香 港 大 學
THE UNIVERSITY OF HONG KONG

APIEMS 2018

CONFERENCE HANDBOOK

APIEMS

The 19th Asia Pacific Industrial Engineering

And Management Systems Conference

Date: 5 - 8 December 2018

Venue: The University of Hong Kong

Regal Hongkong Hotel, Causeway Bay, Hong Kong

Scan for HKU

Scan for Program

Contents

Welcome Message

On behalf of the organizers of the 19th Asia Pacific Industrial and Engineering Management Systems Conference (APIEMS2018), we would like to welcome all the participants and friends to this conference at The University of Hong Kong.

Following a series of successful meetings in Asia-Pacific countries, the APIEMS2018 Conference is organized by HKU and sponsored by Asia Pacific Industrial Engineering and Management Society. The APIEMS2018 continues the series of APIEMS conference to provide a forum for exchanging ideas and information about latest developments in the field of industrial engineering and management system among professionals from Asia-Pacific countries. Experts and educators use this platform to carry out in-depth analysis and discussion upon the theoretical and practical issues related to the new opportunities and challenges in industrial engineering and management system.

Our technical program is rich and includes 4 keynote speeches, an editor forum with editors from 5 famous journals and around 250 technical papers split into several parallel sessions. Besides, open dialogs are also organized for participants to renew friendships, extend networks, and jointly explore current and future research directions. It is hoped that this conference contributes to the development and innovation of industrial engineering and management system field.

Lastly, we would like to thank all the conference participants for their contributions which are the foundation of this conference. We wish all participants of the conference an enjoyable and fruitful experience.

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Professor Fugee Tsung
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Conference Organizations

Conference Chairs

Professor George Q. Huang
Chair professor and Head
Department of Industrial and Manufacturing Systems Engineering
The University of Hong Kong
Professor Fugee Tsung
Professor
Department of Industrial Engineering and Decision Analytics
Hong Kong University of Science and Technology

Program Chairs

Henry Lau, The University of Hong Kong, Hong Kong
Anthony S.F. Chiu, De La Salle University, Philippines

Organizing Committee Chairs

Calvin Or, The University of Hong Kong, Hong Kong
Richard Fung, City University of Hong Kong, Hong Kong

Organizing Committee Members

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S.H. Choi, The University of Hong Kong, Hong Kong
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Gary P.C. Tsui, The Hong Kong Polytechnic University, Hong Kong
Shuaian (Hans) WANG, The Hong Kong Polytechnic University, Hong Kong

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International Scientific and Program Committee Members

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Hing Kai Chan, Nottingham University Business School China, China
Hirokazu Kono, Keio University, Japan
Ho Thanh Phong, International University, Vietnam
Huynh Trung Luong, AIT, Thailand
Ilkyeong Moon, Seoul National University, Korea
Jaewook Lee, Seoul National University, Korea
Jin Peng, Tsinghua University, China
JinWu Gao, Renmin University of China, China
Kai Ling Mak, The University of Hong Kong, Hong Kong
Kanchana Sethanan, Khon Kaen University, Thailand
Kap Hwan Kim, Pusan National University, Korea
Katsuhiko Takahashi, Hiroshima University, Japan
Kazuyoshi Ishii, Kanazawa Institute of Technology, Japan
Kenichi Nakashima, Kanagawa University, Japan
Kim Hua Tan, Nottingham University, Malaysia
Kin Keung Lai, The University of Hong Kong, Hong Kong
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Kuo-Ming Wang, Yuan Ze University, Taiwan
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Mao Jiun Wang, National Tsing Hua University, Taiwan
Mitsuo Gen, Waseda University, Japan
Mooyoung Jung, UNIST, Korea
Nyoman Pujawan, Institut Teknologi Sepuluh Nopember, Indonesia
Rosa Abbou, University of Nantes, France
Shanlin Yang, Hefei University of Technology, China
Sha'ri bin Mohd Yusof, Universiti Teknologi Malaysia, Malaysia
Takashi Irohara, Sophia University, Japan
Takashi Oyabu, Kokusai Business Gakuin College, Japan
Voratas Kachitvichyanukul, AIT, Thailand
Yiming Wei, Beijing Institute of Technology, China
Young Hae Lee, Hanyang University, Korea
Zahari Taha, Universiti Malaysia Pahang, Malaysia

Secretariats

Ms. Abbie Ko, Ms. Crystal Cheung, Dr. Yelin Fu, Ms. Mandy Wang, Mr. Daqiang Guo, Mr. Zhongyuan Lyn, Mr. Zhicheng Liang, Mr. Yijia Wang, Ms. Tianrong Chen, Ms. Min Jiang, Ms. Yue Gao, Ms. Qiqi Chen, Mr. Yan Wang, Mr. Mingxin Li

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Technical support	Dr. Leith Chan	22415178
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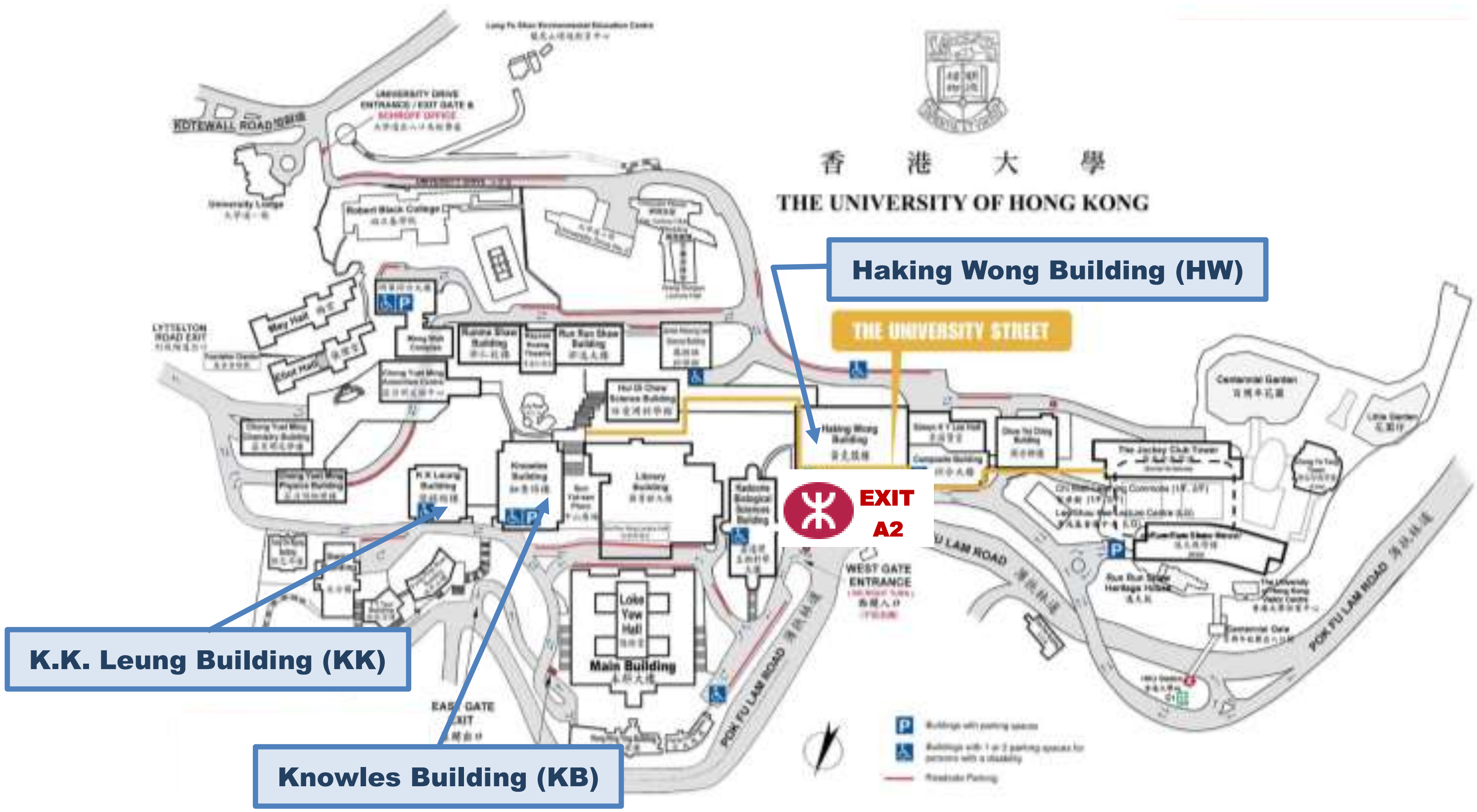
	Mr. Yijia Wang	67208856
Hotel	Ms. Crystal Cheung	28592668
Lunch & Dinner	Ms. Crystal Cheung	28592668
HKU IMSE Dept Office	Ms. Abbie Ko	28578338
IEPGA	Ms. Mandy Wang	68105132

Emergencies

Police, Fire, Ambulance 999

Conference Map and Conference Venue

Go to the Exit A2 of HKU station and take the lift to the HKU Footbridge (FB). Then go ahead and walk to Haking Wong Building on Dec 5th. On Dec. 8th, please go along the University Street to K.K. Leung Building for parallel sessions and Knowles Building for closing ceremony. More details about the venue can be found at http://www.maps.hku.hk/



Venue - Haking Wong Building (Dec 5th), K.K. Leung Building and Knowles Building (Dec 8th)

Regal Hongkong Hotel

Address: 88 Yee Wo St, Causeway Bay, Hong Kong

Website: https://www.regalhotel.com/regal-hongkong-hotel/en/home/home.html

Phone: +852 2890 6633

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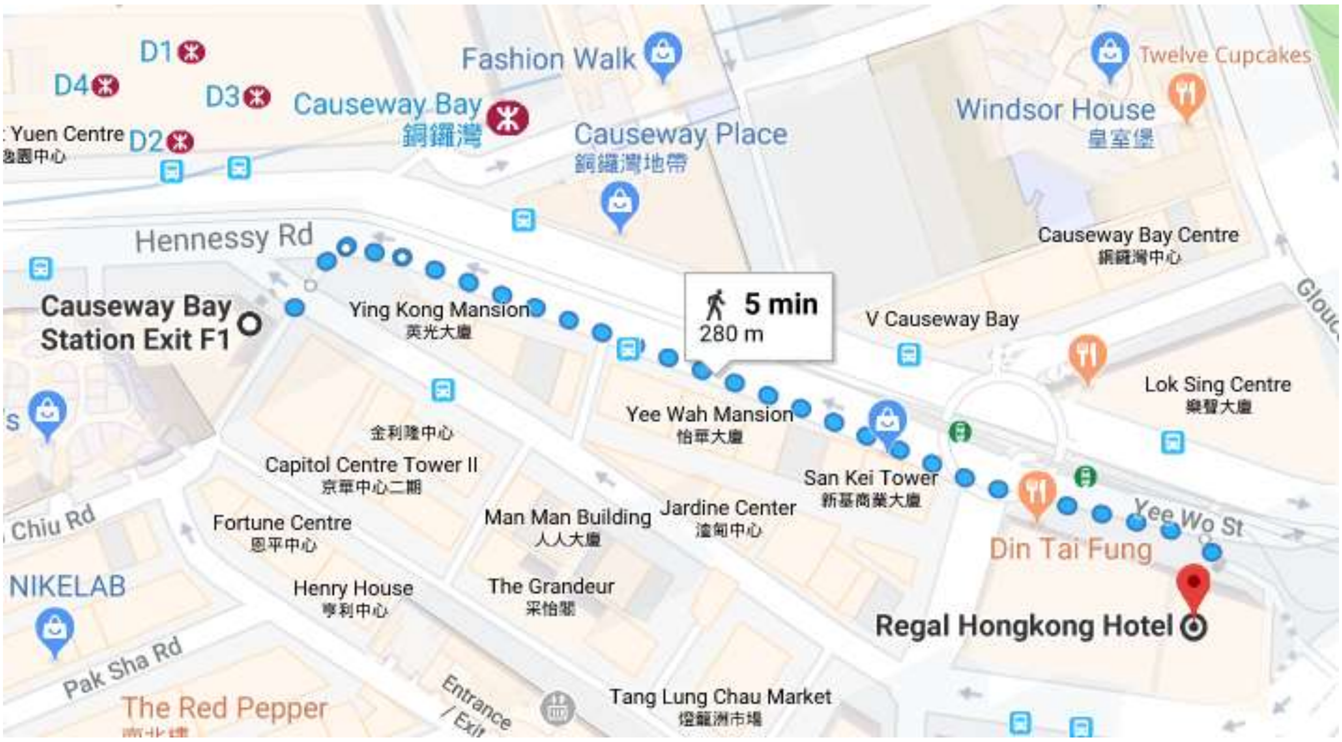
To HKU: 5-min walk to the **Exit F1** of **Causeway Bay** MTR Station, then take the Island Line towards Kennedy Town for 6 stops. Get off at the **HKU** MTR station, and go to the **Exit A2** to HKU campus.



Keynote Speeches

Professor Christopher Tang

UCLA University Distinguished Professor

Edward Carter Chair in Business Administration

UCLA Anderson School

Title: Making Supply Chain Transparent for a Better World: Information and Analysis

Abstract: Companies are gaining more supply chain visibility to reduce their supply chain risks, but few are disclosing what they know with the public. Should a firm disclose its supply chain information to the public? What are the risks and opportunities? I plan to present some recent research and case-based studies to illustrate how supply chain transparency can improve our world: planet, people and profit.

About the speaker: Dr. Tang is a University Distinguished Professor and the holder of the Edward W. Carter Chair in Business Administration at the UCLA Anderson School of Management. He served as Dean at the NUS Business School, and as Senior Associate Dean at the UCLA Anderson School.

Known as a world renowned thought leader in global supply chain management who has published over 130 research articles and 6 books, Chris consulted with over 10 international companies including HP and IBM, taught courses at various universities including Stanford and UC Berkeley; and delivered over 200 keynote speeches and seminars.

Dr. Tang is a fellow of Institute of Operations and Management Sciences (INFORMS), Production and Operations Management Society (POMS), and Manufacturing and Service Operations Management Society (MSOM). Currently, he serves as Editor-in-Chief for a premier journal Manufacturing & Service Operations Management (M&SOM).

Professor Jacob Jen-Gwo Chen

IIE Fellow and WASP Fellow

Board Director and Vice Chairman, Hon Hai/Foxconn Technology Group

Title: The New FOXCONN Way

Abstract: As the leader of manufacturing services and No.1 in numbers of producing 3C products, e.g., smartphone, tablet, notebook, PC, TV, printer, server, networking, set-top box, gaming console, communication equipment, Foxconn has been known as "the King of EMS" and it has been transformed to the leader of intelligent industrial internet. Indeed, the first listed company in China market in industrial internet is the Foxconn Industrial Internet Co Ltd., a subsidiary company of Foxconn. The presentation will cover the vision, chronicle of development including organization and systems, and applications of Industrial Engineering (IE) in SCM, Productivity, Quality and other areas in Foxconn and IE's important and irreplaceable role in Foxconn's intelligent industrial internet development and implementation.

About the speaker: Dr. Jacob Chen is the Board Director and Vice Chairman of Hon Hai/Foxconn Technology Group, the Chairman of Flnet International E-Commerce, and the Founding President of the Foxconn University (Foxconn IE Academy, Corporate University of Foxconn). After receiving his Ph.D. degree in Industrial Engineering from the University of Oklahoma, he accepted a faculty position at the Department of Industrial Engineering, the University of Houston and served as department chairman for few years before taking the Deanship of the College of Science and Engineering at the University of Texas – Pan American in 1998. He joined with Hon Hai/Foxconn in 2001 as the Special Assistant to Chairman. With the rapid growth of Hon Hai/Foxconn, Dr. Chen was promoted to Vice President, Senior Vice President, General Manager of different Business Groups and current position as Vice Chairman of Hon Hai/Foxconn Group.

Dr. Chen has published more than 120 referred articles and supervised 25 Ph.D., 33 M.S. students during his academic career. For professional service, Dr. Chen served as the President of the International Society of Industrial Ergonomics and Occupation Safety in 1996, received the Institute of Industrial Engineers (IIE) Excellence in Productivity Improvement Award in 2006, and is the Fellow of the IIE and the World Academy of Productivity Science. Dr. Chen also served as the adjunct professor at various universities, such as, Tsing Hua University, Huazhong University of Science and Technology, TianJin University, and ChongQing University. Dr. Chen takes a new initiative to work with leading universities and colleges establishing degree programs in the Foxconn University since 2001. Foxconn employees could continue their study toward Associate, B.S., M.S., and Ph.D. Degrees. More than 25,000 Foxconn employees have received their degrees and have more than 25,000 still study.

Professor Lihui Wang

Professor and Chair of Sustainable Manufacturing

KTH Royal Institute of Technology, Stockholm, Sweden

Title: Cloud-Enabled Big Data-Driven Adaptive Process Planning for Machining

Abstract: This presentation covers the concept, approach and the latest development of a cloud-enabled and big data-driven process planning system for machining operations. It applies a closed-loop decision-making approach that enables collaborative and adaptive process planning based on real situations for real machines. To better leverage available resources (both hard and soft), a cloud platform is developed with decision modules for resource monitoring, collaborative process planning, setup planning, process simulation and remote machining. Big data is used to facilitate the decision process. On-board optimisation is another challenge of this work. The ultimate goal is to enable process planning anywhere in the cloud, while machining a part somewhere else, in form of cloud-based services.

About the speaker: Lihui Wang is a Professor and Chair of Sustainable Manufacturing at KTH Royal Institute of Technology, Stockholm, Sweden. His research interests are focused on distributed process planning, cyber-physical production systems, cloud manufacturing, big data analytics, real-time monitoring and remote control, and human-robot collaborations. Professor Wang is actively engaged in various professional activities. He is the Editor-in-Chief of International Journal of Manufacturing Research, Editor-in-Chief of Robotics and Computer-Integrated Manufacturing, Editor of Journal of Intelligent Manufacturing, and Associate Editor of International Journal of Production Research and Journal of Manufacturing Systems. He has published 8 books and authored in excess of 430 scientific publications. Professor Wang is a Fellow of CIRP, SME and ASME, and a registered Professional Engineer in Canada.

Professor Zhen He

Professor, College of Management and Economics
Chair, Department of Industrial Engineering
Tianjin University, P R China

Title: Quality and Innovation: Contradictory or Complementary

Abstract: Today a company will soon die without quality and it cannot survive in long run without innovation. But there are a lot of debates about the relationship between quality and innovation. The presentation highlights the key role of quality and innovation in the economic transformation in China which is in the state of "New Normal". The research of correlation between quality and innovation and some other research topics are addressed. Empirical studies shows that implementing quality initiatives such as Six Sigma or Lean Six Sigma will improve quality and promote innovation. And a company pursuing innovation may not harm quality. The presentation also discusses the necessity and future o research opportunities as of quality and innovation.

About the speaker: Dr. Zhen He is a Changjiang Scholar chair professor in College of Management & Economics, Tianjin University. He is an Academician of International Academy for Quality (IAQ) and the recipient of NSFC (National Natural Science Foundation of China) Outstanding Young Scholar. He received his PhD in Management Science and Engineering from Tianjin University in 2001. As a PI he has conducted nearly 10 NSFC sponsored projects including 3 key projects. His main research interests include quality management and control, Six Sigma and Lean Production with over 100 journal papers and 5 books. He is also the area editor (Statistics, Quality, Reliability and Maintenance) of Computers and Industrial Engineering and editorial board member of several other journals.

Professor Yiming Rong

Southern University of Science and Technology, Shenzhen, China

Title: To be formed: Intelligent Manufacturing Institute at SUSTech

Abstract: Southern University of Science and Technology (SUSTech) is a public university established in 2011, funded by Shenzhen Municipality. Located in Shenzhen, SUSTech is widely regarded as a pioneer and innovator in collectively moving China's higher education forward to match China's ever-growing role in the international arena. Motivated by the implementation of intelligent manufacturing initiatives worldwide, Pearl River Delta is reinventing itself from World Factory to Global Innovator, which urgently needs for intensified fundamental research and innovative technology. Under these circumstances, SUSTech is striving to build a world-class Intelligent Manufacturing Institute, with closely integrated to Pearl River Delta's manufacturing industry. It emphasizes on the entire product lifecycle including intelligent design, intelligent manufacturing, and intelligent service, with integration and interaction between academic research supporting industrial application and industrial application feeding academic research.

About the speaker: Dr. Rong is a Chair Professor and Head of the Department of Mechanical and Energy Engineering at Southern University of Science and Technology (SUSTech). Before returning to China， he was a tenured professor at Worcester Polytechnic Institute (WPI), and was voted "John W. Higgins Professor of WPI" due to his outstanding contribution to the scientific research. He is the Fellow of American Society of Mechanical Engineers (ASME Fellow).

From 2010 to 2015, Dr. Rong was a Professor, Vice Chair of Academic Committee in Mechanical Engineering, and Director of Institute of Manufacturing Engineering at Tsinghua University. His research area involves the entire industrial chain of manufacturing industry, which starts from manufacturing technologies, and extends to the front-end design and back-end services with optimization of the whole manufacturing system. He has presided and co-presided over 50 scientific research projects, funded by the National Science Foundation, the Air Force Basic Research, the Department of Energy, Natural Science Foundation of China, 973 Project, 863 Project, and other major manufacturing companies (GM, Ford, Caterpillar, P&W, Ingersoll, etc.). He has published two academic books, more than three hundred papers and has17 patents, etc.

Preconference Program

Wednesday, 5 December 2018	
16:30 - 19:30	***Welcome Reception & Preconference Workshop* - 1/F, Haking Wong Building, HKU**
17:00 - 17:05	***Innovative Technology Forum* - Room 105, 1/F, Haking Wong Building, HKU**
	Welcome Speech Prof. George Huang, iPark Project Coordinator
17:05 - 17:10	**Room 105, 1/F, Haking Wong Building, HKU**
	iPark Project Introduction Dr. XTR Kong, iPark Project Manager *"The Key Enabler Towards Logistics 4.0 - Intelligent Ecommerce Logistics Park Platform"*
17:10 - 17:15	**Room 105, 1/F, Haking Wong Building, HKU**
	Innovative Technology I Dr. Saijun Shao, iPark Pilot Manager *"Wearable-enabled Digital Supply Network: New Technologies and Practices"*
17:15 - 17:20	**Room 105, 1/F, Haking Wong Building, HKU**
	Innovative Technology II Dr. Zhiheng Zhao, iPark Technical Manager *"Asset Tracking for E-commerce Logistics"*
17:30-18:00	**Room 105, 1/F, Haking Wong Building, HKU**
	Light Meals & Demonstration Smart Manufacturing, iPark, Smart Construction

Conference Day-1 Program

Day 1: Thursday, 6 December 2018	
07:30 - 08:30	***APIEMS Fellow Meeting*** **– Café Rivoli, Regal Hongkong Hotel, Causeway Bay**
08:00 - 16:30	***Registration*** **– Regal Ballroom**
09:00 - 09:20	***Opening Ceremony*** **- Regal Ballroom** (MC: Prof. George Huang) ***Welcome Speech*** Prof. Francis Lau, Associate Dean of Engineering, HKU Prof. Chi-Hyuck Jun, President of APIEMS
09:20 - 10:00	**Regal Ballroom** (MC: Prof. Fugee Tsung) ***Keynote Speech 1*** Prof. Christopher Tang *"Making Supply Chain Transparent for a Better World: Information and Analysis"*
10:00 - 10:40	**Regal Ballroom** (MC: Prof. Fugee Tsung) ***Keynote Speech 2*** Prof. Jacob Chen *"The New FOXCONN Way"*
10:40 - 11:10	***Coffee Break - Monaco Room, B/1***
11:10 - 11:50	**Regal Ballroom** (MC: Prof. George Huang) ***Keynote Speech 3*** Prof. Lihui Wang *"Cloud-Enabled Big Data-Driven Adaptive Process Planning for Machining"*

<table>
<tr><td rowspan="2">11:50 - 12:30</td><td colspan="7">Regal Ballroom (MC: Prof. George Huang)</td></tr>
<tr><td colspan="7">Keynote Speech 4
Prof. Zhen He
“Quality and Innovation: Contradictory or Complementary”</td></tr>
<tr><td>12:30 - 13:30</td><td colspan="7">Lunch - Regal Palace, 3/F</td></tr>
<tr><td rowspan="3">13:30 - 15:00</td><td colspan="7">Parallel Sessions</td></tr>
<tr><td>Regal Ballroom</td><td>Forum Room II</td><td>Forum Room III</td><td>Victoria Room I</td><td>Victoria Room II</td><td>Victoria Room III</td><td>Victoria Boardroom</td></tr>
<tr><td>Workshop
Uncertainty Theory & Application</td><td>Session 1
Transportation</td><td>Session 2
Optimization Technique I</td><td>Special Session I
Sustainability and Supply Chain</td><td>Session 3
Sustainable Management I</td><td>Session 4
Management of Technology and Innovation</td><td>Session 5
Health Care System I</td></tr>
<tr><td>15:00 - 15:30</td><td colspan="7">Coffee Break - Monaco Room, B/1 & outside of Victoria Room, 3/F</td></tr>
<tr><td rowspan="3">15:30 - 17:00</td><td colspan="7">Parallel Sessions</td></tr>
<tr><td>Regal Ballroom</td><td>Forum Room II</td><td>Forum Room III</td><td>Victoria Room I</td><td>Victoria Room II</td><td>Victoria Room III</td><td>Victoria Boardroom</td></tr>
<tr><td>Special Session II
Sustainability and Manufacturing</td><td>APIEMS Board Meeting (16:00-17:00)</td><td>Session 6
Optimization Technique II</td><td>Session 7
Quality Engineering and Management</td><td>Session 8
Sustainable Management II</td><td>Session 9
Ergonomics and Human Factors I</td><td>Session 10
Health Care System II</td></tr>
<tr><td>18:00 - 20:00</td><td colspan="7">Conference Dinner - Maxim's Palace Chinese Restaurant
Venue: Shop B13-B18, B/F Shun Tak Centre, Connaught Road Central, Sheung Wan
(Please refer to Page 43 for recommended activities after dinner.)</td></tr>
</table>

Conference Day-2 Program

<table>
<tr><th colspan="5">Day 2: Friday, 7 December 2018</th></tr>
<tr><td>08:00 - 16:00</td><td colspan="4">Registration - Regal Ballroom</td></tr>
<tr><td rowspan="5">08:30 - 10:00</td><td colspan="4">Editor Forum – Regal Ballroom (MC: Prof. Christopher Tang)</td></tr>
<tr><td colspan="4">Editor in Chief Forum
Prof. Alexandre Dolgui
Editor-in-Chief of International Journal of Production Research
Prof. Andrew Kusiak
Editor-in-Chief of Journal of Intelligent Manufacturing
Prof. Jiuh-Biing Sheu
Editor-in-Chief of Transportation Research Part E
Prof. Lihui Wang
Editor-in-Chief of Robotics and Computer-Integrated Manufacturing
Prof. Christopher Tang
Editor-in-Chief of Manufacturing and Service Operations Management</td></tr>
<tr><td colspan="4">Parallel Sessions</td></tr>
<tr><td>Forum Room II</td><td>Victoria Room I</td><td>Victoria Room II</td><td>Victoria Room III</td></tr>
<tr><td>IFPR-APR Board Meeting</td><td>Session 37
Business Analysis I</td><td>Session 38
Business Analysis II</td><td>Session 39
Ergonomics and Human Factors V</td></tr>
<tr><td>10:00 - 10:20</td><td colspan="4">Coffee Break - Monaco Room, B/1 & outside of Victoria Room, 3/F</td></tr>
</table>

10:20 - 11:50	**Parallel Sessions**						
	Regal Ballroom	**Forum Room II**	**Forum Room III**	**Victoria Room I**	**Victoria Room II**	**Victoria Room III**	**Victoria Boardroom**
	Special Session III Healthcare Systems	**Session 11** Industrial Automation and Green Manufacturing	**Session 12** Financial Models and Engineering I	**Special Session IV** Marketing Analysis I	**Session 13** Simulation	**Session 14** Ergonomics and Human Factors II	**Session 15** Inventory Modeling and Management
12:00 - 13:00	***Lunch - Regal Palace, 3/F***						
13:00 - 14:30	**Parallel Sessions**						
	Regal Ballroom	**Forum Room II**	**Forum Room III**	**Victoria Room I**	**Victoria Room II**	**Victoria Room III**	**Victoria Boardroom**
	Special Session VII Assistive Technology I	**Session 16** Scheduling and Sequencing I	**Session 17** Financial Models and Engineering II	**Special Session V** Marketing Analysis II	**Session 18** Reliability and Maintenance I	**Session 19** Ergonomics and Human Factors III	**Session 20** Supply Chain Management I
14:30 - 15:00	***Coffee Break - Monaco Room, B/1 & outside of Victoria Room, 3/F***						
15:00 - 16:30	**Parallel Sessions**						
	Regal Ballroom	**Forum Room II**	**Forum Room III**	**Victoria Room I**	**Victoria Room II**	**Victoria Room III**	**Victoria Boardroom**
	Special Session VIII Assistive Technology II	**Session 21** Scheduling and Sequencing II	**Session 22** Financial Models and Engineering III	**Special Session VI** Marketing Analysis III	**Session 23** Reliability and Maintenance II	**Session 24** Ergonomics and Human Factors IV	**Session 25** Supply Chain Management II

Conference Day-3 Program

Day 3: Saturday, 8 December 2018						
08:30 - 10:00	**Parallel Sessions**					
	KK LG103	**KK LG105**	**KK LG106**	**KK LG107**	**KK LG110**	**KK LG111**
	Session 26 Decision Modeling and Theory I	**Session 27** Logistics Management	**Session 28** Product Design and Development	**Session 29** Big Data and Applications I	**Session 30** Data Mining I	**Session 31** Artificial Intelligence I
10:00 - 11:30	**Parallel Sessions**					
	KK LG103	**KK LG105**	**KK LG106**	**KK LG107**	**KK LG110**	**KK LG111**
	Session 32 Decision Modeling and Theory II	**Session 33** Other Related Topics in IE/MS I	**Nominations for Best Paper**	**Session 34** Big Data and Applications II	**Session 35** Data Mining II	**Session 36** Artificial Intelligence II
11:30 - 11:50	***Coffee Break - KB G/F***					
11:50 - 12:10	**KB 223, HKU** (MC: Prof. George Huang)					
	Invited Talk Prof. Yiming Rong *"Intelligent Manufacturing: Key Technologies and Practices"*					
12:10 - 13:00	***Closing Ceremony* – KB 223, HKU** (MC: Prof. George Huang)					
	Conferment of Best Paper Award ***Introduction of New Board and Fellow*** ***Announcement of APIEMS 2019***					

Remark: Please refer to Page 6 for venue maps of Knowles Building (KB) and K.K. Leung Building (KK).

Session Details

Day 1: 6 Dec. 2018 (13:30 - 15:00)	**Workshop: Uncertainty Theory & Application** *Chair: Jin Peng* *Room: Regal Ballroom*
	Logistics network optimization with uncertain data Jin Peng
	Uncertainty, risk, and Behavior Jinwu Gao
	The risk path selection problem in uncertain network Shengguo Li
	Cooperative uncertain differential game Yi Zhang
57	**A Beam Search Heuristic for the Unrestricted Container Relocation Problem** Kun-Chih Wu and Ching-Jung Ting
76	**Segmentation of Coffee Plantation Area in Satellite Images Using Fourier Features** Du-Ming Tsai, Wan-Ling Chen and Wei-Yao Chiu

Day 1: 6 Dec. 2018 (13:30 - 15:00)	**Session 1: Transportation** *Chair: Titi Iswari* *Co-Chair: Yijia Wang* *Room: Forum Room II*
310	**A Metaheuristic Approach for the Vehicle Routing Problem with Simultaneous Pick-Up and Delivery (VRP-SPD)** Titi Iswari, Stephen Sanjaya Budi and Paulina Kus Ariningsih
315	**Ambulance Drone Location Optimization Based on Survival Probability** Ke Wang, Xuejie Ren and Lindu Zhao
326	**Shuttle Bus Route Design with Travel Time Dependent Demand** Hyunjoon Kim and Byung-In Kim
361	**Bloodmobile routing for donated blood collection system in Ho Chi Minh city** Do Sy Hoang, Ha Thi Xuan Chi, Nguyen Hoang Huy, Do Vinh Truc and Nguyen Thi Nhung
278	**Solving Aircraft Landing Scheduling Problem with Latest Landing Time** He Pan, Tsui-Ping Chung and Hongda Dou
100	**Genetic Algorithm for Vehicle Routing Problem with Mixed Pickup and Delivery with Time Windows, Duration Time and Rest Area** Kitttitach Kamsopa, Kanchana Sethanan and Thitipong Jamrus

Day 2: 7 Dec. 2018 (13:00 - 14:30)	**Session 16: Scheduling and Sequencing I** *Chair: Nita P.A Hidayat* *Co-Chair: Yijia Wang* *Room: Forum Room II*
341	**A Batch Scheduling Model for The Shop with m Heterogeneous Batch Processors Producing Multiple Items to be Delivered at Different Due Dates** Nita P.A Hidayat, Wisnu Aribowo, Andi Cakravastia, T.M.A Ari Samadhi and Abdul Hakim Halim
356	**Sublot Optimization with Sequence-Dependent Setups and Transfer Times in Job Shop Production** Mohammad Miradj Isnaini and Anas Ma'Ruf
209	**Dual Resource Constrained Job Shop Scheduling with Automated Operations** Katsumi Morikawa, Keisuke Nagasawa and Katsuhiko Takahashi
269	**A Flow Shop Batch Scheduling and Operator Assignment Model with Learning-Forgetting and Fatigue-Recovery Effects to Minimize Total Actual Flow Time** Dwi Kurniawan, Andi Cakravastia Raja, Suprayogi and Abdul Hakim Halim
275	**Batch Scheduling for Unique and Common Components in a Hybrid Assembly Differentiation Flow Shop to Minimize Total Actual Flow Time** Rahmi Maulidya, Rachmawati Wangsaputra, Suprayogi and Abdul Hakim Halim
396	**Close-looped digital twin system on cargo loading planning operations** Eugene Y. C. Wong and Daniel Y. Mo

Day 2: 7 Dec. 2018 (13:00 - 14:30)	**Session 17: Financial Models and Engineering II** *Chair: Norio Hibiki* *Co-Chair: Xin Wang* *Room: Forum Room III*
30	**Asset Allocation with Factor-based Risk Parity Strategy** Hirotaka Kato and Norio Hibiki
31	**A Study on Optimal Limit Order Strategy using Multi-Period Stochastic Programming considering Nonexecution Risk** Shumpei Sakurai and Norio Hibiki
36	**Estimation Decay Kernel of Transient Market Impact Using Multi-Dimentional Hawkes Process** Tomoki Okada and Norio Hibiki
39	**An Optimal Execution Model with S-shaped Temporary and Transient Market Impacts** Yuhei Ono and Norio Hibiki
94	**Construction of Multi-Factor Model in Chinese Stock Market** Yuxi Yang and Takashi Hasuike
372	**Development of Credit Risk Assessment Decision Support System using Python Web Framework** Yung-Chia Chang, Yi-Hsuan Huang, Kuei-Hu Chang, Hung-Chih Chiu, Chih-Cheng Chen, Wan-Jo Lin, Yen-Wei Tseng and Yi-Chun Su

Social Event

Conference Dinner

Date: Thursday, 6 December 2018
Time: 18:00 – 20:00
Location: Maxim's Palace Chinese Restaurant, Sheung Wan
Address: Shop B13-B18, B/F Shun Tak Centre, Connaught Road Central, Hong Kong
By MTR: Sheung Wan MTR station **Exit D**

Recognized as among the finest banquet venues in Hong Kong, Maxim's Palace boasts magnificent decoration making it ideal for casual dining and formal occasions. Renowned for its Guangdong-style dim sum and dishes - with over 100 kinds served every day - Maxim's Palace is sure to offer a classic Chinese yamcha and dining experience.

Travel Tips

Transportation

Public transport is the best way to get around in Hong Kong. The north side of Hong Kong Island and most of Kowloon are well connected by the MTR, Hong Kong's clean and efficient rapid transit railway system, while the extensive bus system enables you to explore the south side of Hong Kong Island and the New Territories.

Sightseeing at Victoria Harbour

Victoria Harbour is known for its panoramic night view and skyline, particularly in the direction towards Hong Kong Island where the skyline of skyscrapers is superimposed over the ridges behind. One of the best places to view the harbour is the promenade of Tsim Sha Tsui on the Kowloon side.

Shopping at Causeway Bay

Causeway Bay or East Point is one of Hong Kong's major shopping districts. It includes the 13-storey Japanese department store Sogo, Times Square, and Hysan Place. Hong Kong is one of the most famous shopping paradises in the world. However, the real shopping heaven of the city should be Causeway Bay. There gathers numerous shopping malls and various boutiques.

Dining at Lan Kwai Fong

Lan Kwai Fong is one of Hong Kong’s most popular nightlife hot spots and home to over 90 restaurants and bars. The atmosphere ranges from stylish wine pairings to raucous jelly shots and the food on offer is as diverse as the clientele. This center of late-night revelry is so renowned that its official street sign is more photographed than many of the celebrities who haunt its clubs. Mostly, the area is crowded with people, eager to shake off the working day or week.

Bird’s Eye View at Victoria Peak

Standing on this highest place of Hong Kong Island, you can enjoy a fantastic bird’s eye view of towering skyscrapers, Victoria Harbor and the skyline of the city. In particular, the sunset view of panorama is quite riveting. Several ways can take you to the peak but undoubtedly the best way is to take a classic tram with 100-year history. However, the weather will affect a lot. Sunny days will give you a clearer view.

A Flow Shop Batch Scheduling and Operator Assignment Model with Learning-Forgetting and Fatigue-Recovery Effects to Minimize Total Actual Flow Time

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Abstract. This paper discusses integrated problems of batch scheduling and operator assignment in flow shops that simultaneously consider the processes of learning, forgetting, fatigue and its recovery experienced by operators. The problem is expressed as a mathematical model, and the objective of the model is to minimize total actual flow time, where the decision variables are operator assignment to each machine, the number of batches, batch sizes and the schedule of the resulting batches. The proposed algorithm solves the problem by trying different numbers of batches, starting from one until the number of batches leading to the best objective function value. Numerical examples show that learning rate, fatigue rate, recovery rate and fatigue alleviation proportion affect the number of batch, batch sizes and total actual flow time in optimal solutions.

Keywords: Batch scheduling, operator assignment, learning-forgetting, fatigue-recovery, actual flow time.

1. Introduction

Scheduling is a process of allocating entities (tasks, events, vehicles or people) to a set of resources in a time period in order to achieve particular objectives and to satisfy a set of constraints (Baker, 1974). Machine and operator are two resources frequently considered in scheduling problems, and they are usually considered separately (Pinedo, 2002). To improve scheduling performances, machine and operator need to be considered simultaneously in scheduling, such as in Mencía et al. (2015) who use fixed processing times, in Kellerer and Strusevich (2008) who propose process acceleration by allocating additional tools, and in Aftab et al. (2012) who propose process acceleration by assigning additional operator. Costa et al. (2013) have also considered machine and operator in scheduling, with processing time variation comes from different skill levels among operators. This occurs in manufacturing systems where operator's skill is essential for production, and there are alternative operators to perform each operation.

In addition to skill levels, processing time may also change due to learning, forgetting, fatigue and its recovery processes experienced by operators (Cheng et al., 2010). According to Yusriski et al. (2015), learning process occurs after an operator performs an operation repeatedly, while forgetting process occurs when an operator experiences a break from performing an operation. Learning and forgetting cause processing time to change among parts, following learning and forgetting functions (Jaber and Bonney, 1996). The phenomenon of a learning function is firstly reported by Wright (1936) who shows that production process repetition leads to a constant decrease in processing time every time the cumulative produced quantity doubles. Meanwhile, the forgetting function is described by Carlson and Rowe (1976) as a negative decay function similar to electrical losses in condensers. The forgetting effect experienced by someone is influenced by the length of previous learning and the length of interruption (Globerson et al., 1989). Meanwhile, fatigue effect appears after operator works for a particular time (Pack et al., 1974), and it reduces operator's learning rate. To alleviate the fatigue, operator needs to take a break during a time interval. The fatigue effect also limits batch processing time so it does not exceed operator's endurance time. After processing a batch, a proportion of fatigue level must be alleviated before the processing of the next batch (Jaber et al., 2013).

Since learning, forgetting, fatigue and its recovery evidently occur in manufacturing systems, scheduling models need to consider them to accurately determine processing times. Additionally, actual flow time is an important performance criterion to ensure due date is satisfied and to minimize the amount of inventory in shop floor (Halim et al., 1994).

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2. Model Development

Parameters and variables used in this paper are shown as follows.

Parameters:

n = number of parts to be processed,
m = number of machines,
o = number of operators,
d = due date, calculated from $t = 0$,
$s_{k,w}$ = set up time per batch on machine k if performed by operator w,
$t_{k,w}$ = processing time of the first unit on machine k if performed by operator w,
ℓ_w = learning gradient of operator w at no-fatigue condition,
g_w = fatigue-to-learning slope of operator w,
λ_k = fatigue rate of operation at machine k,
μ = recovery rate of all operators,
π = proportion of residual fatigue level after recovery,
β, β_0 = parameters for MET calculation.

Variables:

F = total actual flow time of all parts,
N = number of batch,
$Q_{[i]}$ = batch size, number of parts in the batch sequenced in position i from the due date,
$B_{k,[i]}$ = starting time of batch i at machine k,
$X_{k,w}$ = binary variable that equals to 1 if operator k is assigned to machine w, equals to 0 if not,
$f_{k,w;[i]}$ = forgetting gradient of operator w after processing batch i at machine k,
$\alpha_{k,w;[i]}$ = equivalent number of part of retained learning experience when starting batch i at machine k if performed by operator w,
$\ell_{k,w;[i]}$ = learning gradient of operator w at machine k when processing batch i,
$T_{[x]}$ = processing time of the x-th part as a learning function,
$\hat{T}_{[x]}$ = processing time of the x-th part as a forgetting function,
$T_{k,w;[i]}$ = processing time of all parts in batch i at machine k by operator w,
$I_{k,w;[i]}$ = break time after batch i at machine k by operator w,
$\phi_{k,w;[i]}$ = fatigue level of operator w at machine k when starting batch i,
$MET_{k,[i]}$ = maximum endurance time of batch i at machine k,
W = set of operators assigned to machine 1 to k.

According to Jaber and Bonney (1996), learning process occurs when an operator performs an operation repeatedly. Together with learning, the operator will also experience fatigue, which will be accumulated until the operator stops the operation. The learning process follows a learning function (1), while the fatigue level accumulation is related to time elapsed during the operation as expressed in function (2):

$$T_{[x]} = T_{[1]}x^{-\ell} \quad (1)$$

$$\phi = 1 - e^{-\lambda.t} \quad (2)$$

where $0 \le \ell \le 1$; higher value means faster learning.

Interruption in learning process results a forgetting process which starts directly when the learning process stops and follows a forgetting function as expressed in equation (3). Together with forgetting, a recovery process that alleviate operator's accumulated fatigue also occurs following a recovery function as expressed in equation (4).

$$\hat{T}_{[x]} = \hat{T}_{[1]}x^{f} \quad (3)$$

$$\hat{\phi} = \phi.e^{-\mu.t} \quad (4)$$

The fluctuations of part processing time and fatigue level caused by learning-forgetting and fatigue-recovery processes are shown in Figure 1. Learning and fatigue processes occur at AB, DE and FG intervals, while forgetting and recovery processes occur at BD and EF intervals. The forgetting occurs at BD interval is a total forgetting, while the forgetting occurs at EF interval is a partial one.

Suppose that the operator processes Q parts during the learning process. After experiencing a forgetting process during a break time R, the Q units of operator's learning experience will be reduced to α units, where α is the equivalent retained number of parts of the learning experience after forgetting ($0 \le \alpha \le Q$). The value of α is derived from Jaber and Bonney (1996) as follows:

$$\alpha = \max\left(0, Q^{(\ell+f)/\ell}\left(Q^{1-\ell} + (1-\ell)\frac{R}{T_{[1]}}\right)^{\frac{-f}{\ell(1-\ell)}}\right) \quad (5)$$

where $\alpha = 0$ if the operator experiences a total forgetting, or the right segment if the operator experiences a partial forgetting.

The value of the forgetting gradient f is also derived from Jaber and Bonney (1996) as follows:

$$f = \frac{\ell(1-\ell)\log Q}{\log\left(Q^{1-\ell} + (1-\ell)\frac{R}{T_{[1]}}\right) - \log Q} \quad (6)$$

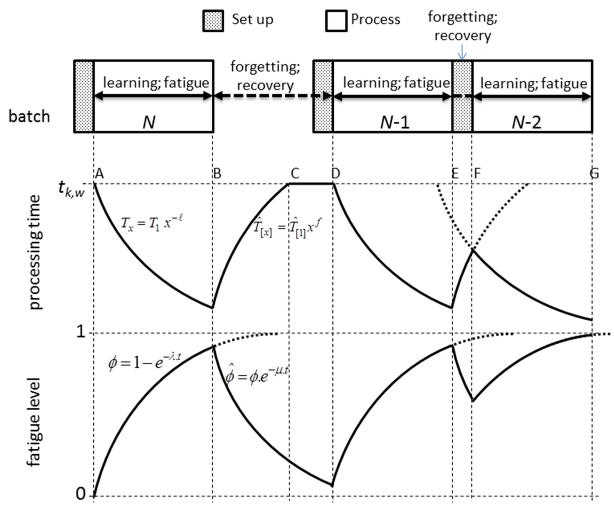

Figure 1. Change of processing time caused by learning and forgetting processes

The fatigue and recovery models are developed from Jaber et al. (2013). A fatigue process occurs during the process of batch N (at AB interval in Figure 1), starts with no-fatigue condition at A ($\phi_A = 0$), follows a fatigue function in equation (2) and results a fatigue level ϕ_B as shown in equation (7). Meanwhile, a recovery process occurs at BD interval, starts with ϕ_B, follows a recovery function in equation (4) and results a residual fatigue level ϕ_D as given in equation (8):

$$\phi_B = 1 - e^{-\lambda . t_{AB}} \tag{7}$$

$$\phi_D = \phi_B . e^{-\mu . t_{BD}} = \left(1 - e^{-\lambda . t_{AB}}\right) e^{-\mu . t_{BD}} \tag{8}$$

where λ and μ are fatigue and recovery rates respectively. The fatigue level ranges from 0 to 1, where 0 means a no-fatigue condition, and 1 means a maximum fatigue. A low value of λ (μ) means a slow fatigue (recovery) process, while a high value means a fast one. The residual fatigue ϕ_D will be carried out to batch N-1, which after fatigue-recovery processes in batch N-1 will result a fatigue level ϕ_F:

$$\phi_F = \left(\phi_D + (1 - \phi_D)\left(1 - e^{-\lambda t_{DE}}\right)\right) e^{-\mu . t_{EF}} \tag{9}$$

The general formula of $\phi_{[i]}$, the fatigue level at the beginning of batch i (i = 1,...,N-1) is given by:

$$\phi_{[i]} = \left(\phi_{[i+1]} + (1 - \phi_{[i+1]})\left(1 - e^{-\lambda T_{[i+1]}}\right)\right) e^{-\mu . I_{[i+1]}} \tag{10}$$

where $T_{[i+1]}$ and $I_{[i+1]}$ are work time and break time of batch i+1.

The accumulated fatigue level will slow the operator's learning process (Pack et al., 1974). Based on the experiment data collected by Pack et al. (1974), operator's learning gradient ℓ is found as an exponential function of the fatigue level (ϕ), following the function in equation (11).

$$\ell = \ell_0 e^{g\phi} \tag{11}$$

The fatigue process experienced by operator will also limit the time length for which a specific muscular effort can be performed to a duration called as maximum endurance time (MET). According to Jaber et al. (2013), the MET value depends on each operation's fatigue rate and β and β_0 parameters. All batch processing times must not exceed MET, which is formulated in equation (12). Additionally, the recovery time must be long enough to alleviate the fatigue to π % of the accumulated fatigue level before processing the next batch, as shown in expression (13).

$$MET = \beta_0 \cdot e^{-(N+1-i)\beta\lambda} \tag{12}$$

$$I \geq -\frac{\ln \pi}{\mu} \tag{13}$$

3. Model and Algorithm

The problem studied in this research is described as follows. A job consisting of n parts will be scheduled. The job will be split into N batches, and each batch i will be processed through m operations with uniform routing. Each operation can be performed by one of o alternative operators with different set up times $s_{k,w}$ and initial processing times $t_{k,w}$. Each operator w experiences a learning process at a rate of δ_w, and each operation at machine k causes fatigue process at a rate of λ_k. All operations must be finished no later than a due date d. The decision variables in the model are assignment of operator w to machine k ($X_{k,w}$), the number of batches N, batch sizes $Q_{[i]}$, and the schedule of operation k in batch i ($B_{k,[i]}$).

Assumptions used in this study are:

1. All parts, machines and operators are ready (can be scheduled) at t = 0.
2. Interruption of an operation is not allowed.
3. Each machine and operator cannot perform more than one operation at a time.
4. Machines are always available during the scheduling time horizon.
5. Set up and process of a particular operation are performed by the same operator.
6. An operator can be assigned to at most one machine.

Based on the model development in Section 2, the flow shop batch scheduling and operator assignment problem to minimize actual flow time is formulated as follows.

Minimize $$F = \sum_{i=1}^{N} \left(d - B_{1,[i]}\right) Q_{[i]} \qquad (14)$$

subject to

$$B_{m,[i]} = d - \sum_{w=1}^{o} X_{m,w} \left(is_{m,w} + \sum_{j=1}^{i} T_{m,w,[j]} \right), \quad i = 1, \ldots, N \qquad (15)$$

$$B_{k,[1]} = B_{k+1,[1]} - \sum_{w=1}^{o} X_{k,w} \left(s_{k,w} + T_{k,w,[1]} \right), \quad k = 1, \ldots, m-1 \qquad (16)$$

$$B_{k,[i]} \le B_{k,[i-1]} - \sum_{w=1}^{o} X_{k,w} \left(s_{k,w} + T_{k,w,[i]} \right), \qquad (17)$$

$k = 1, \ldots, m–1, i = 2, \ldots, N$

$$B_{k,[i]} \le B_{k+1,[i]} - \sum_{w=1}^{o} X_{k,w} \left(s_{k,w} + T_{k,w,[i]} \right), \qquad (18)$$

$k = 1, \ldots, m–1, i = 2, \ldots, N$

$$B_{1,[N]} \ge 0 \qquad (19)$$

$$T_{k,w,[N]} = t_{k,w} \frac{Q_{[N]}^{1-\ell_{k,w,[N]}}}{1-\ell_{k,w,[N]}}, \; k = 1, \ldots, m, \; w = 1, \ldots, o \qquad (20)$$

$$T_{k,w,[i]} = \frac{t_{k,w}}{1-\ell_w} \left[\left(\alpha_{k,w,[i]} + Q_{[i]} \right)^{1-\ell_w} - \alpha_{k,w,[i]}^{1-\ell_w} \right], \qquad (21)$$

$k = 1, \ldots, m, w = 1, \ldots, o, i = 1, \ldots, N$-1

$$\alpha_{k,w,[i]} = \max\left(0, Q_{[i+1]}^{\left(\frac{\ell_{k,w,[i+1]} + f_{k,w,[i+1]}}{\ell_{k,w,[i+1]}} \right)} \left[Q_{[i+1]}^{1-\ell_{k,w,[i+1]}} + \left(1-\ell_{k,w,[i+1]}\right) \frac{I_{k,w,[i+1]}}{t_{k,w}} \right]^{\frac{-f_{k,w,[i+1]}}{\ell_{k,w,[i+1]}\left(1-\ell_{k,w,[i+1]}\right)}} \right)$$

$k = 1, \ldots, m, w = 1, \ldots, o, i = 1, \ldots, N$-1 (22)

$$\ell_{k,w,[i]} = \ell_w e^{g_w \phi_{k,w,[i]}}, \qquad w = 1, \ldots, o \qquad (23)$$

$$f_{k,w,[i]} = \frac{\ell_{k,w,[i]} \left(1-\ell_{k,w,[i]}\right) \log Q_{[i]}}{\log\left(Q_{[i]}^{1-\ell_{k,w,[i]}} + \left(1-\ell_{k,w,[i]}\right) \frac{I_{k,w,[i]}}{t_{k,w}} \right) - \log Q_{[i]}}, \qquad (24)$$

$k = 1, \ldots, m, w = 1, \ldots, o, i = 2, \ldots, N$

$$\phi_{k,w,[N]} = 0 \qquad (25)$$

$$\phi_{k,w,[i]} = \left(\phi_{k,w,[i+1]} + \left(1-\phi_{k,w,[i+1]}\right)\left(1-e^{-\lambda_k T_{k,w,[i+1]}}\right) \right) e^{-\mu \cdot I_{k,w,[i+1]}}, \qquad (26)$$

$k = 1, \ldots, m, w = 1, \ldots, o, i = 1, \ldots, N–1$

$$T_{k,w,[i]} \le MET_{k,[i]}, \; k = 1, \ldots, m, \; w = 1, \ldots, o, \; i = 1, \ldots, N \qquad (27)$$

$$MET_{k,[i]} = \beta_0 \cdot e^{-(N+1-i)\beta\lambda_k}, \qquad k = 1, \ldots, m, \; i = 1, \ldots, N \qquad (28)$$

$$I_{k,w,[i]} = B_{k,[i-1]} - B_{k,[i]} - T_{k,w,[i]}, \qquad (29)$$

$k = 1, \ldots, m, w = 1, \ldots, o, i = 2, \ldots, N$

$$I_{k,w,[i]} \ge -\frac{\ln \pi}{\mu}, \; k = 1, \ldots, m, \; w = 1, \ldots, o, \; i = 2, \ldots, N \qquad (30)$$

$$\sum_{i=1}^{N} Q_{[i]} = n, \qquad (31)$$

$$\sum_{w=1}^{o} X_{k,w} = 1, \qquad k = 1, \ldots, m \qquad (32)$$

$$\sum_{k=1}^{m} X_{k,w} \le 1, \qquad w = 1, \ldots, o \qquad (33)$$

$$X_{k,w} \in \{0, 1\}, \qquad \forall k, w \qquad (34)$$

$$Q_{[i]} > 0, \; 1 \le N \le n, \qquad i = 1, \ldots, N. \qquad (35)$$

Objective function (14) is to minimize the total actual flow time, i.e. the sum of batch actual flow time multiplied by its size. Batch actual flow time is the time spent by the batch on the shop floor, i.e. the time length from the batch arrival at machine 1 to the due date. The starting time calculation of each batch at each machine is expressed in constraint (15) to (18). Since this study performs a backward scheduling, the batch starting time is calculated from the last machine. Constraint (15) defines the starting time of batch i at machine m, constraint (16) defines the starting time of batch 1 at machine k, while constraints (17) and (18) define the starting time of batches other than batch 1 at other than machine m. The set up and processing times in constraints (15) to (18) are multiplied by operator assignment variables, because each operator has different set up and processing times at each machine. Constraint (19) states that the starting time of batch N at machine 1 must be non-negative.

Constraints (20) to (24) incorporate learning and forgetting processes into the batch scheduling in this research. Constraints (20) and (21) define the batch processing times for batch N and for the other batches respectively. The batch processing times are the integration result of part processing time defined in equation (1) where $T_{[1]} = t_{k,w}$, and the integration interval is 0 to $Q_{[N]}$ for batch N, and $\alpha_{k,w,[i]}$ to $\alpha_{k,w,[i]}+Q_{[i]}$ for the other batches. Constraint (22) defines $\alpha_{k,w,[i]}$, the equivalent retained number of parts of learning experience after forgetting process, constraint (23) defines the learning gradient as an exponential function of the fatigue level, while constraint (24) defines the forgetting gradient. The formula of $\alpha_{k,w,[i]}$ and $f_{k,w,[i]}$ are adapted from equations (5) and (6) for a multi-machine and multi-operator batch scheduling.

Constraints (25) to (30) integrate fatigue and recovery processes into the batch scheduling model. Constraints (25) and (26) define the fatigue level at the beginning of batch *i*. Constraint (27) limits all batch processing times not to exceed the MET, which is calculated in constraint (28). Constraint (29) defines the length of the break period, while constraint (32) ensures that the break time is long enough to alleviate the fatigue to a required residual fatigue level. Constraints (25) to (30) are adapted from (7) to (13) for a multi-machine and multi-operator batch scheduling.

Constraint (31) ensures the number of parts in all batches to be equal to the total number of parts. Constraint (32) states that exactly one operator must be assigned to each machine, while constraint (33) states that an operator can be assigned to maximum one machine. Constraint (34) states that operator assignment variables are binary numbers, and constraint (35) states that batch sizes must be positive, and the batch number must be at least one and at most equal to the total number of parts.

The problem formulated in this section is not linear and not convex because it contains discrete variables $X_{k,w}$. To solve the problem, N needs to be relaxed from a decision variable into a parameter. By setting a value for N, the problem becomes convex, thus it can be solved to find the other decision variables, $Q_{[i]}$ and $B_{k,[i]}$. Therefore, a solution method for the problem will try several N values, starting from one, and increase it one-by-one until the objective function value does not improve anymore. The solution method for the problem formulated in this section is described in the following algorithm.

Algorithm.

Step 1. Set parameters n, m, o, d, $s_{k,w}$, $t_{k,w}$, δ_w, h_w, λ_k, μ, π, β and β_0. Go to Step 2.

Step 2. Set $N = 1$. Go to Step 3.

Step 3. Solve the problem, determine $Q_{[i]}$ and F, and set N, W and F as N^*, W^* and F^*, the current best solution. Go to Step 4.

Step 4. If $N = n$, go to Step 7. If not, set $N = N + 1$, go to Step 5.

Step 5. Solve the problem, determine N, $Q_{[i]}$ and F, Go to Step 6.

Step 6. If $F < F^*$, set N, W and F as new N^*, W^* and F^*, go to Step 4. If not, go to Step 7.

Step 7. Stop. The current F^* is the optimal solution.

4. Numerical Examples

The model and algorithm developed in Section 3 will be applied to a number of data sets with different parameter values. All data sets have $m = 2$, $o = 3$, $n = 50$, $d = 50000$, $s_{k,w}$ = (12 18 14, 18 16 18) and $t_{k,w}$ = (4.4 4.8 3.8, 3.4 3.7 3.8). The MET parameters $\beta = 7.6$ and $\beta_0 = 166.55$ are derived from El-ahrache et al. (2006), and we set $h_w = 0.05$ ($\forall w$). The numerical tests are performed in two stages. The first stage has λ_k = (0.02 0.01), $\mu = 0.03$ and $\pi = 0.9$, while δ_w varies to (0.7 0.72 0.78), (0.75 0.77 0.83) and (0.8 0.82 0.88). In the second stage, we fix δ_w = (0.75 0.77 0.83) and varies λ_k from 0.01 to 0.05, μ from 0.03 to 0.07, and π from 0.5 to 0.9. All computations are run using Lingo 16 software installed in a computer with Xeon E5-1620 CPU and 8 GB RAM. The computation results of the first stage are shown in Table 1, while for the second stage in Table 2.

Table 1. The results of the first stage

δ_w	N^*	$Q_{[i]}^*$	F^*
.7 .72 .78	4	46.1 1.0 1.8 1.1	6378.4
.75 .77 .83	5	42.2 1.0 2.5 2.6 1.7	7697.3
.8 .82 .88	6	26.9 1.1 6.6 6.6 6.0 2.7	9326.7

Table 2. The results of the second stage

π	λ_k	μ =.03		μ =.05		μ =.07	
		N^*	F^*	N^*	F^*	N^*	F^*
.9	.04 .05	1	8505.57	1	8505.57	1	8505.57
	.04 .03	2	7548.55	2	7620.27	2	7673.99
	.02 .03	3	7358.44	3	7488.95	3	7550.13
	.02 .01	4	7381.41	3	7558.75	4	7542.34
.7	.04 .05	1	8505.57	1	8505.57	1	8505.57
	.04 .03	2	7550.39	2	7620.27	2	7673.99
	.02 .03	3	7362.30	2	7691.84	3	7549.87
	.02 .01	5	7385.21	4	7482.33	4	7563.81
.5	.04 .05	1	8505.57	1	8505.57	1	8505.57
	.04 .03	1	8505.57	2	7637.52	2	7673.99
	.02 .03	1	8505.57	3	7500.24	3	7547.69
	.02 .01	1	8505.57	5	7525.74	2	7762.13

From the first stage tests, we find that the lower δ_w (the faster learning), the lower number of batch in the optimal solution, and the lower value of the objective function. This is because the faster learning process results more learning experience after the batch processing, and the model keeps this experience from forgetting by reducing the number of batch in optimal solution. This also results a lower total actual flow time in the optimal solution.

From the second stage tests, we find several behaviors of the model. Firstly, the higher the fatigue rates λ_k (which are usually due to more force required when processing batch), the lower number of batch in the optimal solution, and the higher the objective function. Secondly, the higher recovery rate μ, the number of batch in the optimal solution tends to increase, and the objective function decreases. This is because a higher recovery rate will reduce the fatigue level, and gives the contradictory results to the first stage. Lastly, the lower π (the more fatigue alleviation required), the lower number of batch in the optimal solution, and the higher the objective function. This is because a lower π requires longer break times between batches, and the model reduces these break times by reducing the number of batch in the optimal solution.

According to Table 1, the size of batch 1 is always much larger than the size of the other batches. This behavior also appears in optimal solutions of the second stage (the batch sizes are not shown in Table 2). This is because batch 1 is the last batch to be processed in the schedule, and the processing of a large batch will be followed by a rapid forgetting (according to equation (11)); the model prevents this rapid forgetting process from affecting any other batches in the schedule by scheduling the largest batch to be processed last in the schedule (as batch 1).

5. Concluding Remarks

This research develops a flow shop batch scheduling and operator assignment model with learning-forgetting and fatigue-recovery effects to minimize actual flow time. The proposed algorithm works by trying different number of batch started from one, then increasing the number of batches until the best objective function value is found. The faster operator learns, the lower number of batches in the optimal solution, and the greater the size difference between the largest batch and the other batches. The number of batch in the optimal solution will be lower if the fatigue process is faster, the recovery process is slower, or the fatigue alleviation proportion is higher. The model always schedules the largest batch, which is always much larger than the other batches, to be processed last in the schedule. The model developed in this study can be used for all flexible flow shops where each operator can be assigned only to a maximum one machine.

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