rd Floor

Note: - **SESSION 5** at day 1 will be changed to **Room 907 - 9th Floor**
- **Special Talk, Tutorial Talk, and meetings** are at **OPERA III**

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Detailed Program

TOPIC: COMPUTER AND AI

December 11th

TOPIC: DATA MINING

December 10th

TOPIC: E-BUSINESS

December 10th

TOPIC: ERGONOMIC

December 9th - December 11th

TOPIC: HEALTH CARE - ERGONOMIC

December 9th - December 11th

TOPIC: HUMAN COMPUTER INTERACTION - IMAGE PROCESSING

December 10th

TOPIC: LOGISTICS

December 11th

TOPIC: MANAGEMENT

December 11th

TOPIC: MCDM

December 10th

TOPIC: METAHEURISTIC

December 9th

WM4-1 (298)	**Minimization of Makespan in Multi-Door Cross Docking Problems by Particle Swarm Optimization** Warisa Wisittipanich† and Piya Hengmeechai	530

TOPIC: OPERATIONS RESEARCH 1

December 11th

TOPIC: OPERATIONS RESEARCH 2

December 11th - December 10th

TOPIC: OPTIMIZATION

December 11th

TOPIC: OPTIMIZATION TECHNIQUES - METAHEURISTIC

December 9th

TOPIC: PRODUCT DESIGN AND DEVELOPMENT

December 11th - December 9th

TOPIC: PRODUCT PLANNING AND MARKETING

December 9th

TOPIC: PRODUCTION AND OPERATIONS MANAGEMENT

December 9th

TOPIC: PRODUCTION DESIGN AND DEVELOPMENT

December 9th

TOPIC: QUALITY MANAGEMENT

December 10th

TOPIC: RELIABILITY - PROBABILITY MODEL

December 10th

TOPIC: SCHEDULING AND SEQUENCING

December 9th

TOPIC: SERVICE MANAGEMENT

December 10th

TOPIC: SIMULATION

December 10th

TOPIC: SUPPLY CHAIN MANAGEMENT

December 9th

TOPIC: SYSTEM MANAGEMENT

December 11th - December 9th

TOPIC: TOURISM MANAGEMENT

December 9th

TOPIC: TOURIST - EDUCATION

December 11th - December 10th

TOPIC: TRANSPORTATION - LOGISTICS

December 10th

TOPIC: OTHERS

A Joint Replenishment Inventory Model for Imperfect Quality Items with Shortages

The Jin Ai†, Ririn Diar Astanti
Department of Industrial Engineering
Universitas Atma Jaya Yogyakarta, Yogyakarta, Indonesia
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Dah-Chuan Gong
Department of Industrial and Business Management
Chang Gung University, Taoyuan, Taiwan
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Abstract. An *n* items joint replenishment inventory problem is considered here, where the demand of each items are constant and deterministic. A joint replenishment is conducted periodically every T time intervals. However, all items may not be included in each replenishment. Item i is only included every Z_iT time intervals. Replenishment of item are instantaneous and contain of imperfect quality items. After screening, items of poor quality are sorted, kept in stock and sold at a salvage value as a single batch within the replenishment cycle. Shortages are allowed and completely backordered with maximum backordering quantity B_i. Mathematical model is formulated in order to determining the basic time cycle T, replenishment multiplier Z_i, and backordering quantity B_i in order to maximize the expected total profit per unit time. A solution methodology is proposed for solve the model and a numerical example is provided for demonstrating the effectiveness of the proposed methodology.

Keywords: inventory model, joint replenishment, imperfect quality items, shortages.

1. INTRODUCTION

In order to obtain cost efficiency in the multi item inventory system, joint replenishment of items is one possible way to be conducted. In the inventory research literature, a problem so called the joint replenishment problem (JRP) has been investigated in order to address the situation in multi item inventory system where a group of items may be jointly ordered from a single supplier (Khouja and Goyal, 2008; Moon et al., 2008; Tsai et al., 2009; Wang et al., 2012)

Since assumption of perfect quality is unrealistic in the industrial application, nowadays there is a trend for relaxing the assumption of perfect quality in the inventory modeling research area. Salameh and Jaber (2000) proposed an economic production quantity model for a buyer who receives imperfect item from its supplier. After that, some other researchers have been extending their work by considering various operational setting in the inventory modeling (Konstantaras et al., 2007; Yoo et al., 2009; Chang and Ho, 2010). Shortage backorder also had been considered in some extension of this work, i.e. Rezaei (2005) and Wee et al. (2007).

In the JRP research area, only Paul et al. (2014) that has incorporated the relaxation of perfect quality items in the JRP model by considering the cases of with and without price discount. This paper is considering the case of shortage in the JRP model for imperfect quality items, that to the best of authors knowledge never been proposed before. A mathematical model is formulated for this situation and a solution methodology is proposed to solve the mathematical model.

The remainder of this paper is organized as follows: Second section is defining the problem formulation. After that the mathematical modeling and its solution methodology are proposed in section 3 and 4, respectively. Finally, some the conclusion of this study is presented with some suggestions for further research in this research area.

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2. PROBLEM FORMULATION

An n items inventory problem is considered here, where the demand of each items are constant and deterministic. The demand rate of item i is D_i units per unit time. Replenishment of item i is instantaneous with size of y_i units and unit-purchasing price of \$$c_i$. A joint replenishment is conducted periodically every T time intervals. However, all items may not be included in each replenishment. Item i is only included every Z_iT time intervals. In other word, Z_iT is the cycle time of item i. A replenishment incurs of major ordering cost \$$K$ and minor ordering cost \$$k_i$ for every item i included in the replenishment. Each lot received contains p_i fraction of defectives, in which $0 < p_i < 1$, with a known probability density function $f_i(p_i)$. For identifying defectives, a 100% screening process of the lot is conducted at a rate of x_i where $x_i > D_i$. The screening cost of item i is \$$d_i$ per unit. Items of poor quality are sorted, kept in stock and sold at a salvage value of \$$v_i$ per unit as a single batch within the replenishment cycle. The inventory holding cost of item i is \$$h_i$ per unit per unit time and the selling price of good-quantity items is \$$s_i$ per unit. Shortages are allowed and completely backordered. The maximum backordering quantity of item i is B_i and the backordering cost of item i is \$$b_i$ per unit. The decision to be taken in this situation is determining the basic time cycle T, replenishment multiplier Z_i, and backordering quantity B_i in order to maximize the expected total profit per unit time.

Problem Assumption

1. The demand rate for each item is constant and deterministic.
2. The replenishment lead time is known and constant.
3. The replenishment is instantaneous.
4. The entire order quantity is delivered at the same time.
5. The screening process and demand for all items proceed simultaneously, but the screening rates are greater than demand rates, $x_i > D_i$.
6. The defective items exist in lot size y_i. The defective percentage, p_i, has a uniform distribution with $[\alpha_i, \beta_i]$, where $0 < \alpha_i < \beta_i < 1$.
7. Shortage is completely backordered.

3. MATHEMATICAL MODEL

The inventory cycle for item i with imperfect quality and complete backordering is illustrated in Figure 1. After screening process is completed at time t, the inventory level is reduced by p_iy_i unit due to the withdrawal of defective items. Stock shortage are allowed and completely backlogged at the beginning of each cycle. Shortages are avoided within the screening time, hence p_i is restricted to

$$p_i \le 1 - \frac{D_i}{x_i} \tag{1}$$

Total revenue per cycle of item i can be calculated as

$$TR_i = (1-p_i)\, y_i s_i + p_i y_i v_i \tag{2}$$

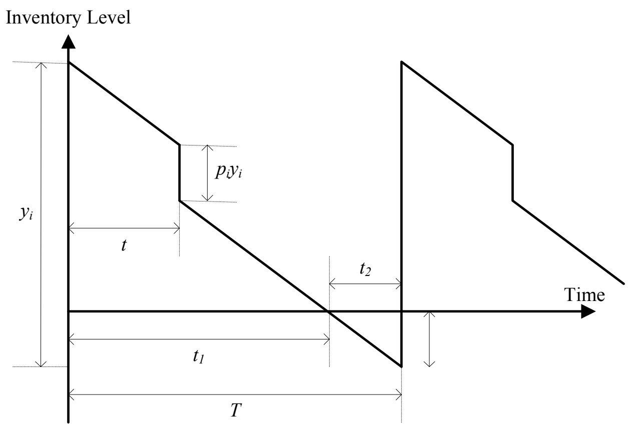

Figure 1. Inventory system behavior

Since $Z_iT = (1-p_i)\, y_i / D_i$, the relationship between order size and replenishment time can be stated as

$$y_i = \frac{Z_i T D_i}{(1-p_i)} \tag{3}$$

Hence, after substituting Eq. (3) into Eq. (2) and some algebra, the total revenue per unit time is

$$TRU = \sum_{i=1}^{n} D_i \left(s_i + \frac{p_i}{(1-p_i)} v_i \right) \tag{4}$$

Therefore, the expected total revenue per unit time for uniformly distributed defective can be formulated as

$$ETRU = \sum_{i=1}^{n} D_i \left(s_i + \frac{\alpha_i + \beta_i}{2} \frac{1}{\beta_i - \alpha_i} \ln\left(\frac{1-\alpha_i}{1-\beta_i} \right) v_i \right) \tag{5}$$

The sum of purchasing cost, screening cost, holding cost, and backordering cost of item i can be stated as

$$TC_i = c_i y_i + d_i y_i + h_i \left(\frac{1}{2} \frac{(y_i - p_i y_i - B_i)^2}{D_i} + \frac{p_i y_i^2}{x_i} \right) + \frac{1}{2} \frac{b_i B_i^2}{D_i} \tag{6}$$

Adding the major and minor ordering cost for the case of joint replenishment, the total cost per unit time can be calculated as

$$TCU = \frac{K}{T} + \frac{\sum_{i=1}^{n} \frac{k_i}{Z_i}}{T} + \sum_{i=1}^{n} \frac{TC_i}{Z_i T} \quad (7)$$

After some algebra and substituting the probability density function of the percentage defective items, the expectation of total cost can be formulated as

$$ETCU = \frac{K}{T} + \frac{\sum_{i=1}^{n} \frac{k_i}{Z_i}}{T} + \sum_{i=1}^{n} \left(c_i + d_i\right) D_i \frac{1}{\beta_i - \alpha_i} \ln\left(\frac{1-\alpha_i}{1-\beta_i}\right) + h_i \left(\frac{1}{2} T Z_i D_i - B_i + \frac{1}{2} \frac{B_i^2}{Z_i T D_i} + \frac{T Z_i D_i^2}{x_i} \frac{\beta_i + \alpha_i}{2} \frac{1}{\left(1-\alpha_i\right)\left(1-\beta_i\right)} \right) + \frac{1}{2} \frac{b_i B_i^2}{D_i T Z_i} \quad (8)$$

The expected net profit per unit time, ETPU, is determined by the expected total revenue per unit time less the expected total cost per unit time

$$ETPU = ETRU - ETCU \quad (9)$$

Therefore, the expected net profit per unit time can be stated as function of variables, i.e. $ETPU = f\left(T, Z_i, B_i\right)$

4. SOLUTION METHODOLOGY

The expression of *ETPU* is consist of both real variables, i.e. T and B_i, and integer variables, i.e. Z_i. Therefore, an iterative procedure is proposed here:

Step 1. Set initial value of $Z_i = 1$, initial value of $B_i = 0$.
Step 2. Given Z_i and B_i, find the optimal value of T. This is a single variable optimization of T, see section 4.1 for the derivation of T.
Step 3. Given T and B_i, find the optimal value of Z_i. The condition for obtaining Z_i is presented in section 4.2
Step 4. Given T and Z_i, the optimal value of B_i can be found independently, see section 4.3 for the derivation.
Step 5. Repeat from step 2 until convergence is reached, i.e. the current result of T is similar with previous calculated T.

4.1. Derivation of *T* in the Step 2

Given the value of Z_i and B_i, the *ETPU* is function of single variable T. Set the necessary condition of single variable optimization, i.e. the first derivative of the function equal to zero, one can obtain

$$T^* = \sqrt{\frac{\left(K + \sum_{i=1}^{n} \left(\frac{k_i}{Z_i} + \frac{h_i}{2} \frac{B_i^2}{Z_i D_i} + \frac{1}{2} \frac{b_i B_i^2}{D_i Z_i} \right)\right)}{\sum_{i=1}^{n} \left(\frac{h_i}{2} Z_i D_i + \frac{h_i Z_i D_i^2}{x_i} \frac{\beta_i + \alpha_i}{2\left(1-\alpha_i\right)\left(1-\beta_i\right)} \right)}} \quad (10)$$

For the first iteration, where all $Z_i = 1$ and $B_i = 0$, the optimal value of T can be simplified into

$$T^* = \sqrt{\frac{\left(K + \sum_{i=1}^{n} k_i\right)}{\sum_{i=1}^{n} h_i \left(\frac{1}{2} D_i + \frac{D_i^2}{x_i} \frac{\beta_i + \alpha_i}{2\left(1-\alpha_i\right)\left(1-\beta_i\right)} \right)}} \quad (11)$$

It is noted that the second derivative of *ETPU* with respect to T can be derived as

$$\frac{d^2 ETPU}{dT^2} = -\frac{2}{T^3} \left(K + \sum_{i=1}^{n} \left(\frac{k_i}{Z_i} + \frac{h_i}{2} \frac{B_i^2}{Z_i D_i} + \frac{1}{2} \frac{b_i B_i^2}{D_i Z_i} \right) \right) \quad (12)$$

Therefore, it can be shown that T^* calculated in Equation (10) or (11) is a maximum point.

4.2. Obtaining Z_i in the Step 3

Given any value of B_i and T, the *ETPU* is a multi variable optimization of integer Z_i. The expression of *ETPU* can be rewritten as follow

$$ETPU = ETPU_0 - \sum_{i=1}^{n} ETPU_i\left(Z_i\right) \quad (13)$$

Therefore, the problem of maximizing *ETPU* can be dividing into problems of minimizing $ETPU_i(Z_i)$ independently. Since Z_i is a discrete integer, the optimality conditions of $ETPU_i(Z_i)$ are

$$ETPU_i\left(Z_i^*\right) \le ETPU_i\left(Z_i^* + 1\right) \quad (14)$$

and

$$ETPU_i\left(Z_i^*\right) \le ETPU_i\left(Z_i^* - 1\right) \quad (15)$$

After some algebra, the optimality condition for Z_i can be written as follow

$$Z_i^*\left(Z_i^* - 1\right) \le \Psi_i \le Z_i^*\left(Z_i^* + 1\right) \quad (16)$$

where

$$\Psi_i = \frac{1}{T^2} \frac{k_i + \frac{B_i^2}{2D_i}\left(h_i + b_i\right)}{\frac{h_i}{2} D_i + \frac{h_i D_i^2}{x_i} \frac{\beta_i + \alpha_i}{2\left(1-\alpha_i\right)\left(1-\beta_i\right)}} \quad (17)$$

4.3. Derivation of B_i in the Step 4

Given any value of Z_i and T, the $ETPU$ is a multi variable optimization of B_i. Since B_i are real variable, one can take the first derivative of the function equal to zero as the necessary optimality condition.

$$\frac{\partial}{\partial B_i} ETPU = h_i - \frac{B_i}{TZ_i D_i}\left(h_i + b_i\right) = 0 \tag{18}$$

Therefore, the optimal value of B_i can be stated as

$$B_i{*} = \frac{h_i}{\left(h_i + b_i\right)} Z_i T D_i \tag{19}$$

It is noted that the second partial derivative of B_i are

$$\frac{\partial^2}{\partial B_i^{\,2}} ETPU = -\frac{\left(h_i + b_i\right)}{TZ_i D_i} \quad \forall i = 1 \ldots n \tag{20}$$

$$\frac{\partial^2}{\partial B_i \partial B_j} ETPU = 0 \qquad \forall i \neq j \tag{21}$$

Hence, one can prove that the Hessian matrix is negative definite. Therefore, it can be shown that the B_i* is the maximum point.

5. NUMERICAL EXAMPLE

In order to show the applicability of the proposed method, a numerical example of 4 items inventory problem is presented here with. The major ordering cost is $40. The other problem parameters are presented in the Table 1.

Table 1: Problem Parameters

i	1	2	3	4
D_i	10000	2000	4000	500
c_i	20	5	30	15
h_i	2	0.5	3	1.5
x_i	20000	3000	7500	2500
d_i	0.4	0.2	0.3	0.5
v_i	10	2.5	15	7.5
k_i	15	15	15	15
α_i	0	0	0	0
β_i	0.25	0.3	0.2	0.25
b_i	5	3	4	10

Following proposed methodology in Section 4, the value of T, Z_i, and B_i can be calculated as shown in Table 2. It is noted that the process is convergence after 6 iterations.

Table 2: Calculation Steps

Iteration	T	i	1	2	3	4
1	0.0716	Z_i	1	1	1	1
		B_i	0	0	0	0
2	0.0665	Z_i	1	2	1	3
		B_i	204.55	40.91	122.73	14.01
3	0.0660	Z_i	1	2	1	3
		B_i	190.05	38.01	114.03	13.01
4	0.0660	Z_i	1	2	1	3
		B_i	188.63	37.73	113.18	12.92
5	0.0660	Z_i	1	2	1	3
		B_i	188.50	37.70	113.10	12.91
6	0.0660	Z_i	1	2	1	3
		B_i	188.48	37.70	113.09	12.91
7	0.0660	Z_i	1	2	1	3
		B_i	188.48	37.70	113.09	12.91

6. CONCLUDING REMARK

This paper is successfully presented a mathematical model for joint replenishment inventory system considering imperfect quality items and shortage. A solution methodology for solving the model is also proposed altogether with one numerical example. This model and solution methodology is ready to be extended to other problem variants that are commonly exist in the inventory research area.

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