



**Proceedings of Abstracts and Papers of  
The 16<sup>th</sup> Asia Pacific Industrial Engineering  
And Management Systems Conference (APIEMS 2015)**

December 8<sup>th</sup> – 11<sup>th</sup>, 2015  
Ho Chi Minh City, Vietnam

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**VNU-HCMC PRESS – 2015**

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

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THE 16<sup>TH</sup> ASIA PACIFIC  
INDUSTRIAL ENGINEERING  
AND MANAGEMENT SYSTEMS  
CONFERENCE (APIEMS 2015)**

*AUTHORS*

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**First published in 2015**

**VNU-HCMC PRESS**

Quarter 6, Linh Trung Ward, Thu Duc District, Ho Chi Minh City  
Block C, 10-12 Dinh Tien Hoang Street, Ben Nghe Ward, District 1, Ho Chi Minh City  
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**DISTRIBUTION OFFICE**

Block C, 10-12 Dinh Tien Hoang Street, Ben Nghe Ward, District 1, Ho Chi Minh City  
Tel: 86 272 6361 – 86 272 6390  
Website: [www.nxbdhqghcm.edu.vn](http://www.nxbdhqghcm.edu.vn)

*Responsible for publishing:*  
**NGUYEN HOANG DUNG**

*Responsible for content:*  
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*Responsible for manuscript and authorship:*  
**VNU-HCMC INTERNATIONAL UNIVERSITY**

*Responsible for editing:*  
**PHAN THI THANH THANH  
BUI TRAN CA DAO  
VU THI HANH TRANG**

*Responsible for printing preparation:*  
**THANH THANH  
AN NHIEU  
CA DAO**

*Cover design:*  
**VNU-HCMC INTERNATIONAL UNIVERSITY**

Quantity: 400 copies,  
Size 20 x 28 cm,  
Publishing Registration No.:  
3677-2015/CIBIPH/  
01-425/DHQGTPHCM,  
Publishing Decision No.: 224/QĐ  
issued on November 30<sup>th</sup> 2015  
by VNU-HCM Publishing House  
Printed at Hung Phu Printing  
and Packaging Company Limited.  
Address: 162A/1 – Quarter 1A – An Phu  
Ward – Thuan An Town – Binh Duong  
Province  
Archival copy submitted:  
Quarter IV/2015

**ISSN: 2350 – 742X**

**ISBN: 978 – 604 – 73 – 3787 – 3**

## 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 16<sup>th</sup> 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!

A handwritten signature in black ink that reads "Bernard C. Jiang". The signature is stylized with a large, sweeping underline.

*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 Analytics to 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 Chien** is 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 a probability distribution, we have to invite some domain experts to evaluate the belief degree that each event will occur. Perhaps some people think that the belief degree is subjective probability or fuzzy concept. However, it is usually inappropriate because both probability theory and fuzzy set theory may lead to counterintuitive results in this case. In order to rationally deal with belief degrees, an uncertainty theory was founded in 2007 and subsequently studied by many researchers. Nowadays, uncertainty theory has 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 *Effectiveness 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.

# CONFERENCE COMMITTEE

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- Karim Labadi (EPMI, France)

## CONFERENCE SCHEDULE

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

# TECHNICAL SESSION SCHEDULE

Dec 9 <sup>th</sup>	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
- ✓ **1<sup>st</sup> number** : Session number
- ✓ **2<sup>nd</sup> number** : Presentation order
- ✓ **Example** : WM1-2 (**Second presentation of Session 1** on Wednesday morning)

<b>Dec 10<sup>th</sup></b>	<b>Day 2</b>								
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	<b>Lunch</b>								
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	<b>Coffee Break</b>								
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

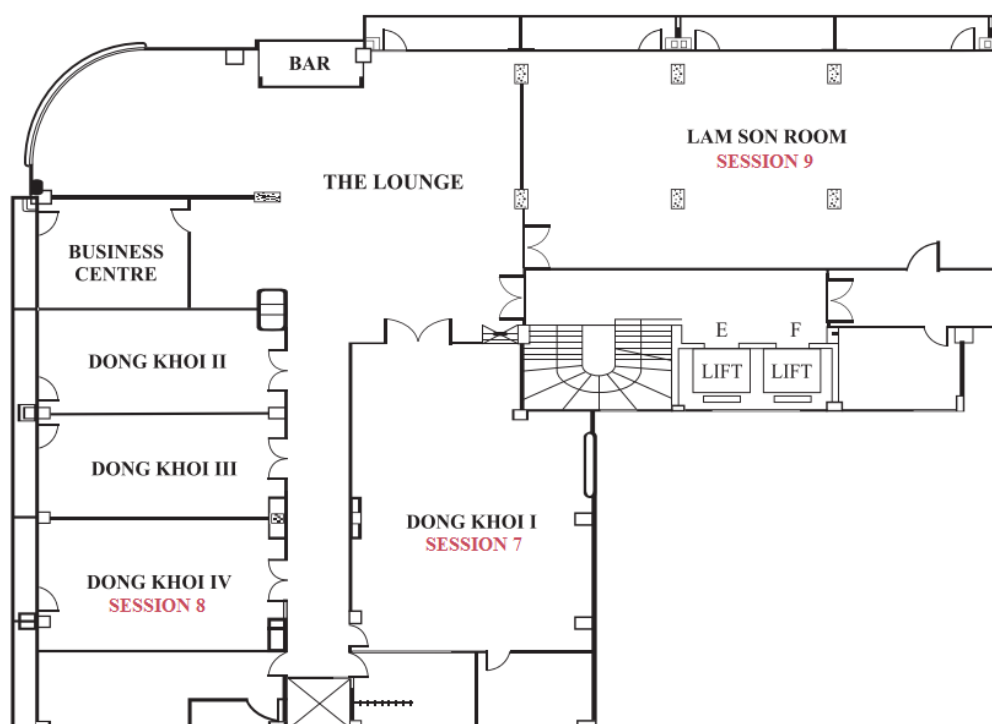
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- ✓ **2<sup>nd</sup> number** : Presentation order
- ✓ **Example** : WM1-2 (**Second presentation of Session 1** on Wednesday morning)

<b>Dec 11<sup>th</sup></b>	<b>Day 3</b>								
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	<b>Coffee Break</b>								
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	<b>Lunch</b>								

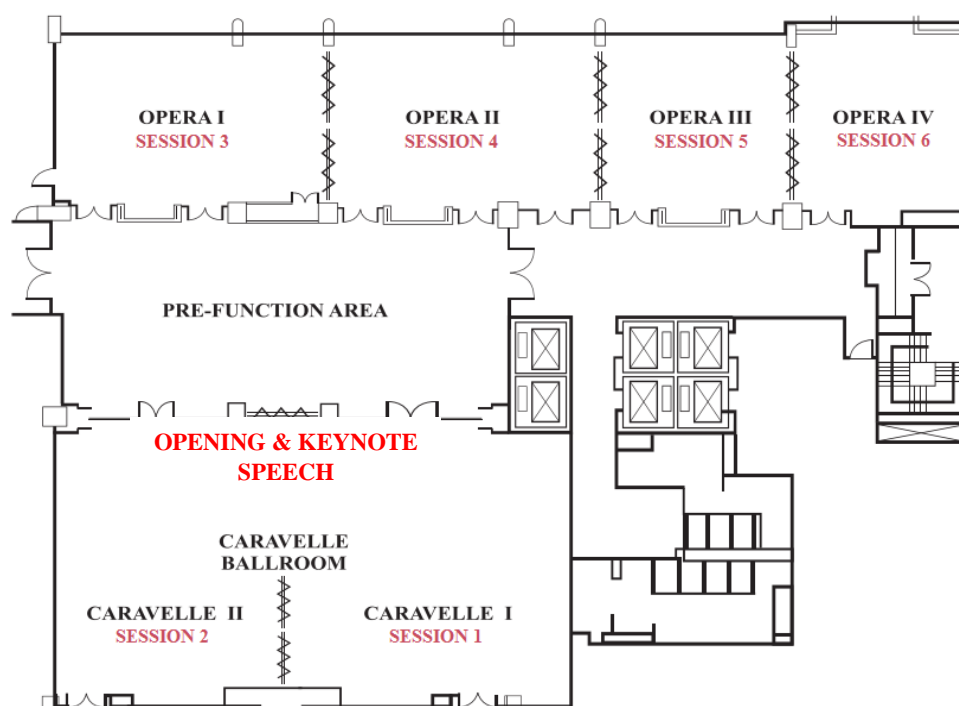
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- ✓ **1<sup>st</sup> number** : Session number
- ✓ **2<sup>nd</sup> number** : Presentation order
- ✓ **Example** : WM1-2 (**Second presentation** of **Session 1** on Wednesday morning)

# CONFERENCE VENUE LAYOUT

## CARRAVELLE HOTEL



**2<sup>nd</sup>  
Floor**



**3<sup>rd</sup>  
Floor**

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



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# Detailed Program

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[TOPIC: DATA MINING](#)

[TOPIC: DECISION MODELING](#)

[TOPIC: E-BUSINESS](#)

[TOPIC: ERGONOMIC](#)

[TOPIC: FINANCIAL - E-BUSINESS](#)

[TOPIC: HEALTH CARE](#)

[TOPIC: HEALTH CARE - ERGONOMIC](#)

[TOPIC: HUMAN COMPUTER INTERACTION - IMAGE PROCESSING](#)

[TOPIC: LOGISTICS](#)

[TOPIC: MANAGEMENT](#)

[TOPIC: MCDM](#)

[TOPIC: METAHEURISTIC](#)

[TOPIC: OPERATIONS RESEARCH 1](#)

[TOPIC: OPERATIONS RESEARCH 2](#)

[TOPIC: OPTIMIZATION](#)

[TOPIC: OPTIMIZATION TECHNIQUES - METAHEURISTIC](#)

[TOPIC: PRODUCT DESIGN AND DEVELOPMENT](#)

[TOPIC: PRODUCT PLANNING AND MARKETING](#)

[TOPIC: PRODUCTION AND OPERATIONS MANAGEMENT](#)

[TOPIC: PRODUCTION DESIGN AND DEVELOPMENT](#)

[TOPIC: QUALITY MANAGEMENT](#)

[TOPIC: RELIABILITY - PROBABILITY MODEL](#)

[TOPIC: SCHEDULING AND SEQUENCING](#)

[TOPIC: SERVICE MANAGEMENT](#)

[TOPIC: SIMULATION](#)

[TOPIC: SUPPLY CHAIN MANAGEMENT](#)

[TOPIC: SYSTEM MANAGEMENT](#)

[TOPIC: TOURISM MANAGEMENT](#)

[TOPIC: TOURIST - EDUCATION](#)

[TOPIC: TRANSPORTATION - LOGISTICS](#)

[TOPIC: OTHERS](#)

## TOPIC: COMPUTER AND AI

December 11th

<b>FM3-1 (195)</b>	<b>Sequencing-Coordinate-Capacity Particle Swarm Optimization Algorithm for Solving the Open Vehicle Routing Problem with Time Windows</b> Chun-Hsiung Lai, Yu-Ren Wang†, Chen-Yang Cheng	1
<b>FM3-3 (209)</b>	<b>Classification of EEG Analysis of Imagined Movement for EEG-Based Brain-Computer Interface</b> MikitoUmeda, SakikoOgoshi†, Yasuhiro Ogoshi, Yoshinori Mituhasi, Tomohiro Takezawa	8
<b>FM3-4 (255)</b>	<b>Observations of coastal fishery in Japan from the viewpoint of work conditions</b> Hideyuki Takahashi†	13
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## TOPIC: DATA MINING

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<b>TA8-1 (45)</b>	<b>A Study On The Estimation Method Of The Resident'S Location Using The Plant Bioelectric Potential</b> Hidetaka Nambo †, Zhang Qiang, Haruhiko Kimura and Masamichi Nitta	1896
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TA8-4 (67)	<b>Estimation of Video Highlight Scenes Using EEG</b> Masashi Miyazaki, Tadanobu Misawa†, Yasuhiro Inazumi and Shigeki Hirobayashi	1915
TA8-5 (68)	<b>Mental stress classification supposing Pulse-wave Computer Interface</b> Yusuke Okutani and Tadanobu Misawa †, and Shigeki Hirobayashi	1921
TA8-6 (78)	<b>Difficulty identification of English sentence</b> Ryo Oguri †, Hidetaka Nambo, Haruhiko Kimura and Hiromi Ban	1929
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# A Joint Replenishment Inventory Model for Imperfect Quality Items with Shortages

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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  $Z_i T$  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  $Z_i T$  time intervals. In other word,  $Z_i T$  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  $p_i y_i$  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

$$p_i \leq 1 - \frac{D_i}{x_i} \quad (1)$$

Total revenue per cycle of item  $i$  can be calculated as

$$TR_i = (1 - p_i) y_i s_i + p_i y_i v_i \quad (2)$$

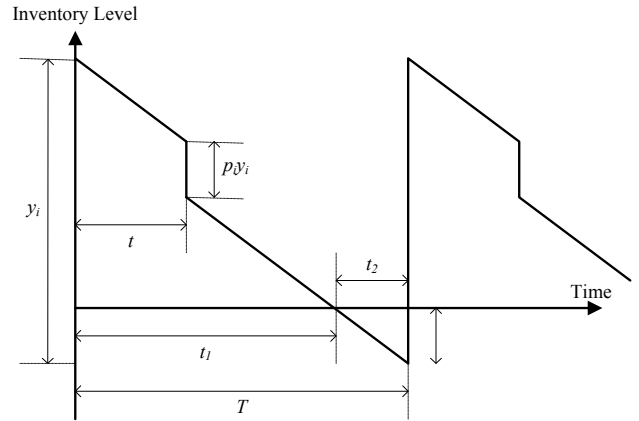


Figure 1. Inventory system behavior

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

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

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

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

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

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

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

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

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

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

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.  $ETPU = f(T, Z_i, B_i)$

## 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

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

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

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

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

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

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

$$ETPU_i(Z_i^*) \leq ETPU_i(Z_i^* + 1) \quad (14)$$

and

$$ETPU_i(Z_i^*) \leq ETPU_i(Z_i^* - 1) \quad (15)$$

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

$$Z_i^* (Z_i^* - 1) \leq \Psi_i \leq Z_i^* (Z_i^* + 1) \quad (16)$$

where

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



#### 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.

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

Therefore, the optimal value of  $B_i$  can be stated as

$$B_i^* = \frac{h_i}{(h_i + b_i)} Z_i T D_i \quad (19)$$

It is noted that the second partial derivative of  $B_i$  are

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

$$\frac{\partial^2}{\partial B_i \partial B_j} ETPU = 0 \quad \forall i \neq j \quad (21)$$

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
$\alpha_i$	0	0	0	0
$\beta_i$	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.

#### ACKNOWLEDGMENT

This work is partially supported by Directorate General of Higher Education, Ministry of Education and Culture, Republic Indonesia under International Research Collaboration and Scientific Publication Research Grant No. 086/SP2H/PL/DIT.LITABMAS/V/2013, No. 1317/K5/KM/2014, and No. 005/HB-LIT/III/2015.

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