THINK Executive White Paper Series

March | 2018

The Logistics Institute Asia Pacific

A Collaboration Between

NUS National University of Singapore

Georgia Institute of Technology

Presented at:

THINK EXECUTIVE SUMMIT: DIGITAL TRANSFORMATION OF SUPPLY CHAINS

2 March 2018

Singapore

EXECUTIVE SUMMARY

The advent of digitalization is upon us. It is pervasive and ubiquitous. Supply chains which previously had inventory as a lubricant to maintain flows, albeit hiding all but the tip of the iceberg, now additionally have to contend with data as the new currency too. A currency that is omnipresent but not sufficiently leveraged. Artificial Intelligence (AI) power has uncovered not only the hidden opportunities but also set the agenda for transformation of the very core of business. Digitalization in supply chains ranges from sensing, the Internet of Things (IOT), through simulation and computational modelling all the way through integrated decision support via platforms that encompass visualization, scenario experimentation, dashboards and decision analysis. This whitepaper sets out the research agenda supported by experts' perspectives and field studies.

In the first section, the white paper focusses on the agenda for digitalization in supply chains. In Chapter 1, the Institute positions its work to date on digitalization through cases and applications and advocates a call to action via a new AI-powered orchestration platform that enhances transparency, collaboration and flexibility. Chapter 2, positions Industry 4.0 that proclaims do-or-die transformation in the disruptive world of a proliferation of digital technologies.

In the second section, the emphasis is on digital methods in managing potential disruptions and to ascertain the resilience and robustness of networks. In Chapter 3, the concept of urban analytics from the perspective of a focal company is presented for quick and reliable detection of disturbances, threats and bottlenecks. Chapter 4 continues the discussion of risk management but with an emphasis on the focal company's suppliers. It builds out their risk profiles through indices and provides for an integrated perspective through methodological simulation and visualization.

In the third section, the emphasis shifts to simulation and computational modelling. Chapter 5 sets out an overarching view on the challenges and methodologies for digitalizing the real world through models that can be dynamically tuned and optimized to achieve insights and agility in the digital age. In Chapter 6, a case study is presented on collaborative coordination mechanisms in practice. It shows that digitalization has massive potential to break away from silo decentralization to a facilitated-function control tower.

Chapters 7 and 8 delve deeply into decision support in healthcare and humanitarian logistics. Chapter 7 presents ground breaking work to enhance the productivity and reduce the bottlenecks of processes related to the different supply chains of several hospitals in Singapore. The challenges are to build capabilities to support hospitals in their business model transformation leveraging smart decision technologies and in readiness for robotics and automation applications. Chapter 8, brings digital decision support to a very traditional field of humanitarian logistics with Indonesia as the backdrop. The challenge was to effectively determine optimal pre-positioning of stocks and optimize the distribution in critical time down to the last mile.

In summary, this white paper positions wide ranging digitalization work in supply chain and logistics transformation. The intent is to create dialogue at the Think Executive session and set forth a call to join us in this journey as research collaborators. I hope you enjoy reading it as much as we did assembling the contributions. It is neither all-encompassing nor conclusive but intended to seed the next phase of research as described at the end of Chapter 1.

TABLE OF CONTENTS


INTRODUCTION

Chapter 1.

DIGITAL TRANSFORMATION IN SUPPLY CHAIN AND LOGISTICS

The Logistics Institute – Asia Pacific, National University of Singapore

The Digital Era

Digital transformation affects everyone in their daily lives. Everything that can be digitalized will be digitalized, and anything that can be connected will be connected. This applies to everything including people, machines, products and services. Customers are moving from traditional catalogue sales to online e-commerce on their personal devices, from printing of photographs to saving and sharing digital photographs through cloud services and social media, from manually turning on/ off home appliances to remotely controlling appliances from anywhere using smart appliances connected to the cloud. All of these are enabled by smart and interconnected devices, where data and applications are stored in the cloud.

Digital Business Transformation

Digital transformation changes the market context for every business.

For businesses, digital transformation changes the market context for every business. It changes the customers' behaviour and interaction, the product offerings, the business operations as well as the source of business services as illustrated in Figure 1.1. Customers have higher expectations and are able to compare the products and services offered easily using available technologies. They can openly share their opinions about certain products and services and read opinions of others before they decide to purchase. They also value the digital experience as an integral part of the product and service. In terms of product offerings, companies may need to develop, implement, test and refine new products and services very rapidly to help customers achieve their desired outcomes. Companies are experiencing the growing need to refine their business operations by intelligently using the data that they have, and collaborating with other stakeholders to expand and optimize the customer experience.

Digital transformation also accelerates the pace of change and, new products are offered more often, (for example from every 5 years to almost every 6 months) to bring new opportunities for companies to unlock new revenue streams by focusing on customers' desired value and interaction using disruptive technologies.

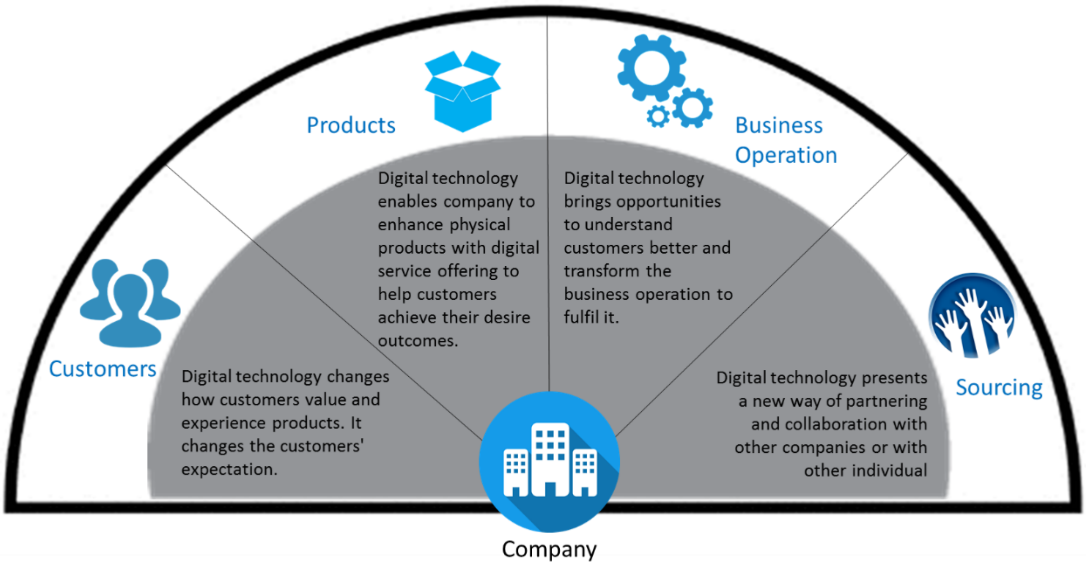


Figure 1.1. Digital Transformation Impact to Business

Navigating Logistics Assets

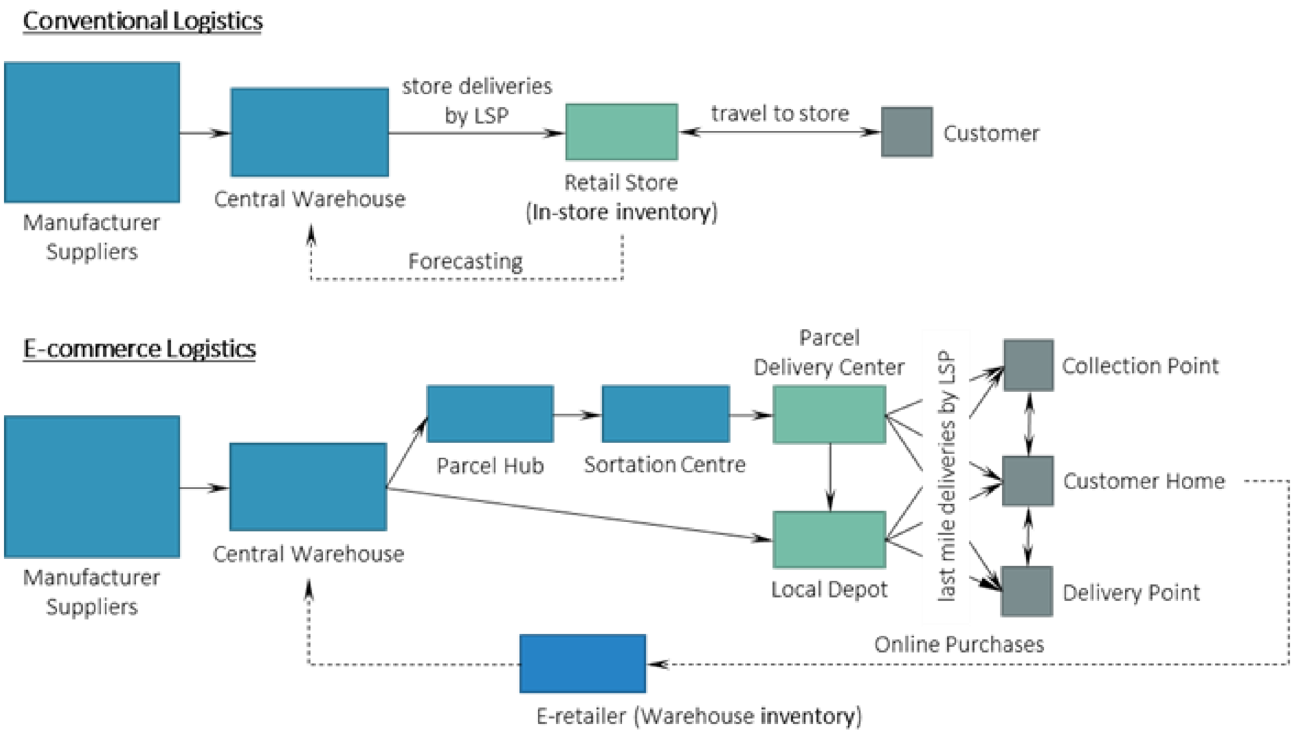
The shift to a digital supply chain creates significant impacts and challenges to the companies/stakeholders involved. Companies need to strategically navigate and explore alternatives to improve their supply chain and logistics to keep up with the changing demands and stay ahead of the competition.

Take for example the e-commerce industry. Most e-commerce customers want fast delivery, the ability to choose their delivery options, guaranteed delivery dates and the ability to specify their delivery time slots[1]. Customers regard these services as important as the products' quality and cost. Customers' satisfaction will eventually transition from pricing to service quality, including faster delivery and reliable services. This is part of their digital agenda.

This makes e-commerce supply chain and logistics management very critical. In addition, e-commerce demand is highly fragmented with smaller packages and higher frequency. Companies need to balance between the cost, time and flexibility of delivery service. On the one hand, they need to deliver the goods quickly according to the customers' preferred time windows, but on the other hand, they also need to provide relatively low delivery cost to the customers. This makes e-commerce logistics different from conventional responsive or efficient logistics to responsive and efficient logistics as illustrated in Figure 1.3.

Figure 1.2. E-Commerce Logistics Characteristics

[1] The Logistics Institute – Asia Pacific, E-Commerce Trends and Challenges: A Logistics ad Supply Chain Perspective, TLI-AP Whitepaper Series, November 2016.



Adapted from Rodrigue J.P. et al., The Geography of Transport Systems, 2017. Available at: https://people.hofstra.edu/geotrans/eng/ch5en/conc5en/ecommercelog.html

Figure 1.3. Conventional and E-Commerce Logistics

Using Simulation Tool to Navigate Infrastructure and Logistics Assets

Placing logistics assets, such as freight facilities, in the correct location is a key element of improving the efficiency and responsiveness of the supply chain and logistics system.

To fulfil the customers' demands and expectations, companies have to place emphasis on the design of their supply chain and logistics systems, including navigating and monitoring their assets to ensure distribution efficiency and customers' satisfaction for quality, speed, reliability and flexibility in deliveries, as well as identifying and mitigating risks in their supply chain and logistics.

Placing logistics assets, such as freight facilities, in the correct location is one of the key element of improving the efficiency and effectiveness of the supply chain and logistics system; thus, the number of and siting of locations should be carefully determined. It needs to consider the current market status such as market trends, proximity to existing customers/demands, and access to suppliers or vendors, transportation cost and travel times. When determining the locations, the companies also need to consider any potential changes in the future (such as changes to customers' demands, location, urban planning and development) because the freight facilities will be functioning for several years or decades in the future. Poor asset resourcing may create bottlenecks and congestion around the freight facility location and delay the deliveries to the customers.

In simulation modelling, a digital prototype is created to model the "real-world" supply chain and analysed using different modelling tools (i.e. discrete event simulation, system dynamic and optimization model).

Various methodologies can be applied to determine the location (or a list of candidate locations) of freight facilities, including simulation modelling. In simulation modelling, a digital prototype (as illustrated in Figure 1.4) is created to model the "real-world" supply chain and analyzed using different modelling tools (i.e. discrete event simulation, system dynamic and optimization model). It takes into consideration the criteria or success factors of the supply chain and logistics design and processes. The alternative solutions can then be generated to improve the supply chain and logistics system. We explore this in the two case studies that follow.

Figure 1.4. Modelling and Simulation Illustration

In e-commerce logistics, the focus thus shifts to last mile distribution, resulting in different logistics strategies and capabilities. Hence, a different supply chain and distribution network is needed to fulfil e-commerce end to end logistics.

Case Study 1: B2C E-Commerce Demand Forecast on Electronics Goods

This case study focuses on navigating infrastructure and logistics assets to fulfil e-commerce demands by answering the following business questions:

1. Where are the sources of B2C e-commerce demand within Singapore?
2. How many warehouses are required to fulfil the B2C e-commerce demand in Singapore?
3. Where should e-commerce businesses locate their warehouse/s to minimize costs?

B2C E-Commerce Demand Forecast

From the B2C e-commerce demand forecast, it can be concluded that higher demands usually correspond with larger planning areas, like the area of Tampines, which has the highest demand.

This case study focuses on B2C on electronics goods. To understand the B2C e-commerce demand for electronic goods for the next ten years, a forecasting method based on Singapore's population [2], population growth, death rate [3] and age specific electronic expenditure [4] and percentage of online purchase[5] is applied.

The results presented, as illustrated in Figure 1.5, represents the total demands in each planning area, in SGD. For that reason, higher values usually correspond with larger planning areas, like the area of Tampines, which has the highest demand.

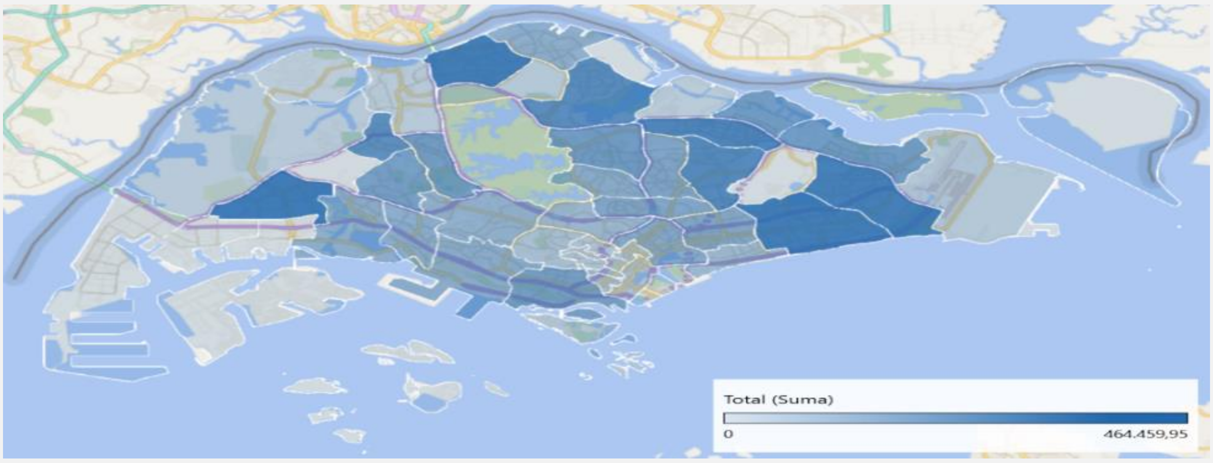


Figure 1.5. Heat Map of B2C E-Commerce Demand Forecast for Electronic Goods

[2] Department of statistics of Singapore, Geographic Distribution, 2017. Available at http://www.singstat.gov.sg/statistics/browse-by-theme/geographic-distribution
[3] Department of Statistics Singapore, Age specific death rate, 2017. Available at http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=13249
[4] Department of Statistics Singapore, Household Expenditure Survey, 2017. Available at: http://www.singstat.gov.sg/statistics/browse-by-theme/household-expenditure-survey-tables
[5] Google, *Consumer Barometer*, 2017. Available at: https://www.consumerbarometer.com/en/

***Determining* Number of Warehouses and the Locations**

Considering the results from the demand forecasting, a simulation model is developed to specify how many warehouses are needed, and where should they be located to minimize costs for the e-commerce market in Singapore. A Green Field Analysis is used using a simulation software to determine the optimal location for the warehouses.

The result of this analysis determined that the optimal location for the warehouse is in Bishan area (as illustrated in Figure 1.6). However, the coordinates proposed by the GFA are not in an appropriate location for a warehouse. Hence, some adequate coordinates are proposed based on the different industrial areas in Bishan, as shown in Figure 1.7.

Figure 1.6. Green Field Analysis Result for B2C E-Commerce Demand for Electronic Goods in Singapore

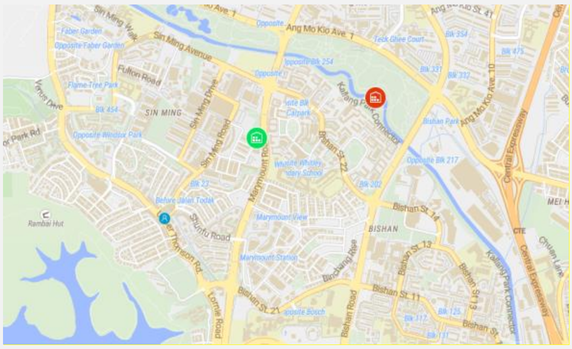


Figure 1.7. Proposed Areas from Green Field Analysis and Industrial Areas around It

Case Study 2: Freight Facility Design and Selection for B2C E-Commerce

To identify important criteria to consider for freight facility, a survey was designed and circulated among industry professionals and academic experts to capture the relative importance of 40 criteria. Respondents were asked to rate the level of importance of each criterion on a scale of 1 to 5 with "1" being "not important at all" and "5" being "extremely important".

A total of 27 responses were received. The results show that the top five criteria are order fill rate, total storage/warehouse capacity, adopting appropriate storage strategy for SKUs, use of integrated warehouse management system (WMS) and proximity to the customers. The summary of the result is shown in Figure 1.8.

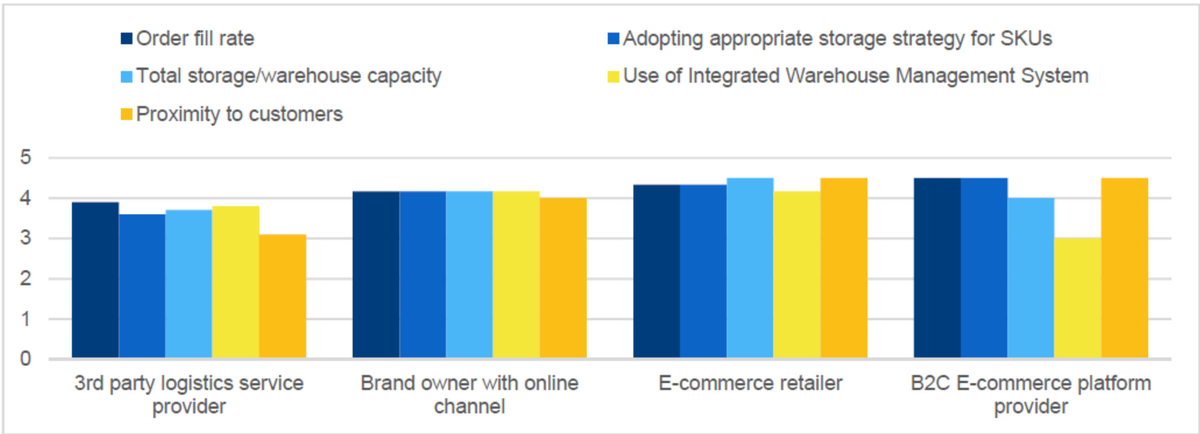
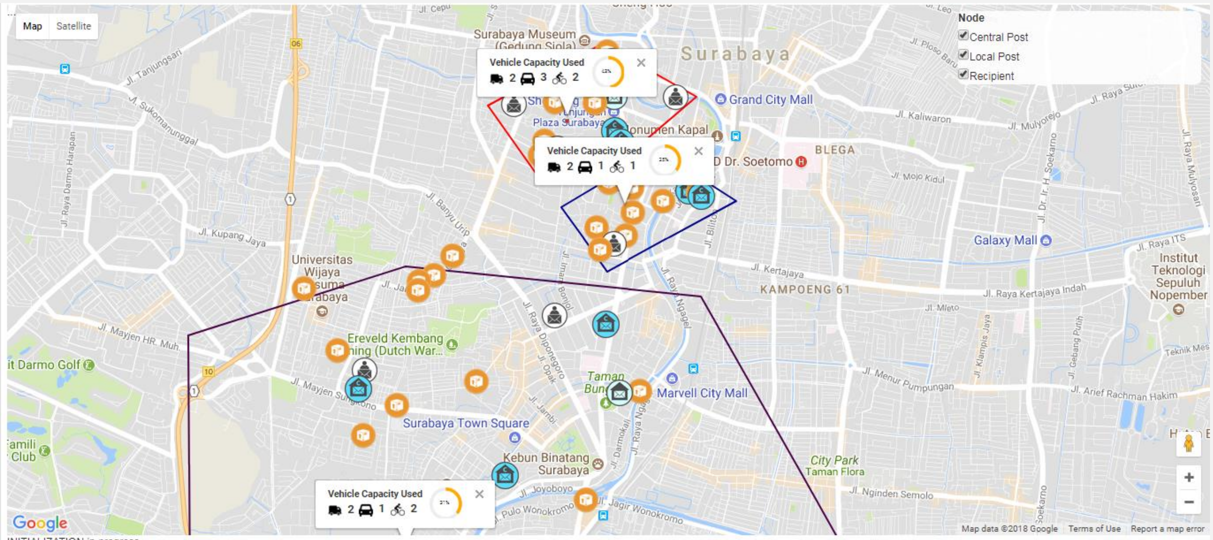


Figure 1.8. Average scores of Top 5 criteria by type of e-commerce players

Application 1: Last Mile Delivery Planning and Monitoring through Smart Analytics Routing Application (SARA)[6]

To tackle the last mile, companies need to be able to plan, schedule, manage and monitor their logistics assets for deliveries across a wide spectrum of parameters (locations, travel time, travel mode, weather, etc.). The advancement in today's communication and software technology makes it possible to do these using for example Smart Analytics Routing Application (SARA) which is currently developed to support supply chain operation and management by displaying and analyzing logistics fleets and its routes.



No.	No.Of Truck	No.Of Lorry	No.Of MotorCycle	Total Amount Of Vehicel	Total Staff
1	5	5	6	16	16

Figure 1.9. Fleet Load Visualization in SARA

SARA would generate and display fleet load and routes by considering last mile routing between each delivery nodes as illustrated in Figure 1.9. It will try to find the optimal fleet for a certain delivery area and generate routes to deliver a given set of shipments to the nodes in this area. The optimal set of routes found by SARA will consider individual segments between nodes with different properties (such as cost, time, distance etc.). The optimal set of routes found by SARA will minimize the total transportation cost based on the total distance travelled as well as the fixed costs associated with the used vehicles and drivers; minimize the number of vehicles needed to serve all customers and maximize service quality or minimize penalties for low quality service.

[6] This section is based on the joint work between The Logistics Institute – Asia Pacific (TLI-AP) and ST Electronics (Info-Software System) Pte Ltd under the Integrated Supply Chain and Logistics project (grant number 152 42 00055).

Application 2: Mitigating Supply Chain Risk using A Web-based Tool for Supply Chain Risk Management

A shift to a more connected supply chain via digital interconnected devices and complex web will make the supply chain network more exposed to numerous risks of supply chain disruptions. These disruptions may have different occurrence frequency and consequences. One disruption may happen more frequently with more severe consequences compared to other disruptions (as illustrated in Figure 1.10).

Supply chain risks are linked to the following areas: suppliers, customers, locations, countries and own sites.

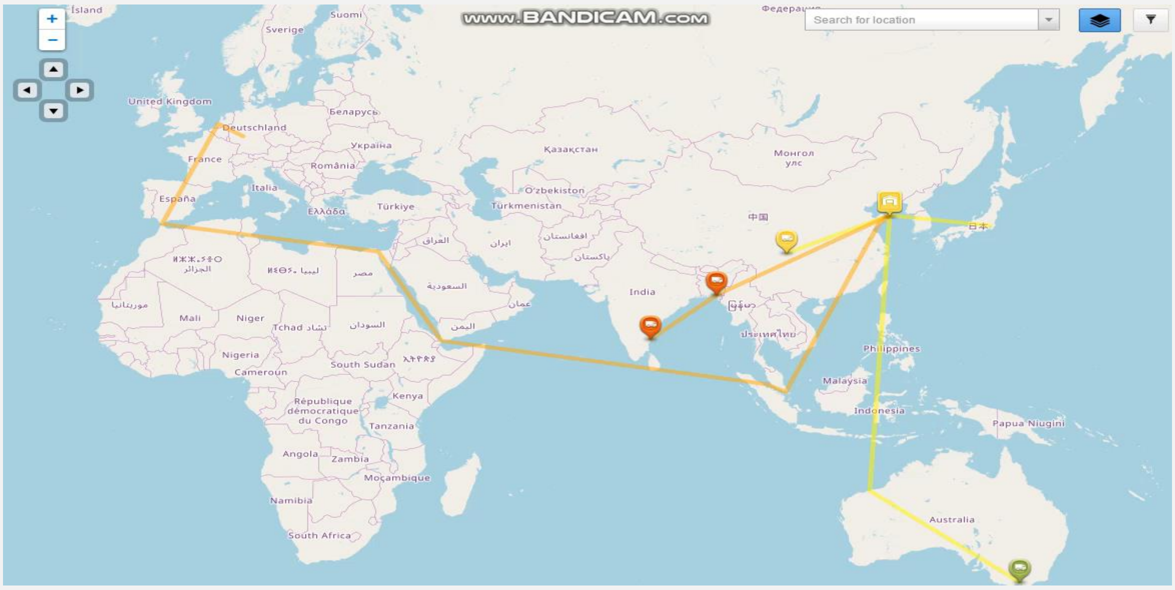


Figure 1.10. Modelling a supply chain through a map in RISKMethods™

Phase 1: Risk identification

Supply chain risks are linked to the following areas: suppliers, customers, locations, countries and own sites.

Supply chain risks are linked to the following areas: suppliers, customers, locations, countries and own sites. The framework in Figure 8.3 is used to categorize risk factors. Companies can identify their own risk factors according to this framework. In each green subgroup, there are lists of risk factors for selection. Those selected risk factors will be tracked and monitored by the tool in real time.

Experimental work with riskmethods software modules as permitted by riskmethods GmbH (riskmethods.net)

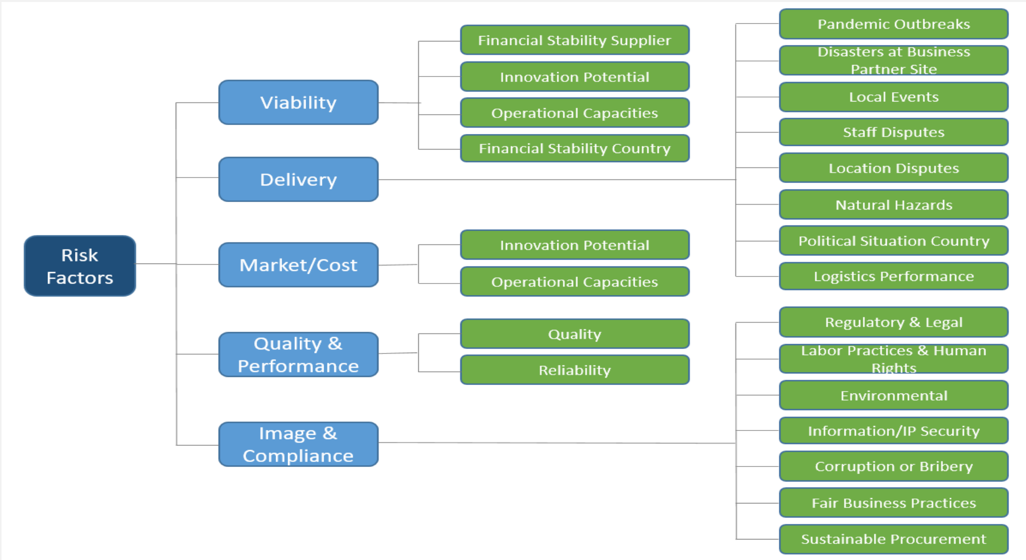


Figure 1.11. Framework of risk factors

Phase 2: Risk Assessment

Risk impact can be assessed based on the questioner built by the companies through this tool. An example of the questionnaire is shown in Figure 1.12. With the risk score and impact score, the risk portfolio can be generated as in Figure 1.13.

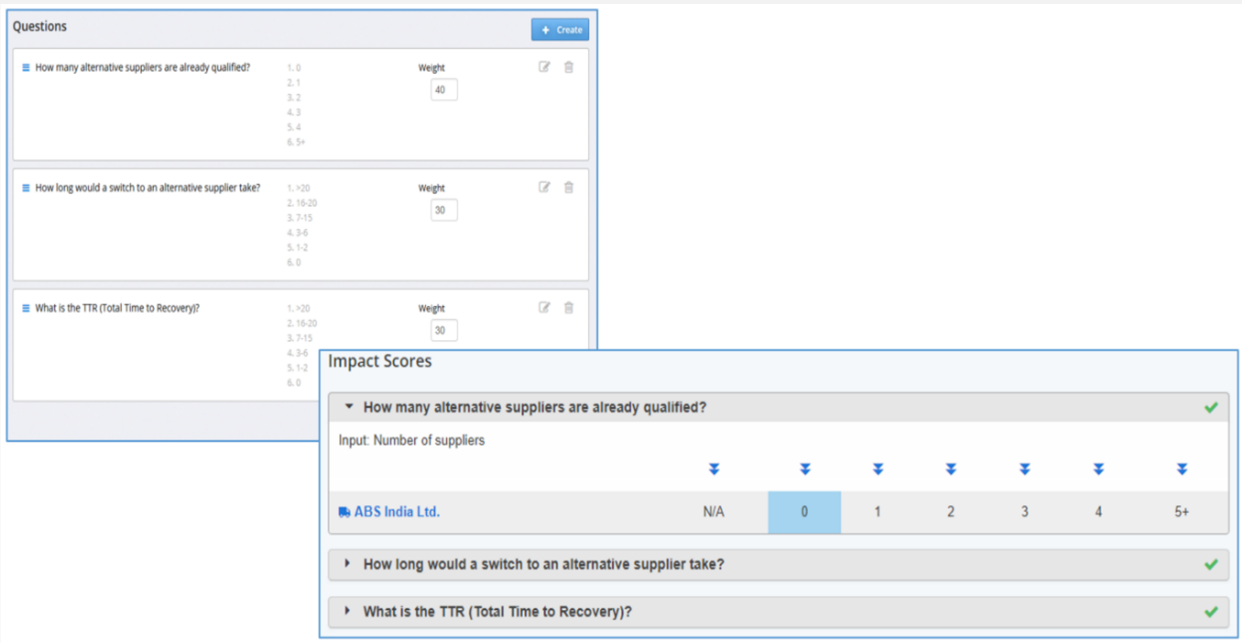


Figure 1.12. Risk impact questionnaire and the weight

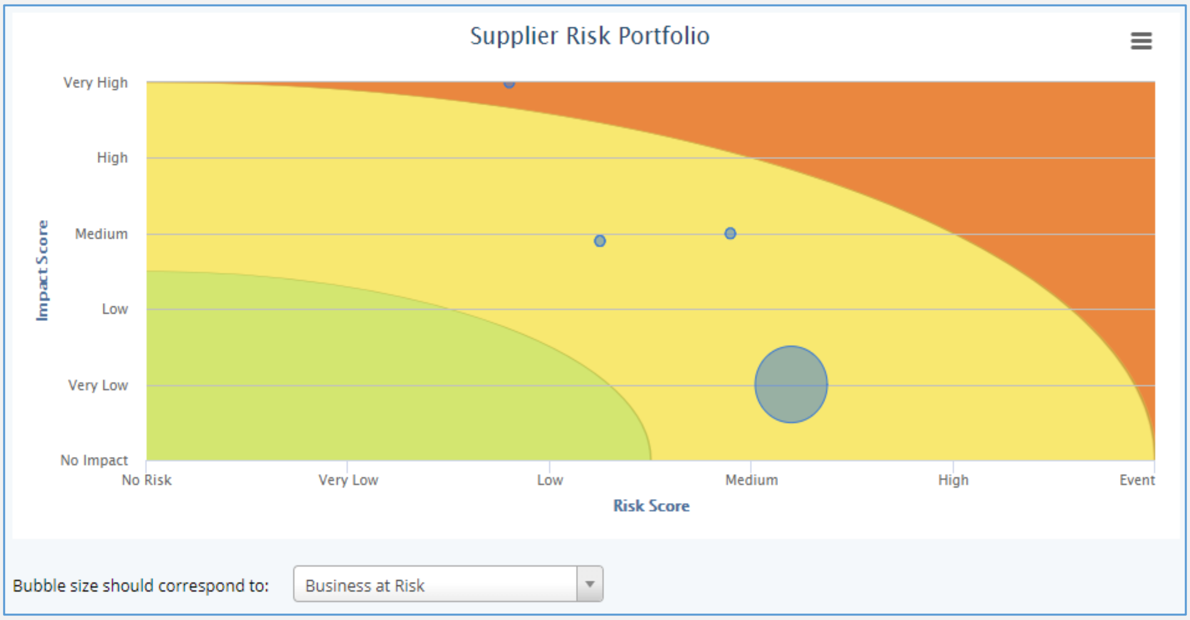


Figure 1.13. Risk portfolio

Phase 3: Risk Mitigation

Based on the risk assessment, the companies can decide whether mitigation strategies can be implemented in advance to reduce the risk level. Figure 1.14 and 1.15 illustrate the functions to activate mitigation action plan for supply chain members.

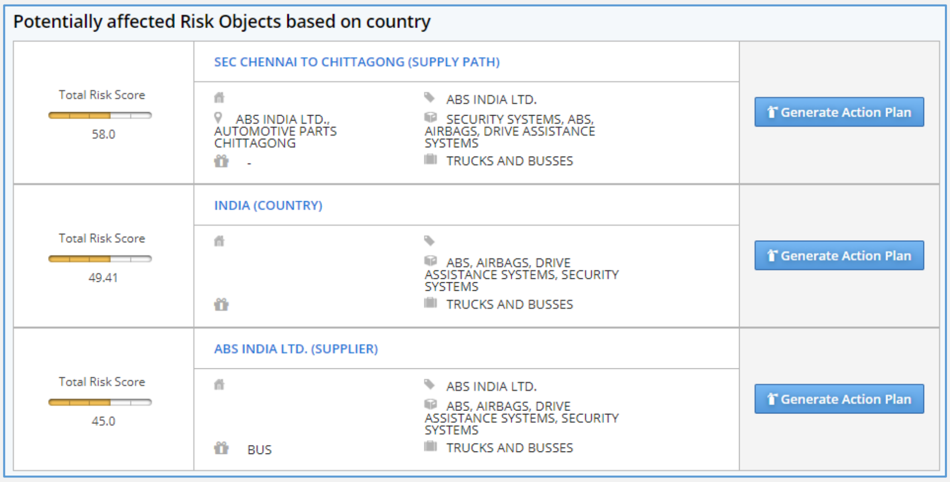


Figure 1.14. Supply chain entities

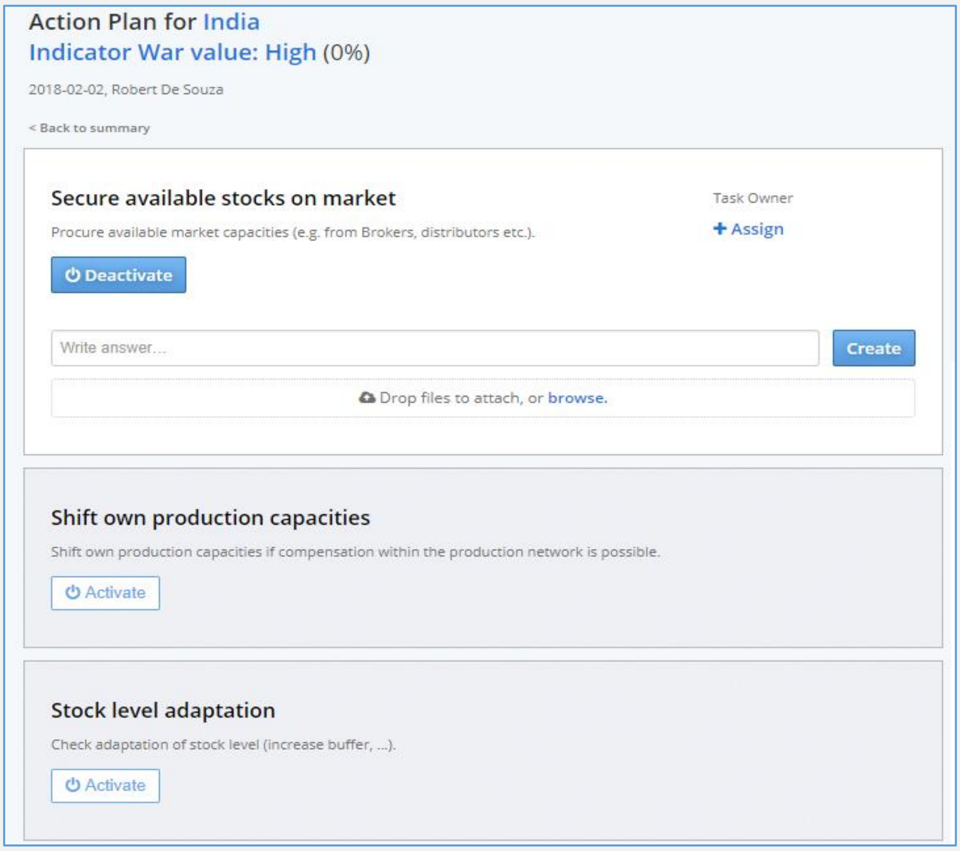


Figure 1.15. Mitigation action plan

Phase 4: Risk Monitoring

For risk monitoring, real time alerts (as illustrated in Figure 1.16) for the registered risk events are very important. It would help the companies to reassess the risk level.

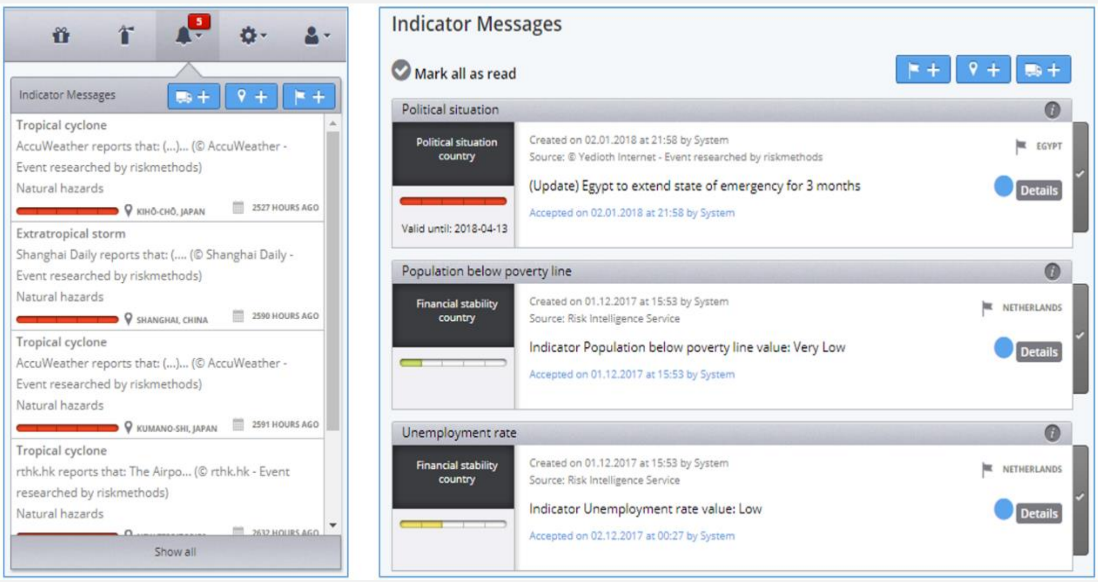


Figure 1.16. Risk monitoring – indicator messages

Overall Risk Level Tracking and Visualization

With risk identification and assessment, the results for different supply chain entities, e.g. suppliers, supply chain paths, locations, and countries, at the current time, are presented in Figure 1.17.

Furthermore, we can also track the history of risk levels of supply chain entities overtime as illustrated in Figure 1.18, which tracks the risk levels of suppliers, supply paths, locations and countries for the last 3.5 years.

Figure 1.17. Risk assessment for different supply chain entities

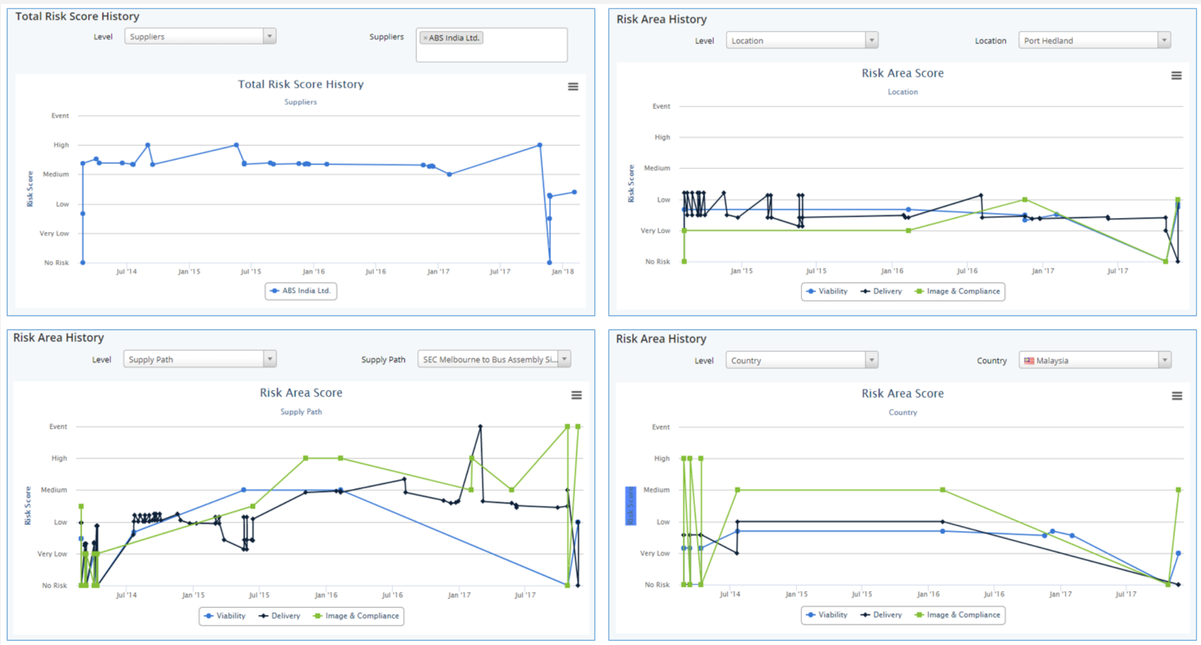


Figure 1.18. Tracking risk levels of supply chain entities in past years

Application 3[7]: Commentary: Use of Statistical Computing in Decision Making

R and Statistical Computing

R is a statistical computing environment that makes it easy to solve mathematical problems relating to optimization, predictive modelling, (time series) forecasting, and visualization. It is also the most popular statistical language among data scientists and mathematicians.

R is free and open source.

Being the most widely used data analysis environment, R is naturally a common tool of choice when it comes to prototyping and building application layers using geo-spatial data. We go through a series of examples to show how anyone can make use of this free, open-sourced and well-developed R ecosystem to aid their decision making and software engineering process. It is our hope that this vignette helps shed light on some of the more foundational engineering processes behind mapping, navigation, route finding or even forecasting solutions widely used throughout commercial applications. It is further our intention that this writing elevates your interest even slightly in the field of applicational data science and more generally, statistical computing.

Developing Mapping Applications

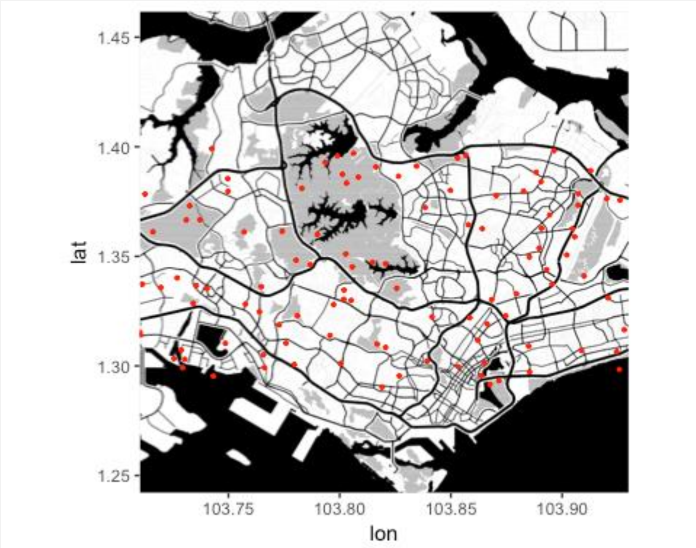
Logisticians or software developers looking to visualize spatial data and develop spatial models can use R and it's "wrapper functions" to query just about any external servers to obtain the underlying spatial data. In the workshop, We demonstrate the use of R to query (and download) maps from Google, OpenStreetMap, and Stamen Maps but these are not the only options!

We can plot the map we created in two lines of code in R and overlay information as aesthetic objects onto our plot:

```
map1 <- ggmap(sing) +
geom_point(data=foo, aes(x = long, y = lat), color = "red", size=0.7)

suppressWarnings(print(map1))
```

[7] This section is contributed by Mr. Samuel Chan, co-Founder Algoritma.

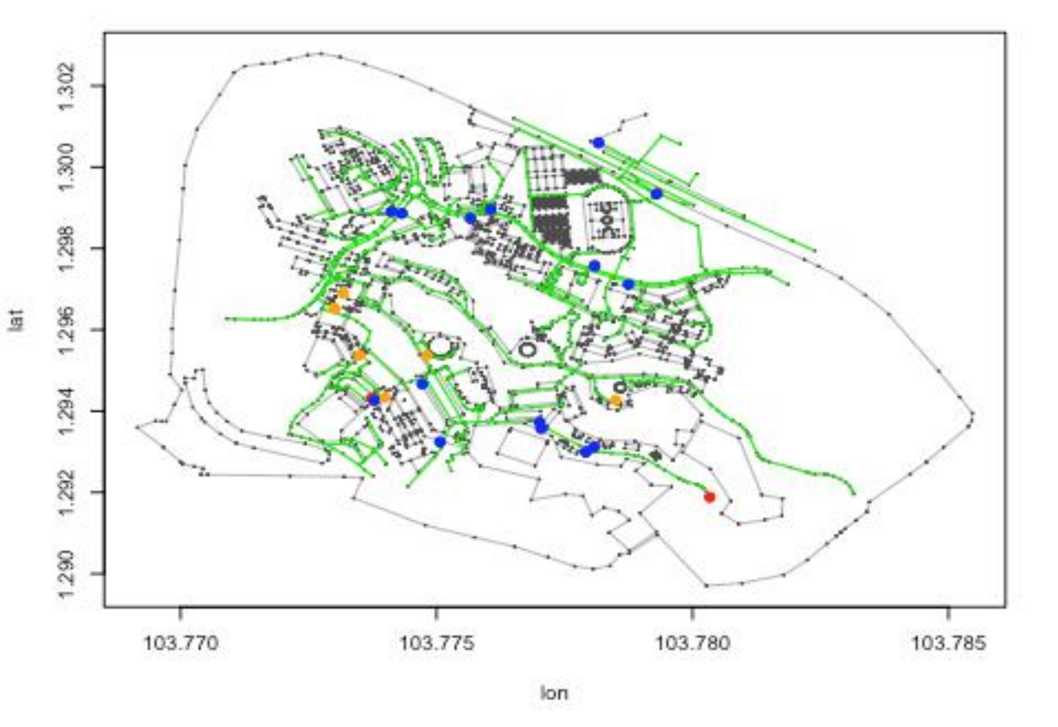


We search up the latitude and longitude of NUS Singapore campus and use Open Street Map's API to download the data into our environment by plugging the longitude and latitude (103.7764 and 1.2966 respectively):

```
## osmar$nodes object
## 3031 nodes, 228 tags
##
## ..$attrs data.frame:
## id, visible, timestamp, version, changeset, user, uid, lat,
## lon
## ..$tags data.frame:
## id, k, v
##
## Bounding box:
##            lat       lon
## min 1.289702  103.7692
## max 1.302787 103.7855
##
## Key-Value contingency table:
##      Key               Value                  Freq
## 1    bus               yes                    16
## 2    highway           bus_stop               15
## 3    public_transport  platform               13
## 4    barrier           lift_gate               9
## 5    amenity           atm                     7
## 6    route_ref         95                      4
## 7    amenity           cafe                    4
## 8    location          Lower Kent Ridge Roa...  4
## 9    location          Prince George's Park    4
## 10   source            survey                  4
```

We can take at a subset of the data we downloaded using find() and subset():

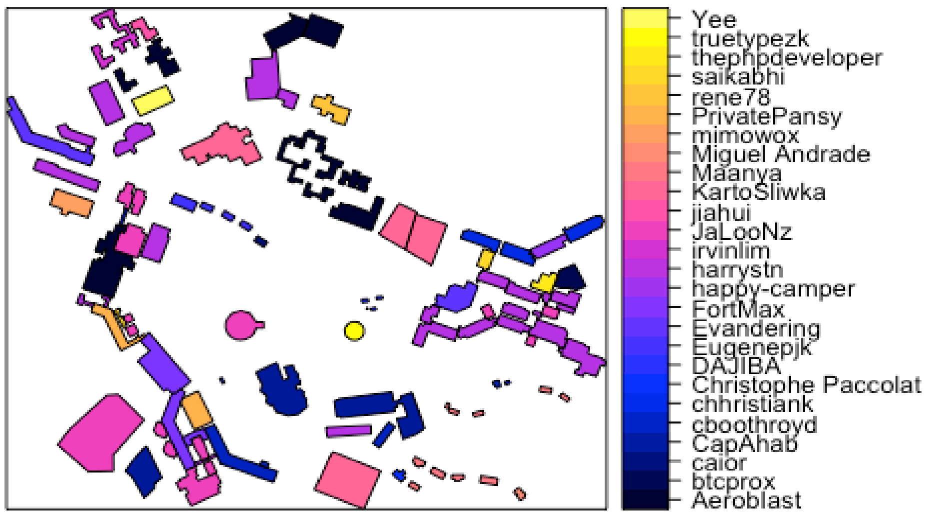
```
## id               k                  v
## 71 1738410357    bus                yes
## 72 1738410357    highway            bus_stop
## 73 1738410357    location           Prince George's Park
## 74 1738410357    name               House 7
## 75 1738410357    public_transport   platform
## 76 1738410359    bus                yes
## 77 1738410359    highway            bus_stop
## 78 1738410359    location           Prince George's Park
## 79 1738410359    name               Opp House 12
## 80 1738410359    public_transport   platform
```



We can, of course, also visualize the data we downloaded from Google and Open Street Map. R and the packages on its ecosystem provide us with a rich collection of tools and functions to model these spatial data.

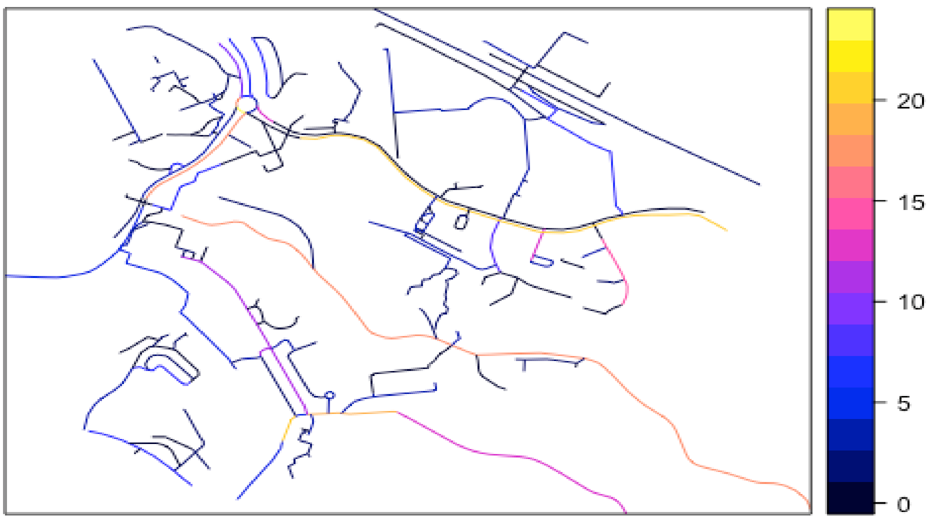
We demonstrate some of the functions common for geolocation and routing, we also note that most of this data we just acquired is "crowd-sourced" by regular folks. We can attribute the contribution of each tags to the "user" through visualization:

```
bg_poly <- as_sp(bg, "polygons")
# change `user` to `version` to see its changes over version
spplot(bg_poly, c("user"))
```



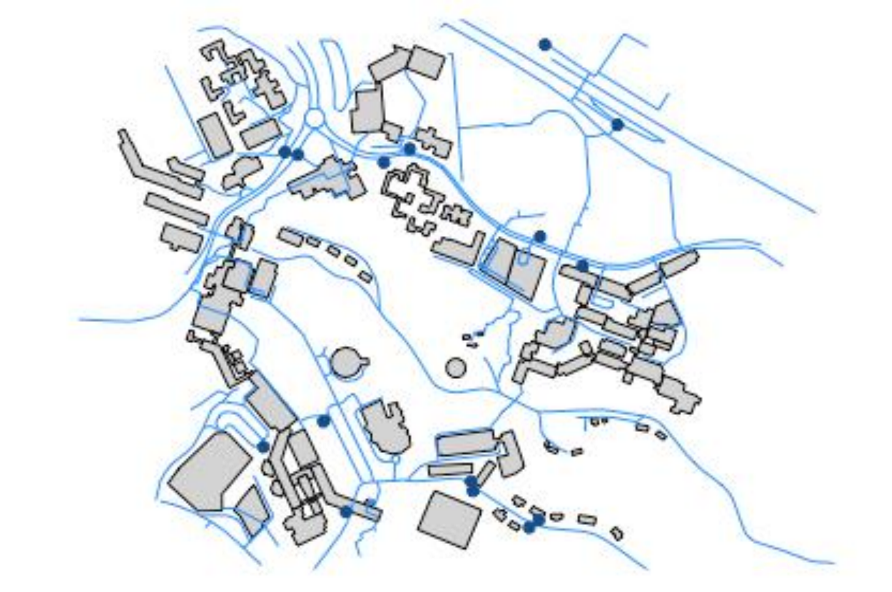
If we wanted to, we can also plot the buildings and pathways around our NUS campus using the crowd-sourced data. This generates an object that serves as a foundational base that we can then use to overlay our routing logic or algorithmic optimization on.

```
hw_line <- as_sp(hw, "lines")
spplot(hw_line, c("version"))
```

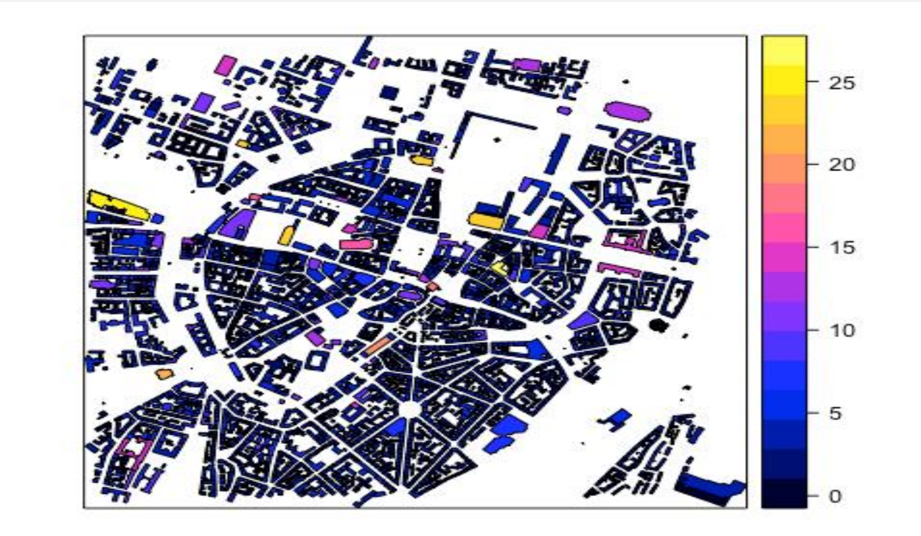


Notice that from the initial server query to visualizing our NUS compound is really a matter of several lines of code. We're taking advantage of crowd-sourcing to help our model figure out the paths, buildings, walkways, amenities and other objects in an open source, full-fledged data environment!

```
par(cex.axis=1, cex.lab=1, cex.main=1.2, cex.sub=1, pch=19, cex=0.7)
plot(bg_poly, col = "lightgray")
plot(hw_line, add = TRUE, col = "dodgerblue1")
plot(bs_points, add = TRUE, col = "dodgerblue4", pch=19)
```



While programming in a statistical environment may seem daunting, or even intimidating in the beginning, such intimidation is short-lived when you realize that a large part of this experience uses a very consistent "grammar". We're dealing with polygons, lines and points for the most part when it comes to spatial visualization and this consistency is observed across many packages in this domain of data science in the R ecosystem. The level of consistency makes it easy to integrate different functionalities from third-party packages authored by independent researchers, professionals and geospatial scientists.



Developing Navigation Abilities

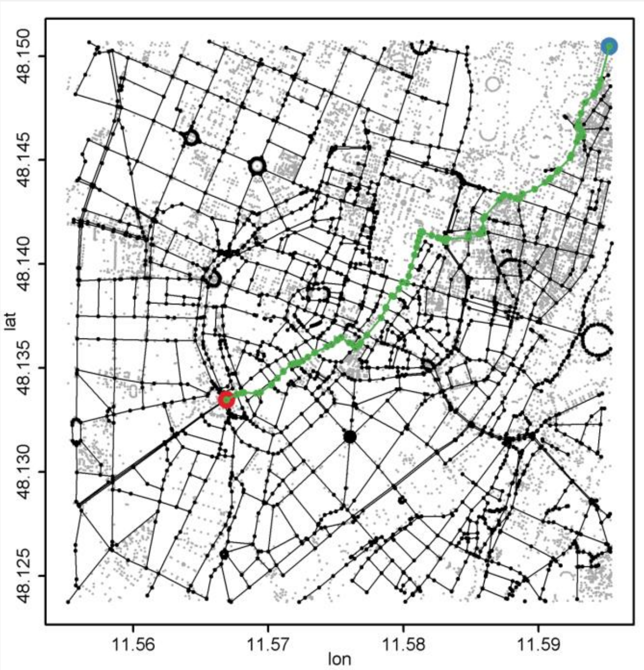
To simulate a navigation device, consider the following graph and our starting (green point) and destination (red point) positions. Using what we've learned so far, we can first plot all existing roads in the region, and then add the red and green labels to the nearest node of our specified starting and destination points.

Consider the number of possible routes or paths between these two points.

```
par(cex.axis=1, cex.lab=1, cex.main=1.2, cex.sub=1, pch=19, cex=2)

plot(mucbg_poly, col = "gray")
plot(muchw_line, add = TRUE, col = "dodgerblue4")
plot(hway_start, add = TRUE, col = "green", pch=19)
plot(hway_end, add = TRUE, col = "red", pch=19)
```

We can now convert the above network of paths into a graph and run an algorithm to compute the shortest distance among all possible combinations of paths. R packages like igraph can also automatically pick an algorithm that most efficiently compute the distances for the supplied weights.

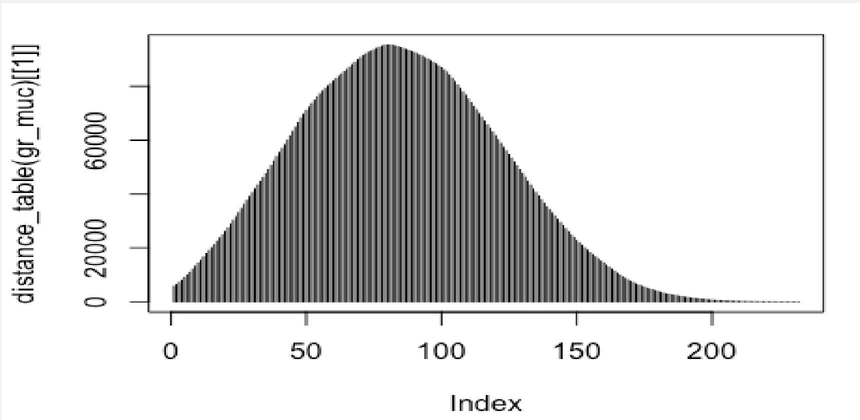


We can also plot a histogram by computing the shortest path length between each pair of vertices in our graph for directed graphs both directions are considered so every pair of vertices appears twice in the histrogram[8].

Loading required package: igraph

##
Attaching package: 'igraph'
The following objects are masked from 'package:stats':
##
decompose, spectrum
The following object is masked from 'package:base':
##

union



Impacts on Supply Chain

A shift to a more connected supply chain, via digital interconnected devices and complex webs, is necessary.

Digital transformation requires companies to rethink not only their current business models but also their whole business operation and corporate culture, including their supply chains. Traditional supply chains with linear and long chains before reaching the customers (as illustrated in Figure 1.19) may not be sufficient. A shift to a more connected supply chain, via digital interconnected devices and complex webs (as illustrated in Figure 1.20), is necessary. This would link suppliers, distributors, wholesalers, transporters and customers to enable supply chains to react faster and be better able to adapt to the fast changing market.

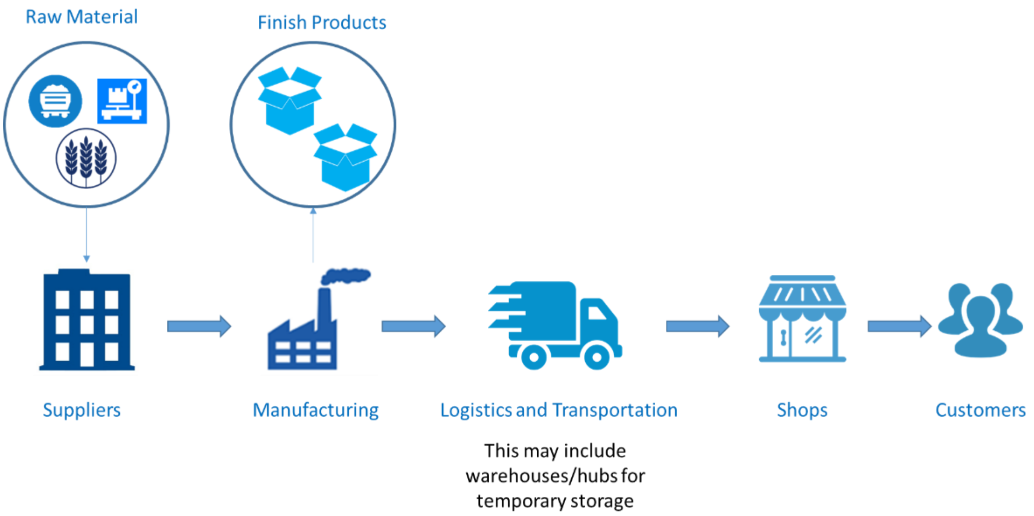


Figure 1.19. Traditional Supply Chain

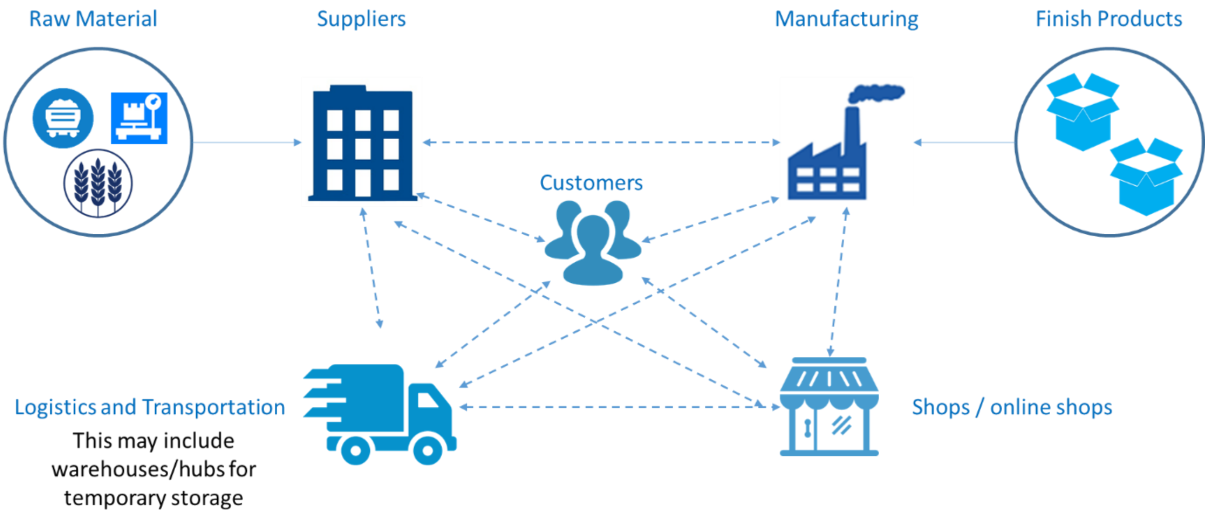


Figure 1.20. Digital Supply Chain

[8] G Csardi, igraph Package in R

Thus, in summary, in this digital era, we are faced with shifting consumer demand patterns, changing market trends, and subtle change in consumer behaviour. Even though supply networks are integrated and information may be shared through centralized platforms, businesses and stakeholders involved may still have different views of consumer demands. Seasonality and weather conditions also impact demands. As a consequence, a mismatch in supply and demand occurs. High costs of operations, poor service level, waste, and low productivity ensue. Therefore, it is imperative to have a more adaptive and more orchestrated mechanism to efficiently help plan and operate supply chain in a changing environment. The main challenges of today's supply chain can be summarized as follows:

Supply Chain Transparency

Coordinated information exchange through the entire chain is still not a common practice. Often, huge data generated by digital technologies is stored in a complex and non-structural form, which is not easily machine readable. Opaque supply chains could lead to poor demand planning and management. This could result in high operating cost, due to excessive inventory and high product return rate (and claims). On the other hand, it could also lead to poor service levels due to stock-out. The slew of new technologies and innovative work in AI-powered production systems calls for innovative collaborative business models. Limited supply chain visibility is a growing concern. The move towards a globally integrated supply chain with near "total transparency' is needed.

Various cutting-edge technologies (e.g. Big Data Analytics and Learning algorithms) must be embedded in solution platforms to ensure that all parties have the same unified view of the database, a feature that will permit a supply chain to respond effectively to increased supply, modal choices and demand volatility.

Supply Chain Collaboration

Siloed execution by supply chain partners especially in the last-mile stage could result in high cost, low productivity, and resource wastage. With limited resources, last-mile logistics has to be managed in innovative ways to ensure timely order fulfilment. Collaboration is a strategic term for integrating different technologies, processes, resources, and also networks to achieve the optimal operations with efficient use of resources. One common approach of supply chain collaboration is last-mile consolidation, where data exchange, demand clustering, and resource management of more than one stakeholder are synchronized. Integration of automation and Artificial Intelligence (AI) in daily logistics operations also help improve productivity and resource usage.

Supply Chain Flexibility

Fragmentation and a stochastic universe hinder flexibility. Real-time planning of inventory and last-mile milk runs are needed. The supply chain network must therefore be dynamically optimized and configured to accommodate changing parametric values such as change or substitution of vendor, order quantity, safety stock, lead time, and so on. Dynamic optimization and multi-scenario simulation are the main tools to help networks self-reconfigure to achieve the flexibility.

Figure 1.21 specifically describes the current problems of today's supply chain in focused industry sectors.

	Retail and E-Commerce	Pharmaceutical	Healthcare	Hospitality	Construction
Supply Chain Transparency	• Demand Forecasting • Inventory Management		• Demand Forecasting • Resource Allocation		• Resource Allocation • Project Management
Supply Chain Collaboration	• Demand Shaping and Clustering • Order Fulfilment • Delivery Planning and Scheduling			• Resource Allocation • Demand Fulfilment	• Operations Scheduling
Supply Chain Flexibility	• Vulnerable Network • Risk Management				

Figure 1.21. Sectoral Problem Statements

Moreover, a lack of transparency, inefficient resource allocation and inflexibility manifest in supply chain problems that are not unique to any one industry sector. Thus, cross sector best practices are best gleaned from an integrated perspective. This is shown in Figure 1.21.

Supply Chain Orchestration Platform

Leveraging on supply chain and logistics capabilities, domain knowledge and notable industry engagements, The Logistics Institute – Asia Pacific (TLI-Asia Pacific) aims to continue to develop innovative, integrated/seamless platforms that will provide solutions and insights to help tackle various challenges in the supply chain and logistics, especially in last mile logistics with enhanced effectiveness and efficiency. The platforms will serve the following firstly, to test breakthrough concepts, strategies and dynamically re-configure the supply chain network with the changing demands and markets, and secondly as an innovative model/tool that explores techniques, data analytics and disruptive technology to support/sustain self-orchestration of entire supply chain networks. Two such platforms have been built as shown in Figure 1.22.

1.22. Integrated platform for Last Mile and E-Commerce Logistics

We propose a new integrated orchestration platform as shown in Figure 1.23. This platform is aimed at dynamic reconfiguration of networks. It has four main interdependent components:

A self-orchestrator, an allocator of resources in real time, a dynamic price setter based on current and predicted conditions and a scenarios planner. Each of these components "interlocks" with the other to give rise to a unique control tower.

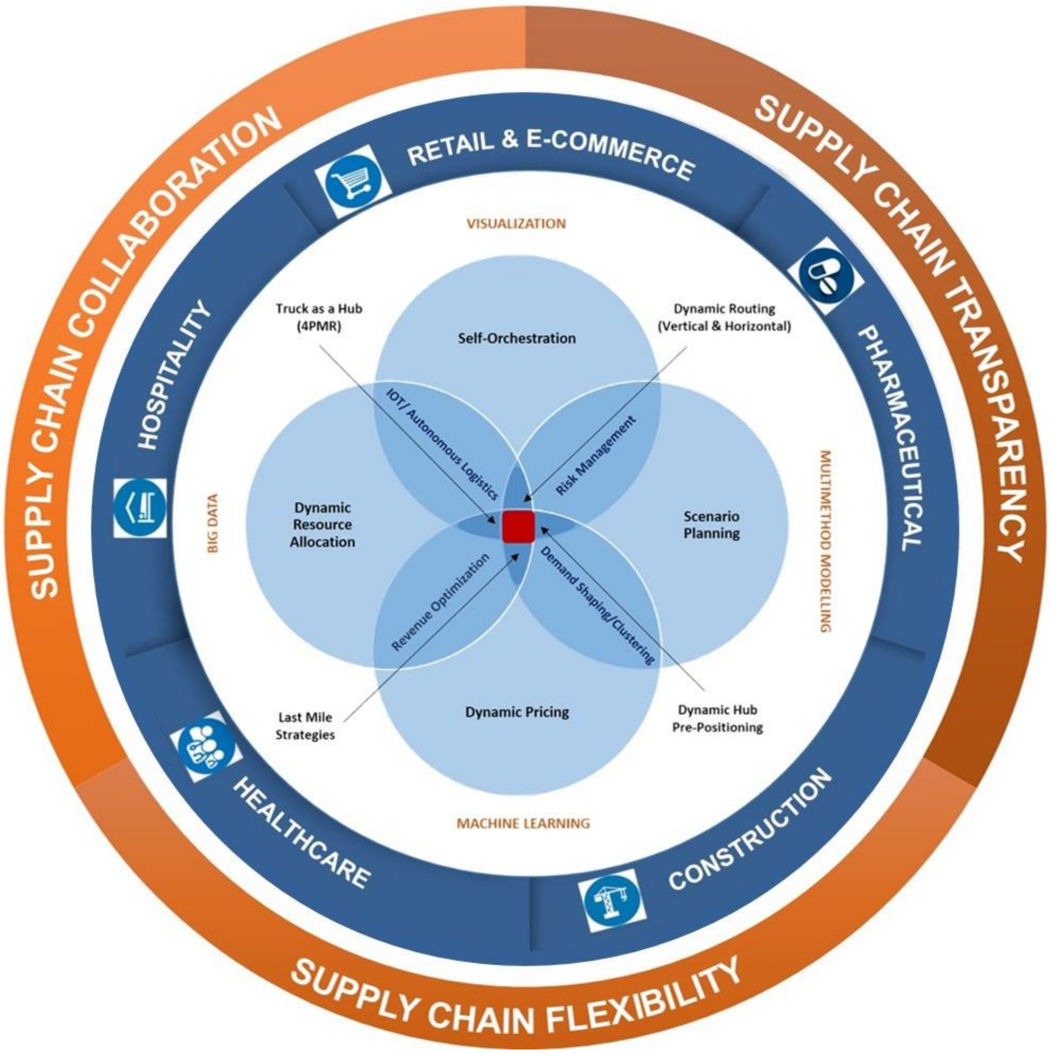


Figure 1.23. Orchestration Platform

The platform has as its core an integrated AI powered engine that provides for different scenario experimentation, visualization and decision dashboards.

To foster the implementation and application of the concepts/strategies/tools/platform, we welcome collaboration from industry with complex supply chain networks to contribute by sharing their supply chain and logistics problems/challenges/ideas and participating in the research.

Chapter 2.

WHAT BENEFITS DO INITIATIVES SUCH AS INDUSTRY 4.0 OFFER FOR PRODUCTION LOCATIONS IN HIGH-WAGE COUNTRIES?

Contributed by Prof. Dr. Paul Schönsleben, Professor for Operations and Supply Chain Management
ETH Zurich, Department of Management, Technology, and Economics

Introduction

Initiatives like the Industry 4.0[9] initiated in Germany are driving a digital revolution in production, through which high-income countries in particular (e.g. USA, German, Japan and Switzerland) are looking to utilize to enhance their positions as production locations. Industry 4.0 postulates a fourth industrial revolution where smart and connected machinery, warehousing systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently rapidly disrupt conventional production systems[10]. The result will be increased production effectiveness and efficiency, or "Smart Factories" that feature (1) more individualization of products to customers' requirements without significantly increasing costs; (2) improved versatility, efficiency, and ergonomics with better integration throughout the entire supply chain; and (3) more autonomous decision making in decentralized product and production systems. Other similar initiatives include Cyber-Physical Systems (CPS)[11] initiated by USA, IVI (Industrial Value Chain Initiative)[12] in Japan or Industry2025[13] in Switzerland.

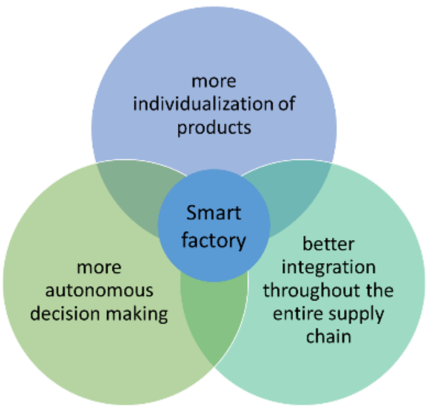


Figure 2.1. Fully Digitalized Smart Factory

[9] Kagermann H., Wahlster W., Helbig J. Securing the Future of German Manufacturing Indystry: Recommendations for Implementing the Strategic Initiative *Industrie 4.0.* Acatech, Final Report of the *Industrie 4.0* Working Group, 2013.
[10] Ibid. Note 1
[11] Lee EA. Cyber-Physical Systems: Design Challenges, Technical Report No. UCB/EECS-2008-8. UC Berkeley, 2008.
[12] Industrial Valuechain Initiative,What is IVI? Available at www.ivi.org/en/ [Accessed 09.03.2017]
[13] Industrie 2025. Portrait. Available at www.industrie2025.ch [Accessed 09.03.2017]

Examples around Industry 4.0

Industry 4.0 is enabled by key technology building blocks for a smart, interconnected system, including concepts like intelligent sensors, the Internet of Things, big data, additive manufacturing, medical engineering etc. These digital components allow automated production to adapt increasingly quickly to changing requirements. Below are some examples of key technology building blocks. Most of these examples are taken from the Swiss industrial and services sectors.

Smart Sensors

Figure 2.2. An example of a smart sensor. Valedo sensor (Source: Hocoma)

A smart sensor can be used to measure things (as a conventional sensor would), process the measured data and make the results available in the required form.

Internet of Things (IOT) and Big Data

Figure 2.3. An example of IOT traker. The Kizy Tracker (Source: Kizy Tracking)

The *IOT* is a network of material or non-material goods and objects ("things") that are connected to each other and that can exchange data, which creates so large and complex data sets (also known as *Big Data*).

Additive Manufacturing (AM)

Figure 2.4. An example of "digital" spare parts for textile machinery (Source: 3D Prints Lechthaler Reinhard)

AM is widely known as *3D printing.* It is a process that offers the possibility of creating three-dimensional objects.

Personalized Medication

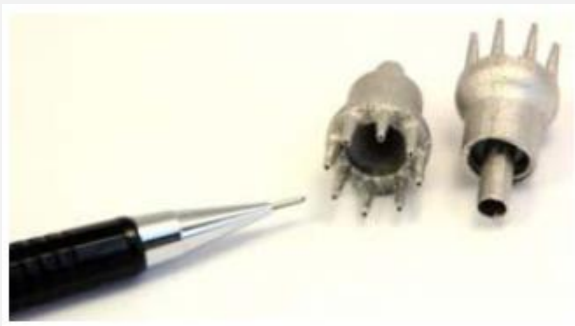


Figure 2.5. High-precision distribution of liquids (Source: 3D Precision SA)

Personalized medication is a patient-focused approach that incorporates both medication and the dispensing process.

Impact of Industry 4.0

In terms of the *medium-term* impact, digital revolution across all sectors and technologies will drive continuous progression. However, companies that are built around specific analogue technologies, such as analogue photography, analogue telephony, offset printing and tooth imprints, are exposed to substantial risk of being replaced by digital technologies. Over the *long term*, initiatives such as Industry 4.0 offer significant benefits for production locations in high-wage countries by giving the countries a competitive edge, because countries are already seeing their status enhanced by these initiatives, which in turn helps them attract the best young talent to the industrial sectors.

Acknowledgement

This chapter is a summary from Schonsleben, P., Fontana, F., Duchi, A., What benefits do initiatives such as Industry 4.0 offer for production locations in high-wage countries?, In The 50^{th} CIRP Conference on Manufacturing Systems, Procedia CIRP 63, pp. 179-183, 2017.


SUPPLY CHAIN RISK
MANAGEMENT

Chapter 3.

Threat Analysis and Resilience of Complex Supply Chains - Urban Analytics

Contributed by Prof. Markus Gerschberger, Professor for Supply Chain Management, University of Applied Sciences Upper Austria, Steyr: and

Prof. Stefan Pickl, Professor for Operations Research, Universität der Bundeswehr München

Society depends decisively on the availability of critical infrastructures such as transportation, energy, telecommunication, banking and finance, health care and governmental and public administration. Even selective disruption of one of these infrastructures may result in disruptions of governmental, industrial or public functions. Vulnerability of infrastructures therefore offers spectacular leverage for natural disasters as well as criminal actions. Threats and risks are part of the technological, economical, and societal development. Increasing complexity of our critical infrastructures exacerbates consequences of natural and/or man-made disasters. Not only primary effects but also cascading effects as result of increasing dependencies and interdependencies of our technological and societal systems demand intelligent simulation and optimization techniques (AI-based) in the area of supply chain and a comprehensive safety and security management.

In order to design supply chains that are less vulnerable to disruptions, researchers have to consider the structure and organization of companies and their supply chains which play an important role in improving supply chain resilience[14]. Originally, resilience has its roots in psychology and ecosystems before it was adapted to supply chain management[15]. For our study we rely on the definition by Ponis and Koronis (2012)[16].

"Supply chain resilience is the ability to proactively plan and design a supply chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a past event robust state of operations, if possible, more favourable than the one prior to the event, thus gaining competitive advantage". This definition was chosen due to the inclusion of design and structure of a supply chain which is the link to our research focus.

---

[14] Datta, P.P., Christopher, M. and Allen P. (2007), "Agent-based modelling of complex production/distribution systems to improve resilience", *International Journal of Logistics Research and Applications,* Vol. 10, No. 3, pp. 187-203

[15] Datta, P.P., Christopher, M. and Allen P. (2007), "Agent-based modelling of complex production/distribution systems to improve resilience", *International Journal of Logistics Research and Applications,* Vol. 10, No. 3, pp. 187-203; Ponomarov, S.Y. and Holcomb, M.C. (2009), "Understanding the concept of supply chain resilience", *International Journal of Logistics Management*, Vol. 20, No. 1, pp. 124–143; Ponis, S.T. and Koronis, E. (2012), "Supply chain resilience: definition of concept and its formative elements", *The Journal of Applied Business Research,* Vol. 28, No. 5, pp. 921–930; Pettit, T.J., Croxton, K.L and Fiksel J. (2013), "Ensuring supply chain resilience: development and implementation of an assessment tool", *Journal of Business Logistics*, Vol. 34, No. 1, pp. 46-76.

[16] Ponis, S.T. and Koronis, E. (2012), "Supply chain resilience: definition of concept and its formative elements", *The Journal of Applied Business Research,* Vol. 28, No. 5, pp. 921–930

Supply chains become more and more complex. On the other side decision makers intend to identify critical situations (mentioned above) in a very quick and reliable way in order to detect disturbances, threats and bottlenecks. The authors present a new holistic approach for a resilient supply chain environment which is based on the following items:

- A model of the supply chain (= view of a focal company)
- A modern management cockpit
- Education and Training Perspective

In a first step, we describe the model of our supply chain network and the underlying network topology.

An Innovative Model of the Supply Chain

Adaptability, Agility and Alignment

Although, literature regarding adaptive supply networks (ASN) may slightly differ, three key characteristics can be recognized. These are: Adaptability, Agility, and Joint Alignment. These keywords are adapted from Lee (2004)[17], as they best describe the requirements for an ASN. However, note that these characteristics require a network structure of the supply chain.

Therefore, we model the supply chain as a multi-layered network. Each layer stands for a certain critical infrastructure view. Based on this basic and generally applicable multi-layered network of critical infrastructure the supply chain layer (= from the perspective of a focal company) is developed consisting of nodes (= companies in involved in the value creation process) and edges (= the transport relations between companies). The relationship between the components are described by mathematical equations and a special network topology. The components are interlinked.

In our opinion graph mining is a very important field in that context. We might differ to aspects:

- mining in a set of graphs and
- mining in a single graph.

For the former one many problems have been examined in the past. During graph mining we might suggest a combination of the analytics of graph structures as well as node attributes. In the show room hybrid approaches might be analysed to identify the evolvement of an certain event in a graph, for example in the context of disaster relief.

In comparison to Guan and Yuan (2014)[18], where in their work they first studied the problem of measuring how strongly such an event that took place in a graph is correlated to the graph structure, i.e. Self Structural Correlation (SSC) a novel measure was introduced to assess SSC. It can be used to derive statistical

[17] Lee, H.L. (2004) "The Triple-A Supply Chain", Harvard Business Review, 82(10), pp. 102-12.
[18] Guan, D.; Yuan, W.; Lee, Y.K., Najeebullah, K., Rasel, M.K. (2014) A review of ensemble learning based feature selection IETE Tech. Rev. 31(3), 190-198.

significance to test if an event is randomly distributed over a graph or not. Our aim is to estimate on their basis very quickly the development in large-scale graphs. Their proposed method is scalable and in their article successfully applied to the co-author DBLP network and a social network extracted from TaoBao.com, the largest online shopping network in China, with many exciting discoveries.

We extend their approach to specific supply chain networks. This process will be embedded in an interactive certain show room "Graph Mining". In order to simulate the complex behaviour, we propose an innovative management cockpit framework which will be the basis of a suitable "business decision room " (as illustrated in Figure 3.1.)

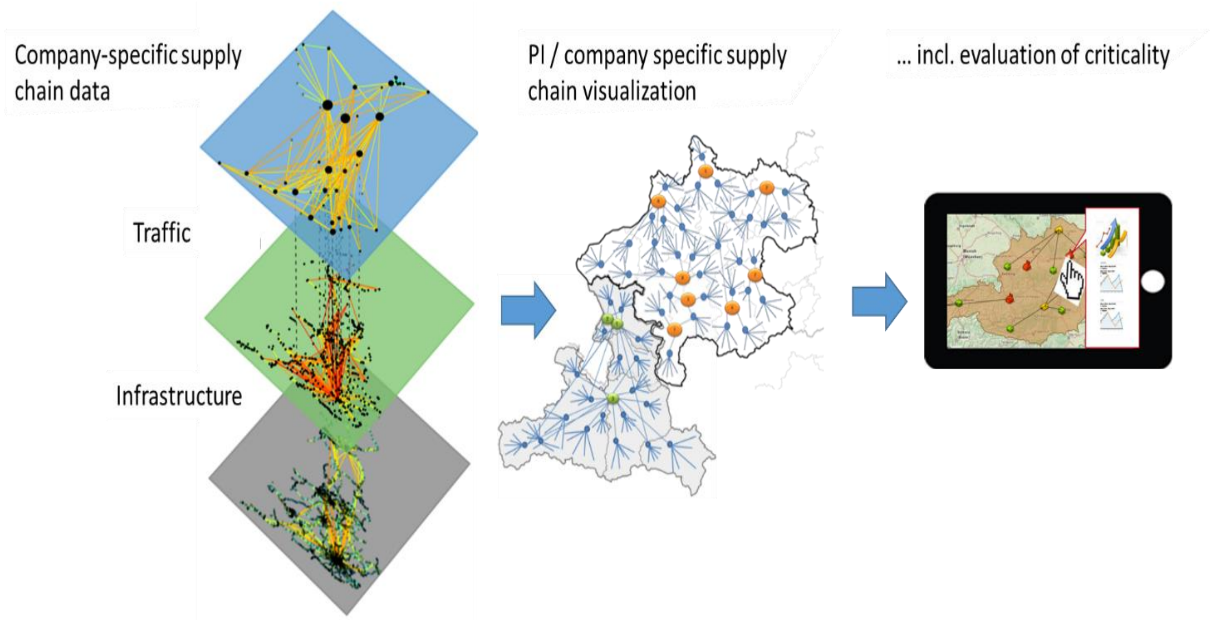


Figure 3.1. Business Decision Room - Framework

The special multi-level approach allows the company-specific illustration of Supply Chains including identification of critical nodes (=companies, transhipment points) and edges (=transport relations). Based on the dynamic identification of criticality in the supply chain, the user has the possibility to consistently derive alternative actions to improve the sustainability and resilience (see also figure Business Decision Room - Framework). The basis of the multi-level network is the mapping of the relevant infrastructure (e.g. demographic indicators, energy networks). Based on that, the transport infrastructure of the analysis area is added as a further level. All levels are in active relationships with each other, which are methodically formulated and integrated into the overall system. Furthermore, after the successful test of the visualization tool any additional levels (e.g., healthcare, emergency systems) may be introduced. Based on this basic network modelling, PI / company-specific supply chain information is applied (e.g., geo-locations of own sites, suppliers and customers as well as actual transport relations).

The resulting transparency across multi-level networks allows the continuous identification and evaluation of critical nodes and edges in the supply chain.

System of Systems

This lead project combines isolated research approaches (Smart Grid, Geo-Modelling, System Dynamics approaches to evaluate interdependencies) to a system of systems, enabling integrated analysis of cause-and-effect relationships. Consistent proactive analysis allows companies to extensively monitor and improve critical nodes and edges in their specific system. This makes their multi-level network more targeted, sustainable and resilient.

Management Cockpit

As the multi-layered perspective is high-dimensional we intend to identify the key parameters of the processes. What are the critical nodes and edges in the supply chain, what are the critical internal and external process? How can we monitor and manage this process, which are the critical control parameters and which parameters guarantee a certain stable behaviour?

Central idea is how executives might "pilot" their business.

Markus Gerschberger

The management cockpit as central element of this business decision room focusses on the

i) the identification of critical events,
ii) the assessment of these events including the development of mitigation strategies and
iii) development of strategic management solutions.

Visual Analytics Tool

In a first step the management cockpit gives an overview on the parameter and steering opportunities. In a second step, we intend to identify criteria. As an innovative approach, we present a special visual analytics tool. In order to improve the visibility, we filter the information. Our approach tries to reduce the complexity, afterwards we integrate additional information. The visual analytics technique simulates the capacity, the different flows and estimate certain graph measures. Key aspect is the improvement of the efficiency. We describe a procedure how we can detect critical zones.

REHSTRAIN, RIKOV - LIVE and ARTEFAL

New methods like predictive analytics, network analysis, system dynamics and artificial intelligence are presented to master such complex networks via modern command & control systems. It presents actual decision support approaches - in the area of modern transportation systems, energy networks and aviation management - via innovative sensor networks, network control and reach back architectures to support an adaptive information and smart management system. Actual heuristics and first computational results for special multi-layered decision problems will be presented. We refer to the projects RIKOV, REHSTRAIN, MILAN, LIVE and ARTEVAL. The control enables the operator to get insight in the process structure, failures of the system and potentialities.

Education and Training using Gamification "Resilience Game"

We design a so-called resilience game to stabilize the behaviour of the supply chain. Actors try to describe certain areas whereas other decision makers try to react, to recover weak zones and to stabilize the process. The players act and interact with their environment.

Urban Analytics is the Key for the Development of Megacities.

Stefan Pickl

We identify equilibria and trajectories via the following techniques

- Predictive Analytics (SAP)
- Fourier Transformation on Graphs
- Dual Treatment

First computational results will be presented at the summit in March 2018.

Chapter 4.

DISRUPTION AND RISK MANAGEMENT OF HEALTHCARE SUPPLY CHAIN TOOLKIT: A CASE STUDY[19]

Contributed by Prof. Mark Goh, Director (Industry Research), The Logistics Institute – Asia Pacific, National University of Singapore

For this study, the focal company is an end-to-end supply chain ecosystem company involved in the procurement of goods from suppliers, managing warehousing facilities, and providing last mile delivery to corporate customers. There is a need for the company to understand the attendant risks of the suppliers and have a sense of the appropriate mitigation strategies to deploy. The accuracy of the risk index is important for the focal company to select the right partners and manage the underlying risks. The calculation of the risk index is based on the quantitative assessment of the risk impact of each supplier to the focal company.

This required assessing and evaluating their supply chain for the effects of various possible disruptions. This was made possible through the development of a simulator of the supply chain. This arms the company with a test bed to assess the effects of any possible scenario. Further to help in easy understanding of the context the risk faced by various entities was quantified in form of a risk index. This was then used to evaluate various suppliers and calculate the real-time risk index. Through a user-friendly interface and Geographic Information System (GIS), the focal company can now update the respective input risk parameters and observe the changes in the risk index. Through this, appropriate mitigation strategies can be offered.

Problem statement

The current case study is divided into two parts:

1. Part 1: Supplier risk index for strategic decision making
2. Part 2: Supply chain risk management platform for visualisation

Part 1 - Risk index for strategic decision making

Part 1 aims to identify a potential supply chain risk index based on the data provided by the focal company and her clients. The company wanted to build a virtual simulator, assess the supplier's risk profile, and identify the potential disruption for each supplier. With this profiling, mitigation strategies for the identified disruptions were developed and the outcome was validated through simulation.

[19] The work is supported by A*STAR under Integrated Supply Chain and Logistics project (grant number 152 42 00055)

Part 2 - Supply chain risk management platform

Part 2 aims to develop a GIS platform to identify the real-time risk indices for each supplier using real-time information feeds and develop a user-friendly interface through which they can update the input data in the simulation model, to continuously update the basis of solutions.

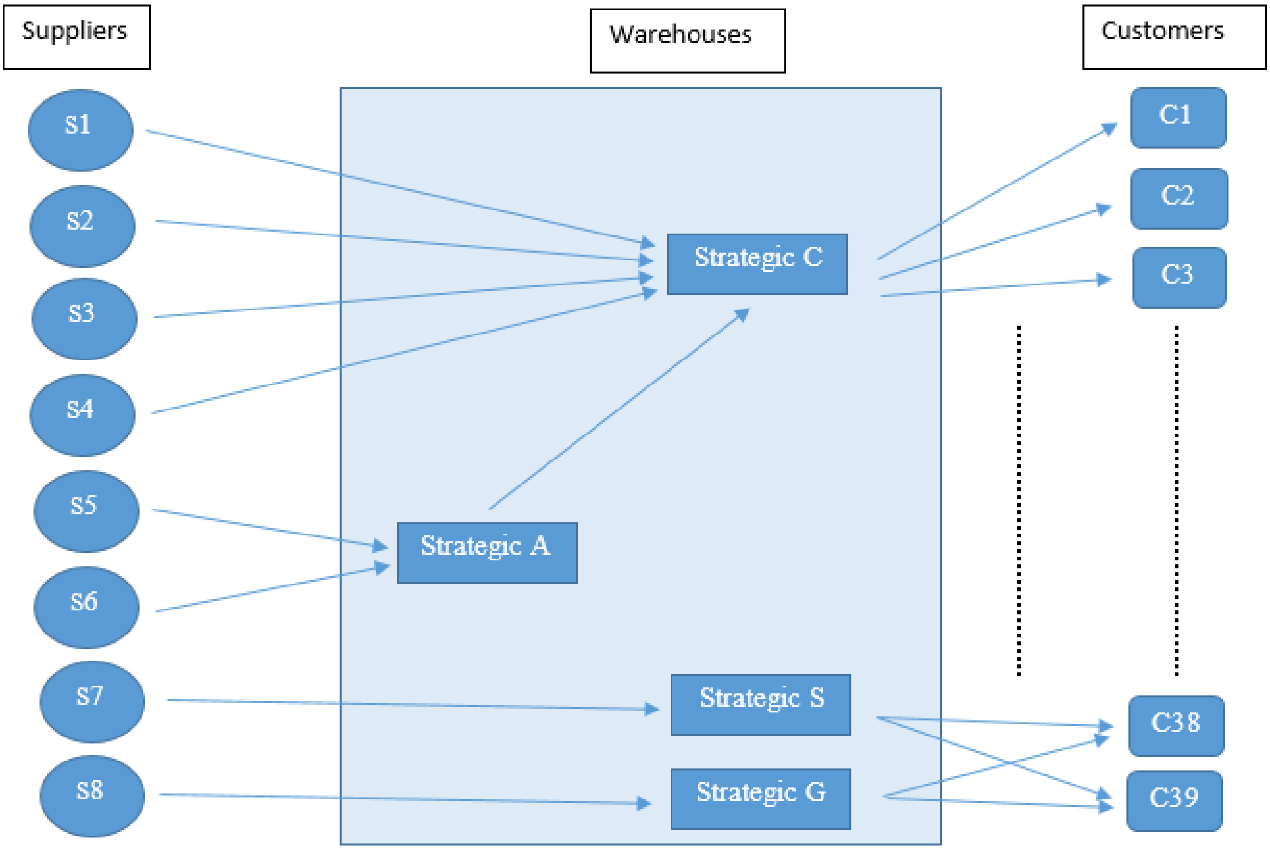


Figure 4.1. Structure of healthcare supply chain of focal firm

Techniques used

The following research methods were applied:

1. **<u>Value at Risk (VaR)</u>:** VaR is the most common risk measure used in finance. This has been adapted here to the supply chain context. The concept is illustrated in Figure 4.2.

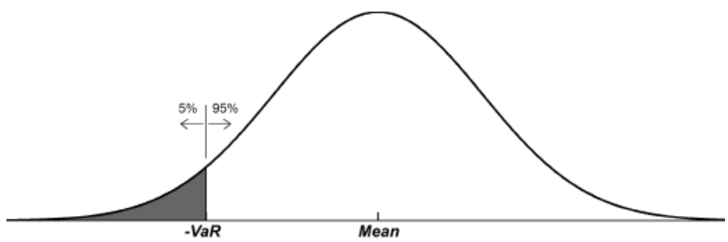


Figure 4.2. Value at risk (VaR 5)

2. **Agent based simulation:** An agent based simulation model was built for this. Agent based modelling was chosen because of its scalability and so that the platform does not become obsolete when changes are made to the supply chain.

3. **Web crawler:** A web crawler platform was built to capture and update the disruption risk data. This platform monitors the latest update from an open source disruption data site and all data relevant to any of the supplier locations would then be added to the simulator database. The programming language Python was used to build this crawler.

4. **Demand analysis:** Visual Basic for Applications (VBA) is used to write the in Microsoft Excel macros, used to process the input demand data into the simulation model.

5. **User Interface (UI):** All three platforms are then connected through an integrated UI built on AnyLogic. The Java language is used for this work.

In the simulation model, the other methods used are: shortest path selection by the built-in GIS of AnyLogic, order consolidation for full truckload delivery, uniform distributions for demand data, control interface to change the parameter values on the fly and see their effects.

Results

The simulation is run for 300 times and each time the potential loss value is calculated. These values are pooled together and then a Normal distribution is fitted. Each supplier has 300 numbers representing the revenue loss caused by their respective risk factors. From these 300 samples of possible revenue loss, we can generate the loss distribution function for each product and thus find the VaR. Figure 4.3 is an example of the loss distribution function of P1 for one year and it's VaR at the 95% confidence interval.

Figure 4.3 shows the distribution of losses due to disruption for 300 simulated runs for Product P1. On average, the loss is expected to be $168,677. The green area shows the lowest 5% of losses with a VaR of $93,937 and the corresponding CVaR[20] is $73,258. Figure 4.4 provides the visual dashboard for operational efficiency, and Figure 4.5 shows the dashboard for the aggregated values of the warehouses.

[20] Conditional value at risk (CVaR) is a risk assessment technique often used to reduce the probability that a portfolio will incur large losses. This is performed by assessing the likelihood (at a specified confidence level) that a specific loss will exceed the value at risk. The smaller the value of the CVaR, the better.

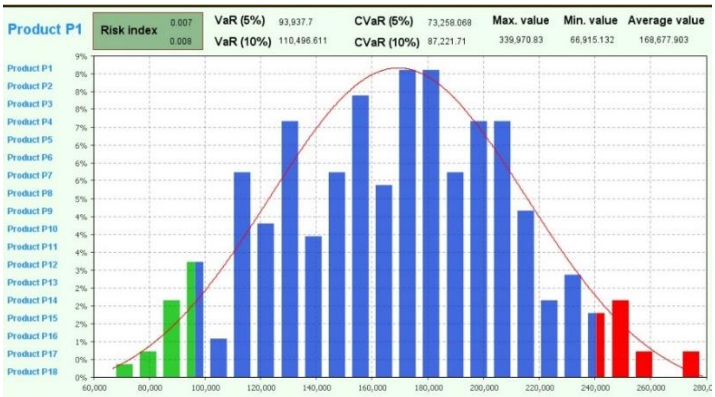


Figure 4.3. Dashboard window showing risk index values

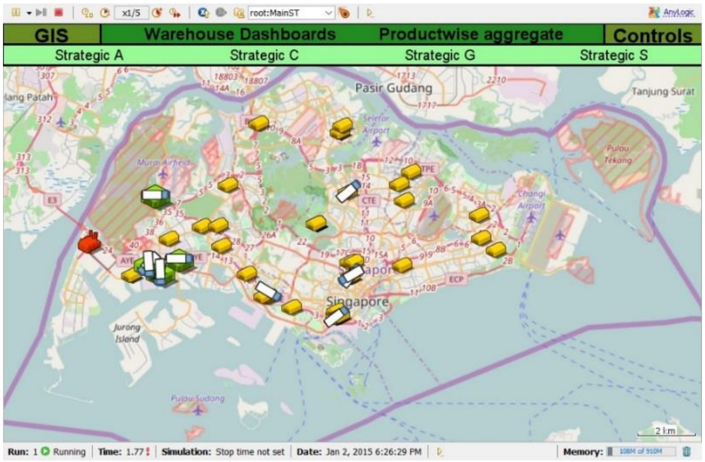


Figure 4.4. Dashboard showing GIS map of deliveries

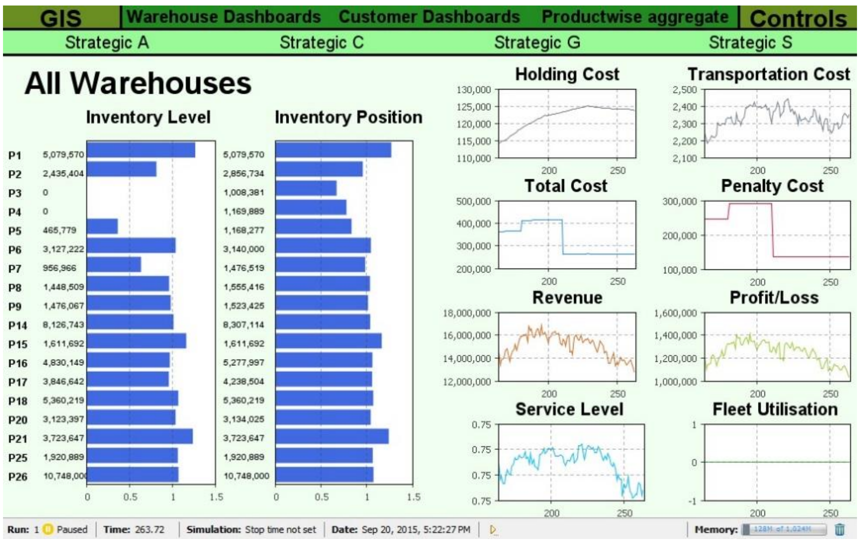


Figure 4.5. Dashboard window showing aggregated values for all warehouses

Table 4.1. Average profit for a year

Product no.	Avg. Profit
1	1000719.1839992598
2	388293.23200399725
3	1043314.3830773791
4	1204188.2192429437
5	752926.1141913177
6	-147490.39406126743
7	435673.5294320771
8	168568.38371838874
9	48995.45016805381
10	208117.56615667167
11	748350.7044939497
12	101897.16124577737
13	89256.43666205244
14	10459.506347246537
15	49827.40285346052
16	6600055.094216719
17	517782.3002070122
18	968944.8714904856

These values are used as the base values from which the profit of the disrupted supply chain is deducted. By populating these values and fitting a Normal distribution curve, the VaR for the revenue loss can be found. The VaR results are listed in column four of Tables 4.2 and 4.3. Table 4.2 shows that the VaR at the 95% confidence interval while Table 4.3 shows the VaR results at the 90% confidence interval. Subsequently, we can obtain risk index (RI) of each supplier through the following equation.

$$RI_i = (VaR_i)/Total\ profit\ for\ the\ company$$

Though we can choose a different base to calculate risk index values, the total profit is chosen as this gives a clearer picture on the portion of the total profit at risk from a disruption of a particular product supply. The results of the risk index for all suppliers are listed in the last columns of Tables 4.2 and 4.3, respectively.

Table 4.2. Supplier risk indices based on VaR values at 95% confidence interval

Supplier	Min loss	Max loss	VaR at 95%	Risk Index
S1	153.57	168,083.031	8550.04305	0.0006
S2	30,049.099	569,981.53	57045.72055	0.004002
S3	66.385	28,575.982	1491.865	0.000105
S4	258.376	50,761.34	2783.1482	0.000195
S5	106.225	9,095.838	555.49	3.9E-05
S6	118.715	5,578.1	391.684	2.75E-05
S7	26,894.859	476,412.896	49369.90185	0.003463
S8	58,502.469	145,667.564	62860.2782	0.004409

Table 4.3. Supplier risk indices based on VaR values at 90% confidence interval

Supplier	Min loss	Max loss	VaR at 90%	Risk Index
S1	153.57	168,083.031	22670.477	0.00159
S2	30,049.099	569,981.53	72891.145	0.005113
S3	66.385	28,575.982	3848.795	0.00027
S4	258.376	50,761.34	6817.9001	0.000478
S5	106.225	9,095.838	1229.828	8.63E-05
S6	118.715	5,578.1	738.9474	5.18E-05
S7	26,894.859	476,412.896	87578.934	0.006143
S8	58,502.469	145,667.564	70269.35114	0.004929

These values show that suppliers S7, S2 and S8 are the critical suppliers to manage from the risk disruption point of view.


SIMULATION AND
COMPUTATIONAL
MODELLING

Chapter 5.

Supply Chain Optimization and Simulation – Technology Overview

Contributed by Timofey Popkov, Director of Business Development, The AnyLogic Company, anyLogistix.com

Introduction

Analytical optimization and dynamic simulation are the two most commonly adopted technologies for solving complex supply chain problems. However, there has been a lot of confusion around the terms "**optimization**" and "**simulation**" in the industry – they are often misinterpreted, used in the wrong context, and given different meanings. Many companies question the differences between these techniques, which one is better or more efficient, and what problem does each one solve? This chapter tries to resolve the confusion and explain when best to apply each method. It will also show why analytical optimization tools already employed by many supply chain strategists should be accompanied by dynamic simulation, and how managers can improve lean and agile supply chain management with this addition.

Supply Chain Challenges by Level of Detail

Managing the supply chain means continuously searching for improvements and meeting new challenges. The solutions can involve different areas of expertise and be from operational, tactical, or strategic management levels. They may also depend on the type of company you are engaged with – distributor, retailer, manufacturer, or a 3PL/4PL operator. Challenges linked to supply chain design, inventory and transportation policies, production planning, and risk management can be grouped into three sections and represented on a pyramid-shaped diagram, Figure 5.1.

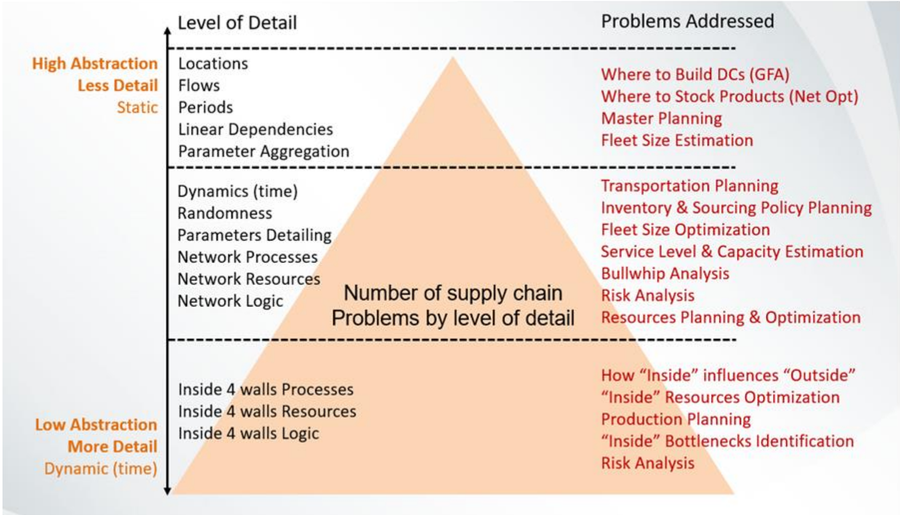


Figure 5.1. Challenges addressed by supply chain models and the level of detail.

Analytical Optimization

Analytical optimization is probably the most common technique for improving supply chains. Most analytical optimization tools allow companies to develop a model to visually describe a supply chain as a graph and parametrize it with a set of criteria. The constraints need to be described clearly and the model populated with data. These tools then try to find the optimal – or suboptimal – solution(s) to a specific supply chain problem. During this stage, the model is converted into a set of linear equations, constituting a linear and mixed integer programming (LP and MIP) problem. These equations are then solved using optimization engines, of which there are many. The results appear in the user interface of the supply chain tool as set of tables with material flows and financial information. Problems that can be solved using analytical optimization includes:

- Supply chain design:
    - Where to locate the facilities?
    - What their throughput should be?
    - How to arrange product flows?

- Master planning by period:
    - Where to produce or stock goods?
    - How much to produce and order?
    - How to provide for seasonal peaks in demand?

- Transportation:
    - What size of the fleet is required?

Limits to Optimization

In order to map a supply chain to a set of equations using analytical optimization tools, companies must simplify the real-world system and employ certain generalizations and assumptions, including (but not limited to):

- All the relations in such a model have to be represented as linear dependencies or step functions – a significant simplification of the world's unevenness.

- Products, orders, and deliveries are modeled as a set of flows between facilities and costs associated with flows, abstracting from unique shipments or product units.

- Time is represented with periods, e.g. week, month, year. Disruptive or random change can only occur at the beginning or the end of a period, and not inside it. Any event may happen only once within a period (e.g. closing a facility). Also, analytical models assume that all parameters are uniformly distributed within a period.

- Analytical models cannot represent actual supply chain behavior, such as process logic, resource availability, randomness, and time-related dynamics.

- Details need to be sacrificed when describing and optimizing a supply chain using an analytical model. As a result, analytical optimization should not be used for issues that need to consider detailed logic and time. The optimizers also work as a black box, denying users insight into the outputs.

Analytical models are ideal for solving supply chain challenges at the network level, when account operational logic, randomness, and dynamics are not considered. If the problem requires considering any of these, analytical optimization can still be used to get a first approximation of a solution, then dynamic simulation modeling used to produce detailed in-depth analysis.

Dynamic Simulation

Dynamic simulation has been less commonly used in the supply chain area until recently, but, with the evolution of modern simulation tools, more companies are starting to empower themselves with its diverse capabilities.

A dynamic simulation model is the description of a system and the rules by which it operates – business process logic, and the interdependencies between system components. Simulation models are dynamic because they are **executable** – they can be run to examine behavior over time. In fact, a dynamic simulation model is a digital twin of a supply chain that allows for experimentation with improvement ideas and to track metrics. The logic behind your supply chain can be defined using a simulation engine. For example: if on-hand inventory is less than 50 units, then the warehouse orders 300 units. The most advanced simulation platforms have pre-built logic that can be flexibly customized to represent the uniqueness of the supply chain. Benefits of using dynamic simulation are summarized in Figure 5.2.

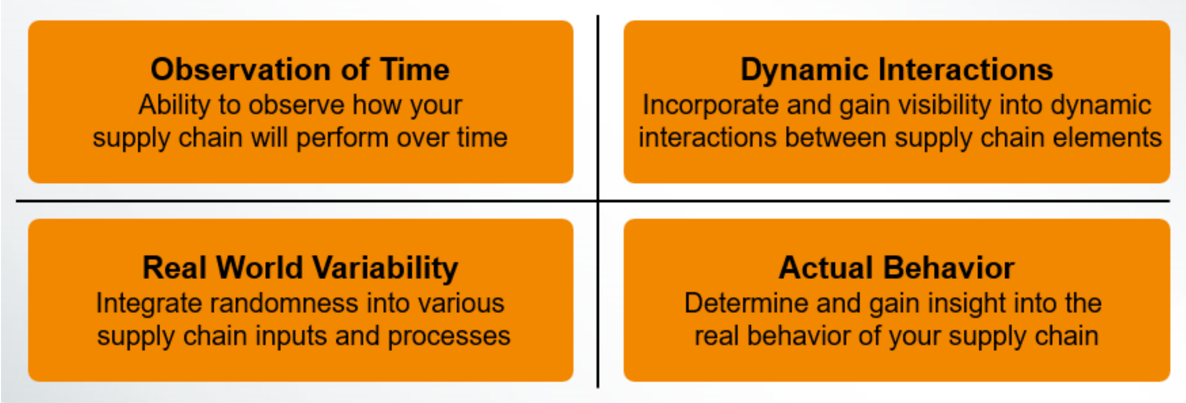


Figure 5.2. Benefits of using dynamic simulation

Dynamic simulation is especially useful when the operational logic and processes inside the supply chain significantly influence financial efficiency and, as a consequence, need to be accounted for during supply chain design stage. Some of the challenges that can be addressed using dynamic simulation:

- Implementing a new supply chain design.
  - How to introduce a solution suggested by network optimization?
  - What if the solution suggested by optimization cannot be implemented in the real world?

- Understanding supply chain operations.
  - To efficiently manage your network, you need to understand how it operates over time and in detail, down to the level of every resource and policy.
  - Estimate safety stock at each facility for each product.

- Experimenting with supply chain innovations.
  - With a high-level network design in place, you may want to know how to improve operational performance.
  - Ideas can be tested prior to implementation.

- Risk assessment.
  - What are the risks related to this supply chain structure?

- "Inside the four walls" business process assessment.
  - How do the internal processes in your DCs or factories influence operations across the whole supply chain?

Limits of dynamic simulation

Several limitations of dynamic simulation are as follows.

1) When using dynamic simulation, a lot of time and effort must be invested in data preparation and the creation of the model itself. Building a model from scratch may be a laborious task. Although, today there are flexible tools that allow analysts to quickly build simulations using out-of-the-box

functionality, without losing the capabilities required for complex challenges and in-depth model customization.

2) The level of abstraction must be carefully considered. Unnecessary details may increase processing time.

3) Dynamic simulation does not calculate the optimum solution, it can only test different what-if scenarios to see which one is better. Simulation-based optimization exists, but it is fundamentally different from analytical, or mathematical, optimization. In the case of simulation, the optimization engine is a separate program working in conjunction with the simulation model. The optimizer measures the model output and generates a new set of input parameters based on this data, trying to better achieve the optimization goals. As a result, a simulation model has to be run many times to achieve an optimal result, and this can take a lot of time – for really data-intensive models on a desktop computer this can be days. However, these problems are now being solved, with an emergence of cloud technologies, and simulation model execution is now moving to the cloud.

Dynamic simulation does not produce an optimal solution from multiple combinations, but allows a comprehensive study, particularly of dynamic scenarios and supply chain interdependencies. Dynamic simulation should be used when the supply chain is heavily affected by uncertainties, influenced by a sites' internal logic and processes, and requires many details to be considered.

Differences between analytical optimization and dynamic simulation are summarized in Table 5.1.

Table 5.1. Summary of differences between analytical optimization and dynamic simulation

Consideration Factors	Analytics Optimization	Dynamic Simulation
Description of the model	Flows (goods or information) between facilities	The logic (a set of rules) of any process in the supply chain
Time dimension	Time as a set of periods (e.g., weeks or months); all the parameters (e.g., shipments) are uniformly distributed within a period	Used only as a unit of measure allowing a dynamic and natural representation of reality.
Risk and Uncertainty	Does not consider randomness. Every parameter (excluding input parameters) is predefined and averaged, including naturally varying things like lead times or demand.	Able to vary internal model parameters, such as production time for each unit.
Model Transparency	Considered as a "black box" The processes of producing the results are not transparent	The model can have interactive animation to show the dynamics of what is happening in the supply chain when the model is running
Measurement Metrics	Typically built around a single supply chain KPI – such as costs and profit	Various metrics can be measured simultaneously.

Why should Optimization and Simulation be used together?

Based on the supply chain challenges diagram (in Figure 5.1), analytical methods cover a number of challenges/problems with a higher level of detail, while dynamic simulation covers more detail and solve more issues. The more details considered, the more opportunities there are for improvement. The more efficient a supply chain analyst wants to become, the more the need for dynamic simulation. It is a crucial tool for making supply chains both lean and agile.

All that doesn't actually mean that dynamic simulation is *better*. It's just targeted at different kinds of challenges/problems: it cannot handle challenges suitable for analytical methods well, and vice versa. Analytical methods handle large-scale problems while dynamic simulation addresses more detail and the dynamics allow for deeper supply chain analysis.

To become efficient, the best option is to use these techniques together.

Professional opinion advises optimization and simulation be utilized together, to complement each other and maximize results[21]:

- Find the solution with optimization, and then check its quality and validity by simulating the resulting scenario.

- Simulate the supply chain to better understand the dynamics of the business system, then create a more tailored optimization model based on these insights.

Combining these two methods is critical for building a proficient supply chain analytics toolset, and more companies are acquiring this technique every day.

[21] Tohamy, N., Combine Simulation and Optimization for More Effective Supply Chain Modeling, Gartner Report, 9 July 2014. Available at https://www.gartner.com/doc/2793018/combine-simulation-optimization-effective-supply

Chapter 6.

LEVERAGING THE DIGITAL ECONOMY – A GOVERNMENT LOGISTICS PERSPECTIVE[22]

Contributed by Max Ma, ST Logistics Pte Ltd

Current Landscape

Digital economy transformation in the commercial logistics industry is growing very fast. Much of the traditional value chains are disrupted by the unprecedented technological advances. The Singapore government is positioning the country as a global logistics hub. The government has set aside $4.5 billion Industry Transformation Programme under the Logistics Industry Transformation Map (ITM)[23]. Under the ITM, the government will work closely with key firms in implementing technologies that "push the frontier of productive operations in Singapore". Singapore's global logistics performance index was ranked 1st in Asia[24]. Leading manufacturers like Henkel and Infineon base their Supply Chain Control Towers[25] and Distribution Centres in Singapore to orchestrate their regional and global supply chains. For the logistics sector serving the Singapore government, it is catching up in digital transformation too.

For government logistics, the shift in focus is to Business-to-Government (B2G) where it relates to trade in products and service between businesses and government. A different way of organizing the supply chain and distribution network is needed to fulfil the B2G logistics demands. This case study focuses to navigate infrastructure and logistics assets to fulfil government logistics demands by answering the following business questions:

1. What challenges do we face in government logistics vis-a-vis commercial logistics?
2. How does digitisation help to navigate in such an environment to track the entire end to end supply chain for government logistics better?

[22] This chapter is based on the joint work between The Logistics Institute – Asia Pacific (TLI-AP) and ST Logistics Pte Ltd under the A*STAR Integrated Supply Chain and Logistics project (grant number 152 42 00055).

[23] The Straits Times, Road map to boost Singapore's role as global logistics hub, 17 Nov 2016, available at http://www.straitstimes.com/business/companies-markets/road-map-to-boost-singapores-role-as-global-logistics-hub

[24] The World Bank's 2016 International LPI Global Ranking.

[25] EDB Singapore, Logistics and Supply Chain Management, 2018, available at https://www.edb.gov.sg/en/our-industries/logistics-and-supply-chain-management.html

Challenges

As the nation embarks on the smart nation initiative, the logistics sector serving the government should drive out business impediments both in regulations and costs to fully benefit from the digital transformation wave. Several challenges are described below. Firstly, unlike commercial logistics, selling into the local government is a different proposition. Firms bidding into government logistics works are preferred to be based locally as it is seen as less risky. Often, logistics is seen as a critical function to support government operations and strategic partnership is formed between the Logistics Service Provider (LSP) and the government. The service required is usually on-site and time critical. Hence offshore outsourcing efforts are generally discouraged. Second, government institutions has to exercise prudence in spending for outsourced activities. One such example would be the cut in ministries' spending to stay 'prudent' during Budget 2017[26]. Logistics company have to deal with issues such as cuts in public spending due to government budget changes which translates to more emphasis on cost competitiveness rather than value.

Third, the preference for logistics service that aligns to Singapore's smart nation initiative. The smart nation initiative was launched as an enabler to facilitate innovation by the public and the private sector[27]. Under the initiative, there has been constant push by the government for smart solutions where digital technology can be operationalised for daily work.

Lastly, the nature of government logistics service covers government to government (G2G) as well. G2G is the relationship between organizations (subjects) of public administration. One such example is in the area of humanitarian logistics that specializes in warehousing and delivery during natural disasters or national emergencies, as well as the operational deployment of critical supply chain and logistics management in-theatre. As Singapore is geographically shielded from natural disasters, humanitarian logistics revolves around supporting regional Humanitarian Aid and Disaster Relief (HADR) efforts and as well as local critical nation-wide emergencies.

Digitization of B2G Supply Chain and Logistics

The proliferation of the digital economy enables interconnectedness between consumers, systems and providers. There is a seamless flow of information on transactions that facilitates agile and adaptive supply chain. Although the nature of government logistics might differ from commercial logistics, the supply chain operations under the government business could benefit from it.

Government logistics requires speed, agility, visibility and 'zero' lead time activation. To achieve such outcome, there is a critical need for visibility in the supply chain. Visibility is defined by the awareness of, and control over, specific information related to product demand forecast, orders and product supply and inventory plus physical shipments, including transport and other logistics activities, and the status of events

---

[26] The Straits Times, Budget 2017: Singapore cuts ministries' spending to stay 'prudent, effective', 20 Feb 2017, available at https://www.channelnewsasia.com/news/budget2017/news/budget-2017-singapore-cuts-ministries--spending-to-stay--prudent-7595228

[27] Smart Nation Singapore, About Smart Nation, 9 Nov 2017, available at https://www.smartnation.sg/about-smart-nation/enablers

and milestones that occur prior to, and in transit[28]. Visibility can be made possible with digitisation which can eventually progress to a one stop information hub which is commonly termed as a supply chain control tower.

The supply chain network that is set up in today's context is often siloes and customer-centric. This is especially so for government institutions where vendors in the supply chain are segmented so that the entire end to end supply chain is not controlled by a single supplier for strategic reasons. This has resulted in a fragmented way of coordinating supply chain operations, and as network gets more complex, it exacerbates the gaps between each node in the supply chain. An ecosystem driven by the digital economy is able to offer a digital supply network. Every node within the supply chain when supported by key technologies is able to provide an aggregated view of information supporting an end to end supply chain coordination. This is largely possible when every step is digitised and made "visible" remotely.

Digitisation is not without challenges. Stovepipe processes, legacy systems and manual paperwork remains the backbone driving supply chain operations in the government sector. However, the government in the recent years has advanced rapidly to make available open data such as real time traffic conditions, carpark availability to third party developers to incorporate into their logistics solutions. Also, the government has started smart initiatives such as contactless payment for public transport and spaces to test bed autonomous technology. Considering the challenges of government logistics and the opportunities of digital economy, we will use a home grown national logistics company as a case study on how it benefitted from digital economy to make operations more efficient.

Conclusion: Support of Government Logistics Made Better by Digitized Supply Chain Control Tower

Digitisation helps in improving the end to end supply chain visibility. Visibility, in itself being the most important factor to handle many ills effecting supply chains, helps to solve many problems. As discussed, few areas where it has direct impact as experienced by the company in our case study, are risk management, humanitarian supply chain etc. Also with the unique challenges brought about by the government logistics, digitisation helps us to break the decentralized way of operating of government supply chains. The digital supply chain has the potential to break these impediments and increase the efficiencies.

The case study such as SiTadeL (in Box 1) is a coordination mechanism to provide facilitative functions for assisting the understanding of risk propagation and coordination of network-based risk management in a sustainable way across networks. Facilitative function of the control tower can aid disrupted logistics in these area: (1) Provide full visibility of the affected region for route planning purposes; (2) Anticipates risk and provide alternatives for the agencies involved; (3) Caters for innovative supply chain solutions

[28] Heaney, B., Supply Chain Visibility and Segmentation: Control Tower Approach, Aberdeen Group Report, 2014

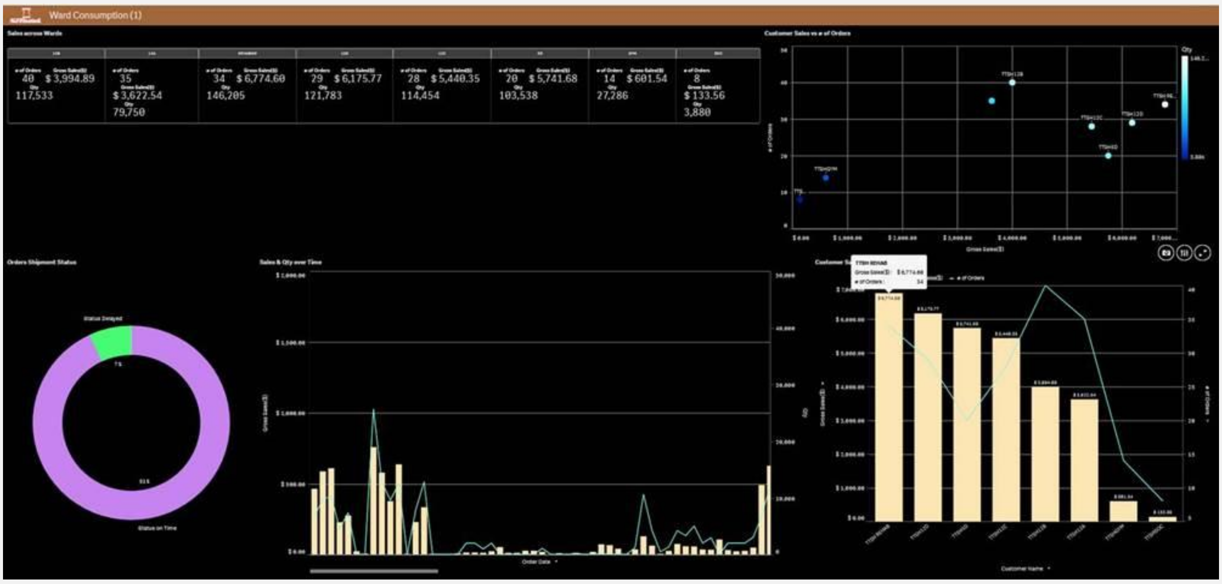
Box 1: A National Logistics Company with a Supply Chain Control Tower

Close Monitoring of Supply Chain Made Possible by Supply Chain Control Tower

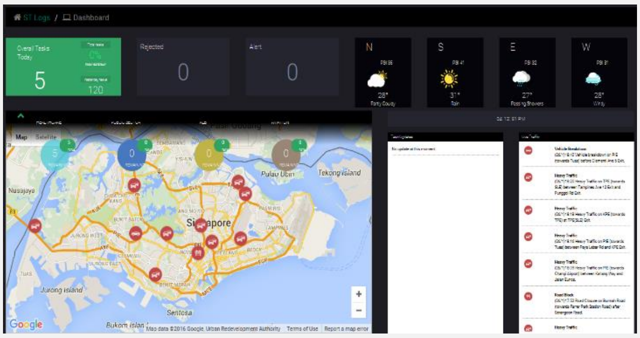
By embracing IT connectivity, big-data analytics, mobile computing and intelligent design in business systems, ST Logistics (STL) is geared towards the potential increase that Smart Technology has to offer in workforce productivity. STL has developed a Supply Chain Control Tower (SiTadeL)- a broad spectrum IT platform that would function as a decision support system for achieving strategic, tactical and operational visibility of the business. SiTadeL provides visibility to the upstream of the supply chain where it begins with the supplie/manufacturer. SiTadeL as an information hub, is able to capture and use the necessary data for decision making, provide resilience to supply chain disruptions and allow operations to be excuted in a single operational hub. In daily operations, the risk resilience platform monitors 'live' events occurring globally and sends notification to operations personnel on their area of operations/supplier's location. When an event/disaster occurs and affects the supplier, the prescriptive module is activated. Mitigating actions can be meted out in accordance to actions that system suggests, and the event is tracked in a methodical manner until the supply chain disruption is restored. 'Live' monitoring of suppliers is important to STL business where the suppliers are supplying important government agencies with products and equipment necessary for the nation's well-being. With SiTadeL, the risk resilience of STL's supply chain is more robust and STL is able to serve their government customers with better supply chain management.

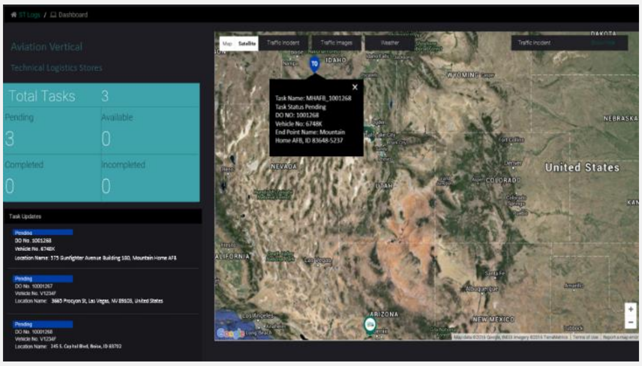
STL manages their supplier's health through risk index. Quantitative approaches suitable where sufficient is data is available. Statistical methods are used to evaluate specific risks where objective input (e.g. historical data) is available. Using statistical moments, risks may be stated in a variety of ways: mean, expected value or standard deviation. In STL case, quantitative risk assessment approach is adopted using an agent based simulation. Simulation program models the supply chain operations of the government business using Agent based methodology. This allows the model to be scalable permitting new additions of entities i.e. customers, warehouses, suppliers and products. A Value-at-Risk (Var) of revenue loss can be calculated and based on the VaR, revenue importance, financial risk and product criticality, a weight risk index is derived to dynamically track supplier's performance.

As the government sector opens up to cashless and paperless transaction, STL capitalize on the opportunity to digitize their operations to serve the government customers as well. In the commercial industry, there has been unprecedented growth in electronic ordering platform such as Qoo10, Lazada..etc to support the eCommerce boom. Similarly, in the government sector, STL supports the eCommerce initiatives by customizing electronic ordering platform for their customers in MINDEF, MHA and MOH. These electronic ordering platform coupled with partnership with last mile delivery platforms supports a seamless order to fulfilment eCommerce ecosystem. This can happen as SiTadeL takes the extension of application to a mobile application that allows any delivery drivers to manage their task and navigate to the delivery location. STL is pushing for all their government customers to adopt the electronic Proof-Of-Delivery (“ePOD”) as an effort to go paperless. In addition, as the ability of SiTadeL spans across from ordering to fulfilment platforms, it enables data mining of valuable data that drives insights such as consumer’s consumption pattern, resource utilization and efficiency of service to value add to STL’s offering. Such data analytics can only be made possible with the government agency’s willingness to join STL in effort to leverage on the digital economy.



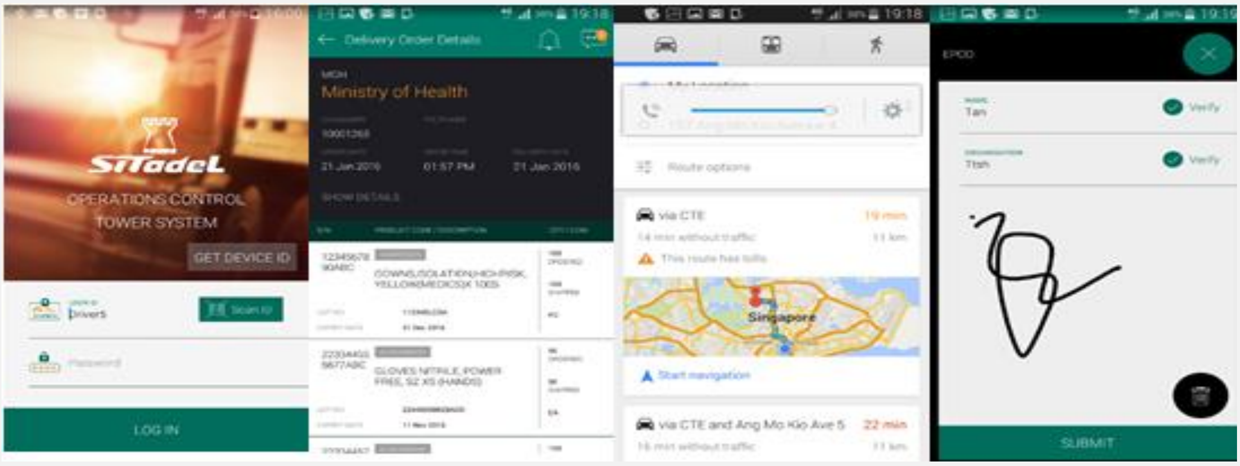
SiTadeL’s Freight solutions track goods from the different ports around the world to Singapore. The web-based tracking platform allows the monitoring statuses of goods, orders and shipments, quickly and real-time. This platform is customer friendly that customers are able to access or enter data for shipment, declarations, orders, security filing, inventory, receipts and accounting information, saving time and reducing data entry work for the operational staff. For last mile delivery during freight shipment, SiTadeL supports vehicle telematics. The geo-fencing capabilities enables alert when vehicle breaches the out of bound regions. ‘Live’ stream images in vehicle cabins and road conditions are also available for secure tracking of valuable goods.





In addition, immobilizers can be installed in every vehicle to disable movement when security is compromised. SiTadeL is STL Supply Chain Control

Tower that is operational in Toll City (owned by Toll). With SiTadeL as an enabler, STL is able to provide the customers with a resilient supply chain and providing an end to end supply chain visibility.



Chapter 7.

Computational Modelling and Robotic Process Automation for Healthcare in Singapore[29]

Contributed by Prof. Mark Goh, Director (Industry Research), The Logistics Institute – Asia Pacific, National University of Singapore

The population of many countries around the world is rapidly ageing (see Figure 7.1). An ageing population would bring challenges to the healthcare systems around the world through the increased share of elderly citizens and chronically ill patients as well as higher demand on the supply side of a hospital to deliver faster, better, cheaper if possible. There is thus a need to strengthen healthcare services for the elderly and the sick, both now and in the future. At the same time, with an ageing population particularly in the workforce, labour productivity has to keep up with rapidly changes in technological developments and maintaining the same level of patient care. Singapore is no exception. Figure 7.2 demonstrates the gap between hospitalization demand and labour force increment.

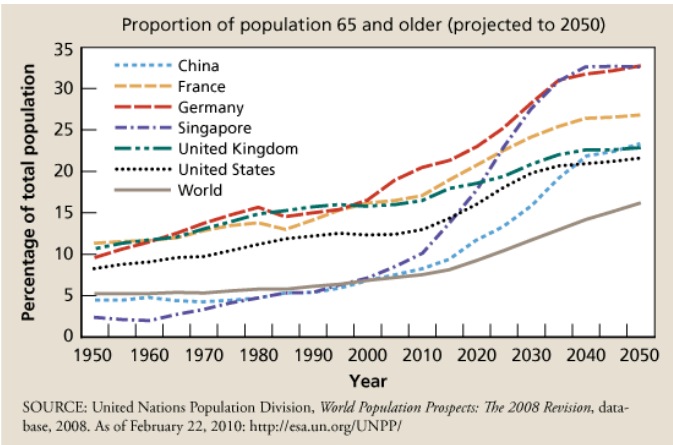


Figure 7.1. Rapidly ageing population in Singapore

[29] TLI-AP gratefully acknowledges the support of A*Star and the NRP in funding this project and for all the assistance rendered.

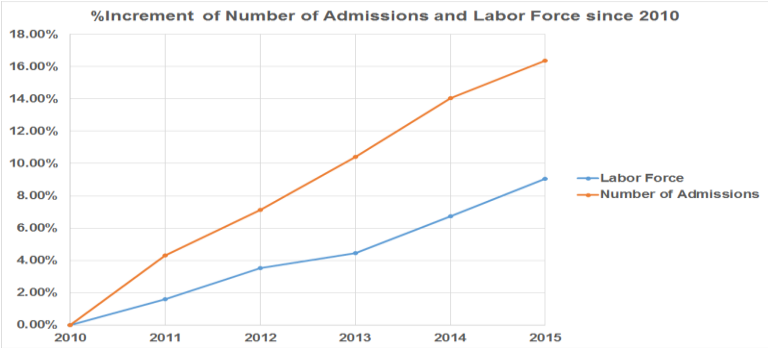


Figure 7.2. Gap between hospitalization demand and labor force increment[30]

As such, there is an imperative for our healthcare system to innovate, work smarter on all levels, leverage on practices used in other sectors, and maintain the same level of productivity. Hospitals in this regard need to consider ways and means to improve operational efficiency and productivity in order to be able to treat more patients without increasing cost, and justify the cost of capital investment. Most of the healthcare institutions in Singapore realise the inevitability of manpower challenges especially at the bottom of workforce pyramid, and have adopted more process based technologies, particularly in robotics and automation. In the hospital of tomorrow, Robotic Process Automation (RPA) will be a part of the Internet of Things (IoT) to assist the new mission. Put simply, ancillary service workers e.g. porters and nurses will in future co-work and collaborate closely with robots (cobots/ umeebots) in a shared workspace to deliver the same level of patient care if not better. Robotic equipment will replace the more labour intensive, repetitive low value added, mundane rule based tasks that needed to be attended to in any hospital such as linen delivery within a hospital, food service to the wards at regular meal times, consumables such as adult diapers, and prescription labelling and dispensing to the patients.

For this to happen, there is a need for a deeper and richer understanding of how human effort can be integrated seamlessly with RPA activities in a hospital setting and to visually show to the operations/ logistics personnel in a healthcare institution the attendant challenges/ bottlenecks. Further, in doing so, the new workflows in particular for hospital logistics need to be re-designed to suit both man and machine to work effectively and nimbly as much as possible. Robots and automated equipment will then take care of the transactional activities in a hospital setting while the existing and new healthcare folks will reap the benefits of working on the less repetitive, more valuable, and higher skilled hospital operation related activities. This frees up scarce resources, improves productivity, reduces unnecessary wait time, and ensures better allocative efficiency. However, before we can arrive at this point, there is a need to understand where the operational challenges lie and how to circumvent them through simple operations analysis techniques such as value streaming, workflow optimization, and bottleneck smoothing. Therefore, building a virtual simulator to show the "guts" (supply chain) and materials flow of a hospital is instructive to guide operational decision making and investment.

The main objective of this simulation/ computational modelling project undertaken by TLI-AP is to enhance the productivity and reduce the bottlenecks of processes related to the different supply chains of several hospitals in Singapore. The primary supply chains considered include Consumables, the Central Sterile

[30] Figure generated from public domain data provided by Government of Singapore.

Services processing (CSSD), Food, Pharmacy, and Linen. This project is a part of the National Robotics Program designed to develop robotics technologies to address national challenges such as an ageing workforce and lagging productivity, and to build capabilities to support organizations in their business model transformations through leveraging on smart technologies.

Problem statement

This study is divided into two phases. In Phase I, an extensive time motion study involving data collection will be undertaken, followed by a value stream mapping of the current set of logistics activities in a typical hospital. Thereafter, an As-Is simulation model will be built for a hospital's supply chain in three dimension space. The 3-D simulation model will map the existing materials flow, identify areas of waste or inefficiencies, highlight the opportunities for using RPA, and detect potential bottlenecks in the existing workflows.

In Phase II, a To-Be simulation model will be built for a hospital's supply chain by considering new healthcare facilities (medical centres, hospital towers) to be built alongside the RPA. A comparative analysis will be conducted to measure the improvement in the respective areas.

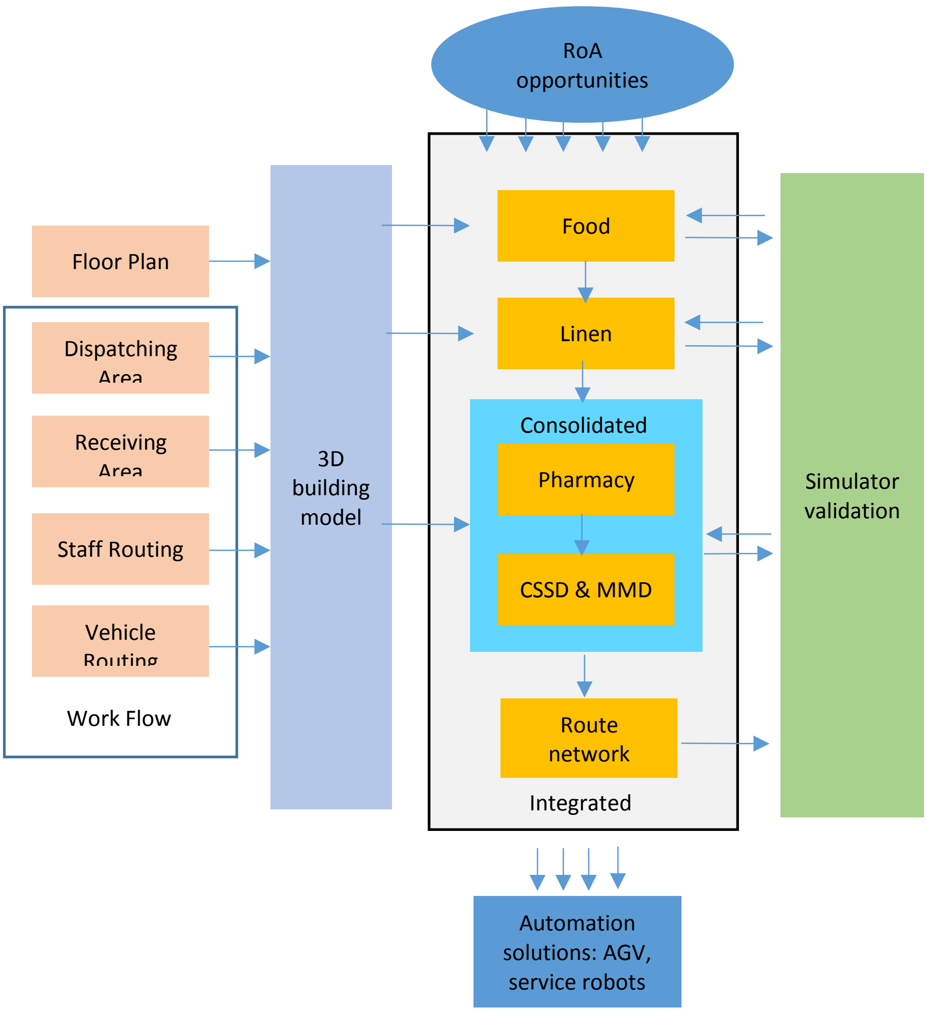


Figure 7.3. Project block diagram

Techniques used

Several techniques were applied in this study. They include the following:

1. **Time motion study**: This approach involves a direct and continuous observation of a mundane task that forms a part of the typical cycle of activities in a hospital material flow. Normally, we use a time-keeping device to record the time taken to accomplish that task. With the primary data collected, we then conducted a time motion analysis to build the necessary distribution as input to the simulator for our computational modelling work. Figure 7.4 provides an example of this technique and outcome.

Data for Value Stream Mapping: Count user inventory and pickup items
Source of data: measured; calculated; provided by SCM manager
Time in sec; path condition default (unless specified)

Time Tag	User	wards (L4)	wards (L5)	wards (L6)	wards (L7)	wards (L8)	wards (L9)	A&E (L1)	SICU (L3)	Endo (L3)	ATA (L1)	DS (L3)	SDA (L3)	clinic (L2)	clinic (L3)	OT (L3)	IB wards (L8)	IB clinic (L3)	Source of Data
	Staff (team)	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDP	PDI	provided
	Staff (number)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	provided
	Amount (min)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	provided
	Amount (max)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	provided
	Amount (unit)	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	trolley	provided
	Amount Type (light / heavy)	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	light	light	light	light	light	heavy	light	light	provided
tc1	**tc1: SCM - Lift (unloaded)**	40	40	40	40	40	40	108	40	54	108	108	40	108	108	40	138	138	calculated
	Note: SCM- Lift																Note1	Note1	note
	Lift Tag	Lift C	Lift C	Lift C	Lift C	Lift C	Lift C	Lift A	Lift C	Lift B	Lift A	Lift A	Lift C	Lift A	Lift A	Lift C	IB Lift H	IB Lift H	provided
	t1 map distance (grid)	8	8	8	8	8	8	22	8	11	22	22	8	22	22	8	28	28	measured
tc2	**tc2: Lift time**	103	121	139	157	175	193	49	85	85	49	85	85	67	85	85	175	85	calculated
	Level Difference	4	5	6	7	8	9	1	3	3	1	3	3	2	3	3	8	3	provided
tc3	**tc3: Lift - User Store (unloaded)**	15	15	15	15	15	15	20	20	25	74	18	20	74	74	25	10	25	calculated
	tc3 map distance (grid)	3	3	3	3	3	3	4	4	5	15	3.5	4	15	15	5	2	5	measured
	tc4: Estimated Counting Time (low)	2400	2400	2400	2400	2400	2400	2400	2400	2400	1200	1200	1200	1200	1200	2400	1200	1200	provided
	tc4: Estimated Counting Time (high)	3600	3600	3600	3600	3600	3600	3600	3600	3600	2400	2400	2400	2400	2400	3600	2400	2400	provided
tc4	**tc4: Estimated Counting Time (avg)**	3000	3000	3000	3000	3000	3000	3000	3000	3000	1800	1800	1800	1800	1800	3000	1800	1800	calculated
		Note2	Note2	Note2	Note2	Note2	Note2	To verify if the estimated counting time is reasonable for the given user									Note2		note
tc5	**tc5: User Store - Lift (unloaded)**	15	15	15	15	15	15	20	20	25	74	18	20	74	74	25	10	25	calculated
tc6	**tc6: Lift time**	103	121	139	157	175	193	49	85	85	49	85	85	67	85	85	175	85	calculated
tc7	**tc7: Lift - SCM (unloaded)**	40	40	40	40	40	40	108	40	54	108	108	40	108	108	40	138	138	calculated
	Time: total travel time	316	352	388	424	460	496	354	290	328	462	422	290	498	534	300	646	496	calculated
tc8	**tc8: Update SAP and Print Pick List**	540	540	540	540	540	540	540	540	540	540	540	540	540	540	540	540	540	measured
tc9	**tc9: Pick items**	3330	3330	3330	3330	3330	3330	3330	3330	3330	1530	1530	1530	1530	1530	3330	1530	1530	calculated
tc10	**tc10: Supervisor cross-check**	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	measured
	time: total pick time (low)	3600	3600	3600	3600	3600	3600	3600	3600	3600	1800	1800	1800	1800	1800	3600	1800	1800	provided
	time: total pick time (high)	5400	5400	5400	5400	5400	5400	5400	5400	5400	3600	3600	3600	3600	3600	5400	3600	3600	provided
	time: total pick time (avg)	4500	4500	4500	4500	4500	4500	4500	4500	4500	2700	2700	2700	2700	2700	4500	2700	2700	calculated
		Note2	Note2	Note2	Note2	Note2	Note2	To verify if the estimated picking time is reasonable for the given user									Note2		note
	Expected Total Cycle Time	7816	7852	7888	7924	7960	7996	7854	7790	7828	4962	4922	4790	4998	5034	7800	5146	4996	calculated

Friday

Day 1, 07:00	Day 1, 08:00:00					
Track date	**Starting offset**	**Ending offset**	**Rate (events per hous) Total**	**Quantity of Sets**	**Quantity of Loose items**	**Week day**
2/6/2017	Day 1, 07:00:00	Day 1, 08:00:00	16	14	2	Friday
9/6/2017	Day 1, 07:00:00	Day 1, 08:00:00	15	12	3	Friday
16/6/2017	Day 1, 07:00:00	Day 1, 08:00:00	4	3	1	Friday
23/6/2017	Day 1, 07:00:00	Day 1, 08:00:00	11	4	7	Friday
30/6/2017	Day 1, 07:00:00	Day 1, 08:00:00	0	0	0	Friday
7/7/2017	Day 1, 07:00:00	Day 1, 08:00:00	7	4	3	Friday
14/7/2017	Day 1, 07:00:00	Day 1, 08:00:00	10	7	3	Friday
21/7/2017	Day 1, 07:00:00	Day 1, 08:00:00	23	12	11	Friday
28/7/2017	Day 1, 07:00:00	Day 1, 08:00:00	23	12	11	Friday
4/8/2017	Day 1, 07:00:00	Day 1, 08:00:00	9	4	5	Friday
11/8/2017	Day 1, 07:00:00	Day 1, 08:00:00	9	3	6	Friday
18/8/2017	Day 1, 07:00:00	Day 1, 08:00:00	20	7	13	Friday
25/8/2017	Day 1, 07:00:00	Day 1, 08:00:00	14	4	10	Friday
1/9/2017	Day 1, 07:00:00	Day 1, 08:00:00	30	17	13	Friday
8/9/2017	Day 1, 07:00:00	Day 1, 08:00:00	12	3	9	Friday
15/9/2017	Day 1, 07:00:00	Day 1, 08:00:00	19	6	13	Friday
22/9/2017	Day 1, 07:00:00	Day 1, 08:00:00	34	21	13	Friday

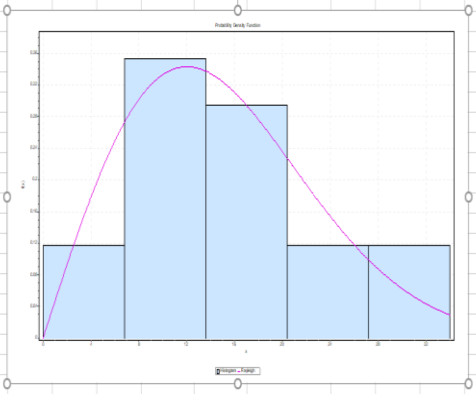


Figure 7.4. Time motion analysis

2. **Value Stream Mapping (VSM):** VSM is a lean management tool used widely in supply chain or logistics studies to analyse the current state of activities from start to finish of a defined process. We used the software eVSM to identify the process and wait times for each activity of a hospital's supply chain. The non-value added times (muda) for a receiving, and scheduled versus non-scheduled in-house delivery process are thus identified, as shown in the sample examples found in Figures 7.5 to 7.7.

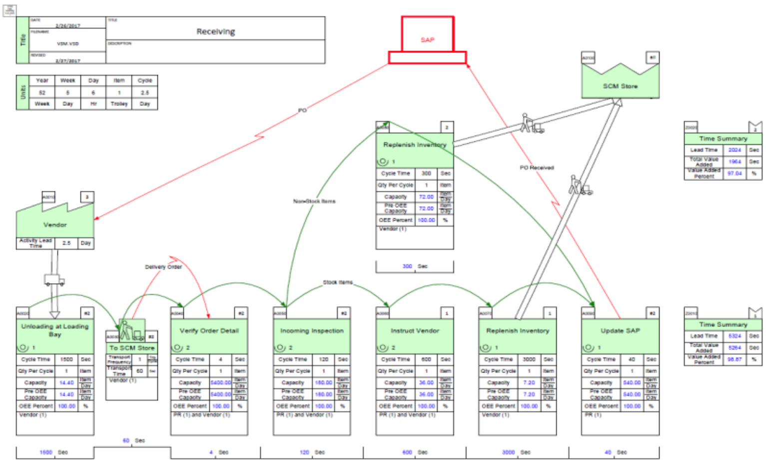


Figure 7.5. Generic VSM of receiving process

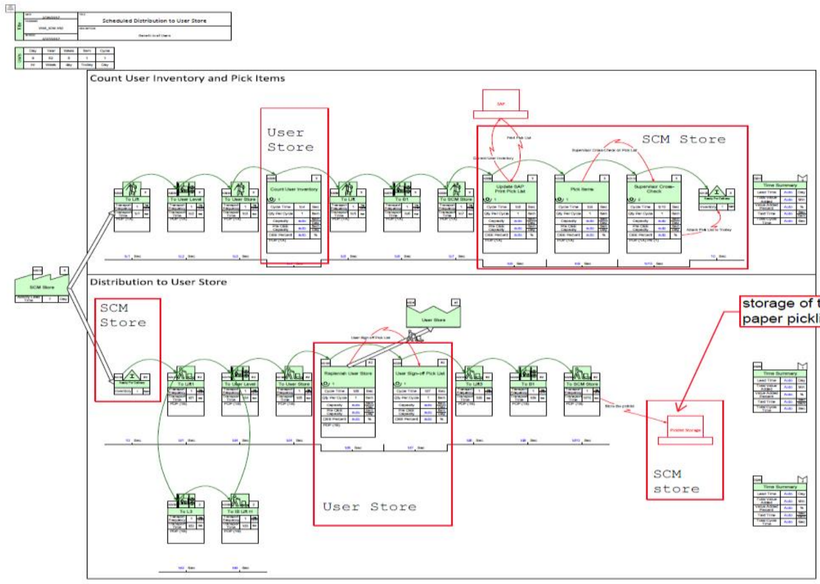


Figure 7.6. Generic VSM of scheduled distribution process

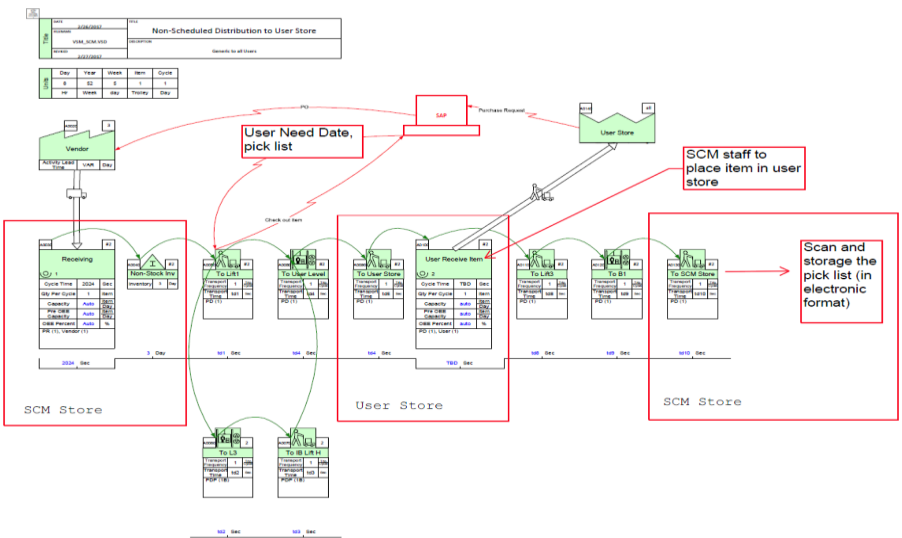


Figure 7.7. Generic VSM of non-scheduled distribution process

3. **SketchUp**: The software SketchUp Pro is a useful and cost effective CAD tool to construct a scaled and accurate 3-D visualiser of a facility, which will be imported into the virtual simulator to provide a physical sense of the workflow.

4. **Discrete-Event Simulation**: The DES as a part of the core computational modelling effort models the operation of a system as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system. Between consecutive events, no change in the system is assumed to occur. Thus, the simulation can directly jump in time from one event to the next. We built our simulator using the software Simio (University edition). Figure 7.8 is a mock-up of the 3-D virtual simulator for an 8-floor building including the basement for AGV docking, done on SketchUp and Simio.

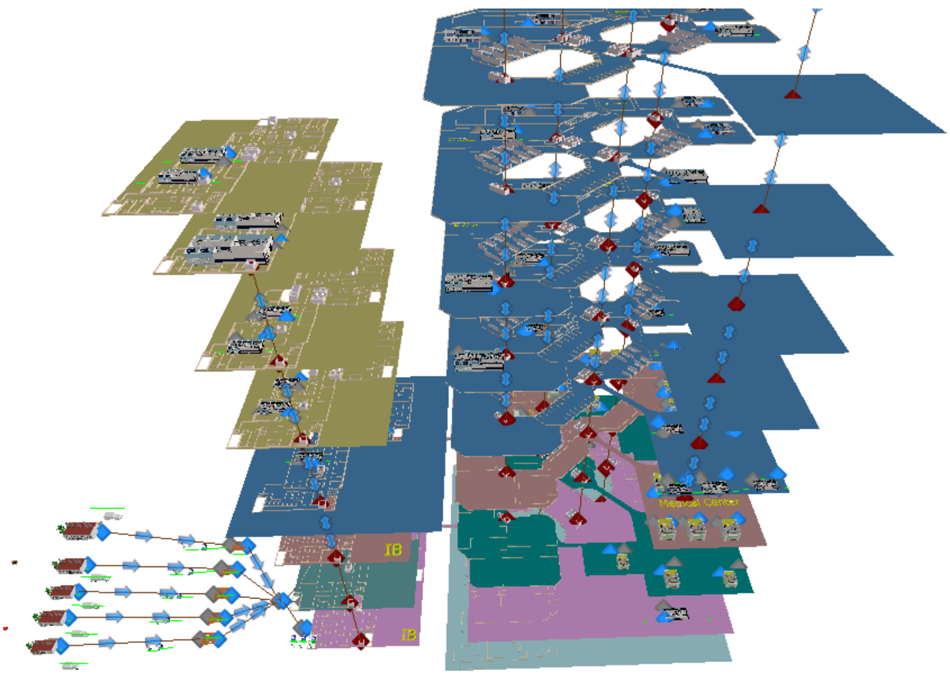


Figure 7.8. Simulation model

Preliminary results and discussion

In this section, we present some sample simulation results for Phase I. The simulator has built a transporter usage (Table 7.1), resource state log (Table 7.2), resource usage log (Table 7.3), workforce schedule (Figure 7.9), and the workflow constraints analysis (Table 7.4). Table 7.1 highlights to the user the state of a particular AGV in use on a work trip of a particular work shift on a particular day of the week. Table 7.2 shows the state of utilization as simulated by Simio. This can be used to compare the productivity offered through RPA. Table 7.3 depicts the simulated workforce level utilization of a staff or work team either in transporting, transferring goods, or waiting for a lift. Figure 7.9 presents a simulated workforce schedule of a particular shift. This is useful for daily workload balancing incorporating both activities that involve humans and machines. Finally, Table 7.4 is the data derived from the virtual simulation of a material flow for a particular supply chain in hospital on the workflow constraints analysis. Such a result can provide useful data driven (though simulated!) evidence of potential areas of bottlenecking after implementing RPA.

At the point of writing, we are now testing the rules of movement and contact for some logistics flows in a hospital. For instance, the road network inside of a hospital facility is fixed by design. All AGVs move on the left and priorities are allocated at the intersection of passageways. Further, the how the queues should be formed at the dispatching areas in order to avoid flow congestion at the intersections or in front of lifts. TLI-AP has also developed an optimal schedule for the AGVs and optimal delivery time windows for each supply chain.

Table 7.1. Transporter usage log

Transporter Id	Transporter	Rider Id	Rider	From Node	To Node	Start Time	Start Ride Time	End Ride Time	End Time	Duration (Minutes)
Vehicle1[1]	Vehicle1[1]	Stock_Items.956	Stock_Items.956	Output@Vendor1	Input@Loading_Unloading_Bay_1	25/9/2017 8:30:00 AM	25/9/2017 8:30:15 AM	25/9/2017 8:34:13 AM	25/9/2017 8:34:23 AM	4.38805
Vehicle2[1]	Vehicle2[1]	Stock_Items.966	Stock_Items.966	Output@Vendor2	Input@Loading_Unloading_Bay_2	25/9/2017 8:30:00 AM	25/9/2017 8:30:15 AM	25/9/2017 8:33:07 AM	25/9/2017 8:33:19 AM	3.31667
Vehicle3[1]	Vehicle3[1]	Stock_Items.976	Stock_Items.976	Output@Vendor3	Input@Loading_Unloading_Bay_3	25/9/2017 8:30:00 AM	25/9/2017 8:30:03 AM	25/9/2017 8:33:54 AM	25/9/2017 8:34:09 AM	4.15
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.986	Non_Stock_Items.986	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:30:00 AM	25/9/2017 8:30:05 AM	25/9/2017 8:34:07 AM	25/9/2017 8:34:17 AM	4.28333
Vehicle5[1]	Vehicle5[1]	Non_Stock_Items.996	Non_Stock_Items.996	Output@Vendor5	Input@Loading_Unloading_Bay_5	25/9/2017 8:30:00 AM	25/9/2017 8:30:20 AM	25/9/2017 8:34:39 AM	25/9/2017 8:34:44 AM	4.73333
Vehicle3[1]	Vehicle3[1]	Stock_Items.977	Stock_Items.977	Output@Vendor3	Input@Loading_Unloading_Bay_3	25/9/2017 8:30:03 AM	25/9/2017 8:30:08 AM	25/9/2017 8:34:09 AM	25/9/2017 8:34:15 AM	4.2
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.987	Non_Stock_Items.987	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:30:05 AM	25/9/2017 8:30:20 AM	25/9/2017 8:34:17 AM	25/9/2017 8:34:32 AM	4.45
Vehicle3[1]	Vehicle3[1]	Stock_Items.978	Stock_Items.978	Output@Vendor3	Input@Loading_Unloading_Bay_3	25/9/2017 8:30:08 AM	25/9/2017 8:31:09 AM	25/9/2017 8:34:15 AM	25/9/2017 8:34:40 AM	4.53333
Staff_4_1[1]	Staff_4_1[1]	ModelEntityA.1008	ModelEntityA.1008	TeamDStart	Input@Ward_58_L8	25/9/2017 8:30:11 AM	25/9/2017 8:30:11 AM	25/9/2017 9:00:27 AM	25/9/2017 9:00:27 AM	30.2734
Staff_3_1[1]	Staff_3_1[1]	ModelEntityA.1007	ModelEntityA.1007	TeamCStart	Input@Ward_29_L9	25/9/2017 8:30:12 AM	25/9/2017 8:30:12 AM	25/9/2017 8:51:52 AM	25/9/2017 8:51:52 AM	21.6667
Staff_2_1[1]	Staff_2_1[1]	ModelEntityA.1006	ModelEntityA.1006	TeamBStart	Input@Ward_17_L7	25/9/2017 8:30:14 AM	25/9/2017 8:30:14 AM	25/9/2017 9:04:02 AM	25/9/2017 9:04:02 AM	33.8067
Vehicle1[1]	Vehicle1[1]	Stock_Items.957	Stock_Items.957	Output@Vendor1	Input@Loading_Unloading_Bay_1	25/9/2017 8:30:15 AM	25/9/2017 8:30:20 AM	25/9/2017 8:34:23 AM	25/9/2017 8:34:28 AM	4.22138
Vehicle2[1]	Vehicle2[1]	Stock_Items.967	Stock_Items.967	Output@Vendor2	Input@Loading_Unloading_Bay_2	25/9/2017 8:30:15 AM	25/9/2017 8:30:27 AM	25/9/2017 8:33:19 AM	25/9/2017 8:33:44 AM	3.48333
Staff_1_1[1]	Staff_1_1[1]	ModelEntityA.1009	ModelEntityA.1009	TeamAStart	Input@Ward_49_L9	25/9/2017 8:30:18 AM	25/9/2017 8:30:18 AM	25/9/2017 9:52:12 AM	25/9/2017 9:52:12 AM	81.8997
Vehicle5[1]	Vehicle5[1]	Non_Stock_Items.997	Non_Stock_Items.997	Output@Vendor5	Input@Loading_Unloading_Bay_5	25/9/2017 8:30:20 AM	25/9/2017 8:31:06 AM	25/9/2017 8:34:44 AM	25/9/2017 8:34:51 AM	4.51667
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.988	Non_Stock_Items.988	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:30:20 AM	25/9/2017 8:30:25 AM	25/9/2017 8:34:32 AM	25/9/2017 8:34:42 AM	4.36667
Vehicle1[1]	Vehicle1[1]	Stock_Items.958	Stock_Items.958	Output@Vendor1	Input@Loading_Unloading_Bay_1	25/9/2017 8:30:20 AM	25/9/2017 8:31:06 AM	25/9/2017 8:34:28 AM	25/9/2017 8:34:43 AM	4.38805
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.989	Non_Stock_Items.989	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:30:25 AM	25/9/2017 8:30:40 AM	25/9/2017 8:34:42 AM	25/9/2017 8:34:57 AM	4.53333
Vehicle2[1]	Vehicle2[1]	Stock_Items.968	Stock_Items.968	Output@Vendor2	Input@Loading_Unloading_Bay_2	25/9/2017 8:30:27 AM	25/9/2017 8:31:20 AM	25/9/2017 8:33:44 AM	25/9/2017 8:33:51 AM	3.4
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.990	Non_Stock_Items.990	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:30:40 AM	25/9/2017 8:30:50 AM	25/9/2017 8:34:57 AM	25/9/2017 8:35:22 AM	4.7
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.991	Non_Stock_Items.991	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:30:50 AM	25/9/2017 8:31:00 AM	25/9/2017 8:35:22 AM	25/9/2017 8:36:02 AM	5.2
Vehicle4[1]	Vehicle4[1]	Non_Stock_Items.992	Non_Stock_Items.992	Output@Vendor4	Input@Loading_Unloading_Bay_4	25/9/2017 8:31:00 AM	25/9/2017 8:32:01 AM	25/9/2017 8:36:02 AM	25/9/2017 8:36:37 AM	5.61667
Vehicle5[1]	Vehicle5[1]	Non_Stock_Items.998	Non_Stock_Items.998	Output@Vendor5	Input@Loading_Unloading_Bay_5	25/9/2017 8:31:06 AM	25/9/2017 8:32:07 AM	25/9/2017 8:34:51 AM	25/9/2017 8:35:56 AM	4.83333
Vehicle1[1]	Vehicle1[1]	Stock_Items.959	Stock_Items.959	Output@Vendor1	Input@Loading_Unloading_Bay_1	25/9/2017 8:31:06 AM	25/9/2017 8:31:21 AM	25/9/2017 8:34:43 AM	25/9/2017 8:34:58 AM	3.87138
Vehicle3[1]	Vehicle3[1]	Stock_Items.979	Stock_Items.979	Output@Vendor3	Input@Loading_Unloading_Bay_3	25/9/2017 8:31:09 AM	25/9/2017 8:31:24 AM	25/9/2017 8:34:40 AM	25/9/2017 8:34:45 AM	3.6
Lift_B[1]	Lift_B[1]	Staff_3_1[1]	Staff_3_1[1]	Lift_B_Node_B1		25/9/2017 8:31:14 AM	25/9/2017 8:31:45 AM	25/9/2017 8:57:44 AM	25/9/2017 8:57:44 AM	26.5
Vehicle2[1]	Vehicle2[1]	Stock_Items.969	Stock_Items.969	Output@Vendor2	Input@Loading_Unloading_Bay_2	25/9/2017 8:31:20 AM	25/9/2017 8:31:25 AM	25/9/2017 8:33:51 AM	25/9/2017 8:34:05 AM	2.75
Vehicle1[1]	Vehicle1[1]	Stock_Items.960	Stock_Items.960	Output@Vendor1	Input@Loading_Unloading_Bay_1	25/9/2017 8:31:21 AM	25/9/2017 8:32:26 AM	25/9/2017 8:34:58 AM	25/9/2017 8:35:04 AM	3.72137
Vehicle3[1]	Vehicle3[1]	Stock_Items.980	Stock_Items.980	Output@Vendor3	Input@Loading_Unloading_Bay_3	25/9/2017 8:31:24 AM	25/9/2017 8:31:34 AM	25/9/2017 8:34:45 AM	25/9/2017 8:34:50 AM	3.43333
Vehicle2[1]	Vehicle2[1]	Stock_Items.970	Stock_Items.970	Output@Vendor2	Input@Loading_Unloading_Bay_2	25/9/2017 8:31:25 AM	25/9/2017 8:31:30 AM	25/9/2017 8:34:05 AM	25/9/2017 8:34:15 AM	2.83333
Vehicle2[1]	Vehicle2[1]	Stock_Items.971	Stock_Items.971	Output@Vendor2	Input@Loading_Unloading_Bay_2	25/9/2017 8:31:30 AM	25/9/2017 8:31:40 AM	25/9/2017 8:34:15 AM	25/9/2017 8:34:25 AM	2.91667

Table 7.2. Resource state log

Resource Id	Resource	State	AutoState	Start Time	End Time	Duration (Minutes)
Staff_4_1[1]	Staff_4_1[1]	Transporting	Busy	25/9/2017 8:30:05 AM	25/9/2017 9:00:27 AM	30.3666
Staff_3_1[1]	Staff_3_1[1]	Transporting	Busy	25/9/2017 8:30:06 AM	25/9/2017 8:51:52 AM	21.7675
Staff_2_1[1]	Staff_2_1[1]	Transporting	Busy	25/9/2017 8:30:07 AM	25/9/2017 9:04:02 AM	33.9266
Staff_1_1[1]	Staff_1_1[1]	Transporting	Busy	25/9/2017 8:30:09 AM	25/9/2017 9:52:12 AM	82.054
Staff_3_1[1]	Staff_3_1[1]	Idle	Starved	25/9/2017 8:51:52 AM	25/9/2017 9:06:34 AM	14.7068
Staff_4_1[1]	Staff_4_1[1]	Idle	Starved	25/9/2017 9:00:27 AM	25/9/2017 9:13:56 AM	13.4826
Staff_2_1[1]	Staff_2_1[1]	Idle	Starved	25/9/2017 9:04:02 AM	25/9/2017 9:10:31 AM	6.48158
Staff_3_1[1]	Staff_3_1[1]	Busy	Busy	25/9/2017 9:06:34 AM	25/9/2017 9:10:46 AM	4.20217
Staff_2_1[1]	Staff_2_1[1]	Busy	Busy	25/9/2017 9:10:31 AM	25/9/2017 9:14:42 AM	4.18742
Staff_3_1[1]	Staff_3_1[1]	Idle	Starved	25/9/2017 9:10:46 AM	25/9/2017 9:12:47 AM	2.0075
Staff_3_2[1]	Staff_3_2[1]	Busy	Busy	25/9/2017 9:10:47 AM	25/9/2017 10:01:53...	51.1134
Staff_3_1[1]	Staff_3_1[1]	Transporting	Busy	25/9/2017 9:12:47 AM	25/9/2017 10:26:00...	73.2242
Staff_4_1[1]	Staff_4_1[1]	Busy	Busy	25/9/2017 9:13:56 AM	25/9/2017 9:18:09 AM	4.21717
Staff_2_1[1]	Staff_2_1[1]	Idle	Starved	25/9/2017 9:14:42 AM	25/9/2017 9:16:43 AM	2.00975
Staff_2_2[1]	Staff_2_2[1]	Busy	Busy	25/9/2017 9:14:43 AM	25/9/2017 9:46:30 AM	31.7867
Staff_2_1[1]	Staff_2_1[1]	Transporting	Busy	25/9/2017 9:16:43 AM	25/9/2017 10:08:24...	51.6838
Staff_4_1[1]	Staff_4_1[1]	Idle	Starved	25/9/2017 9:18:09 AM	25/9/2017 9:20:10 AM	2.00775
Staff_4_2[1]	Staff_4_2[1]	Busy	Busy	25/9/2017 9:18:10 AM	25/9/2017 9:44:57 AM	26.7834
Staff_4_1[1]	Staff_4_1[1]	Transporting	Busy	25/9/2017 9:20:10 AM	25/9/2017 9:49:50 AM	29.6722
Staff_4_2[1]	Staff_4_2[1]	Idle	Starved	25/9/2017 9:44:57 AM	25/9/2017 10:07:33...	22.6093
Staff_2_2[1]	Staff_2_2[1]	Idle	Starved	25/9/2017 9:46:30 AM	25/9/2017 10:27:06...	40.5888
Staff_4_1[1]	Staff_4_1[1]	Idle	Starved	25/9/2017 9:49:50 AM	25/9/2017 10:03:19...	13.4826
Staff_1_1[1]	Staff_1_1[1]	Idle	Starved	25/9/2017 9:52:12 AM	25/9/2017 10:15:24...	23.2013
Staff_3_2[1]	Staff_3_2[1]	Idle	Starved	25/9/2017 10:01:53...	25/9/2017 10:55:38...	53.746
Staff_4_1[1]	Staff_4_1[1]	Busy	Busy	25/9/2017 10:03:19...	25/9/2017 10:07:33...	4.23017
Staff_4_1[1]	Staff_4_1[1]	Idle	Starved	25/9/2017 10:07:33...	25/9/2017 10:09:33...	2.00775
Staff_4_2[1]	Staff_4_2[1]	Busy	Busy	25/9/2017 10:07:33...	25/9/2017 10:44:30...	36.9434
Staff_2_1[1]	Staff_2_1[1]	Idle	Starved	25/9/2017 10:08:24...	25/9/2017 10:22:53...	14.4816
Staff_4_1[1]	Staff_4_1[1]	Transporting	Busy	25/9/2017 10:09:33...	25/9/2017 10:51:34...	42.0091
Staff_1_1[1]	Staff_1_1[1]	Busy	Busy	25/9/2017 10:15:24...	25/9/2017 10:19:35...	4.175
Staff_1_1[1]	Staff_1_1[1]	Idle	Starved	25/9/2017 10:19:35...	25/9/2017 10:21:35...	2.00717

Table 7.3. Resource Usage log

Resource Id	Resource	Resource List	Node List	Owner Id	Owner	Start Time	End Time	Duration (Minutes)	Avg	Min	Max
Staff_4_1[1]	Staff_4_1[1]			Staff_4_1[1]	Staff_4_1[1]	25/9/2017 8:30:05 AM	25/9/2017 9:00:27 AM	30.3666	1	1	1
Staff_3_1[1]	Staff_3_1[1]			Staff_3_1[1]	Staff_3_1[1]	25/9/2017 8:30:06 AM	25/9/2017 8:51:52 AM	21.7675	1	1	1
Staff_2_1[1]	Staff_2_1[1]			Staff_2_1[1]	Staff_2_1[1]	25/9/2017 8:30:07 AM	25/9/2017 9:04:02 AM	33.9266	1	1	1
Staff_1_1[1]	Staff_1_1[1]			Staff_1_1[1]	Staff_1_1[1]	25/9/2017 8:30:09 AM	25/9/2017 9:52:12 AM	82.054	1	1	1
Staff_3_1[1]	Staff_3_1[1]	TeamC		VehicleX9[1]	VehicleX9[1]	25/9/2017 9:06:34 AM	25/9/2017 9:10:46 AM	4.20217	1	1	1
Staff_2_1[1]	Staff_2_1[1]	TeamB		VehicleX8[1]	VehicleX8[1]	25/9/2017 9:10:31 AM	25/9/2017 9:14:42 AM	4.18742	1	1	1
Staff_3_2[1]	Staff_3_2[1]	TeamC		VehicleX9[1]	VehicleX9[1]	25/9/2017 9:10:47 AM	25/9/2017 10:01:53 AM	51.1134	1	1	1
Staff_3_1[1]	Staff_3_1[1]			Staff_3_1[1]	Staff_3_1[1]	25/9/2017 9:12:47 AM	25/9/2017 10:26:00 AM	73.2242	1	1	1
Staff_4_1[1]	Staff_4_1[1]	TeamD		VehicleX10[1]	VehicleX10[1]	25/9/2017 9:13:56 AM	25/9/2017 9:18:09 AM	4.21717	1	1	1
Staff_2_2[1]	Staff_2_2[1]	TeamB		VehicleX8[1]	VehicleX8[1]	25/9/2017 9:14:43 AM	25/9/2017 9:46:30 AM	31.7867	1	1	1
Staff_2_1[1]	Staff_2_1[1]			Staff_2_1[1]	Staff_2_1[1]	25/9/2017 9:16:43 AM	25/9/2017 10:08:24 AM	51.6838	1	1	1
Staff_4_2[1]	Staff_4_2[1]	TeamD		VehicleX10[1]	VehicleX10[1]	25/9/2017 9:18:10 AM	25/9/2017 9:44:57 AM	26.7834	1	1	1
Staff_4_1[1]	Staff_4_1[1]			Staff_4_1[1]	Staff_4_1[1]	25/9/2017 9:20:10 AM	25/9/2017 9:49:50 AM	29.6722	1	1	1
Staff_4_1[1]	Staff_4_1[1]	TeamD		VehicleX10[1]	VehicleX10[1]	25/9/2017 10:03:19...	25/9/2017 10:07:33 AM	4.23017	1	1	1
Staff_4_2[1]	Staff_4_2[1]	TeamD		VehicleX10[1]	VehicleX10[1]	25/9/2017 10:07:33...	25/9/2017 10:44:30 AM	36.9434	1	1	1
Staff_4_1[1]	Staff_4_1[1]			Staff_4_1[1]	Staff_4_1[1]	25/9/2017 10:09:33...	25/9/2017 10:51:34 AM	42.0091	1	1	1
Staff_1_1[1]	Staff_1_1[1]	TeamA		VehicleX7[1]	VehicleX7[1]	25/9/2017 10:15:24...	25/9/2017 10:19:35 AM	4.175	1	1	1
Staff_1_2[1]	Staff_1_2[1]	TeamA		VehicleX7[1]	VehicleX7[1]	25/9/2017 10:19:35...	25/9/2017 10:53:05 AM	33.5	1	1	1
Staff_1_1[1]	Staff_1_1[1]			Staff_1_1[1]	Staff_1_1[1]	25/9/2017 10:21:35...	25/9/2017 11:43:47 AM	82.1963	1	1	1
Staff_2_1[1]	Staff_2_1[1]	TeamB		VehicleX8[1]	VehicleX8[1]	25/9/2017 10:22:53...	25/9/2017 10:27:05 AM	4.20042	1	1	1
Staff_2_2[1]	Staff_2_2[1]	TeamB		VehicleX8[1]	VehicleX8[1]	25/9/2017 10:27:06...	25/9/2017 11:33:49 AM	66.7236	1	1	1
Staff_2_1[1]	Staff_2_1[1]			Staff_2_1[1]	Staff_2_1[1]	25/9/2017 10:29:06...	25/9/2017 11:29:13 AM	60.1207	1	1	1
Staff_3_1[1]	Staff_3_1[1]	TeamC		VehicleX9[1]	VehicleX9[1]	25/9/2017 10:51:25...	25/9/2017 10:55:38 AM	4.21517	1	1	1
Staff_3_2[1]	Staff_3_2[1]	TeamC		VehicleX9[1]	VehicleX9[1]	25/9/2017 10:55:38...	25/9/2017 11:25:04 AM	29.4262	1	1	1
Staff_3_1[1]	Staff_3_1[1]			Staff_3_1[1]	Staff_3_1[1]	25/9/2017 10:57:38...	25/9/2017 11:39:57 AM	42.3205	1	1	1
Staff_4_1[1]	Staff_4_1[1]	TeamD		VehicleX10[1]	VehicleX10[1]	25/9/2017 11:05:13...	25/9/2017 11:09:27 AM	4.23017	1	1	1
Staff_4_2[1]	Staff_4_2[1]	TeamD		VehicleX10[1]	VehicleX10[1]	25/9/2017 11:09:28...	25/9/2017 11:47:39 AM	38.1908	1	1	1
Staff_4_1[1]	Staff_4_1[1]			Staff_4_1[1]	Staff_4_1[1]	25/9/2017 11:11:28...	25/9/2017 11:29:03 AM	17.5865	1	1	1
Staff_2_1[1]	Staff_2_1[1]	TeamB		VehicleX8[1]	VehicleX8[1]	25/9/2017 11:41:01...	25/9/2017 11:45:13 AM	4.20042	1	1	1
Staff_2_2[1]	Staff_2_2[1]	TeamB		VehicleX8[1]	VehicleX8[1]	25/9/2017 11:45:14...	25/9/2017 12:19:17 PM	34.0512	1	1	1
Staff_2_1[1]	Staff_2_1[1]			Staff_2_1[1]	Staff_2_1[1]	25/9/2017 11:47:14...	25/9/2017 12:17:50 PM	30.6016	1	1	1

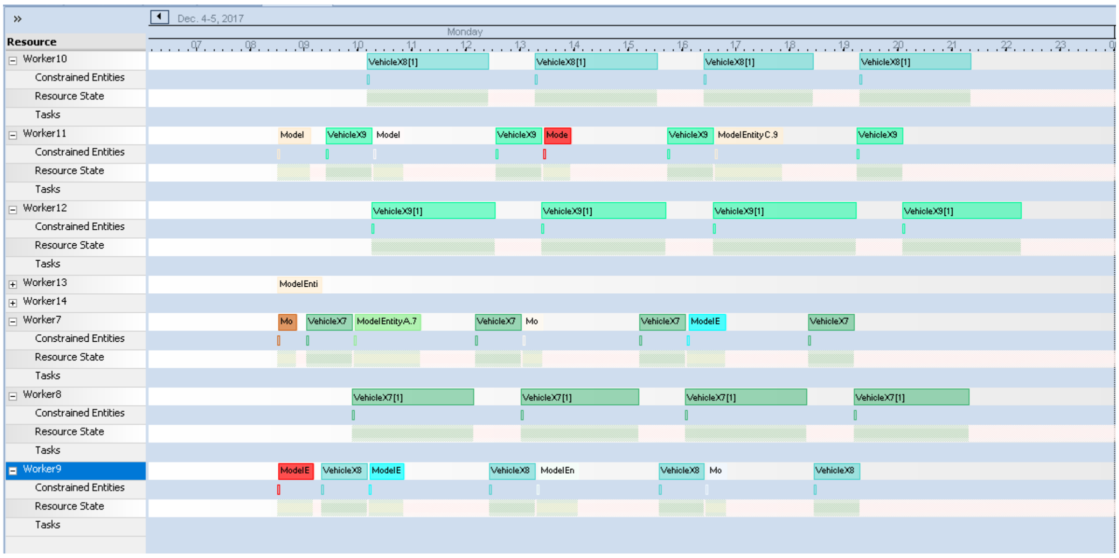


Figure 7.9. Workforce schedule

Table 7.4. Workflow constraints analysis

Generated On: 23/1/2018 10:22:02 AM

Resource Arrival			
Constraint Item	Occurences	Average Wait (Minutes)	Total Wait (Minutes)
Staff_1_1[1]	22	1.0431	22.9492
Staff_1_2[1]	22	3.7430	82.3465
Staff_2_1[1]	19	1.0446	19.8478
Staff_2_2[1]	19	4.1805	79.4291
Staff_3_1[1]	15	1.0347	15.5204
Staff_3_2[1]	15	1.0336	15.5037
Staff_4_1[1]	13	1.0395	13.5141
Staff_4_2[1]	13	1.0468	13.6088
Vendor_1[1]	38	38.2234	1452.4881
Vendor_2[1]	41	32.6585	1339.0000
Vendor_3[1]	41	28.7805	1180.0000
Vendor_4[1]	39	38.7436	1511.0000
Vendor_5[1]	43	30.2791	1302.0000

Summary

A computational model have been developed to display the behavior an actual complex hospital logistics system using computer simulation, executed on Simio. The As-Is simulator is validated by primary data collected through VMS and time motion studies. Further, several 3-D facility models of, associated with logistics dispatching area, receiving area, staff routing, vehicle routing, lift entry, ward sizes, lift locations, and AGV docking stations have been built. Through this tool, scenario planning can be performed and situations tested through the computational experiments to gain a realistic understanding of how RPA can complement human effort for maximal resource usage and productivity gains.

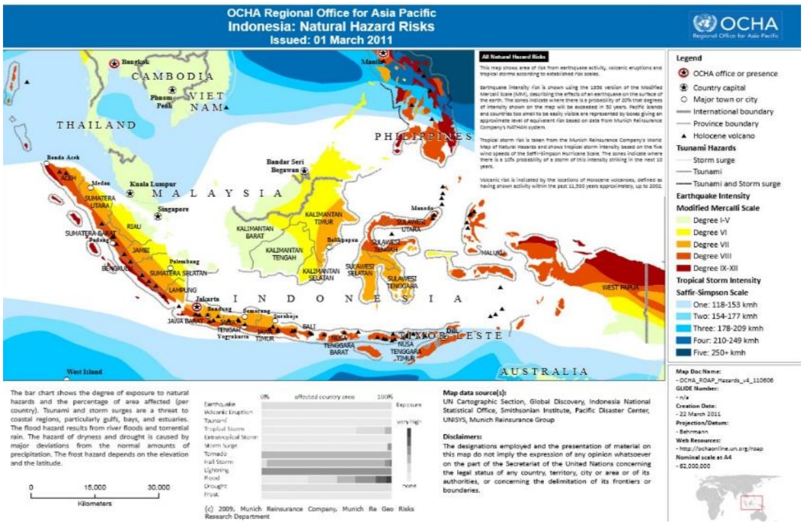
CHAPTER 8.

LOGISTICS PREPAREDNESS FOR DISASTER RESPONSE IN INDONESIA

Contributed by Dr. Robert de Souza, Executive Director, Giuseppe Timperio and Lee Cher Kian, The Logistics Institute – Asia Pacific, National University of Singapore

OVERVIEW

Located on the edges of two continental and two oceanic tectonic plates, Indonesia is home to more than 500 volcanoes (128 of which are active), and threatened by some of the greatest seismic activity in the world. Furthermore, much of this activity is offshore and brings the significant added risk of tsunamis (as shown in Figure 5.1). The country experiences recurring small/medium scale natural disasters compounded by a high risk of less frequent, but very large-scale, natural disasters that necessitate a system wide international humanitarian response.



Source: From Indonesia Natural Hazard Risks, by United Nations Office for the Coordination of Humanitarian Affairs - regional Office for Asia and the Pacific (OCHA ROAP), ©2011 United Nations. Reprinted with the permission of the United Nations

Figure 8.1. Hazard risks map Indonesia (earthquake and tsunami)

When disasters strike, especially in remote areas of the Indonesian archipelago, existing response capacities are invariably stretched. Besides operational challenges brought about by the country's geographical characteristics, national disaster response capabilities are further limited by:

- Poor logistics infrastructure, especially in remote areas;
- Lack of facilities to store, handle, and consolidate humanitarian cargo for distribution in disaster affected areas.

CHALLENGES

This case study focuses on navigating infrastructure and logistics assets for pre-positioning critical relief supplies in Indonesia. The research question is formulated as:

- What is the most optimum network configuration for prepositioning stockpiles of life-saving goods in Indonesia to distribute in the aftermath of disaster events?
- How does the network selected using a network optimization approach perform in response to sudden onset calamities in Indonesia?

SOLUTION APPROACH

To address the identified research question a multi-phase framework was conceptualized as summarized in Figure 8.2:

- Phase 1. Identification, assessment, and selection of suitable locations for facilities;
- Phase 2. Structuring and optimizing the supply network;
- Phase 3. Simulating and measuring supply network performances.

Figure 8.2. Integrated Decision Support Framework for Facility Prepositioning

Phase 1. The project began with the identification of all potential candidate locations, and the subsequent selection of suitable network nodes. This phase was undertaken through an ad-hoc decision support framework which fully leveraged operational research techniques.

Based on the following premises:

- Twenty-one cities were initially identified as potential nodes;
- Eight criteria were defined;
- Fuzzy AHP (f-AHP) using synthetic extent value method was used to determine criteria weightage.

Nine locations were selected as suitable sites for siting relief facilities. In light of the network design requirements[31] set by the national government, only six strategic locations are to be selected.

[31]Indonesia national master plan for the acceleration and expansion of the country over 2011-2025 identifies six economic corridors, which for humanitarian response were further organized in the geographies of 1) Sumatra, 2) Java-Bali-East Nusa Tenggara (NTT)-West Nusa Tenggara (NTB), 3) Kalimantan, 4)Maluku, 5)Papua, and 6) Sulawesi. Each of the six main Indonesian islands is requested to be equipped with its own emergency response facility (DC).

Phase 2. Using a simulation software, the optimal configuration for the prepositioned network was defined. The most appropriate six locations were identified, and the optimal flows across the nodes were computed. Particularly, demand data of a) Eleven big scale humanitarian emergencies affecting the country in the period 2004-2016 and b) 489 recurrent small/medium scale disasters for the biennium 2014-2015 [32] were considered. Optimizations were conducted on the various what-ifs scenarios and identified the best supply chain configuration in terms of response time, risk exposure, and logistics costs.

Phase 3. A discrete event simulation model was built, and a two tiers supply chain (as shown in Figure 8.3) was considered. Simulation setting includes a single sourcing strategy from Distribution Centres (DCs) to beneficiaries, and demand being triggered by actual events as well as potential forceful disasters which are assumed to occur in two highly populated areas in the islands of Java and Sumatra.

Figure 8.3. Supply Chain Design Structure

OUTCOMES

Four different experiments (summary on Table 8.1, with illustrations on Figure 8.4) were run as to capture operational performances of feasible network configurations.

Alternative solutions were analysed and cross compared, with the “basic configuration” fixed as reference point. Using network optimization tool in modelling the logistics preparedness for disaster response, this case study improved the capabilities to cope with disasters by achieving an average transportation time to disasters affected zone of **0.23 days**[33]. Compared to the basic solution identified through operations research, the network identified via Network Optimization tool reduces **transportation cost by 29%**, with no compromise to be made on the service level.

The simulation consisted of robustness and resilience stress tests of the optimum solution of phase 2, which is configuration 3 from Figure 8.4. Experiments were performed subject to historical demand, 489 recurrent small/medium scale disasters for the biennium 2014-2015, and two major disaster scenarios respectively in Sumatra and Java. By using a dynamic simulation approach (illustrated in Figure 8.5), supply chain

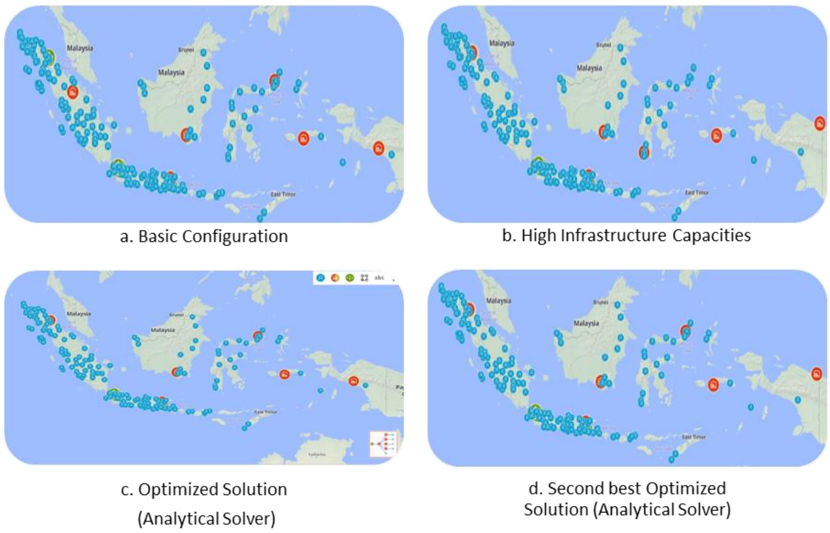
[32] Considered disasters include 431 floods, 18 landslides, 13 volcano eruptions, 13 floods with landslides, 8 droughts, 3 forest fires, 2 tornadoes, and 1 tsunami with more than 500 people affected. Available at www.dibi.bnpb.go.id.

[33] Lead time considers only geographical distance, with no considerations on disruptions and infrastructural damages in affected zones.

performances such as lead time, fleet size, service level, and transportation costs were accurately computed and observed over time.

Table 8.1. Description of Selected Experiments

No.	Network Nodes/ Configuration	Defined by
1	Pekanmbaru, Surabaya, Banjarmasin, Ambon, Timika, Manado (Figure 8.4.a)	Timperio, et al. (2017), and named "Basic Configuration"[34]
2	Surabaya, Banjarmasin, Ambon, Medan, Jayapura, Makassar (Figure 8.4.b)	Timperio, et al. (2017), and named "High Infrastructure Capacities"[34]
3	Surabaya, Banjarmasin, Ambon, Timika, Manado, Medan (Figure 8.4.c)	Analytical solver, and named "Optimized Solution"
4	Surabaya, Banjarmasin, Ambon, Manado, Medan, Jayapura (Figure 8.4.d)	Analytical solver, and named "Second best Optimized Solution"



a. Basic Configuration

b. High Infrastructure Capacities

c. Optimized Solution (Analytical Solver)

d. Second best Optimized Solution (Analytical Solver)

Figure 8.4. Alternative Network Configurations

[34] See: How to Identify the Most Appropriate Locations for Establishing an Efficient Network of Emergency Response Facilities (Vol 16-Mar-HL)

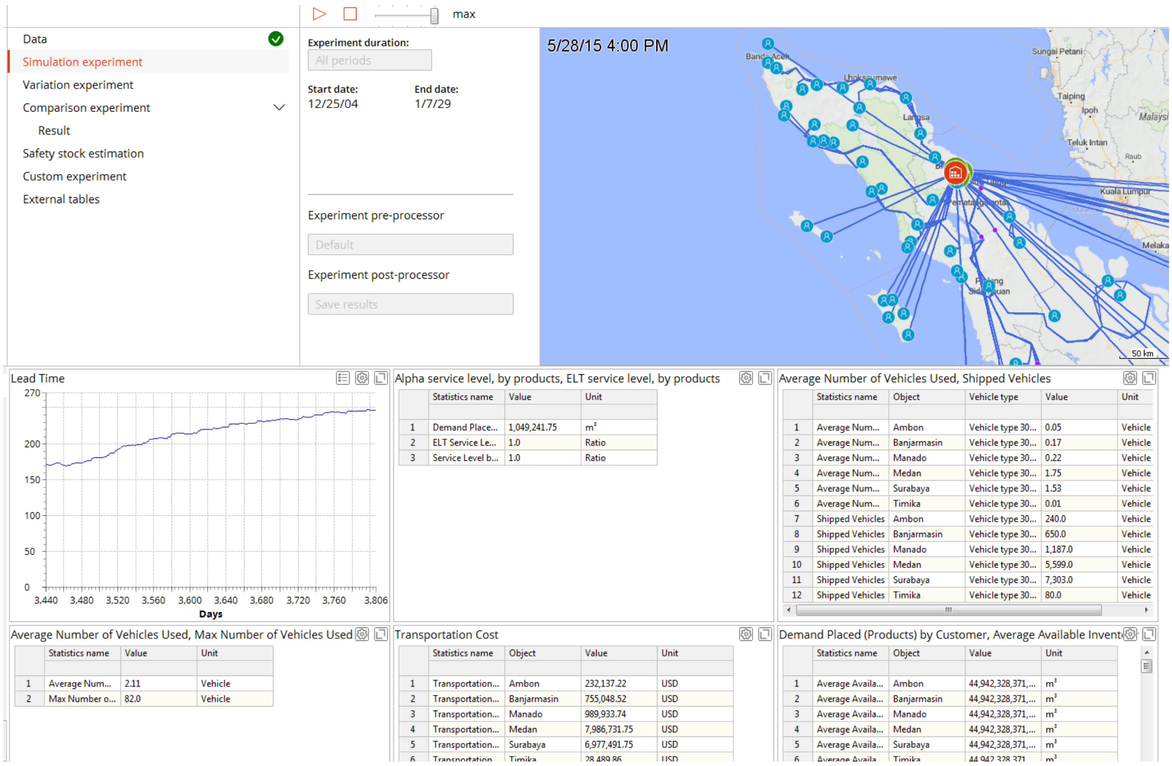
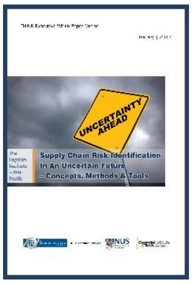
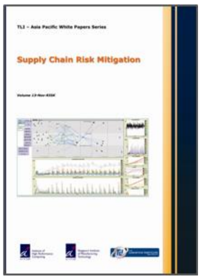


Figure 8.5. Simulation Dashboard

TLI-Asia Pacific White Paper Series on Supply Chain Risk Management includes:

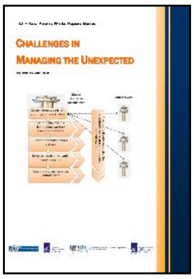


Supply Chain Identification in an Uncertain Future – Concepts, Methods and Tools (Jan 2017)



Supply Chain Risk Mitigation

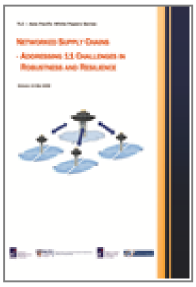
(Vol 13-Nov-RISK)



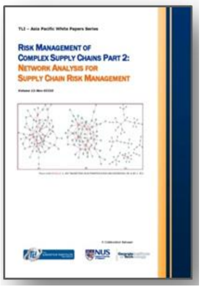
Challenges in Managing The Unexpected
(Vol 15-Apr-RISK)

Risk Management of Complex Supply Chains Part 1: Supply Chain Risk and Complex Systems

(Vol 12-Nov-SCI09)

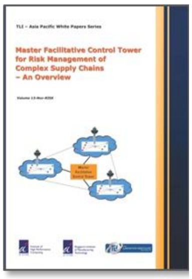


Networked Supply Chains – Addressing 11 Challenges in Robustness and Resilience
(Vol 14-Mar-RISK)



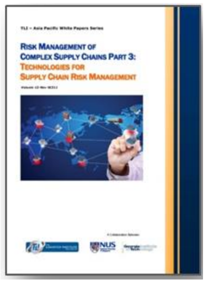
Risk Management of Complex Supply Chains Part 2: Network Analysis for Supply Chain Risk Management

(Vol 12-Nov-SCI10)



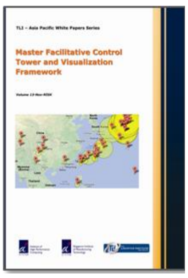
Master Facilitative Control Tower for Risk Management of Complex Supply Chains – An Overview

(Vol 13-Nov-RISK)



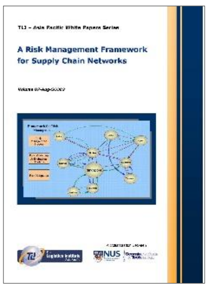
Risk Management of Complex Supply Chains Part 3: Technologies for Supply Chain Risk Management

(Vol 12-Nov-SCI11)



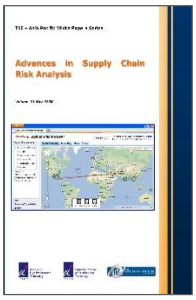
Master Facilitative Control Tower and Visualization Framework

(Vol 13-Nov-RISK)



A Risk Management Framework for Supply Chain Networks

(Vol 07-Aug-SCO03)



Advances in Supply Chain Risk Analysis

(Vol 13-Nov-RISK)

Please visit www.tliap.nus.edu.sg for more reports.

The Logistics Institute – Asia Pacific
National University of Singapore
21 Heng Mui Keng Terrace, #04-01
Singapore 119613
Tel: (65) 6516 4842 • Fax: (65) 6775 3391
E-mail: tlihead@nus.edu.sg • Website: www.tliap.nus.edu.sg