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TEACHING SUPPLY CHAIN SIMULATION - FROM BEGINNERS TO PROFESSIONALS

Terrence Perera

Department of Engineering & Mathematics
Sheffield Hallam University
Sheffield S1 1WB, UK

Thashika Rupasinghe

Department of Industrial Management
University of Kelaniya
Kelaniya, SRI LANKA

ABSTRACT

Both in academia and industry, supply chain simulation is a relatively mature subject. Academic researchers have produced supply chain modelling/simulation frameworks and have used simulation to teach supply chain dynamics. A review of industrial applications however points to the heavy use of consultants and/or simulation software vendors. The shortage of in-house supply chain simulation skills/practitioners appears to be hampering the wider use of simulation. Although many universities in the UK offer postgraduate programs in Supply Chain Management a very few provide opportunities to learn and experience hands-on simulation. This paper presents how a commercial simulation software that understands supply chain language was used in various settings to develop simulation skills and teach supply chain dynamics. This paper will also outline how an integrated environment involving simulation software and an industry standard supply chain management framework can be used to develop the simulation skills and competencies of supply chain professionals.

1 INTRODUCTION

Supply chains are inherently complex and dynamic systems (Surana et al. 2005) involving many different types of physical entities such as manufacturers, distributors and retailers who work together to achieve a common goal i.e. meeting customer demand. Operating policies, developed and deployed at each entity, ensure efficient flow of products through supply chains. Given the ever-changing technologies, consumer behaviors and operational environments, the design, management and enhancement of supply chains has become increasingly challenging (Global Supply Chain Institute 2013). Like in many other dynamic systems, simulation can provide insights into operational behaviors which can be strategically used for improving supply chain performance. Indeed, simulation has been successfully used in supply network design (Bottani and Montanari 2010, Jayant et al. 2014), supply chain performance analysis (Umeda S and Zhang F 2010), improving distribution logistics (De Oliveira 2014), inventory management (Zhang et al. 2014) and in many other areas as outlined by Owen et al. (2010) and Antuela and Robinson (2012).

However, it appears that the logistics and supply chain sectors heavily rely on consultants and simulation software vendors when it comes to real industrial applications. This is evidenced by the lack of reported real world case studies in academic literature. There are two major reasons for engaging experts (a) *one-off applications* – it may be cost effective to engage external consultants instead of developing the required capabilities internally. It is also a low-risk and fast track approach. (b) *lack of in-house expertise* – the only option is to involve external experts. If companies continue to use external consultants, eventually such engagements may become financially prohibitive and the use of simulation will diminish leading to missed opportunities to deploy this powerful technology for competitive advantage. This was the case with discrete event simulation in the early 90's, where the lack of in-house simulation expertise prevented the wider of use of the technology (Crosbie 2000) . By embedding discrete event simulation as

a core element in the curricula, and by using educational versions of simulation software supplied free by the vendors, universities led the way to address skill gaps (De Vin 2001). Evolution of simulation software from programming-based platforms to simple click-and-build systems also immensely contributed to accelerated learning.

This paper argues that supply chain simulation, as an essential element of supply chain management, now requires a similar transformation. It presents the experience of staff and students who have used a commercial simulation environment and how it was used to develop simulation skills in different settings. Furthermore, the authors argue that supply chain simulation should be an integral part of Logistics and Supply Chain Management curricula and simulation systems that can comprehend supply chain language should be used instead of general purpose discrete event simulation systems. It also examines how this system can be extended to support the development of simulation skills and competencies of supply chain professionals.

2 SUPPLY CHAIN SIMULATION

As outlined above, supply chains are inherently complex systems and understanding their operating dynamics is incredibly challenging. End customers create the demand which propagates through the supply chain creating many "supplier-customer" pairs. Sourcing, transportation and inventory management policies which are operated at each entity govern the overall operation to ensure that the demand at each supplier-customer pair is met. In addition to these policies, a combination of push and pull strategies (Kim 2012) is also deployed to orchestrate operations closer to “demand driven” networks which typically maximize operational efficiencies. Stochastic behaviors such as demand fluctuations and lead time variations add further complexities. Without some form of simulation technique, it is impossible to comprehend the impact of policies, strategies and stochastic behaviors on the overall performance of the supply chains.

Simulation is universally recognized as the best modelling tool when the behavior of dynamic systems is investigated and studied (Negahban and Smith 2014). Its ability to capture operational dynamics in detail and the resulting high accuracy of outputs are its major strengths. Built-in animation further strengthens simulation and is often used to visualize operations.

Building, testing and use of simulation models demand a wide range of skill sets. Simulation analysts are required to have skills and competencies such as data analysis, system thinking, validation methods and statistical techniques (Rohrer and Banks 1998). Skills required to build and verify computer models vary from system to system as different modelling paradigms and user-interfaces are used to capture system dynamics and data required to drive simulation models. When discrete event simulation began to make inroads into industry in the early 90s there was a shortage of graduates and professionals who are competent with the required skills. Universities, in collaboration with simulation vendors who supplied free-educational versions, led the way to address shortages in the skill inventory and simulation became a core discipline particularly in the fields of Industrial Engineering/Manufacturing Systems related courses.

In the last decade, to meet the demand for supply chain specialists, driven by the rapid advances in globalization, universities around the world began to offer postgraduate courses in logistics and supply chain management (Lancioni et al. 2001). These courses are the perfect platforms to develop the supply chain simulation skill set of professionals who aim to develop their careers in logistics and supply chain sectors.

3 REVIEW OF LOGISTICS/SUPPLY CHAIN MANAGEMENT COURSES IN THE UK

A review of logistics and supply chain management postgraduate courses in the UK was conducted to establish to what extent simulation has become a mainstream discipline in these courses. Among the 126 universities in the UK, 56 institutions (just under 45%) offer a total of 67 postgraduate courses in different combinations of logistics and supply chain management disciplines. This pool of courses includes two MBA degrees and the rest are MSc degrees. MSc in Logistics and Supply Chain

Management is the most popular title. As expected, Business/Management Schools dominate the field. however in 11 institutions, nearly 20%, engineering/technology departments have taken the lead to develop and deliver courses (Figure 1).

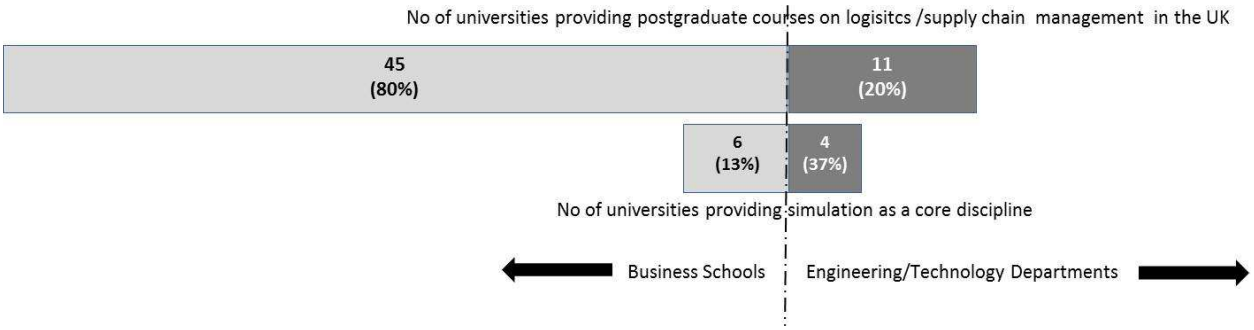

Figure 1: Provision of postgraduate courses in Logistics and Supply Chain Management and Simulation in the UK.

Further analysis of courses revealed that only 10 institutions out of 56 (17%), offer simulation as a core subject in their courses. Three (3) further institutions offer simulation as an elective subject. In a few other courses, simulation was mentioned under other subject headings but simulation was not a prominent topic. Out of the 10 institutions which offer simulation as a core subject, in 4 cases (40%), the development of courses has been led by engineering/technology departments. If business/management schools and engineering/technology departments are considered as two distinct clusters, only 13% of business/management schools offer simulation as a core subject whereas for the engineering/technology cluster this percentage jumps to 37%. This shows that simulation is a well-established discipline in engineering/technology departments hence integration of simulation is more likely to occur when new course offerings come from those departments.

If simulation is to be made a mainstream tool in logistics and supply chain sectors it is vitally important that postgraduate courses incorporate simulation as a core subject in their curricula. There are several possible reasons for the current low adoption of simulation; (a) The majority of Logistics and Supply Chain Management postgraduate students come from a business management background and simulation is seen as a "techie" subject. Hence teaching simulation to business management graduates is considered to be challenging. (b) There is a desire to incorporate simulation into the curriculum but model building has a steep learning curve and (c) Course designers are not fully aware of the power of simulation and the wide variety of tools and techniques available for teaching and learning.

It is most likely that (a) and (b) are the major reasons. A user-friendly simulation system which can understand the "supply chain language" most probably overcomes the aforementioned challenges. The rest of the paper will focus on how these issues were systematically addressed within the context of developing a portfolio of courses at Sheffield Hallam University.

4 DEVELOPMENT OF SUPPLY CHAIN MANAGEMENT TEACHING PORTFOLIO

At Sheffield Hallam University, a team of academics based in the Engineering Department has been instrumental in developing a portfolio of courses in Logistics and Supply Chain Management. Simulation being one of the key research areas of the team, the team makes every effort to embed simulation in new developments. In the following sections, five different developments and the challenges faced when embracing simulation are presented.

4.1 Development 1: MSc degree in Logistics and Supply Chain Management

In response to growing demand for logistics/supply professionals, the team designed a new postgraduate provision, MSc degree in Logistics and Supply Chain Management. Since its launch in 2007, it has become a flagship course in the department, attracting students from many parts of the world. Simulation being one of the core research thrust areas of the team, modelling/simulation was added as a mainstream module and a general purpose simulation package, was chosen as the teaching platform. There were two major reasons for this choice (a) the team was fully conversant with the package (b) a free educational version was available. Although students value the subject, for some, particularly with business management backgrounds, it was challenging as the modelling framework has fairly low resemblance to real-world supply chain operations. Only a few scenarios were modelled and the creation of even moderately complex supply chains was not possible given the steep learning curve involved.

4.2 Development 2: Logistics and Supply Chain Management – Undergraduate Top-Up Course

The University has a long-term partnership with Tunku Abdul Rahman University College, a higher education institution in Malaysia, and its students visit Sheffield to study a full semester. In 2010, the partner requested the department to design a single semester program in Logistics and Supply Chain Management for its business management students. One of the three modules was Design, Simulation & Operations of Supply Chains. The team realized that for this group of students, the general purpose simulation package was not a realistic option as the students had hardly used any software other than office applications.

4.3 Development 3: Redesigning a Masters Degree Program in Logistics

In 2011, following the appointment of the principal author as a visiting professor, in a university in Southeast Asia, he was asked to lead the re-design of their MSc Logistics course. One of the modules in the program, Transportation Systems & Modelling, didn't fit well with the course objectives and complex mathematical models formed the core parts of the module. The students, predominately with business management backgrounds, requested that the module should have more practical elements in relation to distribution and transportation. It was therefore necessary to identify a simulation platform which provides distribution/transportation optimization and simulation capabilities.

4.4 Development 4: Summer School in Logistics and Supply Chain Management

The team also designed a three week summer school in Logistics and Supply Chain Management including a two-day session on modelling and simulation. The expectation was that the students would be able to build models themselves within two days. In 2013, a group of 23 students, from a private college in India joined the program.

4.5 Development 5: Delivery of the MSc Degree Program at a Partner Institution

Sri Lanka Institute of Information Technology (SLIIT) is a long-term academic partner of Sheffield Hallam University. To meet the growing demand for supply chain professionals in Sri Lanka, the MSc degree program mentioned under Development 1 was launched at SLIIT in January 2015. The majority of the participants are logistics/supply chain sector professionals and their learning expectations are high. Meeting their expectations is critical to establish and enhance the program in Sri Lanka. Table 1 summarizes the key requirements in each development.

Table 1: Development of the Teaching Portfolio and Key Requirements.

Development	**Requirements**
MSc Logistics and Supply Chain Management -2007	Ability to model moderately complex supply chain with ease.
Logistics and Supply Chain Management – undergraduate top-up course - 2010	Embed computer simulation for business management students.
Redesigning a masters program in Logistics - 2012	Introduce elements of distribution/transportation optimization and simulation capabilities.
Summer school - 2013	Ability to model simple scenarios within 2 days.
Delivery of the MSc degree program at a partner institution - 2015	Meeting the high expectations of sector professionals

When the principal author was working on Development 2, a comprehensive feasibility study was conducted to identify simulation packages specifically designed for supply chain modelling. There were only a very few candidates, among them SupplyChainGuru©, developed by Llamasoft, which emerged as a preferred solution as its modelling framework understands the Supply Chain Language.

5 SUPPLYCHAINGURU SOFTWARE

SupplyChainGuru©(SCG),with nearly 20 years of development history behind it, is an innovative product. Its great strength is that its modelling framework speaks supply chain language (Lllamasoft Inc.). Models are built by populating data grids which associate with physical entities such as sites and products and policies relating to sourcing, transportation and inventory management. The SCG suite has undergone constant innovation, adding transportation, data, mobile and cloud-based products to the suite. As shown in Table 2, with the positive experience gained through Development 2 in 2010, SCG has been gradually embedded in all developments.

Table 2: Use of SupplyChainGuru© and key outcomes.

Development	**Outcomes**
MSc degree Logistics and Supply Chain Management	During the transition from the general purpose simulation package to SCG, in one year, both systems were used. Students were able to model moderately complex simulation models within a few weeks. Students strongly supported the use of SCG.
Logistics and Supply Chain Management – undergraduate top-up course	Before the very first teaching session, students expressed their concerns about using simulation citing they had very limited experience in computer software. However, within two weeks, they started building models with confidence
Redesigning a masters program in Logistics	As optimization and simulation are integrated within the same environment, students found it very easy to use and the student feedback was very positive on the re-designed module
Summer school	Within the two day window, students were able to build simple models and understand the modelling framework
Delivery of the MSc program at a partner institution	Participants came from a set of diverse backgrounds where spreadsheet models have been used as a typical modelling tool. With the introduction of SCG the students explored

	the domain specific dynamics of supply chains and used it as a sandbox to construct simple to complex scenarios in multiple application domains. Furthermore, the students have further expressed their willingness to use SCG for their research and dissertation work to validate new policies and network constructs.

There are three major reasons behind this success; (a) Modelling framework – students can easily connect with the software as SCG is a domain specific package and the supply chain language is used in the modelling framework. (b) Model Building – SCG models are built by populating data grids. It is easy to use and the built-in model verification tool helps to identify any missing data. (c) Visualization – A wide range of visualization tools including animation, state-of-the-art interactive Geographical maps and GIS tools help the users to understand complex scenarios and interpret results for quick decision making.

6 NEW DIMESNSIONS TO USE SUPPLYCHAINGURU AS A TEACHING AND LEARING AID IN SUPPLY CHAIN MANAGEMENT

Simulation Games have been widely used to support the teaching of supply chain dynamics (Knolmayer et al. 2007). Among them, Beer Game is a popular tool which is based on a linear supply chain. Although it is an effective business game, Knolmayer et al. (2007) argues that the beer game has several limitations, for example, inflexible structure and infinite capacities at nodes. As an alternative, the authors propose a computer simulation model built using a general purpose simulation software, Extend. Given the simplicity of SCG, it is much easier to build simulation models which can be used to support teaching. For example, a range of models was developed to teach supply chain dynamics beyond the Bullwhip effect. Examples include (a) Push, pull and hybrid operations (b) Postponement strategies (c) Supply chain sustainability (d) Assembly-oriented supply chain operations and (e) Transportation/Distribution policies. With its other modules such as Data Guru, Transportation Guru and Network Optimization further models can be developed to illustrate other operational and strategic aspects of supply chains and logistics.

7 IMPROVING SUPPLY CHAIN SIMULATION SKILLS OF PROFESSIONALS

Mangan and Christopher (2005) provide an elegant insight into skills and competency requirements of supply chain managers. Dittmann (2012) lists five key qualities that visionary supply chain leaders must have (a) Global orientation (b) Systems thinking (c) Inspiring and influential leadership (d) Technical savvy and (e) Superior business skills. Whilst a broad program of learning is required to develop these qualities, simulation is the ideal platform for developing system thinking abilities . Simulation enables supply chain professionals to comprehend the connections and interdependencies across operational areas and understand resulting supply chain dynamics.

As outlined above, SCG can be used to teach different facets of supply chain dynamics. However, a much more sophisticated and systematic learning platform built on simulation is required to upskill professionals in a holistic manner. Integration of simulation models with an industry standard framework such as SCOR may provide a robust platform. Webb (2014) reports a simulation game developed on SCOR which ultimately helps the practitioners and educators to bridge the gap between what's taught and practiced in the real world.

8 LIMITATIONS AND IMPROVEMENTS

At present the evaluation version of SCG is only available for 90 day use, barely enough to cover a single semester's teaching. Almost all general purpose simulation software vendors provide their evaluation versions without any time restrictions and this strategy has helped them not only to promote their

products to a wider professional audience but also make a significant contribution to develop the skill set required by simulation analysts.

Post-program feedback analyses from the staff/students in Sheffield and Sri Lanka suggest a few improvements to the current SCG. The majority argued that there is scope to improve how data is organized within data grids. For example, "tabs" can be used to organize data under different headings. It is also useful, if key performance data can be appended to the visual modeler so that the performance across the supply chain can be grasped in one step. Context-sensitive on-line is helpful and effective, however, the provision of further examples to illustrate complex policies will be a welcome addition.

9 CONCLUSIONS

Academia has acted proactively by developing masters degree program in logistics and supply chain management to meet the growing demand for professionals. However the proliferation of supply chain simulation within these program is disappointingly low. In the UK, only about 20% of institutions offer simulation as a core module in their masters provisions. Simulation is now increasingly used in the design and operation of supply chains and opportunities to improve competitive advantage will be missed unless steps are taken to build the required skills sets.

The feedback received from the five different developments leads to the conclusion that SCG provides an ideal platform to teach simulation skills as well as supply chain management principles. The time restriction of the 90 days license for the evaluation version was seen as the main barrier for the wider use within the teaching environments. Its ability to understand supply chain language and the use of data grids for model building are the major strengths. Once the basic modelling principles are understood, moderately complex supply chain models can be built within weeks.

SCG presents an integrated environment where simulation and optimization studies can be carried out without duplicating the effort to capture and record data. The addition of other modules such as Data Guru further extends the use of SCG beyond simulation.

As SCG is set to reach a wider academic and professional audience in both developed and developing countries many new avenues will emerge to advance research, applications and thereby the knowledge base.

REFERNCES

Antuela, T., and S. Robinson. 2012. "The Application of Discrete Event Simulation and System Dynamics in the Logistics and Supply Chain Context." *Decision Support Systems* 52(4):802-815.

Bottani, E., and R. Montanari. 2010. "Supply Chain Design and Cost Analysis through Simulation." *International Journal of Production Research* 48(10): 2859-2886.

Crosbie, R. E. 2000. "A Model Curriculum in Modeling and Simulation: Do we need it? Can we do it?", In *Proceedings of the 2000 Winter Simulation Conference*, edited by J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1666-1668. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

De Oliveira, L. K. E., B. R. P. Oliveira, and V. De Assis Correia. 2014. "Simulation of an Urban Logistic Space for the Distribution of Goods in Belo Horizonte, Brazil." *Procedia - Social and Behavioral Sciences* 125(20): 496–505.

De Vin, L. J., and M. Jägstam. 2001. "Why We Need to Offer a Modelling and Simulation Engineering Curriculum." In *Proceedings of the 2001 Winter Simulation Conference*, edited by B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, 1599-1604. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Dittmann, J. P. 2012. "Skills and Competencies That Supply Chain Professionals Will Need." *Supply Chain Management Review*, Accessed March 10. http://www.scmr.com/article/skills_and_competencies_that_supply_chain_professionals_will_need/

Global Supply Chain Institute. 2013. "Game Changing Trends in Supply Chains." Technical Report No. 1, Faculty of Supply Chain Management, University of Tennessee, Tennessee.

Jayant, A, P. Guptab, and S. K. Garg. 2014. "Simulation Modelling and Analysis of Network Design for Closed-Loop Supply Chain: A Case Study of Battery Industry." *Procedia Engineering* 97: 2213–2221.

Kim, S. H., J. W. Fowler, D. L. Shunk, and M. E. Pfund. 2012. "Improving the Push–Pull Strategy in a Serial Supply Chain by a Hybrid Push–Pull Control with Multiple Pulling Points." *International Journal of Production Research* 50(19): 5651-5668.

Knolmayer, G., R. Schmidt, and S. Rihs. 2007. "Teaching Supply Chain Dynamics - Beyond the Beer Game." Working Paper No. 197, Institute of Information Systems, University of Bern, Switzerland.

Lancioni, R., H. Forman, and M. F. Smith. 2001. "Logistics and Supply Chain Education – Roadblock and Challenges." *International Journal of Physical Distribution & Logistics Management* 31(10): 733 – 745.

Llamasoft Inc. (USA). 2015. Accessed March 12. http://www.llamasoft.com/about-us

Mangan, J., and M. Christopher. 2005. "Management Development and the Supply Chain Manager of the Future." *The International Journal of Logistics Management* 16(2): 178 – 191.

Nance, R. E. 2000. "Simulation Education: Past Reelections and Future Directions." In *Proceedings of the 2000 Winter Simulation Conference*, edited by J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick,1595-1601. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Negahban, A., J. S. and Smith. 2014. "Simulation for Manufacturing System Design and Operation: Literature Review and Analysis." *Journal of Manufacturing Systems* 33(2): 241–26.

Owen, C., P. Albores, A. Greasley, and D. Love. 2010. "Simulation in the Supply Chain Context: Matching the Simulation Tool to the Problem." In *Proceedings of the Operational Research Society Simulation Workshop 2010 (SW10)*, 229-242.

Rohrer, M., and J. Banks. 1998. "Required Skills of a Simulation Analyst." *IIE Solutions* 30(5): 20-23.

Surana A., S. Kumara, M. Greaves, and U. N. Raghavan. 2005. "Supply-chain Networks: a Complex Adaptive Systems Perspective." *International Journal of Production Research* 43(20): 4235-4265.

Umeda, S., and F. Zhang. 2010. "A Simulation Modeling Framework for Supply Chain System Analysis." In *Proceedings of the 2010 Winter Simulation Conference*, Edited by B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, 2011-2022. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Webb, G. S., S. P. Thomas, and S. Liao-Troth. 2014, "Teaching Supply Chain Management Complexities: A SCOR Model Based Classroom Simulation." *Decision Sciences Journal of Innovative Education* 12(3): 181-198.

Zhang, X., D. Meiser, Y. Liu, B. Bonner, and L. Lin. 2014. "Kroger Uses Simulation-Optimization to Improve Pharmacy." *Interfaces* 44(1):70-84.

AUTHOR BIOGRAPHIES

TERRENCE PERERA is a Professor in the Department of Engineering and Mathematics, Sheffield Hallam University, United Kingdom. He is a well-established academic, researcher and consultant in the field of systems modelling and simulation. He led a major program of research at BAE SYSTEMS to develop a framework for deploying simulation technologies across the design and manufacture of airframes. Manufacturing, food and healthcare companies have sought his expertise to develop simulation-based solutions. His clients include Caterpillar, Bosch, Sweden Post, Anglo Beef Processors (ABP), Fosters Bakery and Sheffield Teaching Hospitals. He is a Mechanical Engineering graduate of University of Moratuwa, Sri Lanka. He received his PhD from the University of Strathclyde, UK for a program of research in the planning and control of flexible manufacturing systems. His email address is T.D.Perera@shu.ac.uk.

THASHIKA RUPASINGHE is a Senior Lecturer in the Department of Industrial Management, Faculty of Science, University of Kelnaiya, Sri Lanka. She received her Ph.D. and M.Sc. degrees are in Industrial Engineering from Clemson University in the USA. Her first degree was in Industrial Management, graduating with first class honors from the University of Kelaniya. She had worked at SYSCO Corporation, USA as a Senior Supply Chain Analyst and a Manager in Supply Chain and has gained expertise in designing and planning analytics to optimize supply chain operations. Her areas of interest in teaching, research, and consulting are in Industrial Engineering, Supply chain Optimization & Metaheuristics, and Advanced Analytics. Her email address is thashika@kln.ac.lk.