Industrial Engineering and Engineering Management (IEEM), 2014 IEEE International Conference on

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Filter Results

Displaying Results 1 - 25 of 305

1. Cover page
   Publication Year: 2014, Page(s): 1
   PDF (1646 KB)

2. Copyright page
   Publication Year: 2014, Page(s): 1
   PDF (37 KB)

3. Organizers & committees
   Publication Year: 2014, Page(s): i - ii
   PDF (1090 KB)

4. Table of contents
   Publication Year: 2014, Page(s): iii - xxi
   PDF (581 KB)

5. Simultaneous consideration of remanufactured and new products in optimal product line design
   Aydin, R.; Kwong, C.K.; Ji, P.
   Publication Year: 2014, Page(s): 1 - 5
   PDF (527 KB)

6. The optimal ordering quantity with uncertain food's safety environment
   Shu-Yen Hsu ; Lin, T.T.
   Publication Year: 2014, Page(s): 6 - 10
   PDF (799 KB)

7. Reduced Recursive Inclusion-exclusion Principle for the probability of union events
   Chen, S.G
   Publication Year: 2014, Page(s): 11 - 13
   PDF (501 KB)

8. A Bi-level algorithm for product line design and pricing
   Shui Wu ; Songlin Chen
   Publication Year: 2014, Page(s): 14 - 18
   PDF (536 KB)

9. An optimal electricity consumption decision with a limited carbon emission concept
   Lin, T.T.; Hsi-Chen Lan
   Publication Year: 2014, Page(s): 19 - 23
   PDF (492 KB)
Welcome Message


IEEM2014 is the ninth in the series of IEEM conferences since 2006. It is the first time the conference is jointly organized by IEEE Technology Management Council Malaysia and Hong Kong Chapters. The conference is supported by Monash University and the City University of Hong Kong.

The strength of IEEM conference is its high conference standard and diversity, bringing together researchers and practitioners from different branches of industrial engineering and engineering management from around the world. In keeping a high standard as for the past IEEM series, each paper went through a rigorous review process. IEEM2014 received almost 550 submissions and each paper was sent to 3-5 reviewers. The acceptance decisions were made based on at least two consistent recommendations. To represent the global diversity, we have an outstanding program, including 20 topics presented in oral and poster sessions, as well as a distinguished set of keynote speakers:

Hean Teik Chuah, President, Universiti Tunku Abdul Rahman (UTAR), Malaysia, will present “Science, Engineering, Technology & Innovation (SETI) Education for Economy Transformation.”

Tariq S Durrani, Research Professor, University of Strathclyde, United Kingdom, will discuss “Science, Engineering, Innovation and Competitiveness - An international assessment and comparison.”

Thomas L. Magnanti, President, Singapore University of Technology and Design (SUTD), Singapore, will highlight “Educating Technology Leaders for Design-Driven Innovation.”

The organising committee is very grateful to Professor Hean Teik Chuah, Professor Tariq S Durrani and Professor Thomas L. Magnanti to deliver their keynote speech at this conference. We would like to thank all the authors and participants for their contribution and support. We would also like to acknowledge the contribution by technical programme committee members and the reviewers for their help in the review process.

We hope you enjoy the conference and the cultural and scenic experiences in Malaysia.

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<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ming-Gong LEE</td>
<td>Chung Hua University, Taiwan</td>
</tr>
<tr>
<td>Chun-Cheng LIN</td>
<td>National Chiao Tung University, Taiwan</td>
</tr>
<tr>
<td>Chu-Ti LIN</td>
<td>National Chiayi University, Taiwan</td>
</tr>
<tr>
<td>Jun LIN</td>
<td>Xian Jiaotong University, China</td>
</tr>
<tr>
<td>Tyrone T. LIN</td>
<td>National Dong Hwa University, Taiwan</td>
</tr>
<tr>
<td>Weidong LIN</td>
<td>Temasek Polytechnic, Singapore</td>
</tr>
<tr>
<td>Bor-Shong LIU</td>
<td>St. John’s University, Taiwan</td>
</tr>
<tr>
<td>Yiliu LIU</td>
<td>Norwegian University of Science and Technology, Norway</td>
</tr>
<tr>
<td>Mei-Chen LO</td>
<td>National United University, Taiwan</td>
</tr>
<tr>
<td>Huitian LU</td>
<td>South Dakota State University, United States</td>
</tr>
<tr>
<td>Jose MACHADO</td>
<td>University of Minho, Portugal</td>
</tr>
<tr>
<td>Virginia MACHADO</td>
<td>UNIDEMI, FCT-UNL, Portugal</td>
</tr>
<tr>
<td>Romeo MANALO</td>
<td>Manila Electric Company, Philippines</td>
</tr>
<tr>
<td>Lars MOENCH</td>
<td>University of Hagen, Germany</td>
</tr>
<tr>
<td>Wasawat NAKKIEW</td>
<td>Chiang Mai University, Thailand</td>
</tr>
<tr>
<td>Ville OJANEN</td>
<td>Lappeenranta University of Technology, Finland</td>
</tr>
<tr>
<td>Selma OLIVEIRA</td>
<td>University of São Paulo, Brazil</td>
</tr>
<tr>
<td>Samia OURARI</td>
<td>The Algerian Centre for Development of Advanced Technologies (CDTA), Algeria</td>
</tr>
<tr>
<td>Taezoon PARK</td>
<td>Soongsil University, South Korea</td>
</tr>
<tr>
<td>Jennifer PERCIVAL</td>
<td>University of Ontario Institute of Technology, Canada</td>
</tr>
<tr>
<td>Gyan PRAKASH</td>
<td>Indian Institute of Information Technology and Management, India</td>
</tr>
<tr>
<td>Suksan PROMBANPONG</td>
<td>King Mongkut’s University of Technology Thonburi, Thailand</td>
</tr>
<tr>
<td>Kit Fai PUN</td>
<td>University of the West Indies, Trinidad and Tobago</td>
</tr>
<tr>
<td>Ralph RIEDEL</td>
<td>Chemnitz University of Technology, Germany</td>
</tr>
<tr>
<td>Fernando ROMERO</td>
<td>University of Minho, Portugal</td>
</tr>
<tr>
<td>Mojahid SAEED OSMAN</td>
<td>King Fahd University of Petroleum and Minerals, Saudi Arabia</td>
</tr>
<tr>
<td>Tomoko SAIKI</td>
<td>Tokyo Institute of Technology, Japan</td>
</tr>
<tr>
<td>Kin Meng SAM</td>
<td>University of Macau, China</td>
</tr>
<tr>
<td>Premaratne SAMARANAYAKE</td>
<td>University of Western Sydney, Australia</td>
</tr>
<tr>
<td>Ilias SANTOURIDIS</td>
<td>TEI of Larissa, Greece</td>
</tr>
<tr>
<td>Kiyoshi SAWADA</td>
<td>University of Marketing and Distribution Sciences, Japan</td>
</tr>
<tr>
<td>Mahmood SHAFIEE</td>
<td>School of Applied Sciences, Cranfield University, United Kingdom</td>
</tr>
<tr>
<td>Ahm SHAMSUZZOHA</td>
<td>University of Vaasa, Finland</td>
</tr>
<tr>
<td>Ali SIADAT</td>
<td>Arts et Metiers ParisTech, France</td>
</tr>
<tr>
<td>Ronnachai SIROVETNUKUL</td>
<td>Mahidol University, Thailand</td>
</tr>
<tr>
<td>Stuart SO</td>
<td>The University of Queensland, Australia</td>
</tr>
<tr>
<td>Harm-Jan STEENHUIS</td>
<td>Department of Management, Eastern Washington University, United States</td>
</tr>
<tr>
<td>S. SYAFIIE</td>
<td>University Putra Malaysia, Malaysia</td>
</tr>
<tr>
<td>Fabrice TALLA NOBIBON</td>
<td>FedEx, Belgium</td>
</tr>
<tr>
<td>Yoshinobu TAMURA</td>
<td>Yamaguchi University, Japan</td>
</tr>
<tr>
<td>Purit THANAKIJKASEM</td>
<td>King Mongkut’s University of Technology Thonburi, Thailand</td>
</tr>
<tr>
<td>Norbert TRAUTMANN</td>
<td>University of Bern, Switzerland</td>
</tr>
<tr>
<td>Yuan-Jye TSENG</td>
<td>Yuan Ze University, Taiwan</td>
</tr>
<tr>
<td>David VALIS</td>
<td>University of Defence, Czech Republic</td>
</tr>
<tr>
<td>Yonggui WANG</td>
<td>University of International Business and Economics, China</td>
</tr>
<tr>
<td>Gede Agus WIDYADANA</td>
<td>Petra Christian University, Indonesia</td>
</tr>
<tr>
<td>Seng Fat WONG</td>
<td>University of Macau, Macau</td>
</tr>
<tr>
<td>Zhengguo Xu</td>
<td>Zhejiang University, China</td>
</tr>
<tr>
<td>Bingwen YAN</td>
<td>Cape Peninsula University of Technology, South Africa</td>
</tr>
<tr>
<td>Jaekyung YANG</td>
<td>Chonbuk National University, South Korea</td>
</tr>
<tr>
<td>QZ YANG</td>
<td>Circular Economy Research Centre, China</td>
</tr>
<tr>
<td>Norio YOSHIDA</td>
<td>University of Toyama, Japan</td>
</tr>
<tr>
<td>Cai Wen ZHANG</td>
<td>School of Business, Sun Yat-sen University, China</td>
</tr>
<tr>
<td>Linda ZHANG</td>
<td>IESEG School of Management, France</td>
</tr>
<tr>
<td>Xu ZHANG</td>
<td>Beijing Institute of Technology, China</td>
</tr>
</tbody>
</table>
# Table of Contents

## Decision Analysis & Methods I

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simultaneous Consideration of Remanufactured and New Products in Optimal Product Line Design</td>
<td>1</td>
</tr>
<tr>
<td><em>Ridvan AYDIN, C.K. KWONG, Ping JI</em></td>
<td></td>
</tr>
<tr>
<td>The Optimal Ordering Quantity with Uncertain Food's Safety Environment</td>
<td>6</td>
</tr>
<tr>
<td><em>Shu-Yen HSU, Tyrone T. LIN</em></td>
<td></td>
</tr>
<tr>
<td>Reduced Recursive Inclusion-exclusion Principle for the Probability of Union Events</td>
<td>11</td>
</tr>
<tr>
<td><em>Shin-Guang CHEN</em></td>
<td></td>
</tr>
<tr>
<td>A Bi-level Algorithm for Product Line Design and Pricing</td>
<td>14</td>
</tr>
<tr>
<td><em>Shuli WU, Songlin CHEN</em></td>
<td></td>
</tr>
<tr>
<td>An Optimal Electricity Consumption Decision with a Limited Carbon Emission Concept</td>
<td>19</td>
</tr>
<tr>
<td><em>Tyrone T. LIN, Hui-Chen LAN</em></td>
<td></td>
</tr>
<tr>
<td>An Integrated Data Envelopment Analysis (DEA) and Hedge Accounting Approach for Risk Management Efficiency Measurement: Evidence From Derivative Market in Asia-pacific Banks</td>
<td>24</td>
</tr>
<tr>
<td><em>Shahsuzan ZAKARIA, Sardar M. N. ISLAM</em></td>
<td></td>
</tr>
</tbody>
</table>

## Decision Analysis & Methods II

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Fuzzy Linguistic Representation Model for Decision Making Under Uncertainty</td>
<td>29</td>
</tr>
<tr>
<td><em>Wen-Tao GUO, Van-Nam HUYNH</em></td>
<td></td>
</tr>
<tr>
<td>Post Optimality Analysis of Pareto Optimal Set Through Weights Robustness</td>
<td>34</td>
</tr>
<tr>
<td><em>Maria KALININA, David SUNDGREN</em></td>
<td></td>
</tr>
<tr>
<td><em>Bennie Seck-Yong CHOO, Jenson Chong-Leng GOH</em></td>
<td></td>
</tr>
<tr>
<td>A Framework to Identify Sustainability Indicators for Product Design</td>
<td>44</td>
</tr>
<tr>
<td><em>Sam Yeon KIM, Seung Ki MOON, Hyung Sool OH, Taezoon PARK, HaeIn CHOI, Hungsun SON</em></td>
<td></td>
</tr>
<tr>
<td>An Interactive Bi-criteria Heuristic Algorithm for the Coherent System Assembly</td>
<td>49</td>
</tr>
<tr>
<td><em>Abdel-Aziz M. MOHAMED</em></td>
<td></td>
</tr>
<tr>
<td>Optimal Trial Number for D-optimal Designs Based on Efficiency-cost Ratio Analysis</td>
<td>54</td>
</tr>
<tr>
<td><em>XiuTing LIU, Sen LIN, Jun YANG</em></td>
<td></td>
</tr>
<tr>
<td>Swarm Based Mean-variance Mapping Optimization (MVMO’s) for Economic Dispatch Problem with Valve - Point Effects</td>
<td>59</td>
</tr>
<tr>
<td><em>Khoa TRUONG, Pandian VASANT, Balbir Singh MAHINDER SINGH, Dieu VO</em></td>
<td></td>
</tr>
</tbody>
</table>

## Operations Research I

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Multicriteria Decision Model for Technology Readiness Assessment for Energy Based on PROMETHEE Method with Surrogate Weights</td>
<td>64</td>
</tr>
<tr>
<td><em>Adiel ALMEIDA, Danielle C MORAIS, Luciana ALENCAR, Tharcylla CLEMENTE, Eduardo KRYM, C. Z. BARBOZA</em></td>
<td></td>
</tr>
</tbody>
</table>
An Imperialist Competitive Algorithm for the Job Shop Scheduling Problems
Hamed PIROOZFARD, Kuan Yew WONG

Impact Evaluation of MGNREGA Using Data Envelopment Analysis
Devaraj HANUMAPPA, Parthasarathy RAMACHANDRAN, T. G. SITHARAM

Critical Literature Review on Maturity Models for Business Process Excellence
Saja ALBLIWI, Jiju ANTONY, Norin ARSHED

A Modified Genetic Algorithm for Precedence Constrained Operation Sequencing Problem in Process Planning
Yuliang SU, Xuening CHU, Dongping CHEN, Dexin CHU

Building Master Surgery Schedules with Leveled Bed Occupancy and Nurse Workloads
Zakaria ABDELRASOL, Nermin HARRAZ, Amr B. ELTAWIL

Operations Research II

Resolution of Resource Conflicts in the CCPM Framework Using a Local Search Method
Hiroki KOGA, Hiroyuki GOTO, Eishi CHIBA

A Heuristic Algorithm for the Prize Collecting Steiner Tree Problem
Yuki Hosokawa, Eishi CHIBA

3D Loading Problem Formulation Using Mixed Integer Nonlinear Programming
Mojahid SAEED OSMAN, Bala RAM

A Hybrid PSO-TS Approach for Proportionate Multiprocessor Open Shop Scheduling
Tamer ABDELMAGUID

An Improved Approach for the Quay Crane Assignment Problem with Limited Availability of Internal Trucks in Container Terminal
A. KARAM, Amr B. ELTAWIL, Nerming HARRAZ

Asset Integrity of Deepwater Petroleum Production Facilities
Mayang KUSUMAWARDHANI, Tore MARKESET

Standardization Programs in the Industrial Plant Business: Best Practices and Lessons Learned
Michael GEPP, Jan VOLLMAR, Thomas SCHAEFFLER

Quality Control & Management I

Modeling Autocorrelated Process Control with Industrial Application
Siaw Li LEE, Maman Abdurachman DJAUHARI, Ismail MOHAMAD

Estimation of Population Generalized Variance: Application in Service Industry
Revathi SAGADAVAN, Maman Abdurachman DJAUHARI, Ismail MOHAMAD

Factors Affecting Quality in a Manufacturing Environment for a Non-repairable Product
Rene LOMBARD, Corro VAN WAVEREN, Kai-Ying CHAN

Improving Quality of Operations via Industry-specific Empowerment Antecedents: A Study of the Oil and Gas Industry
NgoziONYEMEH, Chan Wai LEE

Application of Six Sigma in Oil and Gas Industry: Converting Operation Data into Business Value for Process Prediction and Quality Control
Wai Kit CHENG, Amir Farid AZMAN, Mohamad Hisham HAMDAN, Rachel FRAN MANSA
Mishandled Baggage Problem: Causes and Improvement Suggestions

Imad ALSYOUF, Fatima HUMAID, Shaima AL KAMALI

Service Innovation & Management I

Priority Investment Components of Emotional Intelligence Effective on Marketing with AHP Method
Parissa TAVAKOLI-TARGHI, Yousef GHOLOPOUR KANANI

Workforce Planning for Global Network Delivery Model
Sumit RAUT, Kishore PADMANABHAN, Muralidharan SOMASUNDHANRAM, Natarajan VIJAYARANGAN

CSF in Product Innovation Process: A Comparative Study of Three Malaysian Manufacturing SMEs
Noor Hidayah ABU, Baba MD DEROSES, Mohd Fitri MANSOR

Supporting the Cross-disciplinary Development of Product-service Systems Through Model Transformations
Thomas WOLFENSTETTER, Konstantin KERNSCHMIDT, Christopher MÜNZBERG, Daniel KAMMERL, Suparna GOSWAMI, Udo LINDEMANN, Birgit VOGEL-HEUSER, Helmut KRCMAR

Structural Investigation of a Healthcare Value Chain: A Social Network Analysis Approach
Vipul JAIN, Sumit SAKHUJA

Investigating the Effects of Project Scales on the Patterns and Performance of Successfully Funded, Technology-oriented Innovative Crowdfunding Projects
Chien-Liang KUO, C.J.H. LIN, S.X.S. HUANG, Yu-Chen LIN

Supply Chain Management I

Supplier Selection Activities in the Service Sector: A Case Study in Nigeria
Dotun ADEBANJO, Matthew TICKLE, Frank OJADI, Petros IEROMONACHOU, Tritos LAOSIRIHONGTHONG, Roula MICHAELIDES

Managing Supply Disruption in a Three-tier Supply Chain with Multiple Suppliers and Retailers
Sanjoy Kumar PAUL, Rahul SARKER, Daryl ESSAM

Collaborative Inventory Distribution Management in a Supply Chain: A Simulation Perspective
Joby GEORGE, Nimmy J.S., V. Madhusudanan PILLAI

In-house Capacity Investment and Outsourcing Under Competition
Tarun JAIN, Jishnu HAZRA

Optimization of Multi-commodities Consumer Supply Chains Part II: Simulation Modeling
Zeinab HAJIABOLHASANI, Romeo M. MARJIAN, Lee LUONG

Identifying Critical Success Factors for Green Supply Chain Management Implementation Using Fuzzy DEMATEL Method
Rakesh Kumar MALVIYA, Ravi KANT

Warehouse Storage Assignment: The Case Study of a Plastic Bag Manufacturer
Chompoonoot KASEMSET, J. SUDPHAN

Manufacturing Systems I

Comparing Malaysian and Scottish Firms on Practices for Strategic Capability Management
Rob DEKKERS, Kanagi KANAPATHY
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Moderation Effect of the Cultural Dimension &quot;Individualism/Collectivism&quot; on Toyota Way Deployment - A Global Study on Toyota Facilities</td>
<td>228</td>
</tr>
<tr>
<td>Nihal JAYAMAHA, Jurgen WAGNER, Nigel GRIGG</td>
<td></td>
</tr>
<tr>
<td>Assessment of the Teamwork Organization in a Production Plant of a Major German Automobile Manufacturer</td>
<td>233</td>
</tr>
<tr>
<td>Robert STRANZENBACH, Philipp M. PRZYBYSZ, Susanne MÜTZE-NIEWÖHNER, Stephan SCHEEL, Christopher M. SCHLICK</td>
<td></td>
</tr>
<tr>
<td>Modeling Cognitive Network of a Physical System Using Design Knowledge Base</td>
<td>238</td>
</tr>
<tr>
<td>Shah LIMON, Om Prakash YADAV, Bimal NEPAL</td>
<td></td>
</tr>
<tr>
<td>Theoretical considerations for Make-or-buy Decisions During ‘Product Design and Engineering’: Three Indian Case Studies</td>
<td>243</td>
</tr>
<tr>
<td>Rob DEKKERS</td>
<td></td>
</tr>
<tr>
<td>Lean Transformation Efforts of the Wood Industry in Virginia</td>
<td>249</td>
</tr>
<tr>
<td>Omar ESPINOZA, Urs BUEHLMANN, C FRICKE</td>
<td></td>
</tr>
<tr>
<td>Optimal Control Synthesis for a Flexible Manufacturing System Based on Minimal Cuts</td>
<td>254</td>
</tr>
<tr>
<td>Sadok REZIG, Zied ACHOUR, Nidhal REZG, Mohamed-Ali KAMMOUN</td>
<td></td>
</tr>
<tr>
<td>Technology &amp; Knowledge Management I</td>
<td>259</td>
</tr>
<tr>
<td>A Behavioral Loyalty Model of Portable Computers</td>
<td></td>
</tr>
<tr>
<td>Mohammad Reza SHAHRIARI, Ali HAJIHA, Sara DEHGHAN</td>
<td></td>
</tr>
<tr>
<td>Regionalization of Engineering - Framework and Scenarios</td>
<td>264</td>
</tr>
<tr>
<td>Thomas SCHAEFFLER, Rudolf KODES, Michael GEPP, Nadja HOßBACH, Arndt LÜDER</td>
<td></td>
</tr>
<tr>
<td>The Marketing Strategy for Successful Product Development Performance in Iranian Nanotechnology-based Enterprises</td>
<td>270</td>
</tr>
<tr>
<td>Naser KHOSRAVI, Mohsen SADEGHI</td>
<td></td>
</tr>
<tr>
<td>Forecasting of Diffusion Pattern: A Case Example of OLED Technology</td>
<td>275</td>
</tr>
<tr>
<td>Pawat TANSURAT, Nathasit GERDSRI</td>
<td></td>
</tr>
<tr>
<td>Nguyen Thi Duc NGUYEN, Atushi AOYAMA</td>
<td></td>
</tr>
<tr>
<td>Identifying Knowledge Components in Software Requirement Elicitation</td>
<td>286</td>
</tr>
<tr>
<td>Laleh TAHERI, Noraini CHE PA, Rusli ABDULLAH, Salfarina ABDULLAH, Mohammad Yaser SHAFAZAND</td>
<td></td>
</tr>
<tr>
<td>Information Processing &amp; Engineering I</td>
<td>292</td>
</tr>
<tr>
<td>A Bayesian Accelerated Degradation Studies on Nitrile Rubber O-ring</td>
<td></td>
</tr>
<tr>
<td>Lizhi WANG, Xiaohong WANG, Yuxiang LI, Wenhui FAN</td>
<td></td>
</tr>
<tr>
<td>Interview Study: Decisions and Decision Criteria for Development in Industry</td>
<td>297</td>
</tr>
<tr>
<td>Danilo Marcello SCHMIDT, Sebastian SCHENKL, Eduard MUNKHART, Susanne NILSSON, Markus MÖRTL</td>
<td></td>
</tr>
<tr>
<td>Theoretical Analysis of RFID Security Protocols</td>
<td>302</td>
</tr>
<tr>
<td>Azam ZAVVARI, Mohammad Turiqul ISLAM, Masoud SHAKIBA, Mandeep Jit SINGH</td>
<td></td>
</tr>
<tr>
<td>Analyzing and Visualizing News Trends Over Time</td>
<td>307</td>
</tr>
<tr>
<td>Lubaba Farin TANISHA, Bishwajit Banik PATHIK, Manzur H. KHAN, Md. Mamun HABIB</td>
<td></td>
</tr>
</tbody>
</table>
A Novel Tool for Reducing Time and Cost at Software Test Estimation: An Use Cases and Functions Based Approach  
Shaiful ISLAM, Bishwajit Banik PATHIK, Manzur H. KHAN, Md. Mamun HABIB

Self-focusing Appearance in Ultra-compact 3×3 Multimode Interference Coupler Based on Silicon on Insulator  
Mehdi TAJALDINI, Mohd Zubir MAT JAFRI

Healthcare Systems & Management

Healthcare Platforming for Healthcare Service Development in Hospitals  
Linda L. ZHANG, Michel ALDANONDO, Arun KUMAR

Design of a Dynamic Bi-objective Relief Routing Network in the Earthquake Response Phase  
Shadab SHISHEHGAR, Reza TAVAKKOLI-MOGHADDAM, Ali SIADAT, Mehrdad MOHAMMADI

Towards an Instrumented Tissue Expander  
Annette BÖHMER, Alexander ZÖLLNER, Ellen KUHL, Udo LINDEMANN

Health System Design: A Financial Perspective  
Hans-Jakob LUETHI, C. MANDL, Philippe WIDMER

An Employee Assistance Program by Analyzing the Correlation Between Work Stress and Dreams for Chinese Employees  
Kuei-Chen CHIU, Tsai-Wei HUANG, Shulan HSIEH

A Novel Simulated Metamorphosis Algorithm for Homecare Nurse Scheduling  
Michael MUTINGI, Charles MBOHWA

Education Management in Healthcare Communities  
Juha PUUSTJÄRVI, Leena PUUSTJÄRVI

Intelligent Systems I

Study on the Production Forecasting Based on Grey Neural Network Model in Automotive Industry  
Bin LIN, Seng Fat WONG, Weng Ian HO

The Need for Integrating Statistical Process Control and Automatic Process Control  
Abdul-Wahid A. SAIF

Modeling Novices in Decision-problem Structuring for Collective Intelligence  
Dianne Lee-Mei CHEONG

Survey on Tools and Systems to Generate ER Diagram from System Requirement Specification  
Wasana C. UDUWELA, Gamini WIJAYARATHNA

A Methodology for Fuzzy Multi-criteria Decision-making Approach for Scheduling Problems in Robotic Flexible Assembly Cells  
Khalid ABD, Kazem ABHARY, Romeo M. MARIAN

Application of a Fuzzy Multi-criteria Decision-making Approach for Dynamic Scheduling in Robotic Flexible Assembly Cells  
Khalid ABD, Kazem ABHARY, Romeo M. MARIAN

Overtime Capacity Expansion in Order Acceptance with Node Based Estimation of Distribution Algorithms  
Watcharee WATTANAPORN PROM, Tieke LI, Warin WATTANAPORN PROM, Prabhas CHONGSTITVATANA
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Modeling and Analysis of LM6000 Gas-turbine Synchronous Generator</td>
<td>389</td>
</tr>
<tr>
<td>Roozbeh ESHRAGHNIA, Randy J. KLEEN</td>
<td></td>
</tr>
<tr>
<td>Simulation Based Lean Six Sigma Approach to Reduce Patients Waiting Time in an Outpatient Eye Clinic</td>
<td>394</td>
</tr>
<tr>
<td>Weidong LIN, Xianfei JIN, Sie Yong CHIA</td>
<td></td>
</tr>
<tr>
<td>Combining Set-based Concurrent Engineering and Function- Means Modelling to Manage Platform-based Product Family Design</td>
<td>399</td>
</tr>
<tr>
<td>Dag RAUDBERGET, Marcel MICHAELIS, Hans JOHANNESSON</td>
<td></td>
</tr>
<tr>
<td>Simulation of New System Departure Terminal Soekarno-Hatta International Airport</td>
<td>404</td>
</tr>
<tr>
<td>Dimas NOVRISAL, Nuraida WAHYUNI, Nadia HAMANI, Abderrahman ELMHAMEDI, Tresna SOEMARDI</td>
<td></td>
</tr>
<tr>
<td>Numerical Simulation of Stress Distribution of a Femur-Menisci-Tibia Bone During Normal Standing, Normal Walking, and Standing with a Cane</td>
<td>409</td>
</tr>
<tr>
<td>Angkhana PROMMARAT, Athassawat KAMMANEE, Thitikom PUAPANSAWAT, Farida CHAMCHOD</td>
<td></td>
</tr>
<tr>
<td>Statistical Analysis and a Social Network Model Based on the SEIQR Framework</td>
<td>414</td>
</tr>
<tr>
<td>Benjamas CHIMMALEE, Wannika SAWANGTHONG, Rawee SUWANDECHOCHAI, Farida CHAMCHOD</td>
<td></td>
</tr>
<tr>
<td>Placing a Liaison with Long Communication Lengths to the Same Level in an Organization Structure</td>
<td>419</td>
</tr>
<tr>
<td>Kiyoshi SAWADA</td>
<td></td>
</tr>
<tr>
<td>Setting Up An Intellectual Properties Intermediary Service: DMAIC Way</td>
<td>423</td>
</tr>
<tr>
<td>Kim SIOW</td>
<td></td>
</tr>
<tr>
<td>Modular, Building Blocks - Based Approach for Information and Documentation Management in Planning Projects</td>
<td>428</td>
</tr>
<tr>
<td>Daniel OEHME, Ralph RIEDEL, Egon MÜLLER</td>
<td></td>
</tr>
<tr>
<td>Establishing the Development Mechanism of ERP Report</td>
<td>433</td>
</tr>
<tr>
<td>Te- King CHIEN, Hou-Yi LIN</td>
<td></td>
</tr>
<tr>
<td>Multi-objective Optimization and Risk Assessment in System Engineering Project Planning by Ant Colony Algorithm</td>
<td>438</td>
</tr>
<tr>
<td>Pablo BAROSO, Thierry COUDERT, Eric VILLENEUVE, Laurent GENESTE</td>
<td></td>
</tr>
<tr>
<td>Analyzing Implementation of Lean Production Control with the Viable System Model</td>
<td>443</td>
</tr>
<tr>
<td>Fatos ELEZI, Michael Timo SCHMIDT, Iris TOMMELEIN, Udo LINDEMANN</td>
<td></td>
</tr>
<tr>
<td>Development of QuicKaizen™ Technique for Productivity Execution Management for Singapore SMEs</td>
<td>448</td>
</tr>
<tr>
<td>Chin Wei GAN, Ming Hon TOH, Roland LIM, Bin MA, Puay Siew TAN, Amrik Singh BHULLAR</td>
<td></td>
</tr>
<tr>
<td>The Resource-constrained Project Scheduling Problem with Stochastic Activity Durations</td>
<td>453</td>
</tr>
<tr>
<td>Stefan CREEMERS</td>
<td></td>
</tr>
<tr>
<td>A Comparative Study Among Stakeholders on Causes of Time Delay in Malaysian Multiple Design and Build Projects</td>
<td>458</td>
</tr>
<tr>
<td>Ramanathan CHIDAMBARAN, Narayanan SAMBU POTTY</td>
<td></td>
</tr>
</tbody>
</table>
Human Factors I

Enhancing Work System Design and Improvement by Further Developments of Value Stream Mapping
Peter KUHLANG, Thomas EDMAYR, Alexander SUNK, Thomas MÜHLBRADT

Influence of Human Factors Over Idea Generation: a Qualitative and Quantitative Analysis of an Enterprise of the Graphic Sector in Medellin
Manuela ESCOBAR SIERRA, Luz Dinora VERA ACEVEDO

The Effect of Font Size on Typing Performance and Sitting Posture
Harutetaj LOHASIRIWAT, Tensin WATTANAPANICH, Panmeq SAECHAN

Improvement of Workstation by Providing Ergonomically Designed Chair and Table for the Water Hyacinth Weaving Department of the Villar Foundation
Devie Ann GAMATA, Ralph OROZCO, J K. C. LASERNA, J. A. MEDINA, Sheily MENDOZA, R J. U. GARCIA

The Effect of Psychosocial Stress on Trapezius Muscle Activity During Computer Work: A Review
Mohd Firdaus MOHD TAIB, Myung Hwan YUN

Parametric Modeling of 3D Human Faces Using Anthropometric Data
Chun-Yang TSENG, I-Jan WANG, Chih-Hsing CHU

Chien-Sing LEE, K. Daniel WONG

Production Planning & Control I

Process Family Planning: An Optimization-based Approach
Roel LEUS, Linda L. ZHANG, Daniel KOWALCZYK

Efficient Symmetry-breaking Formulations for Grouping Customer Orders in a Printing Shop
Philipp BAUMANN, Norbert TRAUTMANN

Continuous Precise Workload Control Method
Hakan AKILLIOGLU, Joao-Dias FERREIRA, Antonio MAFFEI, Pedro NEVES, Mauro ONORI

Economic Level of Detail for Assembly Planning
Achim KAMPKER, Peter BURGGRAF, Yvonne BÄUMERS

Scheduling a Dynamic Flowshop to Minimize the Mean Absolute Deviation from Distinct Due Dates
Ahmed W. EL-BOURI

A Hybrid EOQ and Fuzzy Model to Minimize the Material Inventory in Ready Mixed Concrete Plants
Mehdi RAVANSHADNIA, Milad GHANBARI

A Structural Equation Model Linking Forecasting, Planning and Controlling with SME Performance
Biju PUTHANVEETTIL, Bhasi MARATH

Decision Analysis & Methods III

Design for Open Innovation (DfOI) - Product Structure Planning for Open Innovation Toolkits
Maik HOLLE, Udo LINDEMANN
Effects of Different Classifiers in Detecting Infectious Regions in Chest Radiographs
Wan Siti Halimatul Munirah WAN AHMAD, Rajasvaran LOGESWARAN, Mohammad Faizal AHMAD FAUZI, Wan Mimi Diyana WAN ZAKI

Parallelization of Industrial Process Control Program Based on the Technique of Differential Evolution Using Multi-threading
Rajeev AGRAWAL, Abhinav GOYAL, Debjani SAMBASIVAM, Arya K BHATTACHARYA

Weibull Component Reliability Evaluation With Masked Data
Jieqiong MIAO, Xiaogang LI, Renxi LUO

An Extension of PROMETHEE to Divisive Hierarchical Multicriteria Clustering
Yves DE SMET

Effectiveness Assessment for Waste Management Decision-support in the Arctic Drilling
Yonas Zewdu AYELE, Abbas BARABADI, Javad BARABADI

Decision Analysis & Methods IV

Afshan NASEEM, Shoab Ahmed KHAN, Asad WAQAR MALIK

An Approach to Analyse Key Renewable Energy Technologies: A Case from Sri Lanka
Amila WITHANAARACHCHI, Julian NAYAKKARA, Chamli PUSHPAKUMARA

Bibliometric Methodology to Detect Collaborative and Competitive Countries
Shino IWAMI, Francisco TACOA, Junichiro MORI, Yuya KAJIKAWA, Ichiro SAKATA

Fuzzy Decision Making in Shape Feature Design for Product Development
Ching-Hu YANG, Chung-Shing WANG, Chin-Fu CHEN, P.Y. LIN, Chung-Chuan WANG

An ANP-based Multi Criteria Decision Making Model for Supplier Selection
Hisham ALIDRISI

Multi-granules Evaluation Model Through Fuzzy Random Regression Analysis
Nureize ARBAIY

Decision Analysis & Methods V

A Case Study on Mining Social Media Data
Hing Kai CHAN, Ewelina LACKA, Rachel W. Y. YEE, Ming K. LIM

Understanding Sustainability in Healthcare Systems: A Systems Thinking Perspective
Michael MUTINGI, Charles MBOHWA

Mitigating the Effort for Engineering Changes in Product Development Using a Fuzzy Expert System
Tobias KINDSMULLER, Florian H BEHNCKE, Benjamin STAHL, Klaus DIEPOLD, Martina WICKEL, Daniel KAMMEREI, Konstantin KERNSCHMIDT

Information Communications Technology (ICT) Infrastructure Impact on Stock Market-Growth Nexus: The Panel VAR Model
Rudra P PRADHAN

A Mathematical Formulation for Low Carbon Electricity Planning in the Presence of Technology and Policy Interventions
Amrutha APPIYAH, Mathu MATHIRAJAN, Balachandra PATIL
Five Factors That Make Pervasive Business Intelligence a Winning Wager
Riccardo COGNINI, Flavio CORRADINI, Alberto POLZONETTI, Barbara RE

S. M. MOUSAVI, Hossein GITINAVARD, Ali SLADAT

Operations Research III
A New DEA Model for Six Sigma Project Selecting: Case Study on Esfahan Province Electricity Distribution Co (EPEDC)
Ali YOUSEFI, Amir Reza AQAMOHAMMADI

Khaoula HAMDI, Nacima LABADIE, Alice YALAQUI

Electricity System Sustainability Transitions: An Integrated Methodology
Taran SHARMA, Patil BALACHANDRA

Multi-project Flexible Resource Profiles Project Scheduling with Ant Colony Optimization
Elena ROKOU, Manos DERMITZAKIS, Konstantinos KIRYTOPOULOS

An Efficient Solution Framework for a Large Scale Delivery Problem
Sayan TENG, Edmund CHAN, Changjun YANG, Mingyen YU, Siow Hwei TAN

Second Order-response Surface Model for the Automated Parameter Tuning Problem
Aldy GUNAWAN, Hoong Chun LAU

Operations Research IV
A Bootstrap Data Envelopment Analysis (BDEA) Approach in Islamic Banking Sector: A Method to Strengthen Efficiency Measurement
Shahsuzan ZAKARIA, Mad Ithnin SALLEH, Shamsuriati HASAN

A Rule-based Heuristic Procedure for the Container Pre-marshalling Problem
Mohamed GHEITH, Amr B. ELTAWIL, Nermine HARRAZ

Operational Excellence Frameworks - Case Studies and Applicability to SMEs in Singapore
Amrik Singh BHULLAR, Chin Wei GAN, Andy ANG, Bin MA, Roland LIM, Ming Hon TOH

A Mathematical Model and a GRASP Metaheuristic for a Faculty-course Assignment Problem for a University in Saudi Arabia
Khaoula HAMDI

Multi-objective Vehicle Refueling Planning Using Mixed Integer Programming
Shieu-Hong LIN

Solving the Toll Optimization Problem by a Heuristic Algorithm Based Upon Sensitivity Analysis
Vyacheslav KALASHNIKOV, Nataliya KALASHNYKOVA, Roberto Carlos HERRERA-MALDONADO

Global Manufacturing & Engineering
Drivers and Barriers in Sustainable Manufacturing Implementation in Malaysian Manufacturing Firms
Norani NORDIN, Hasbullah ASHARI, Mohamad Ghozali HASSAN
Choose Whom to Date Wisely: Explaining the Performance Variation in Strategic Alliances
Mait RUNGI, Valeria STULOVA

Smart Factories in Industry 4.0: A Review of the Concept and of Energy Management Approached in Production Based on the Internet of Things Paradigm
Fadi SHROUF, Joaquin ORDIERES, Giovanni MIRAGLIOTTA

Application of Lean Manufacturing in Mass Production System: A Case Study in Indian Manufacturing Unit
Mahadevan KISHORE KUMAR, A. JOHN RAJAN, R. KAJA BANTHA NAVAS, S. SAHAYA RUBINSON

Simultaneous Configuration of Product Families and Supply Chains for Mass Customization Using Leader-follower Game Theory
Dong YANG, Roger J. JIAO

Operations Research V

Management of the Care Activities in Home Health Care Services: the Routing and Scheduling of Caregivers Level
Rabeh REDJEM, Eric MARCON, Xiaolan XIE

Optimal Cost Drivers in Activity Based Costing Based on Artificial Neural Network
Noppadol AMDEE, Kawin SONTHIPERMPOON, Thongchai ARUNCHAI, Phanboonme WARAWUT

Icing and Performance of Offshore Production Facilities in Cold Climate Region
Rezgar ZAKI, Abbas BARABADI

Petri Net Representation for 0-1 Integer Programming Problems
Akito KODAMA, Tatsushi NISHI

Algorithms for the Min-max Regret Generalized Assignment Problem with Interval Data
Wei WU, Manuel IORI, Silvano MARTELLO, Mutsunori YAGIURA

Network Optimization for Capturing and Transporting CO2
Ho-Yoeng YUN, Lianxi BAI, Kyung-Sup KIM, Suk-Jae JEONG

Laboratory Measurement: Chlorophyll-a Concentration Measurement with Acetone Method Using Spectrophotometer
Fairooz JOHAN, Mohd Zubir MAT JAFRI, Hwee San LIM, Wan Maznah WAN OMAR

Quality Control & Management IV

Comparative Analysis of Taguchi’s Crossed Array Approach vs Combined Array Approach to Robust Parameter Design: A Study Based on Apparel Industry
Pramila GAMAGE, Nihal JAYAMAHA, Nigel GRIGG, Manjula NANAYAKKARA

Total Quality Management in Product Life Cycle
Dinh Son NGUYEN

Fuzzy Mean and Range Control Charts for Monitoring Fuzzy Quality Characteristics: A Case Study in Food Industries Using Chicken Nugget
S. Mojtaba ZABIHINPOUR, M. K. A. ARIFFIN, S. H. TANG, A. S. AZFANIZAM, Omid BOYER

One Hotelling T2 Chart Based on Transformed Data for Simultaneous Monitoring the Frequency and Magnitude of an Event
Yuan CHENG, Amitava MUKHERJEE
Quality Operating of Information Systems and Service Level Agreement
David TCHOFFA, El Mouloudi DAFAOUI, Abderrahman ELMHAMEDI, Luminita DUTA

Drilling Waste Minimization in the Barents Sea
Rezgar ZAKI, Abbas BARABADI

Service Innovation & Management II

Influence of Task Characteristics on Team Performance
Philipp M. PRZYBYLSZ, Sönke DUCKWITZ, Christopher M. SCHLICK

Multi-screen Services Adoption and Use-diffusion: The BEST Model Perspective
Hung Chih LAI, Yao Cheng YU, Yi-Min TUAN, Hui Shan KUO

Effects of the Electromobility on Rescue Service Provisions
Francoise MEYER, Alexander RANNACHER, Sönke DUCKWITZ

TRIZ Based Approach to Improve Public Bus Service Quality
Christina WIRAWAN, Astrid AYU

Design and Development Waste Management System in Hong Kong
Carman Ka Man LEE, Trevor WU

Maximizing Service Value: A Case Study of Online Hotel Reservation
Napaporn RIANTHONG, Aussadavut DUMRONGSIRI, Youji KOHDA

Quality Control & Management II

Driving 'Soft' Factors for Sustaining Quality Excellence: Perceptions from Quality Managers
Mehran DOULATABADI, Sha’ri MOHD YUSOF

Robust On-line Monitoring for Univariate Processes Based on Two Sample Goodness-of-fit Test
Chen ZHANG, Nan CHEN

Critical Success Factors of Six Sigma: An Overview
Diego TLAPA, Jorge LIMON, Yolanda BÁEZ, Delia VALLES-ROSALES

Human Values for Implementation of Total Quality Management: Proposed Conceptual Framework of an Automated Tool
Muhammad Noman MALIK, Sha’ri MOHD YUSOF

Factors that Impact Project Quality at a Nuclear Power Plant in South Africa
Stanley FORE, W. GALETTA

Improving Overall Equipment Effectiveness (OEE) Through the Six Sigma Methodology in a Semiconductor Firm: A Case Study
Kam-Choi NG, Kuan Eng CHONG, Gerald Guan Gan GOH

Quality Control & Management III

Optimal Integrated Maintenance Policy Based on Quality Deterioration
Meriem KOUKI, Sofiene DELLAGI, Zied ACHOUR, Walid ERRAY

A Study on the Optimization of Wafer Pre-treatment Conditions for Thin Film Stability Monitor
Taicheng Kevin GONG, Yanju Lisa YU, Yan Kaily CAO, Xueliang Ruben ZHANG, Kaitiuan Kevin CHANG, Weiting Kary CHIEN
Monitoring Correlation Structures Stability in Foreign Exchange Market
Siew Lee GAN, Maman Abdurachman DJAUHARI, Zuhaimy ISMAIL 848

Control of pH Neutralization System Using Nonlinear Model Predictive Control with I-controller
Ayman HERMANSSON, S SYAFIE 853

An Efficient Discrete Particle Swarm Optimization for Solving Multi-mode Resource-constrained Project Scheduling Problems
Jianshuang CUI, Liruoyang YU 858

Reliability Analysis Based on Three-dimensional Stochastic Differential Equation for Big Data on Cloud Computing
Yoshinobu TAMURA, Kenta MIYAOKA, Shigeru YAMADA 863

Supply Chain Management II

Sourcing Decision with Correlated Supplier Disruption: An MV Framework
Pritee RAY, Mamata JENAMANI 868

A Brief Review on Information Sharing within Supply Chains
Farnoush FARAJPOUR, Mohammad Taghi TAGHAVIFARD 872

Ant Colony Optimization for One-to-Many Network Inventory Routing Problem
Lily WONG, Noor Hasnah MOIN 877

Analysis of Quantity Discounts for Multi-period Production Planning for Single Supplier and Retailer Under Uncertain Demands
Okihiro YOSHIDA, Tatsushi NISHI, Guoqing ZHANG 882

The Cluster Policies to Nation Competitiveness Based on Business Ecosystem Perspective - Case Study of Taiwanese Smart Phone Industry
Yan-Ru LI 887

Mitigating Supply Chain Risk: A Real Options Approach
Nunzia CARBONARA, N. COSTANTINO, Roberta PELLEGRINO 892

Supply Chain Management III

SCM Trends and Challenges - Implications from a Cross-industry Analysis
Felix FRIEMANN, Markus GERSCHBERGER, Kathrin REITNER, Paul SCHÖNSLEBEN 897

Vehicle Routing with Time Window for Regional Network Services - Practical Modelling Approach
Iman NIROOMAND, Amir H. KHATAIE, Masoud RAHIMINEZHAD GALANKASHI 903

Development of a General Collaboration Model - Basis for the Establishment of a Collaboration Compass
Xiao-li CHEN, Antonia MAHLING, Ralph RIEDEL, Egon MÜLLER 908

Solving Inventory Routing Problem with Backordering Using Artificial Bee Colony
Huda Zuhrah AB HALIM, Noor Hasnah MOIN 913

Big Data Analytics for Supply Chain Management
Jens LEVELING, Matthias EDELBROCK, Boris OTTO 918

Multi Objective Supply Chain Network Design Considering Customer Satisfaction
Mahdi BASHIRI, Hanieh KHORASANI, Mahdyeh SHIRI 923

Supply Chain Risk Management: A Method and Tool Contributing to the Operational Aspects
Elena ROKOU, Konstantinos KIRYTOPOULOS 928

xiv
Manufacturing Systems II

Joint Optimization of Production-maintenance Plans Based on Optimal Production Rates
Jeremie SCHUTZ 933

A New Bi-objective Mathematical Model for Sustainable Dynamic Cellular Manufacturing Systems
Farzad NIAKAN, Armand BABOLI, Thierry MOYAUX, Valerie BOLTA-GENOUZ 938

Optimization of Green Electrical Discharge Machining Using an Integrated Approach
JAGADISH, Amitava RAY 943

Rashmi SINGH, Muthu MATHIRAJAN 948

Applying Lean and TOC to Improvement Delivery Performance for Machine Tool Manufacturers
Chuang-Chun CHIOU, T.W. JHANG, Y. X. DENG, J.T. TSAI, C. PERNG 953

Interactive Virtual Machining System Using Informative Data Structure and On-site Machine Tool Status
Aini Zuhra ABDUL KADIR, Xun XU 958

A Simulation Based System for Manufacturing Process Optimisation
Hossam ISMAIL, Lina WANG, Jenny POOLTON 963

Manufacturing Systems III

Multi-skeleton Model for Top-down Design of Complex Modular Products
Dexin CHU, Xuening CHU, guolin LV, Yuliang SU, Dongping CHEN 968

Optimized Tool Path Planning in 5-Axis Flank Machining using Electromagnetism-like Algorithms
Chi Lung KUO, Chih-Hsing CHU, Ying LI, Xinyu LI, Liang GAO 973

Signal Propagation Model Calibration Under Metal Noise Factor for Indoor Localization by Using RFID
Seng Fat WONG, Xue NI 978

Experiential Learning: Lean Team at Virginia Tech
Urs BUEHLMANN, Omar ESPINOZA 983

The Backward Growing Method for Constructing 3D Process Models in the Machining Process Planning
Jinfeng LIU, Xiaojun LIU, Yalong CHENG, Zhonghua NI 988

Proposal of a Decision Making Model to Select the Best Fitting Cost Estimation Technique in an ETO-MC Environment
Aldo DUCHI, Golboo POURABDOLLAHIAN, Davide SILI, Matteo CIOFFI, Marco TAISCH 993

Information Processing & Engineering II

Development of a Methodology for Cost-oriented Ramp-up Design
Achim KAMPKER, Christoph DEUTSKENS, Andreas MAUE 998

Discovering Product Feature and Affective Associations Through Collaborative Tagging
S. C. Johnson LIM, Siuaili JAWARIS 1003

Construction of an Interactive Behavioral and Feature Structure Model for Facebook
Tsung-Yi CHEN, Meng-Che TSAI, Yuh-Min CHEN 1008
SWOT Analysis of NPTEL Knowledge Portal
Kalyan Kumar BHATTACHARJEE

Life Cycle Inventory Analysis and Equivalent Carbon Dioxide Emissions Calculation of the Mining and Ore Concentration Processes of PGM at The Anglo American Platinum Ltd, South Africa
Junior MABIZA, Charles MBOHWA, Michael MUTINGI

Technology & Knowledge Management II
Methodology for Resource Allocation in the Tool and Die Industry
Guenther SCHUH, Martin PITSCH, Thomas KÜHN, Advan BEGOVIĆ

Measuring the Quality of Cooperation in Interdisciplinary Research Clusters
Stefan SCHRÖDER, Markus KOWALSKI, Claudia JOOSS, R. VOSSEN, Anja RICHERT, Sabina JESCHKE

Do We Miscount Patent Citations? An Empirical Study on the Impact of Overlooking the Citations to a Patent's Pre-grant Publication
Chung-Huei KUAN, Hsiang-Jui CHENG

The Contribution of Technology to Improving Meanings: The Quantitative Analysis of Meanings
Satoru GOTO, Shuichi ISHIDA

Advance of Research on Technology Acceptance
Ruiping YANG, Liyan ZHOU, Xinxin HOU, Yiming XIANG

Readiness of Malaysian E-Commerce Companies to Harness Web2.0’s Competitive Advantage: An Engineering Management Approach
Ching Chieh KIU, Chien-Sing LEE

Educational Leadership: The Effects of Leadership in Students Educational Performance in Engineering Institutes
Subhashini GOPAL KRISHNAN, Vinesh THIRUCHELVAM

Information Processing & Engineering III
An Efficient Method for Checking Overlaps and Construction Algorithms for the Bitmap Shape Packing Problem
Sho FUKATSU, Yannan HU, Hideki HASHIMOTO, Shinji IMAHORI, Mutsunori YAGIURA

Managing Conflict in Distributed Projects
Ramin SHAHZADI, Mohsen SADEGHI, Asal AGHAZ

Analysis of Scientific Research Structure in Singapore Using Bibliometrics and Network Analysis for Understanding Their Characteristics of R&D: A Case Study of Biomedical Field
Ken HAYASHIMA, Haruki SAWAMURA, Ichiro SAKATA, Yoichiro MATSUMOTO, Hajime SASAKI

Modelling Financial Flow of the Supply Chain
Mohammad Hossein JAHANGIRI, Franjo CECELJA

Role of Walsh Codes and Pseudorandom Noise Sequences in CDMA
Puneet CHAWLA, Balwinder SINGH

Learning from Past Changes - Towards a Learning-oriented Engineering Change Management
Christoph HOLLAUER, Martina WICKEL, Udo LINDEMANN

A Study of Applying Severity-weighted Greedy Algorithm to Software Test Case Prioritization During Testing
Yen-Ching HSU, Kuan-Li PENG, Chin-Yu HUANG
Technology & Knowledge Management III

Fasten Your Seatbelts, Turbulence Ahead: Environmental Turbulence as a Determinant of Absorptive Capacity
Valeria STULOVA, Mait RUNGI
1091

A Preliminary Survey on Modeling Customer Requirements from Product Reviews Under Preference Uncertainty
Anies ZAKARIA, S. C. Johnson LIM
1096

Hybrid Intelligent Patent Mapping for Offshore Wind Industry Analysis
Chin Yuan FAN, Shou Hao CHANG, P. S. FAN, L. F. KAO
1101

Users’ Acceptance of IT and Its Impact on Knowledge Sharing: A Case in the South African Banking Industry
Abdulkadir Kolawole BELLO, Kai-Ying CHAN
1106

Interpretive Structural Model of Key Performance Indicators for Sustainable Manufacturing Evaluation in Cement Industry
Elita AMRINA, Annike LUTFIA VILSI
1111

What Innovation Managers Really Do - An Empirical Study About Tasks, Skills and Traits of Innovation Managers in Germany
Maximilian A. MAIER
1116

E-Business & E-Commerce

Adoption of Near Field Communication for Mobile Payment: Evidence from Macau
Kin Meng SAM, Chris CHATWIN, Jing Xin ZHANG
1121

The Implementation Strategy of Key Task for ERP Activities
Te- King CHIEN, Ming-Sian CHENG
1126

Consumer Attitudes Toward Online Video Advertising: An Empirical Study on YouTube as Platform
Keng-Chieh YANG, Conna YANG, Chia-Hui HUANG, Po-Hong SHIH, Su Yu Yang YANG
1131

The Role of Perceived Value on Customer E-shopping Intention Using Technology Acceptance Model, (TAM)
Ali HAJIHA, Mohammad Reza SHAHRIARI, Nayereh VAKILIAN
1136

Probation of the Private Enterprises’ Informatization in Wenzhou
Jindong LI, Jixuan FENG
1141

Cloud Manufacturing for a Service-oriented Paradigm Shift
Yuqian LU, Xun XU
1146

Reliability & Management Engineering

Software Hazard Rate Modeling with Multiple Change-Point Occurrences
Shinji INOUE, Shigeru YAMADA
1151

Reliable System Design Under Uncertainty
Mengqi LI, Minghong HAN, Jiaqi XU
1156

Integration of Failure Prediction Bayesian Networks for Complex Equipment System
Weitao SI, Zhiqiang CAI, Shudong SUN, Shubin SI
1161
# Prediction of Vehicle further Operation and Fault Based on Tribo-diagnostic Data

David VALIS, Libor ZAK, J. CHALOUPKA

# Estimation of System Residual Useful Life Based on Selected Tribo Data

David VALIS, Ondrej POKORA

## Project Management II

### Knowledge Transfer in Project-based Organizations. A Conceptual Model for Investigating

Knowledge Type, Transfer Mechanisms and Transfer Success

Corro VAN WAVEREN, Leon OERLEMANS, Marthinus PRETORIUS

### A Conceptual Multi-dimensional Evaluation Model for New Product Portfolio Management – Using Hybrid Fuzzy Model of AHP-DEA

Kirannayi PULIPAKA, Muthu MATHIRAJAN

### A Recommendation on PLUS Highway Development: A Social Network Analysis Approach

Norhaidah MOHD ASRAH, Maman Abdurachman DIAUHARI

### Evaluating Risk Factors in the Operation of Virtual Teams in ICT Projects

Nikos RASSIAS, Konstantinos KIRYTOPOULOS

### Instructional Design for Online Course Delivery in Engineering Management: Synthesizing Learning Styles, Pedagogical Perspectives and Contingency Factors

Senevi KIRIDENA, Premaratne SAMARANAYAKE, David HASTIE

### Identifying Critical Project Management Techniques and Skills for Construction Professionals to Achieving Project Success

Jui-Sheng CHOU, Ngoc-Tri NGO

## Systems Modeling & Simulation II

### An Ising-based Approach to the Study of Inter-organizational Team Dynamics

Ilaria GIANNOCARO, Ilario DE VINCENZO, Giuseppe CARBONE

### Individual Versus Integrated Simulation Techniques in Healthcare Applications

Mohammed ABDELGHANY, Amr B. ELTAWIL

### CFD Analysis of Chlorine Gas Dispersion In Indoor Storage: Temperatures with Wind Velocities Effect Studies

Mohsen SAFAKAR, S SYAFIIE, Robiah BT. YUNUS

### Depicting Product-service Systems in the Early Phase of the Product Development

Daniel KAMMERL, Martin ENSELEIT, Robert ORAWSKI, Danilo Marcello SCHMIDT, Markus MÖRTL

### No Clutch Fuzzy Logic-controlled Hybrid Transmission

Essam ESMAIL, Hamed HUSSAIN, Rahman HUSSAIN

### Fractional Order PI Controller for Wind Farm Supervision

Boualem BENLAHBIB, Noureddine BOUARROUDJ, Farid BOUCHAFAA, Bachir BATON

### Multi-objective Genetic Algorithm in Green Just-in-time Logistics

Ashkan MEMARI, Abdul Rahman ABDUL RAHIM, Robiah AHMAD
Safety, Security & Risk Management

A Taxonomy of Security and Privacy Requirements for the Internet of Things (IoT)
Israa ALQASSEM, Davor SVETINOVIC 1244

Friction Measurements on Floors Under Solid Contaminated Conditions
Kai-Way LI, T-Y PEI 1249

Understanding Hazards and Risks in Modern Sociotechnical Systems: Systemic Approach to Identify Human, Organizational and Technical Factors
Haftay Hailay ABRAHA, Jayantha P. LIYANAGE 1253

Effects of Demography and Occupational Traits on Consequence of Injury of Underground Coal Miners
Sanjay Kumar PALEI, Netai Chandra KARMAKAR, Rutwick S. M. REDDY 1260

Risk Analysis and Rescue Operation for Machine Roomless Lift: A Case Study
Choo Yong LEE, Chin Huat LIM 1265

Modeling of Tolerable Repair Time Without Affecting System Reliability
Aishwarya MISHRA, Pranab MURARI, Sanjay Kumar PALEI, Suprakash GUPTA 1270

Production Planning & Control II

Planning and Scheduling across the Supply Chain: Simulation-based Validation of the Unitary Structuring Technique
Premaratne SAMARANAYAKE, Senevi KIRIDENA, Dalin CAI 1275

Optimal Planning of Biodiesel Supply Chain Using a Linear Programming Model
Maryam VALIZADEH, Syafie SYAFIE, I.S. AHAMAD 1280

A Simple Multiple Objective Linear Programming Model on Customization Manufacturing for Metal Steel Making Effectiveness
Earl-Juei WANG, Chint-Shih TSOU 1285

Mixture of Two Different Scheduling Policies in a Class of Discrete Event Systems
Hiroyuki GOTO, Hajime YOKOYAMA 1290

A Cloud-based Approach for Collaboration of Serviced-enhanced Products
Bholanathsingh SURAJBALI, Adrian JUAN-VERDEJO, Holger BAER, Spiros ALEXAKIS, Gerald HÜBSCH, Markus BAUER 1295

Human Factors II

Selecting a Shift System Based on the Analytical Hierarchy Process
Alexander RANNACHER, Susanne MÜTZE-NIEWÖHNER, Christopher M. SCHLICK 1300

Differentiated Customer Needs’ Analysis for User Experience
Danilo Marcello SCHMIDT, Josu URQUIDI GUERRERO, Ioanna MICHAILIDOU, Udo LINDEMANN 1305

Deriving the Relationship Between User Satisfaction on Engine Sounds and Affective Variable Sets Based on Classification Algorithms
Wonjoon KIM, Gawon KIM, Yushin LEE, Myung Hwan YUN 1310

Gesture Interface Appropriateness Analysis on Smart TV Functions
Jaehong LEE, Byungki JIN, Soo-chan JEE, Jiyoon HAN, Myung Hwan YUN 1314
Employee Involvement and Training in Environmentally Conscious Manufacturing Implementation for Indian Manufacturing Industry
Perminderjit SINGH, Kuldip Singh SANGWAN

A Toolkit Based on NK Fitness Landscape for Behavioral Investigation in Complex Supply Chains
Ilaria GIANNOCARO

Intelligent Systems II

A Priority Based Optimization Algorithm for Multi-objective Integrated Process Planning and Scheduling Problem
Muhammad Farhan AUSAF, Xinyu LI, Liang GAO

The Knowledge Sharing Model on Supply Chain Simulation Using Recurrent Neural Network
Fumiaki SAITO

Implementation of Line Tracking Algorithm using Raspberry Pi in Marine Environment
Samreen AMIR, Ali Akbar SIDDQUI, Nimrah AHMED, Bhavani Shankar CHOWDHRY

Physical Layer Design of Optical Networks with Practical Considerations
Kin Fan POON, Anis OUALI, Beum LEE

Developing Target Marketing Models for Personal Loans
Jen-Ying SHIH, Wun-Hwa CHEN, Yu-Jung CHANG

Developments and Trends in Shopfloor-related ICT Systems
Olaf SAUER

Poster Session

A Study on RFID-based Kanban System in Inventory Management
Alireza GHELICHI, Ahmed ABDELGAWAD

The Economic Analysis Model of Operations Strategy
Chun-Ying SHEN

Solving an Economic and Environmental Dispatch Problem Using Evolutionary Algorithm
Forhad ZAMAN, Ruhul SARKER, Tapabrata RAY

Message Sequencing of Rational and Emotional Appeals: A Study on Consumer Brand and Product Attitudes
Weng Marc LIM, Pei-Lee TEH, Pervaiz Khalid AHMED

A Conceptual Neural Model for Business Selection in Multi Business Unit Firms
Saeed KHODAMORADI, Jalal ABDELLAHI

Optimal Inventory Policies for Remanufacturing Inventory Systems with Multiple Returns
Xue-Ming YUAN, Z. L, TAN, Amrik Singh BHULLAR

A New Conceptual Design Approach for Context-aware Product Service System
Dongqin CHEN, Xuening CHU, Yaliang SU, Dexin CHU

Evaluation of Equipment Renewal Based on Combination Weighting Method
Lei CHEN, Chuqing WANG, Xuedong LIANG, Zhaxia GUO, Da WANG

Applied Cognitive Psychology in Software Debugging Process to Predict Software Reliability Growth
Kuei-Chen CHIU
Assessing Survivability for Damaged Aircraft in the Combat Environment
Yang PEI, Tao CHENG, Min XIE

An Efficient Genetic Algorithm for Flexible Job-Shop Scheduling Problem
Ali MOKHTARI MOGHADAM, Kuan Yew WONG, Hamed PIROOZFARD

A Integrated Inventory Model with Imperfect Production and Inspection Under Trade Credit Financing
Chia-Hsien SU, Liang-Yuh OUYANG

Least Cost Design of Green Buildings by Genetic Algorithms
Kang-Ting TSAI, Min-Lun LYU, Min-Der LIN

Performance Analysis of Autonomous Vehicle Storage and Retrieval Systems Depending on Storage Management Policies
Sascha KACZMAREK, Jonas GOLDENSTEIN, Michael TEN HOMPEL

Integrating Fuzzy Logic to Systems Dynamics for Decision Support
Ifeyinwa ORJI, Sun WEI

Effect of Inspirational and Motivational Leadership on Creativity and Innovation in SMEs
Wilson MALADZHI, Bingwen YAN

In Search of Measuring Organizational Culture: ICT Peculiarities
Maria KÜTT, Mait RUNGI

Investigating Factors Behind Choosing a Cryptocurrency
Aamna AL SHEHHI, Mayada OUDAH, Zeyar AUNG

Model of Human Reliability for Manual Workers in Assembly Lines
Yolanda BáEZ, Manuel RODRÍGUEZ, Jorge LIMON, Diego TLAPA

Influence of Online Store Belief and Product Category on Impulse Buying: An Empirical Investigation on Consumer Perceptions
Qiong ZHOU, Xi CHEN, Yi-Wen CHEN

Exploring Effects of Ecosystem Clockspeed on Product Performance
Saku MÄKINEN, Ozgur DEDEHAYIR, Roland ORTT

Impact of Lean Development System Implementation on the Product Development Process
Uwe DOMBROWSKI, Kai SCHMIDTCHEN, Philipp KRENKEL

Internet-of-things Disrupting Business Ecosystems: A Case in Home Automation
Saku MÄKINEN

Postural Load Balancing in Daily Personnel Planning in an Assembly Line for Trailer Production by Working Posture Analysis
Christopher BRANDL, Alexander MERTENS, Jennifer BÜTZLER, Christopher M. SCHLICK

An Enterprise System Virtual Factories Platform for Collaborative Business Environment
Yuqiuge HAO, Ahm SHAMSUZZOHA, Petri HELO

Factors Affecting Product Quality and Reliability: A Comparison of Developed and Developing Countries
Pei-Lee TEH, Dotun ADEBANJO, Pervaiz Khalid AHMED

Towards Recursive Plan-Do-Check-Act Cycles for Continuous Improvement
Michael Timo SCHMIDT, Fatos ELEZI, Iris TOMMELEIN, Udo LINDEMANN

A Study on Developing the Indicators of Energy Conservation and Carbon Reduction for the Business
Liang-kong LIN, Walter DEN, Ying-Chyi CHOU, Hsin-Yi YEN, Ching-Hua LU
Abstract – This paper aims to analyze the relationships among the Key Performance Indicators (KPIs) for sustainable manufacturing evaluation in the cement industry. The initial KPIs have been identified and derived from literature, and then validated by industry survey. As a result, three factors dividing into a total of thirteen indicators have been proposed as the KPIs for sustainable manufacturing evaluation in cement industry. Interpretive structural modeling (ISM) methodology is applied to develop a network structure model of the KPIs. The results show the indicators of economic factor are regarded as the basic indicator, while the indicators of environmental factor are indicated to be the leading indicator. Of those indicators, raw material substitution is regarded as the most influencing indicator. The ISM model can aid the cement companies by providing a better insight in evaluating sustainable manufacturing performance.

Keywords - Cement, interpretive structural modeling, key performance indicators, sustainable manufacturing

I. INTRODUCTION

Nowadays, the cement industry is facing challenges to implement sustainable manufacturing into their products and processes. Cement plants have been characterised as an intensive consumer of natural raw materials and have remarked as emitters of pollutants [1, 2]. Furthermore, the cement industry has regarded as one of the most energy intensive consumers amongst industries in the world [3]. Thus, evaluating sustainable manufacturing has become a necessity for this industry.

Sustainable manufacturing defined as the creation of manufactured products that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound [4]. The general principle of sustainable manufacturing is to reduce the intensity of materials use, energy consumption, emissions, and the creation of unwanted by-products while maintaining, or improving, the value of products to society and to organizations [5].

Sustainable manufacturing must respond to [6]: (i) economical challenges, by producing wealth and new services ensuring development and competitiveness through time; (ii) environmental challenges, by promoting minimal use of natural resources (in particular non-renewable) and managing them in the best possible way while reducing environmental impact; and (iii) social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs.

It has been suggested that sustainable manufacturing has to be evaluated based on the triple bottom line of economic, environmental, and social performance [7] as well as to consider their interdependencies [8]. In this research, attempt is made to analyze the relationships amongst the KPIs. A network structure model has been developed using the Interpretive Structural Modeling (ISM) methodology.

II. METHODOLOGY

The methodology has three main stages.

Stage 1: Identification of KPIs

This study starts with the development of initial key performance indicators (KPIs) for sustainable manufacturing evaluation in cement industry. A literature review was carried out in an attempt to determine indicators that are most commonly used. The initial KPIs are constructed using the triple bottom line of sustainability consisting of environmental, economic, and social factors. As a result, the initial KPIs consist of three factors divided into nineteen indicators are identified as shown in Table I.

<table>
<thead>
<tr>
<th>TABLE I INITIAL KPIs</th>
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<tbody>
<tr>
<td><strong>Factors</strong></td>
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<td>7. Energy consumption</td>
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<td>9. Land utilization</td>
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<td>10. Material consumption</td>
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<td>11. Noise pollution</td>
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<td>12. Nonproduct output</td>
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<td>13. Water utilization</td>
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<td>3. Social</td>
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<td>15. Employee involvement</td>
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<td>16. Gender equity</td>
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<td>17. Labor relationship</td>
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<td>18. Occupational health and safety</td>
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<td>19. Training and education</td>
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</tbody>
</table>
Stage 2: Conducting industry survey

The initial KPIs were then validated by an industry survey conducted to a cement manufacturing company located in Padang, Indonesia. Established in 1910, the company is the first cement manufacturing plant in Indonesia. Currently, the company has four plants with a total of production capacity of 5,240,000 tons per year. The company has been certified by ISO 9001, ISO 14001, and OHSAS 18001. A total of 15 managers of production and manufacturing division were asked to rate the importance level of each initial KPIs of sustainable manufacturing evaluation in cement industry. A five-point Likert scale ranging from 1 (not important at all) to 5 (very important) was used to rate the perspective of managers on the importance level of the initial KPIs. The mean importance values ranged from 3.083 to 4.750 as shown in Table II.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Mean</th>
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<tbody>
<tr>
<td>Material cost</td>
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<tr>
<td>Energy consumption</td>
<td>4.667</td>
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<td>Inventory cost</td>
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<tr>
<td>Occupational health and safety</td>
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<tr>
<td>Fuel consumption</td>
<td>4.500</td>
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<td>Labor cost</td>
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<td>Accident rate</td>
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<td>Training and education</td>
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<td>Product delivery</td>
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<td>Raw material substitution</td>
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<td>Air emission</td>
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<td>Labor relationship</td>
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<td>Material consumption</td>
<td>4.083</td>
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<td>Employee involvement</td>
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<td>Noise pollution</td>
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<td>Water utilization</td>
<td>3.750</td>
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<td>Gender equity</td>
<td>3.417</td>
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<td>Land utilization</td>
<td>3.417</td>
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<tr>
<td>Nonproduct output</td>
<td>3.083</td>
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</tbody>
</table>

The results indicated material cost is regarded as the most important KPI with a mean importance value of 4.750. This followed by three indicators of energy consumption, inventory cost, and occupational health and safety with a same mean importance value of 4.667. On the other hand, six indicators of employee involvement, noise pollution, water utilization, gender equity, land utilization, and nonproduct output were regarded as the least important indicators.

Based on the results, the initial KPIs of sustainable manufacturing evaluation in cement industry have been modified. Due to the less importance, six indicators were removed from the initial KPIs. Finally, three factors with a total of thirteen indicators have been proposed as the KPIs for sustainable manufacturing evaluation in cement industry as shown in Table III.

### Table III

<table>
<thead>
<tr>
<th>Factors</th>
<th>Indicators</th>
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</thead>
<tbody>
<tr>
<td>1. Economic</td>
<td>1. Inventory cost</td>
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</table>

Stage 3: Conducting ISM survey

An ISM survey was conducted to develop a network structure model of the KPIs for sustainable manufacturing evaluation in cement industry. A questionnaire was then designed and sent to 15 managers from the cement company in Padang, Indonesia. Those managers were carefully selected based on their experience in cement industry. Details are given in the following section.

### III. DEVELOPMENT OF INTERPRETIVE STRUCTURAL MODEL

Interpretive Structural Modeling (ISM) methodology is an interactive learning process that enables one to develop a map of the complex relationships among many elements involved in a complex problem [9]. ISM helps build an interaction map to identify the interrelationships among system variables. It provides a better understanding of a system structure and draws up a useful guideline in generating a graphical representation of the structure [10]. The following steps show the development of an interpretive structural model of the thirteen KPIs for sustainable manufacturing evaluation in cement industry.

#### A. Structural self-interaction matrix (SSIM)

Through the ISM survey, fifteen experts were consulted to identify the relationships amongst the KPIs of sustainable manufacturing evaluation in cement industry. Answers to the questions from the experts were averaged. The results indicated a total of 30 direct relationships amongst the KPIs. The SSIM for the KPIs is presented in Table IV.

Four symbols are used to denote the direction of relationship between the indicators (i and j):

- V for the relation from i to j
- A for the relation from j to i
- X for both directions, relations from i to j and j to i.
- O if the relation between the indicators does not appear valid.
Table IV

<table>
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<tr>
<th>Indicators</th>
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B. Initial reachability matrix

The SSIM is then transformed into the initial reachability matrix by substituting the symbols of V, A, X, and O into a binary matrix of I and 0, where 1 means there is relationship between the indicators and otherwise, 0 means there is no relationship between the indicators. The substituting process is as per the following rules:

1) If (i, j) entry in the SSIM is V, then (i, j) entry in the reachability matrix is 1 and (j, i) entry is 0.
2) If (i, j) entry in the SSIM is A, then (i, j) entry in the reachability matrix is 0 and (j, i) entry is 1.
3) If (i, j) entry in the SSIM is X, then entry for both (i, j) and (j, i) is 1.
4) If (i, j) entry in the SSIM is O, then entry for both (i, j) and (j, i) is 0.

The initial reachability matrix of the KPIs for sustainable manufacturing evaluation in cement industry is obtained by the rules above and the result is shown in Table V.

Table V

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<th>Indicators</th>
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<tr>
<td>12</td>
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</tr>
</tbody>
</table>

C. Final reachability matrix

The final reachability matrix is developed from the initial reachability matrix by incorporating the transitivities using the following equation:

\[ M = M^k = M^{k+1}, k>1 \]

where \( k \) denotes the powers and \( M \) is the reachability matrix. Noted that the reachability matrix is under the Boolean operations. The transitivity is a basic assumption of ISM methodology, which stated that if variable-A related to variable-B and variable-B related to variable-C, then variable-A necessarily related to variable-C [9]. The final reachability matrix of the KPIs is shown in Table VI.

Table VI

<table>
<thead>
<tr>
<th>Indicators</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving power</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>5</td>
<td>4</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

The driving power and dependence power for each indicator are also presented in the table. The driving power is the total number of indicators (including indicator itself) which it may relate, while the dependence power is the total number of indicators which may relate to it.

It can be seen from the table that raw material substitution, energy consumption, fuel consumption, and material consumption have the highest value of driving power. On the other hand, three indicators of inventory cost, labor cost, and material cost have the least driving power. On the other hand, three indicators of inventory cost, labor cost, and material cost have the least driving power. The driving power means these indicators are not affecting the other indicators. In term of dependence power, labor cost is the most dependent indicator, followed by accident rate, and occupational health and safety. Training and education has the least value of dependence power that means this indicators is not affected by any other indicators.

D. Level partitions

From the final reachability matrix, the reachability set and antecedent set [11] for each indicator can be obtained. The reachability set consists of the indicator itself and the other indicators, to which it may relate. The antecedent set consists of the indicator itself and the other indicators, which may relate to it. The intersection of these sets then is derived for all indicators. The indicators for which the reachability and the intersection sets are the same are put into the top-level indicators in the ISM hierarchy. After the identification of the top-level indicators, those indicators discarded from the other remaining indicators.
This iteration is continued until the level of all indicators is obtained as shown in Table VII.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Reachability set</th>
<th>Antecedent set</th>
<th>Intersection set</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Inventory cost</td>
<td>1, 2, 3</td>
<td>1, 4, 5, 7, 8, 9</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td>2. Labor cost</td>
<td>2</td>
<td>2, 5, 6, 7, 8, 9</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>3. Material cost</td>
<td>3</td>
<td>3, 4, 5, 7, 8, 9</td>
<td>3</td>
<td>I</td>
</tr>
<tr>
<td>4. Product delivery</td>
<td>1, 3, 4</td>
<td>4, 5, 7, 8, 9</td>
<td>4</td>
<td>II</td>
</tr>
<tr>
<td>5. Raw material substitution</td>
<td>1, 2, 3, 4, 5, 6</td>
<td>5, 7, 8, 9</td>
<td>5, 7, 8, 9</td>
<td>IV</td>
</tr>
<tr>
<td>6. Air emission</td>
<td>2, 6, 10, 12</td>
<td>6, 7, 8, 9</td>
<td>6</td>
<td>III</td>
</tr>
<tr>
<td>7. Energy consumption</td>
<td>2, 6, 10, 12</td>
<td>6, 7, 8, 9</td>
<td>6</td>
<td>III</td>
</tr>
<tr>
<td>8. Fuel consumption</td>
<td>7, 8, 9, 10, 12</td>
<td>7, 8, 9, 10, 12</td>
<td>7, 8, 9, 10, 12</td>
<td>IV</td>
</tr>
<tr>
<td>9. Material consumption</td>
<td>1, 2, 3, 4, 5, 6</td>
<td>5, 7, 8, 9</td>
<td>5, 7, 8, 9</td>
<td>IV</td>
</tr>
<tr>
<td>10. Accident rate</td>
<td>2, 10, 12</td>
<td>10, 12</td>
<td>10, 12</td>
<td>II</td>
</tr>
<tr>
<td>11. Labor relationship</td>
<td>2, 10, 12</td>
<td>10, 11, 12, 13</td>
<td>10, 11, 12, 13</td>
<td>III</td>
</tr>
<tr>
<td>12. Occupational health and safety</td>
<td>2, 10, 12</td>
<td>10, 11, 12, 13</td>
<td>10, 11, 12, 13</td>
<td>III</td>
</tr>
<tr>
<td>13. Training and education</td>
<td>2, 10, 11, 12, 13</td>
<td>13</td>
<td>13</td>
<td>IV</td>
</tr>
</tbody>
</table>

The process of level partitions for the indicators involved four iterations. In the first iteration, inventory cost, labor cost, and material cost were identified as the indicators to level I. Then, three indicators of product delivery, accident rate, and occupational health and safety were determined to be placed at level II through the second iteration. In the third iteration, air emission, labor relationship, and training and education were included into level III. Finally, the remaining five indicators were determined into level IV. The identified levels of the indicators will aid in building the digraph and the final model of ISM [9]. The final reachability matrix then is converted into the canonical matrix by arranging the indicators according to their determined levels as shown in Table VIII.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>1</th>
<th>2</th>
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<th>4</th>
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<th>11</th>
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</thead>
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<td>2. Labor cost</td>
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<tr>
<td>5. Raw material substitution</td>
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<tr>
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<tr>
<td>7. Energy consumption</td>
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<td>12. Occupational health and safety</td>
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<td>13. Training and education</td>
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</tbody>
</table>

The identified levels of the indicators will aid in building the digraph and the final model of ISM [9]. The final reachability matrix then is converted into the canonical matrix by arranging the indicators according to their determined levels as shown in Table VIII.

The indicators were then categorized based on their driving power and dependence power using MICMAC analysis. The MICMAC analysis is used to analyze the driving power and dependence power of the indicators [12]. The indicators are classified into four clusters named autonomous, dependent, linkage, and driver as depicted in Fig. 1.

E. MICMAC analysis

The indicators were then categorized based on their driving power and dependence power using MICMAC analysis. The MICMAC analysis is used to analyze the driving power and dependence power of the indicators. The process of level partitions for the indicators involved four iterations. In the first iteration, inventory cost, labor cost, and material cost were identified as the indicators to level I. Then, three indicators of product delivery, accident rate, and occupational health and safety were determined to be placed at level II through the second iteration. In the third iteration, air emission, labor relationship, and training and education were included into level III. Finally, the remaining five indicators were determined into level IV. The identified levels of the indicators will aid in building the digraph and the final model of ISM [9]. The final reachability matrix then is converted into the canonical matrix by arranging the indicators according to their determined levels as shown in Table VIII.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Inventory cost</td>
<td>I</td>
</tr>
<tr>
<td>2. Labor cost</td>
<td>I</td>
</tr>
<tr>
<td>3. Material cost</td>
<td>I</td>
</tr>
<tr>
<td>4. Product delivery</td>
<td>II</td>
</tr>
<tr>
<td>5. Raw material substitution</td>
<td>IV</td>
</tr>
<tr>
<td>6. Air emission</td>
<td>III</td>
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<tr>
<td>7. Energy consumption</td>
<td>IV</td>
</tr>
<tr>
<td>8. Fuel consumption</td>
<td>IV</td>
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<tr>
<td>9. Material consumption</td>
<td>IV</td>
</tr>
<tr>
<td>10. Accident rate</td>
<td>III</td>
</tr>
<tr>
<td>11. Labor relationship</td>
<td>III</td>
</tr>
<tr>
<td>12. Occupational health and safety</td>
<td>III</td>
</tr>
<tr>
<td>13. Training and education</td>
<td>IV</td>
</tr>
</tbody>
</table>

It can be seen that there is no linkage indicator (in the third quadrant) in the driver-dependence power diagram. This indicated no dominant indicator of the KPIs which has both high driving power and dependence power. In the first quadrant, four indicators of product delivery, air emission, labor relationship, and training and education identified as autonomous indicators. These indicators have both low driving power and low dependence power. Training and education is identified as the most independent indicators since has no affected by any other indicators.

Five indicators of inventory cost, labor cost, material cost, accident rate, and occupational health and safety are in second quadrant as dependent indicators. Three of those indicators are not driving any other indicators but driven by other indicators. Accident rate was identified as the most dependent indicator. The remaining two indicators have low driving power and high dependence power. On the other hand, raw material substitution, energy consumption, fuel consumption, and material consumption in fourth quadrant as the most driver indicators, are driving the other ten indicators but only driven by three other indicators. Any action on these indicators will have a significant effect on the other indicators. Thus, the decision makers should pay more attention to these indicators in the context of sustainable manufacturing evaluation.

F. ISM-based network model

An ISM-based network model is then generated based on the relationships of indicators given in the canonical matrix. The transitivities of the indicators are removed from the matrix. The KPIs are organized in a hierarchical structure into four levels as shown in Fig. 2.
Inventory cost, labor cost, and material cost are regarded as the basic indicators in evaluating sustainable manufacturing in cement industry. All these indicators are KPIs of the economic factor. It can be concluded that economic still has get more attention from the cement industry. Level II consists of one indicator of economic factor of product delivery, and two indicators of social factors of accident rate, and occupational health and safety. Air emission and labor relationship are indicated as intermediate indicators at level III. It can be concluded that the cement industry has been put much effort to reduce air emission as one of sustainability issue in the cement industry.

Five indicators at level IV consisting of raw material substitution, energy consumption, fuel consumption, material consumption, and training and development were indicated to be the leading KPIs in achieving sustainable manufacturing in cement industry. The first four of those indicators are the most important issues in the context of sustainable manufacturing and related to the environmental aspect. Of those indicators, raw material substitution is regarded as the most influencing indicator for sustainable manufacturing evaluation in the cement industry.

IV. CONCLUSION

This paper has developed an interpretive structural model (ISM) of key performance indicators (KPIs) for sustainable manufacturing evaluation in cement industry. The KPIs are structured into four levels. The network model establishes the interrelationships amongst the KPIs. The interdependencies amongst the KPIs are also given by driver-dependence power diagram. The ISM-based model provides a better understanding of the interrelationship amongst the KPIs. The model can aid the decision makers with a more realistic representation of relationships amongst the KPIs for sustainable manufacturing evaluation in cement industry. Future work will further incorporate the model into Analytical Network Process (ANP) methodology to the development of sustainable manufacturing evaluation tool for cement industry.

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