Chance Constrained Optimization for Petrochemical Supply Chain with the Validation Technique

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ABSTRACT

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Nowadays, the profit is more concern in industry due to high business competition. Therefore, reducing the cost is needed to survive competition. Stochastic optimization had been interesting method to reduce opportunity and over-demand loss in the supply chain under uncertainties. Chance constrained optimization is one of the approaches to stochastic optimization. The uncertainties are included in chance constraint of event under level of confidence. This method is used to design the realistic supply chain giving more stabilities than deterministic optimization.

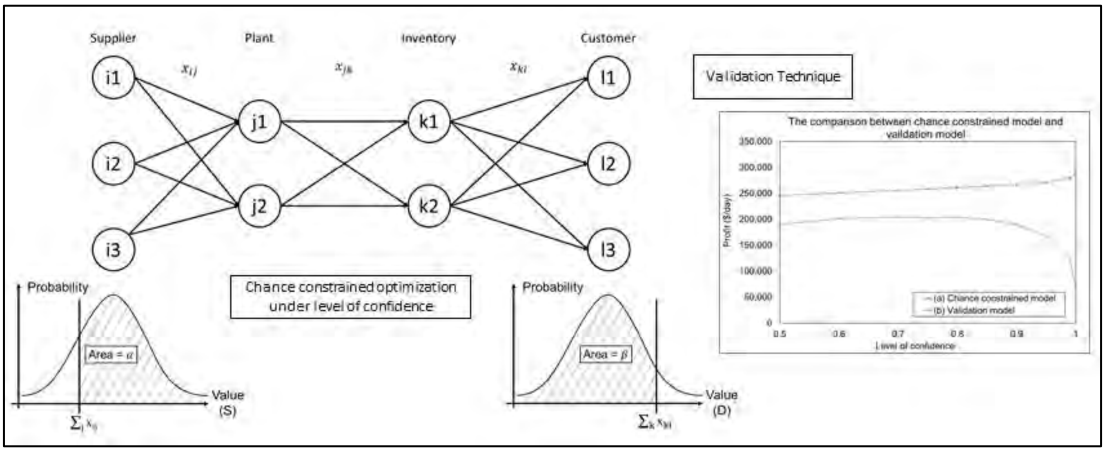
The two case studies have been used to show the effectiveness of chance constrained optimization: the simple supply chain network and the biodiesel supply chain network. The objective of the optimization is to maximize the profit under the different levels of confidence. After obtaining the optimized supply chain, the networks from chance constrained optimization and deterministic optimization have been investigated and compared on the validation and violation of constraints. The results show that the chance constrained optimization can provide higher profit than the deterministic optimization under appropriate level of confidence. The violation of constraints results show that the stability of the network has been improved at higher levels of confidence. Finally, the sensitivity analysis shows that the opportunity loss played the major effect in the system.

บทคัดย่อ

กันต์ รุ่งพานิช : ชื่อหัวข้อวิทยานิพนธ์ การหาค่าเหมาะที่สุดแบบเงื่อนไขบังคับโอกาส สำหรับห่วงโซ่อุปทานของปิโตรเคมีและวิธีการการตรวจสอบ (Chance Constrained Optimization for Petrochemical Supply Chain with the Validation Technique) อ. ที่ปรึกษา : ผศ.ดร. กิติพัฒน์ สีมานนท์ ๑๒๐ หน้า

ในปัจจุบันการแสวงหากำไรในการทำอุตสาหกรรมเป็นเรื่องที่กังวนมากขึ้น เนื่องจากการที่มีคู่แข่งทางการค้ามากขึ้น ดังนั้นการลดต้นทุนจึงเป็นสิ่งสำคัญเพื่อให้กิจการอยู่รอดได้ การหาค่าเหมาะที่สุดแบบสโทแคสติกเป็นหนึ่งในวิธีที่น่าสนใจในการลดต้นทุนจากความสูญเสียในระบบเนื่องจากความแปรปรวน การหาค่าเหมาะที่สุดแบบเงื่อนไขบังคับโอกาสเป็นหนึ่งในวิธีการแก้ไขปัญหาแบบสโทแคสติกโดยการแปลงความแปรปรวนของเหตุการเป็นเงื่อนไขโอกาสภายใต้ระดับของความมั่นใจ ข้อดีของวิธีการนี้คือทำให้ได้ห่วงโซ่อุปทานที่สมจริงมากขึ้นและมีเสถียรภาพกว่าการหาค่าเหมาะที่สุดแบบเชิงกำหนด ตัวอย่างสองตัวอย่างถูกนำมาใช้ในการแสดงศักยภาพของการหาค่าเหมาะที่สุดแบบเงื่อนไขบังคับโอกาส ตัวอย่างแรกคือห่วงโซ่อุปทานอย่างง่ายและตัวอย่างที่สองคือห่วงโซ่อุปทานของไบโอดีเซล โดยวัตถุประสงค์ของการหาค่าเหมาะที่สุดคือการหาค่าที่มากที่สุดของกำไรภายใต้ระดับของความมั่นใจที่แตกต่างกัน หลังจากได้ห่วงโซ่อุปทานที่ได้รับการหาค่าที่มากที่สุดแล้วจึงทำการสอบสวนที่มาของคำตอบโดยการทำการตรวจสอบความถูกต้องของกำไรและความมั่นคงของห่วงโซ่อุปทาน ผลที่ได้คือการหาค่าเหมาะที่สุดแบบเงื่อนไขบังคับโอกาสนั้นช่วยทำให้กำไรมากขึ้นจากการหาค่าเหมาะที่สุดแบบเชิงกำหนดภายใต้ระดับของความมั่นใจที่เหมาะสม และความมั่นคงของระบบได้มีการพัฒนาขึ้น

GRAPHICAL ABSTRACT



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NOMENCLATURE

Set

I	Set of suppliers
J	Set of plants
K	Set of inventories
L	Set of customers
N	Set of order of magnitude to conversion correlation

Index

i	Index of suppliers	$i \in I$
j	Index of plants	$j \in J$
k	Index of inventories	$k \in K$
l	Index of customers	$l \in L$
n	Index of order of magnitude to conversion correlation	$n \in N$

Scalar

M	Big positive number

Parameter

α, β	Level of confidence	
C	Conversion correlation	
	C_{CU}	cold utility usage correlation factor
	C_{EU}	electric energy usage correlation factor
	C_{H_2}	hydrogen usage correlation factor
	C_{HU}	hot utility usage correlation factor
	C_s	conversion of steric acid correlation factor
c	Cost	
	c_p	opportunity loss cost per unit
	c_t	transportation cost per unit
p	Price	

p_{BD} biodiesel price

p_{CU} cold utility price

p_{EU} electric energy price

p_{H_2} hydrogen price

p_{HU} hot utility price

p_s steric acid price

SP Specification

SP_{av} average value of specification

SP_{sd} standard deviation value of specification

SP_{rand} random value of specification

SP_{LB} lower bound value of specification

SP_{UB} upper bound value of specification

x_s Initial state supply chain network

Variable

CU Quantity of cold utility usage

EU Quantity of electric energy usage

HU Quantity of hot utility usage

x_{H_2} Quantity of hydrogen usage

P Loss in the system

P^{po} over-demand loss

P^{ne} opportunity loss

R Remainder

x Quantity in supply chain network

x_r recalculated quantity in supply chain network

y Decision variable

zz Objective value (profit)

Function

Pr Cumulative distribution function

ϕ^{-1} Inverse cumulative distribution function for normal distribution

CHAPTER I
INTRODUCTION

1.1 Supply chain network and optimization role in supply chain network

In business and finance study, supply chain network is the system to organize information or resources. Main activities involve conversion of raw materials to products and transportation of products to customers (Nagurney 2006). The supply chain network is used to simplify information of the flow of raw materials, but more importantly, total cost that occur in the system.

Nowadays the industry is more competitive. The reduction of the cost and loss becomes main focus to maintain competitiveness. Optimization has played the huge role to achieve the minimum-cost supply chain network.

1.2 Mathematical model of supply chain network

In general, the mathematical model means the representation of experienceable system with mathematical equations (Dubois 2018). The main advantage of the mathematical model is it can be used to predict the outcome of the system. In the supply chain network case, the main objective of the mathematical model usually is minimizing cost or maximizing profit. Then constraints such as specification and mass balance equations are added to the system. After that, the optimizer is used to give the optimized solution under the constraints.

There are two approaches of the optimization. The first one is the deterministic optimization, the certain values or known values are used in this type of the optimization. The other is the stochastic optimization, the uncertain values or unknow values are used. The uncertain values can be expressed in term of the probability density function, the most common used one is the normal distribution. Nowadays, the stochastic optimization gained the popularity due to real processes always have the uncertainty. The advantage is that the stochastic optimization can detect and optimize loss in the system that deterministic optimization cannot do. This brings the new optimum points. But the disadvantages are more complexity of the model and more the computational time used in the stochastic optimization.

The purpose of this work is to create model for stochastics supply chain network in petrochemical processes and optimize the model to design the most profitable petrochemical supply chain with the validation method to see the effect of uncertainty.

1.3 The biodiesel supply chain network

In this work, the biodiesel supply chain network is used to show the effectiveness of the stochastic optimization. Energy is one of the necessities in everyday life and its demand is getting higher every year. The U.S. Energy Information Administration (2019) reported that the total energy usage in 2018 was 105.72×10^9 GJ and they predict that it will grow to 112.50×10^9 GJ in 2050. The transportation segment is the second largest. Therefore, the sustainable energy has been concerned. The first generation of biodiesel is Fatty Acid Methyl Esters (FAME) via transesterification process. However due to high oxygenated contents in this type of biodiesel, the fuel cannot be used practically as transportation fuel. The next generation of biodiesel is Bio Hydrogenated Diesel (BHD) via dehydrogenation process. This method improves fuel properties by remove oxygenated group from product (Chen *et al.* 2019).

When production scale of biodiesel increases, the supply chain problems of uncertainty occurs (Gao and You 2017) especially in availability of feedstock and demand for biodiesel. For the availability of feedstock, currently the main raw material for biodiesel is edible plants (Avhad and Marchetti 2015) that share demand with food production. For the demand, biodiesel and diesel share demand in transportation fuel leading to uncertain demand of biodiesel. Therefore, the stochastic optimization is used to handle this problem.

CHAPTER II
LITERATURE REVIEW

2.1 Supply chain network

Harrison and Hoek (2008) defined supply chain as the flow of materials or information from basic commodities or raw materials to final products for end-customer through many processes that are linked together to form the chain. From above definition, the supply chain can be divided into two types; materials and information flow supply chains. The main focus of this thesis is on the materials flow supply chain. Figure 2.1 shows the simple materials flow of raw materials from supplier to plant then transform into products at the plant and finally transfer to customer.

Figure 2.1 The example of simple materials flow supply chain for factory.

But in the reality, more suppliers compete for selling more raw materials. More plants produce more products (in case of a new plant). Customers demand more products under production limitation. And finally, more units, like inventory unit, are needed in supply chain. The supply chain network can be formed as shown in Figure 2.2.

To formulate the mathematical problem, the objective function can be formulated as minimizing cost or maximizing profit. Material balance is one of the fundamental equations used to connect input and output in each node in supply chain. For suppliers, customers and plants, they have specification for themselves. Suppliers have upper limit of supplier's capacity, customers have lower limit of demand and plants have conversion. The inventories can be formulated as steady state that have only upper limit capacity or can be formulated as time dependent (so-called inventory routing problem). In this work, the steady state assumption has been applied.

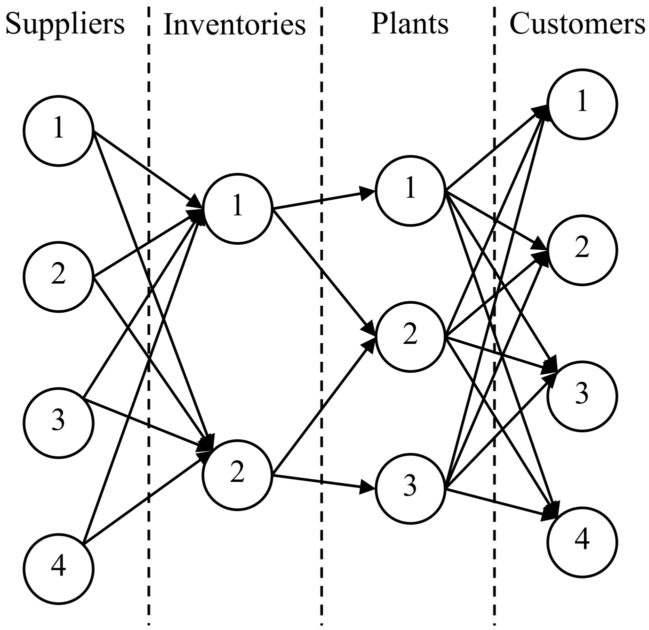

Figure 2.2 General flow diagram of supply chain network.

2.2 Stochastic optimization problems

In the general, stochastic means random determined, random possibility or pattern. So, stochastic optimizations mean that the using of random variable in optimization problem. The stochastic optimizations are widely used than the deterministic optimization because the randomness or noise can be concluded in the models (Gentle *et al.* 2004). The examples of stochastic optimizations problem are supply chain problem (Kim *et al.* 2011, Shaw *et al.* 2016, Gonela 2018), inventory policies problem (Lin and Wang 2018), process design problem (Steimel and Engell 2015) and process control problem (Li *et al.* 2008).

2.3 Chance constrained optimization

One of the approaches in stochastic optimization is chance constrained optimization introduced by Charnes and Cooper (1959) and Miller and Wagner (1965). The main feature is that the optimum solutions ensure with certain probability, i.e. level of confidence by applying the chance constraints. Thus, the relationship between solution and reliability can be found. Li *et al.* (2008) classify the chance constrained optimization as shown in Table 2.1. The individual or single chance constraint is the most used to optimize problem due to the problem simplicity and calculation time.

Table 2.1 Classification of chance constrained optimization (Adapt from Li *et al.* (2008)).

Process		Uncertainty	Chance constraint
1) Linear	1) Steady state	1) Constant	1) Individual or Single
2) Nonlinear	2) Dynamic	2) Time-dependence	2) Joint

The general form of individual chance constrained problem is shown as follows:

$$\max/\min f(\mathbf{x}, \boldsymbol{\xi}) \tag{2.1}$$

Subject to:

$$g_n(\mathbf{x}, \boldsymbol{\xi}) = 0 \qquad n = 1, \dots, N \tag{2.2}$$

$$h_m(\mathbf{x}, \boldsymbol{\xi}) \geq 0 \qquad m = 1, \dots, M \tag{2.3}$$

$$\Pr\big(\mathbf{x} \leq \mathbf{b}(\boldsymbol{\xi})\big) \geq \boldsymbol{\alpha} \tag{2.4}$$

Where f is objective function. g and h are the equality and inequality constraints in model. $\mathbf{x}$, $\mathbf{b}$ and $\boldsymbol{\xi}$ are state value in model where $\boldsymbol{\xi}$ represent the uncertainty in system. Finally, the individual chance constraint is shown in equation (2.4).

2.3.1 Deterministic equivalence (Charnes and Cooper 1959, Bilsel and Ravindran 2011, Nazemi and Tahmasbi 2013)

The chance constraint can be rewritten into the cumulative density function for any probability distribution. Therefore, equation (2.4) can be rewritten to equation (2.5) where $\mathrm{f}_{\mathbf{b}(\boldsymbol{\xi})}$ is the probability density function for random variable $\mathbf{b}(\boldsymbol{\xi})$. The main problem is to handle the integral sign inside the optimization.

$$-\int_{-\infty}^{\mathbf{x}} \mathrm{f}_{\mathbf{b}(\boldsymbol{\xi})}(\mathrm{t})\mathrm{dt} \geq \boldsymbol{\alpha} \tag{2.5}$$

Deterministic equivalence is one of method to solve chance constrained problem. The special form of deterministic equivalence can be applied to normal distribution variable as shown in Table 2.2. Where ϕ^{-1} is inverse cumulative distribution function for normal distribution, $\overline{\mathbf{b}}$ and $\mathbf{b}_{sd}$ represent $\mathbf{b}(\boldsymbol{\xi})$ in term of average and standard distribution.

Table 2.2 Some of the deterministic equivalence form (Nazemi and Tahmasbi 2013)

Chance constraint	Deterministic equivalence form
$\Pr\big(\mathbf{x} \leq \mathbf{b}(\boldsymbol{\xi})\big) \geq \boldsymbol{\alpha}$	$\mathbf{x} \leq \overline{\mathbf{b}} + \phi^{-1}(1 - \boldsymbol{\alpha})\mathbf{b}_{sd}$
$\Pr\big(\mathbf{x} \geq \mathbf{b}(\boldsymbol{\xi})\big) \geq \boldsymbol{\alpha}$	$\mathbf{x} \geq \overline{\mathbf{b}} - \phi^{-1}(1 - \boldsymbol{\alpha})\mathbf{b}_{sd}$

CHAPTER III
METHODOLOGY

3.1 Chance constrained mathematical model

For the first case study, the supply chain has with four echelons: suppliers(i), plants(j), inventories(k) and customers(l). The uncertainties in the system only affect suppliers and customers. The mathematical model for designing supply chain network is expressed as shown below.

$$\max(zz) = p \sum_k \sum_l \left(x_{kl} - P_l^{po}\right) - \left[\sum_i \sum_j c_{t,ij} x_{ij} + \sum_j \sum_k c_{t,jk} x_{jk} + \sum_k \sum_l c_{t,kl} x_{kl} \right] - c_p \sum_l P_l^{ne} \quad (3.1)$$

Subject to:

$$\sum_i x_{ij} = \sum_k x_{jk} \quad (3.2)$$

$$\sum_j x_{jk} = \sum_l x_{kl} \quad (3.3)$$

$$\sum_k x_{jk} \geq SP_{j,av,LB} \quad (3.4)$$

$$\sum_k x_{jk} \leq SP_{j,av,UB} \quad (3.5)$$

$$\sum_j x_{jk} \leq SP_{k,av} \quad (3.6)$$

$$\Pr\left(\sum_j x_{ij} \leq SP_{i,rand}\right) \geq \alpha_i \quad (3.7)$$

$$\Pr\left(\sum_k x_{kl} \geq SP_{l,rand}\right) \geq \beta_l \quad (3.8)$$

The main objective for this model is to maximize profit. The objective function is expressed into four parts: revenue, transportation cost and penalty cost as shown in equation (3.1). The penalty in this model is opportunity loss but the over demand products are not sold to customers. Equation (3.2) deals with mass balance around plants. equation (3.3) deals with mass balance around inventories. equations (3.4) and (3.5) deal with the minimum and maximum capacity of plants, respectively. equation (3.6) deals with the maximum capacity of inventories. equations (3.7) and (3.8) deal with suppliers and customers in term of chance constraints within different levels of confidence (α_i and β_j).

The deterministic equivalent form is used to solve this problem. Equations (3.7) and (3.8) (the chance constraints equation) are transformed to Equation (3.9) and (3.10) respectively.

$$\sum_j x_{ij} \leq SP_{i,av} + \phi^{-1}(1 - \alpha_i) \bullet SP_{i,sd} \tag{3.9}$$

$$\sum_k x_{kl} \geq SP_{l,av} - \phi^{-1}(1 - \beta_l) \bullet SP_{l,sd} \tag{3.10}$$

Furthermore, the equation (3.10) has been modified to equations (3.11) - (3.13) to calculate penalty in model.

$$\sum_k x_{kl} + P_l^{ne} - P_l^{po} \geq SP_{l,av} - \phi^{-1}(1 - \beta_l) \bullet SP_{l,sd} \tag{3.11}$$

$$\sum_k x_{kl} - P_l^{po} \leq SP_{l,av} - \phi^{-1}(1 - \beta_l) \bullet SP_{l,sd} \tag{3.12}$$

$$\sum_k x_{kl} + P_l^{ne} \geq SP_{l,av} - \phi^{-1}(1 - \beta_l) \bullet SP_{l,sd} \tag{3.13}$$

3.2 Investigation on optimized supply chain network

The optimized supply chain network has been investigated on stability of supply chain network and validation of profit under certain time period. The stability and validation test are used to see the effect of uncertainty in supply chain network. The time period in this work is 3,300 days (330 days/year and 10 years).

3.2.1 Validation of the optimized supply chain network

The validation of the optimized supply chain network is a challenge problem because the optimized supply chain network can be infeasible under new random values for example the random capacity of supplier can be less than the require value in optimized supply chain network. This leads to error in the calculation. Therefore, validation model has been introduced to recalculate the network from the initial state. The validation model can be expressed as shown below.

$$\max(zz) = p \sum_k \sum_l \left(x_{r,kl} - P_l^{po}\right) - \left[\sum_i \sum_j c_{t,ij} x_{r,ij} + \sum_j \sum_k c_{t,jk} x_{r,jk} + \sum_k \sum_l c_{t,kl} x_{r,kl} \right] - c_p \sum_l P_l^{ne} \tag{3.14}$$

Subject to:

$$x_{r,ij} + R_{ij} = x_{s,ij} \tag{3.15}$$

$$x_{r,jk} + R_{jk} = x_{s,jk} \tag{3.16}$$

$$x_{r,kl} + R_{kl} = x_{s,kl} \tag{3.17}$$

$$M \bullet (y_i - 1) \leq SP_{i,rand} - \sum_j x_{s,ij} \leq M \bullet y_i \tag{3.18}$$

$$y_i \bullet \left(\sum_j x_{r,ij} - \sum_j x_{s,ij}\right) = 0 \tag{3.19}$$

$$(1 - y_i) \bullet \left(\sum_j x_{r,ij} - SP_{i,rand}\right) \leq 0 \tag{3.20}$$

$$\sum_i x_{r,ij} = \sum_k x_{r,jk} \tag{3.21}$$

$$\sum_j x_{r,jk} = \sum_l x_{r,kl} \tag{3.22}$$

$$\sum_k x_{r,jk} \geq SP_{j,av,LB} \tag{3.23}$$

$$\sum_k x_{r,jk} \leq SP_{j,av,UB} \tag{3.24}$$

$$\sum_j x_{r,jk} \leq SP_{k,av} \tag{3.25}$$

$$\sum_j x_{r,ij} \leq SP_{i,rand} \tag{3.26}$$

$$\sum_k x_{r,kl} + P_l^{ne} - P_l^{po} = SP_{l,rand} \tag{3.27}$$

$$\sum_k x_{r,kl} - P_l^{po} \leq SP_{l,rand} \tag{3.28}$$

$$\sum_k x_{r,kl} + P_l^{ne} \geq SP_{l,rand} \tag{3.29}$$

The new variable x_r and parameter x_s have been introduced as recalculated supply chain network and initial state supply chain network respectively. Equations (3.15) - (3.17) are used to balance the recalculated supply chain network and initial state supply chain network with remainder R. Therefore, the maximum value of recalculated supply chain network is equal to the initial state supply chain network. Equation (3.18) is used to deals with decision for the mode of recalculation. Equations (3.19) and (3.20) are used to recalculate the new values of supply chain network as same as initial state or lower than the specification values. Finally, the variable x_r is used to substitute x in the previous model so the model can use the recalculated supply chain network value in the model. The objective function is rewritten into equation(3.14). The constraints equations (3.2) - (3.6), (3.9) and (3.11) - (3.13) are rewritten into equations (3.21) - (3.29).

3.2.2 Stability test of the optimized supply chain network

The stability of network can be obtained from non-violation or feasibility condition in constraints; Equations (3.7) and (3.8) where $SP_{i,rand}$ and $SP_{l,rand}$ are randomly generated based on normal distribution data of suppliers availability and demand, respectively. Then the levels of confidence of suppliers and customers are validated from total number of feasible data points over total number of random data points (time period of 3,330 days). In addition, the higher data points (time period of 100,000 days) are used to see the effect of the number of the data points on the accuracy of the calculated levels of confidence.

3.3 An illustrative example

3.3.1 Simple supply chain network

The simple supply chain network with four echelons: suppliers (i), plants (j), inventories (k) and customers (l) is shown in Figure 3.1. In this case, the presumable data is used to show the effectiveness of the chance constrained model. The objective of the optimization is maximized profit under uncertainty in suppliers and customers with different level of confidence. Then the results are investigated by validation model and stability test. Table 3.1 shows data related to capacity of suppliers, plants, inventory and demand of customers. Table 3.2 shows product price and penalty cost. Table 3.3 shows transportation cost in dollar per unit.

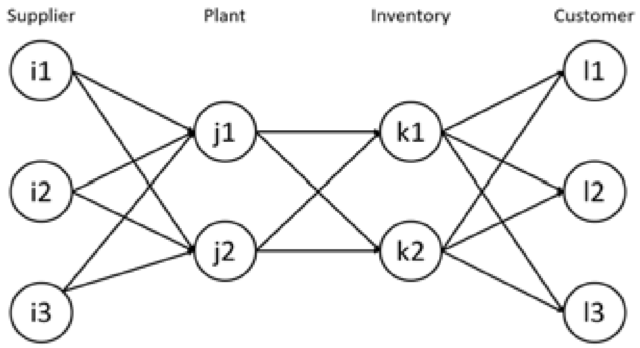

Figure 3.1 The simple supply chain network diagram

Table 3.1 Data related to capacity and demand for simple supply chain network.

		Supplier			Plant		Inventory		Customer		
		i1	i2	i3	j1	j2	k1	k2	l1	l2	l3
Average Capacity	UB:	300	350	300	350	250	250	300	-	-	-
or Demand (unit/d)	LB:	-	-	-	-	-	-	-	100	150	100
Standard Deviation (unit/d)		30	35	30	-	-	-	-	10	15	10

Table 3.2 Price and penalty cost for simple supply chain network.

Price			Penalty cost		
Raw material	-	$/unit	Opportunity loss	12	$/unit
Product	15	$/unit	Over demand loss	0	$/unit

Table 3.3 Transportation cost for simple supply chain network.

Transportation cost from supplier to plant ($/unit)			Transportation cost from plant to inventory ($/unit)			Transportation cost from inventory to customer ($/unit)			
	j1	j2		k1	k2		l1	l2	l3
i1	2	4	j1	3	1	k1	2	3	2
i2	3	5	j2	2	4	k2	1	4	2
i3	1	3							

3.3.2 Biodiesel supply chain network

The biodiesel plant has been simulated. Steric acid from vegetable oil is the main feed with hydrogen as co-feed to produce BHD. The kinetic models of BHD process are used to calculate biodiesel production rate, hydrogen, hot utility, cold utility and electric energy usage in biodiesel plant. The kinetic models of BHD process can be expressed by Arrhenius equation as shown in equation (3.30) with constant parameters, shown in Table 3.4.

$$k = A_0 e^{-Ea/RT} \tag{3.30}$$

Where

k	is the rate constant
A_0	is the pre-exponential factor
Ea	is the activation energy
R	is the gas constant
T	is the temperature

The detail of the simple biodiesel plant is shown in Table 3.5. The product specification of biodiesel is 90 % w/w purity. The simulation data of biodiesel production rate, hydrogen usage, hot utility, cold utility and electrical energy usage which are collected at different feed flow rates of steric acid to find the correlation between them.

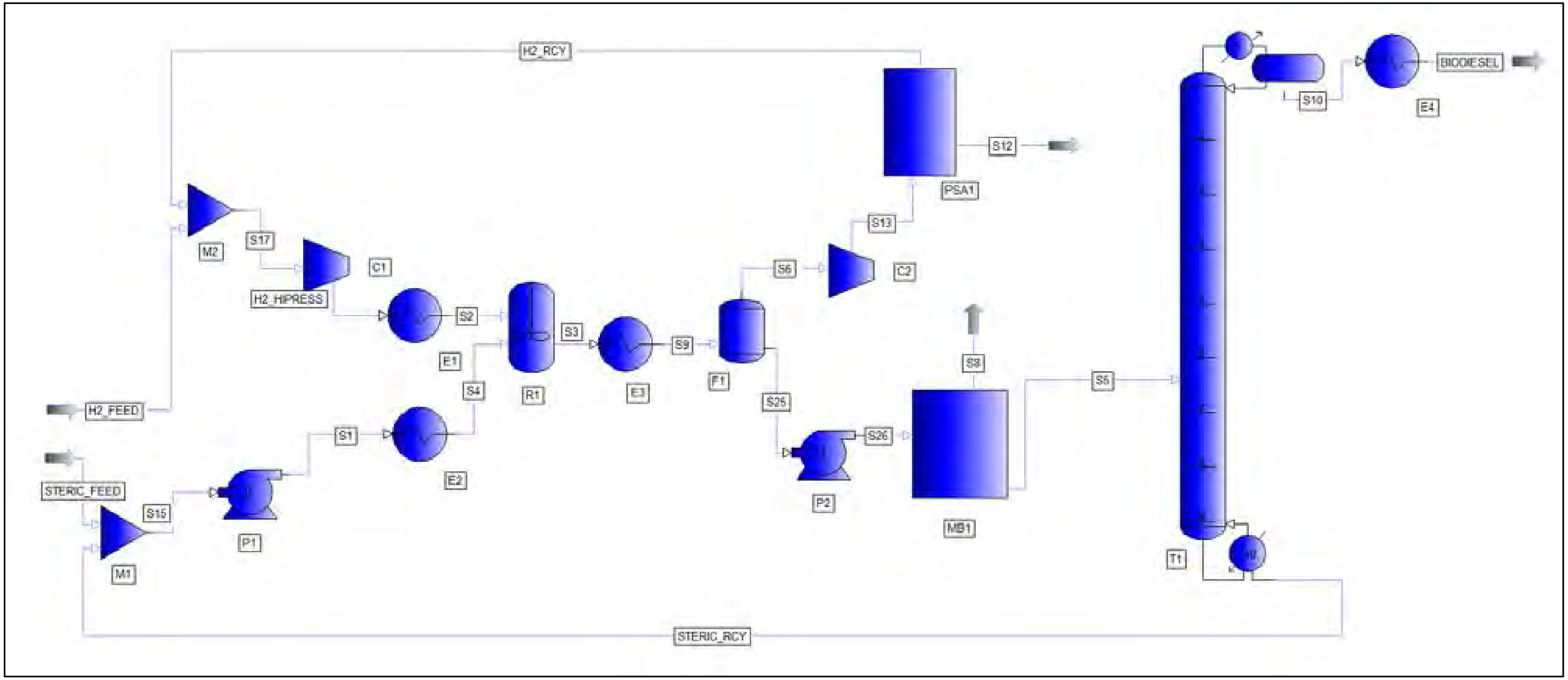

Figure 3.2 The design of biodiesel plant.

Table 3.4 Kinetic models for biodiesel plant (Kumar *et al.* 2014).

Reaction	Ea (kJ/mol)	A_0 (s^{-1})
$C_{17}H_{35}COOH + 2H_2 \rightarrow C_{18}H_{37}OH + H_2O$	175.4	$5.57x10^{12}$
$C_{18}H_{37}OH \rightarrow C_{17}H_{36} + H_2 + CO$	250.0	$1.34x10^{21}$
$C_{18}H_{37}OH + H_2 \rightarrow C_{18}H_{38} + H_2O$	190.9	$4.77x10^{13}$
$C_{18}H_{37}OH + 2H_2 \rightarrow C_{15}H_{32} + C_3H_8 + H_2O$	387.7	$5.08x10^{32}$
$C_{18}H_{37}OH + 2H_2 \rightarrow C_{16}H_{34} + C_2H_6 + H_2O$	377.2	$1.08x10^{32}$

Steric acid is $C_{17}H_{35}COOH$ BHD is $C_{15}H_{32}$, $C_{16}H_{34}$, $C_{17}H_{36}$ and $C_{18}H_{38}$

Table 3.5 The specification of the biodiesel plant.

Name	Unit operation	Specification
E1	Heat exchanger	Cold product temperature 563 K
E2	Heat exchanger	Cold product temperature 563 K
E3	Heat exchanger	Hot product temperature 298.15 K
E4	Heat exchanger	Hot product temperature 298.15 K
C1	Compressor	Outlet pressure 8 bar, 100% efficiency
C2	Compressor	Outlet pressure 10 bar, 100% efficiency
P1	Pump	Outlet pressure 8 bar, 100% efficiency
P2	Pump	Outlet pressure 20 bar, 100% efficiency
R1	Reactor	Reactor size 1.57 m^3 (D = 1 m, L = 2 m) Fixed temperature 563 K Ratio between hydrogen and steric acid feed into reactor = 6:1
MB1	Membrane	100% recovery H_2, H_2O, CO, Ethane, Propane Outlet pressure 1 bar
PSA1	Pressure swing adsorption	85% recovery H_2 Outlet pressure 10 bar
T1	Tower	Number of trays: 10 Feed tray: 7 Condenser type: Bubble temperature Top tray pressure: 1 bar Specification 1: Steric flow rate (kg/h) in recycle line divided by Steric flow rate (kg/h) in feed to tower equal to 0.85. Specification 2: Tower reflux ratio equal to 2.

The biodiesel supply chain network is shown in Figure 3.1. Table 3.6 shows data related to capacity of suppliers(i), plants(j), inventory(k) and demand of customers(l). Table 3.7 shows product price and penalty cost. Table 3.8 shows transportation cost in dollar per unit.

Table 3.6 Data related to capacity and demand for biodiesel supply chain network.

		Average Capacity or Demand (l/d)	Standard Deviation (l/d)
Supplier	i1	UB: 10,000	1,000
	i2	UB: 12,500	1,250
	i3	UB: 9,500	950
Plant	j1	UB: 8,000 LB: 5,000	-
	j2	UB: 15,000 LB: 6,000	-
Inventory	k1	UB: 15,000	-
	k2	UB: 10,000	-
Customer	l1	LB: 3,000	300
	l2	LB: 7,500	750
	l3	LB: 5,000	500

Table 3.7 Price and penalty cost for biodiesel supply chain network.

Fluid price			Utility cost			Penalty cost		
Steric acid	20	$/l	Hot utility	5	$/kW·h	Opportunity loss	62.375	$/l
Hydrogen	5	$/l	Cold utility	2.5	$/kW·h	Over demand loss	0	$/l
Biodiesel	49.9	$/l	Electric energy	1.25	$/kW·h			

Table 3.8 Transportation cost for biodiesel supply chain network.

Transportation cost from supplier to plant ($/l)			Transportation cost from plant to inventory ($/l)			Transportation cost from inventory to customer ($/l)			
	j1	j2		k1	k2		l1	l2	l3
i1	2	4	j1	3	1	k1	2	3	2
i2	3	5	j2	2	4	k2	1	4	2
i3	1	3							

The mathematical model from the simple supply chain network has been modified as follows; adding the operation cost (3rd term) into objective function as shown in equation (3.31). Equation (3.2) is modified to equation (3.32) to calculate the biodiesel production rate in the plant. Finally, Equations (3.33) - (3.36) are added to calculate operating utilities of plants including hydrogen, hot utility, cold utility and electrical energy.

$$\max(zz) = p_{BD} \sum_k \sum_l \left(x_{kl} - P_l^{po}\right) - \left[\sum_i \sum_j c_{t,ij} x_{ij} + \sum_j \sum_k c_{t,jk} x_{jk} + \sum_k \sum_l c_{t,kl} x_{kl} \right]$$
$$- \left[p_s \sum_j x_{ij} + p_{H_2} \sum_j x_{H_2,j} + p_{HU} \sum_j HU_j + p_{CU} \sum_j CU_j + p_{EU} \sum_j EU_j\right]$$
$$-c_p \sum_l p_l^{ne} \quad (3.31)$$

$$\sum_n C_{s,n} \left(\sum_i x_{ij}\right)^n = \sum_k x_{jk} \quad (3.32)$$

$$x_{H_2,j} = \sum_n C_{H_2,n} \left(\sum_i x_{ij}\right)^n \quad (3.33)$$

$$HU_j = \sum_n C_{HU,n} \left(\sum_i x_{ij}\right)^n \quad (3.34)$$

$$CU_j = \sum_n C_{CU,n} \left(\sum_i x_{ij}\right)^n \quad (3.35)$$

$$EU_j = \sum_n C_{EU,n} \left(\sum_i x_{ij}\right)^n \quad (3.36)$$

In addition, sensitivity analysis of the optimized supply chain network is used to see the opportunity loss and the price of biodiesel effect on profit at different levels of confidence. For the sensitivity analysis of opportunity loss, the result can be obtained by varying penalty cost of opportunity loss with the same prices and costs. For the sensitivity analysis of biodiesel price, the result can be obtained by varying prices with the same penalty cost of opportunity loss. Then recalculate the validate profit at different levels of confidence for each case.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Simple Supply Chain Network

The network diagram at levels of confidence of 0.50, 0.80 and 0.999 are shown in Figure 4.1 to Figure 4.3. All of the network can be found in appendix A.

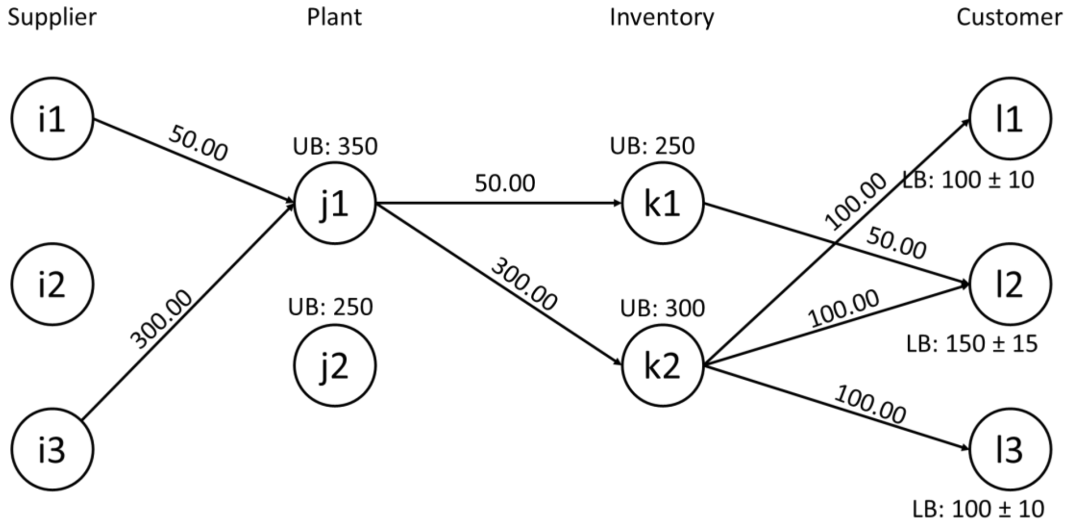

Figure 4.1 Supply chain network diagram for simple supply chain case at 0.50 level of confidence.

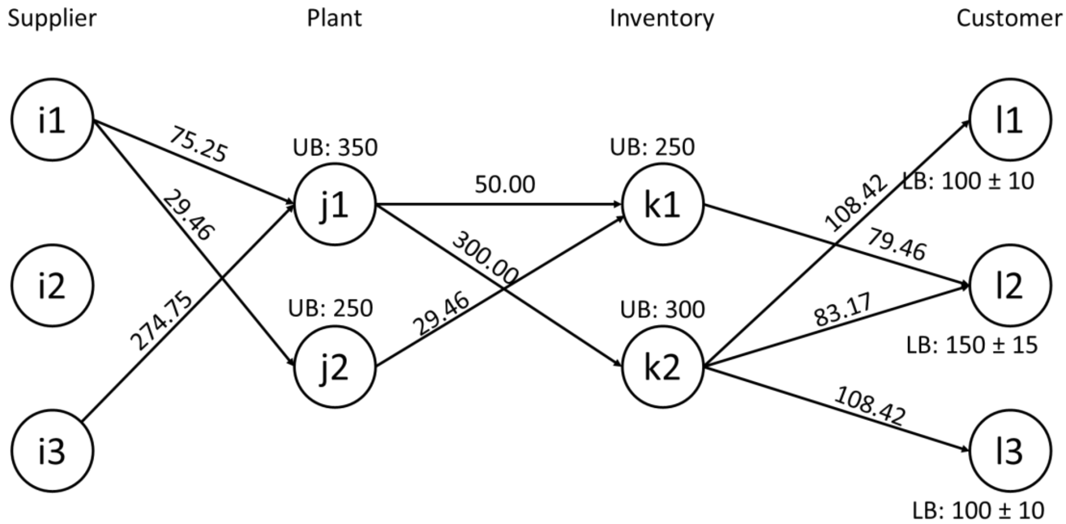

Figure 4.2 Supply chain network diagram for simple supply chain case at 0.80 level of confidence.

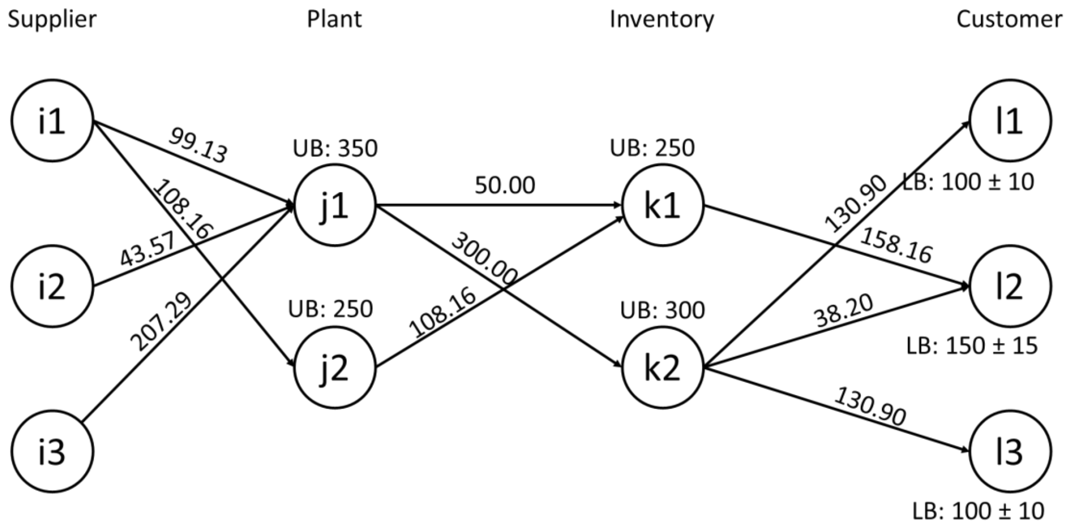

Figure 4.3 Supply chain network diagram for simple supply chain case at 0.999 level of confidence.

Figure 4.4 shows the result of optimized network for simple supply chain network by chance constrained optimization at different levels of confidence. The total value of each bar represents the revenue for each case. The level of confidence of 0.50 is representative of deterministic optimization. The result shows that at higher level of confidence, the higher profit can be obtained. This is because when deterministic equivalent form is used, the uncertainty in the system is converted as shown in the right hand side of equations (4.1) and (4.2). Table 4.1 shows that the capacity for each supplier decreases below the average values but the demand increases above the average values when using the deterministic equivalent form. Therefore, the required quantity in supply chain increases, resulting in increases of revenue and total cost.

$$\sum_j x_{ij} \leq SP_{i,av} + \phi^{-1}(1 - \alpha_i) \bullet SP_{i,sd} \tag{4.1}$$

$$\sum_k x_{kl} \geq SP_{l,av} - \phi^{-1}(1 - \beta_l) \bullet SP_{l,sd} \tag{4.2}$$

Table 4.1 Deterministic equivalent values of each node under uncertainty at different levels of confidence.

Node	AV	SD	Deterministic equivalent values (unit)						
			0.50	0.80	0.85	0.90	0.95	0.99	0.999
i1	300	30	300.00	274.75	268.91	261.55	250.65	230.21	207.29
i2	350	35	350.00	320.54	313.72	305.15	292.43	268.58	241.84
i3	300	30	300.00	274.75	268.91	261.55	250.65	230.21	207.29
l1	100	10	100.00	108.42	110.36	112.82	116.45	123.26	130.90
l2	150	15	150.00	162.62	165.55	169.22	174.67	184.90	196.35
l3	100	10	100.00	108.42	110.36	112.82	116.45	123.26	130.90

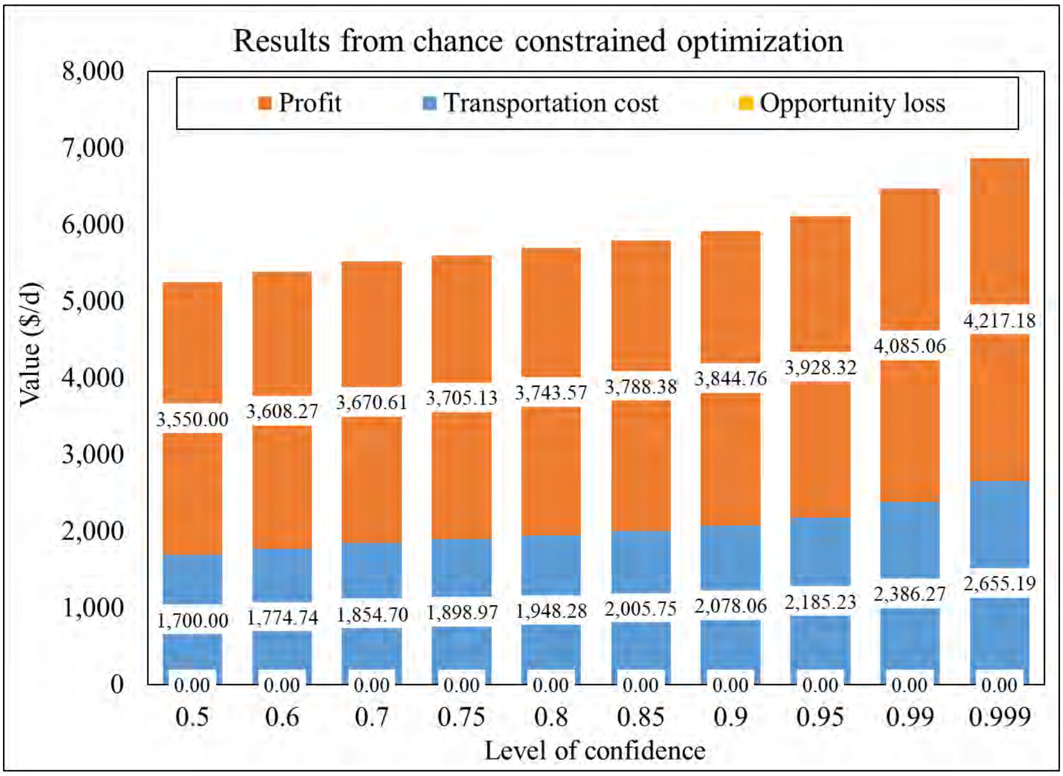

Figure 4.4 The results from chance constrained model for simple supply chain network.

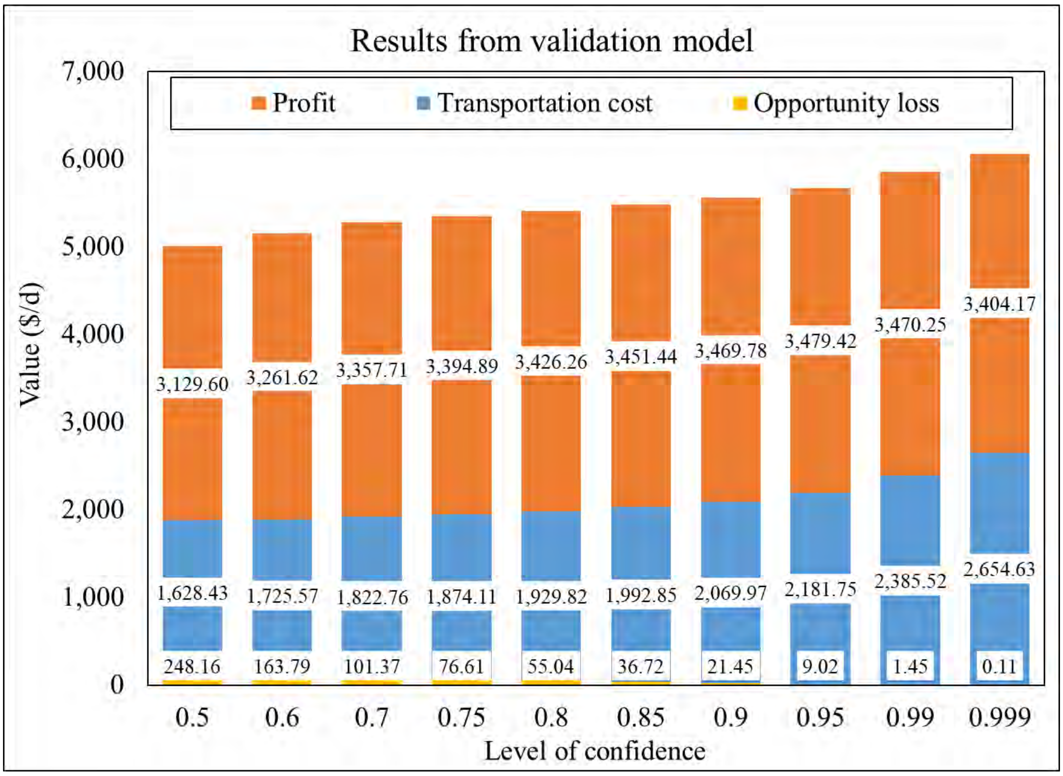

Figure 4.5 The results from validation model for simple supply chain network.

However, Figure 4.5 shows that the validated profit is lower than predict. Because the deterministic equivalent chance constrained model cannot calculate the penalty in the system. When deterministic equivalent form is used, the uncertainty in the system is converted as shown in Table 4.1. Therefore, the model trends to satisfy the constraint at the new certain value and does not have penalty in the network to minimize the cost in the system. The validation model is used to handle this problem.

The trend of profit has been investigated. Validated profit increases when level of confidence increases but at 0.999 level of confidence, the profit decreases, as shown as Figure 4.5. This can be explained as follows. The revenue and the transportation cost always increase due to higher material flow in network to satisfy more demands when level of confidence increases as shown in Figure 4.6 to Figure 4.11 where stability are shown for supply nodes; i1, i2 and i3 and demand node; l1, l2 and l3, at levels of confidence of 0.5, 0.8 and 0.999. In addition, the opportunity loss decreases when the level of confidence increases as the same reason. Therefore, the validated profit increases when the level of confidence increases.

However, at 0.999 level of confidence, the validated profit decreases due to the effect of over-demand in the network. The definition of the over-demand is the excess quantity of the product that larger than demand. In this case, the over demand does not add value toward the revenue but more transportation cost is added into the system. In addition, the penalty cost does not change significantly due to the less unsatisfaction occurs. Therefore, the profit is lower.

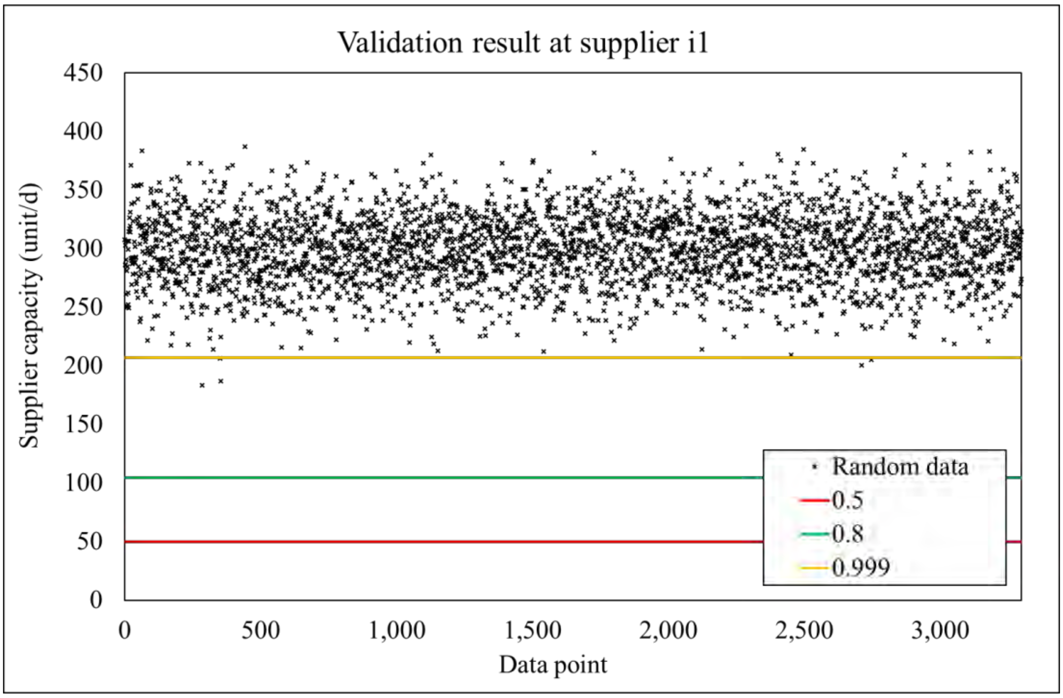

Figure 4.6 Validation result at supplier i1 for simple supply chain network.

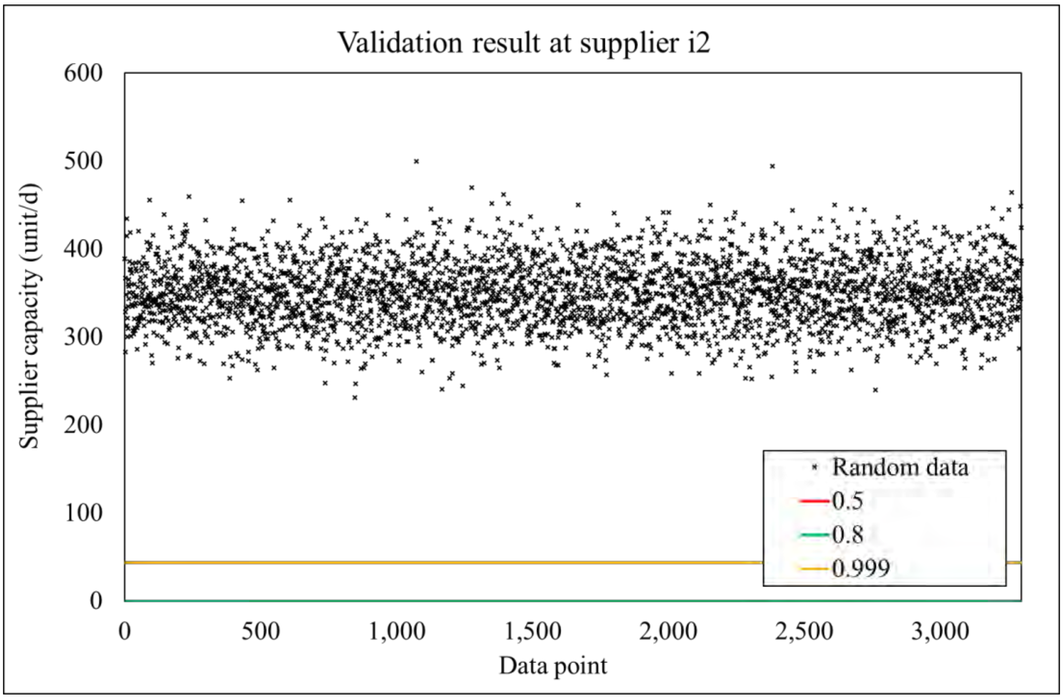

Figure 4.7 Validation result at supplier i2 for simple supply chain network.

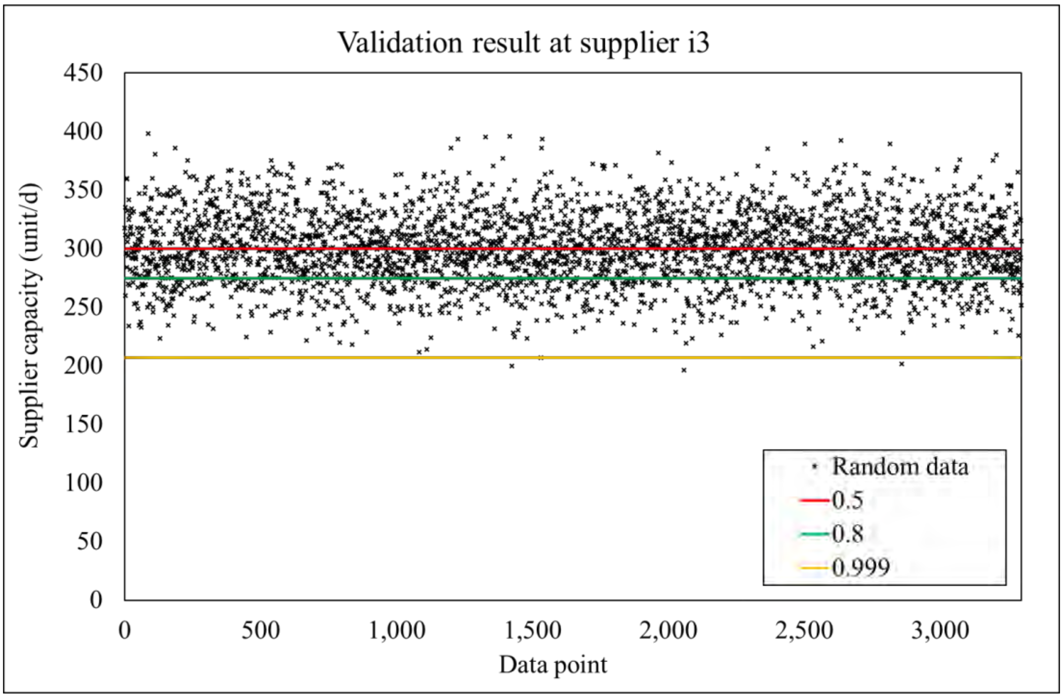

Figure 4.8 Validation result at supplier i3 for simple supply chain network.

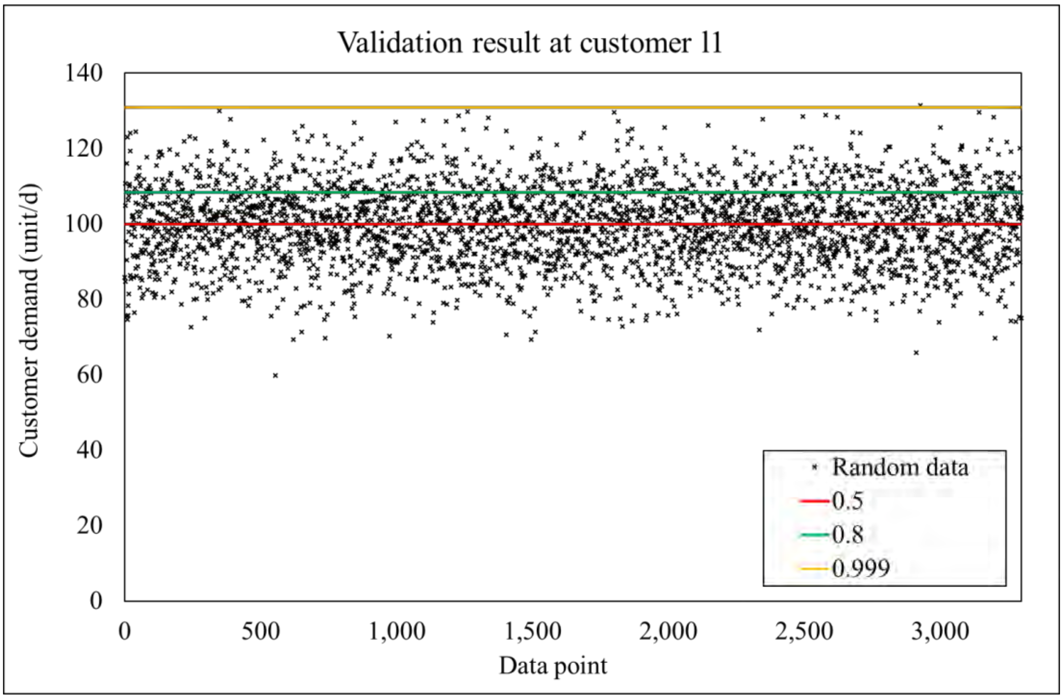

Figure 4.9 Validation result at customer l1 for simple supply chain network.

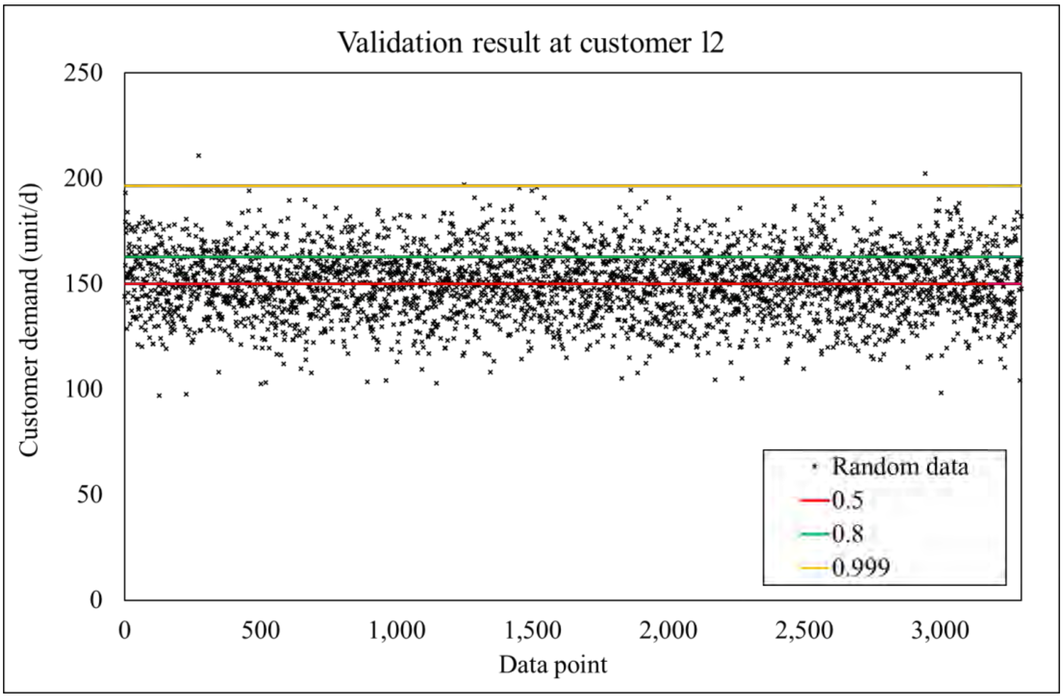

Figure 4.10 Validation result at customer l2 for simple supply chain network.

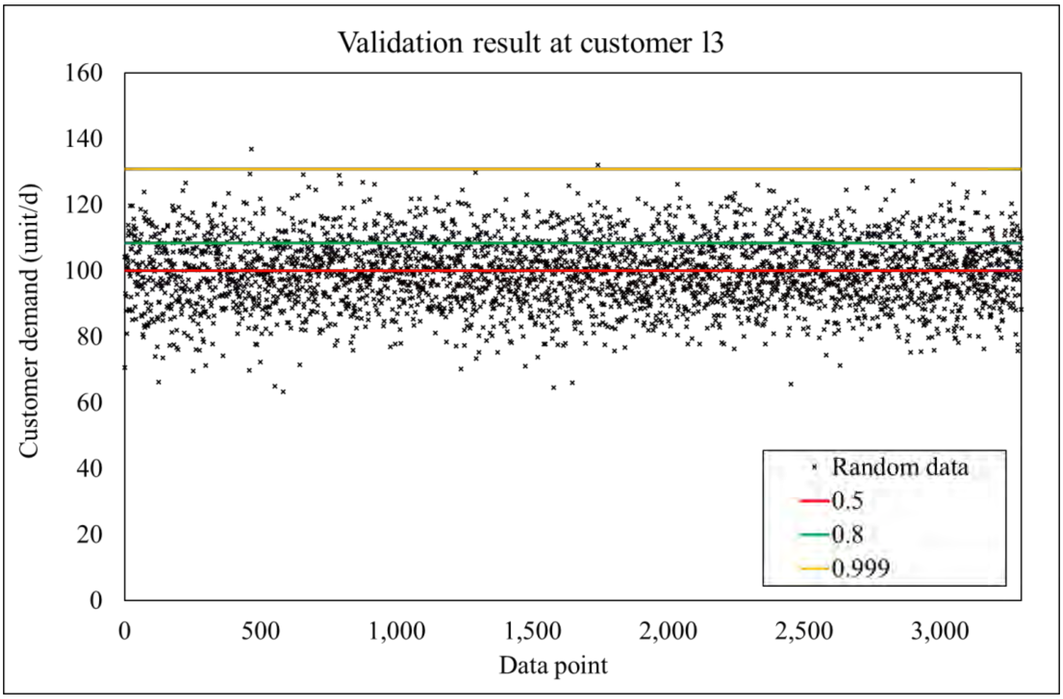

Figure 4.11 Validation result at customer l3 for simple supply chain network.

Figure 4.12 to Figure 4.17 show the summary result of stability of the network from the validation model for supply nodes; i1, i2 and i3 and demand node; l1, l2 and l3, at levels of confidence of 0.5, 0.8 and 0.999. The detailed results of the stability test can be found in appendix A. The result shows that the calculated values of level of confidence obtained from validation model are around or above the diagonal line; meaning that observed events, the maximum capacity of suppliers and the minimum demand of customers, are satisfied under the level of confidence used in chance constrained equations. Therefore, the chance constrained optimization gives the optimized network that did not violate the level of confidence.

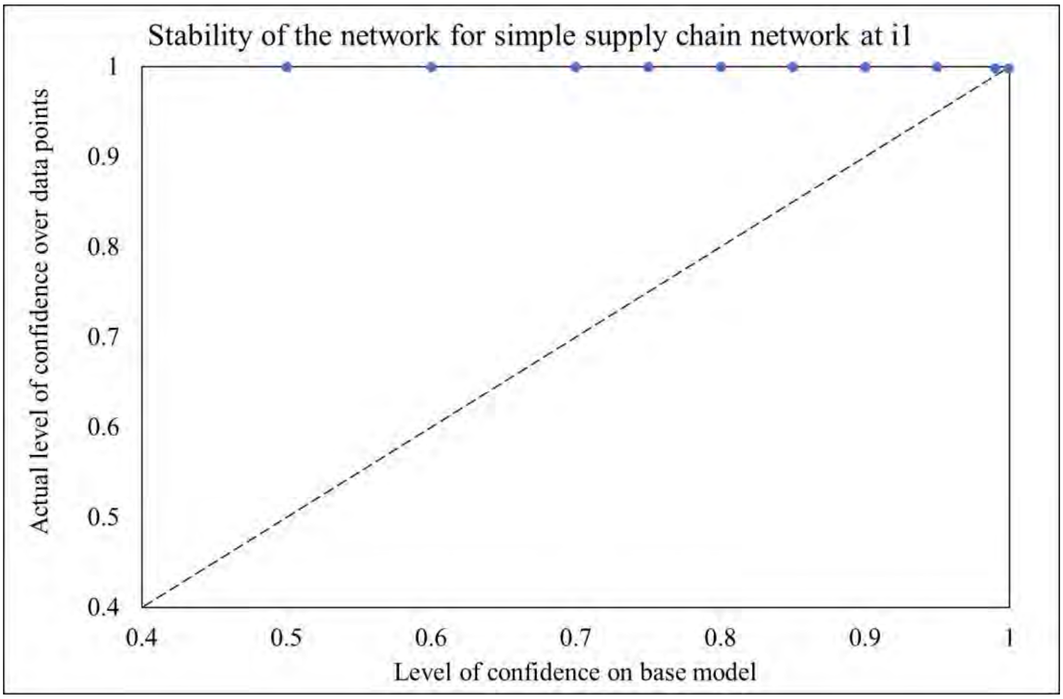

Figure 4.12 Result on the stability of network for simple supply chain case at i1.

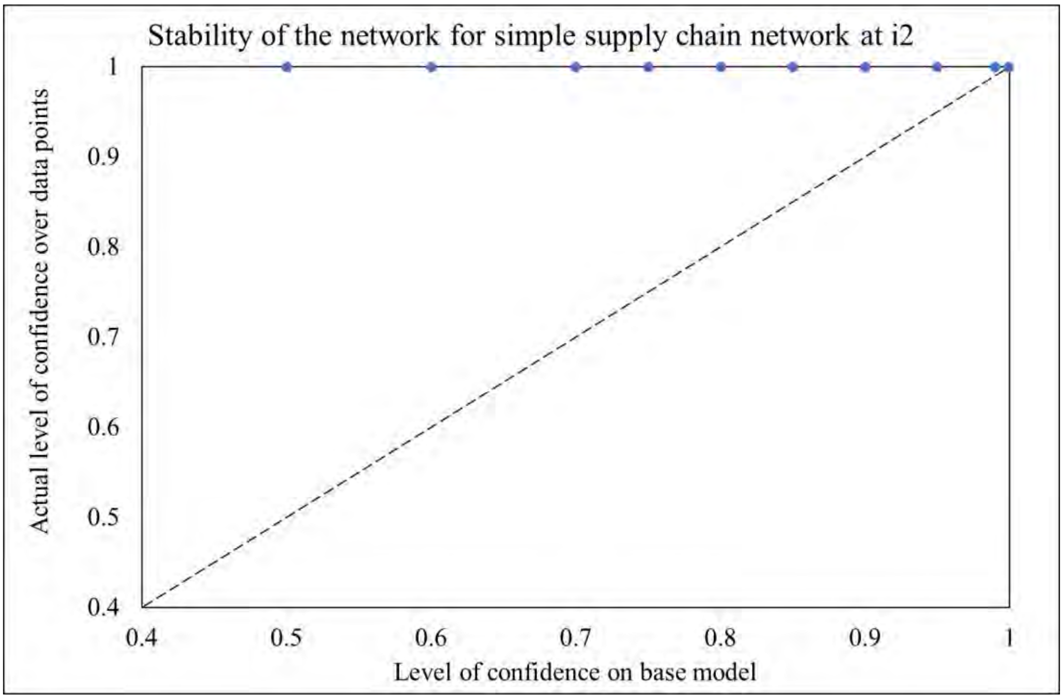

Figure 4.13 Result on the stability of network for simple supply chain case at i2.

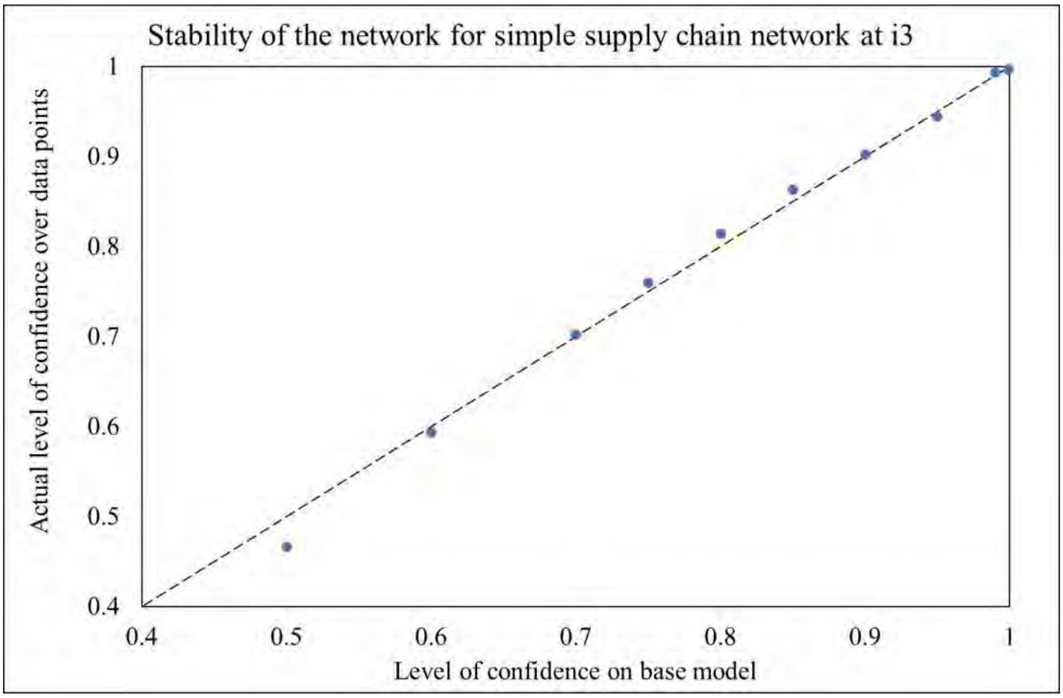

Figure 4.14 Result on the stability of network for simple supply chain case at i3.

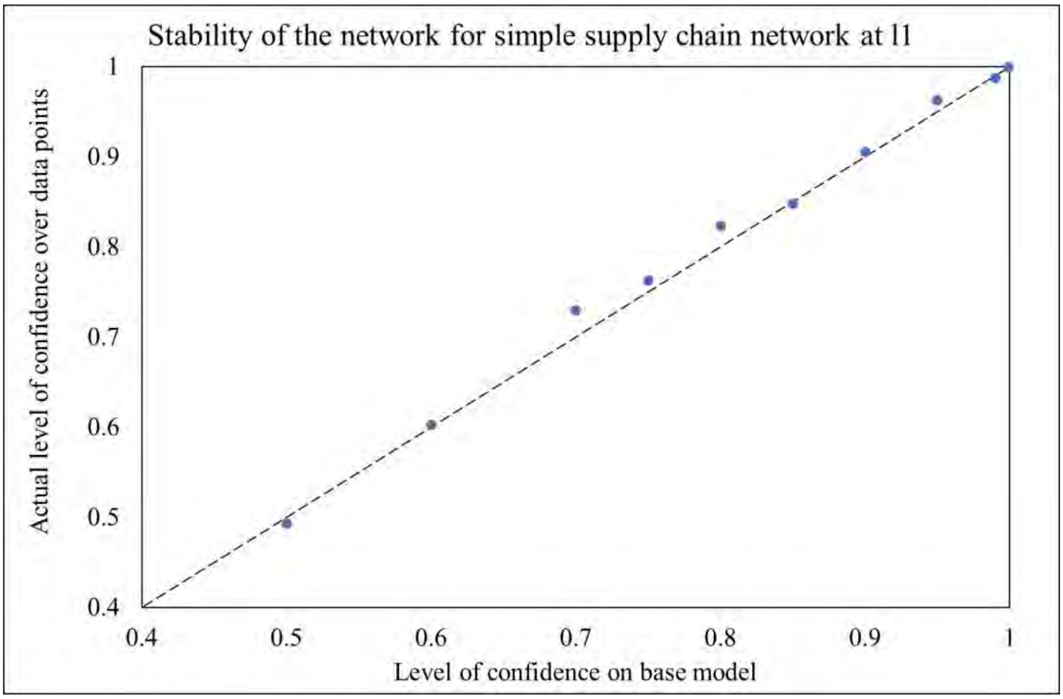

Figure 4.15 Result on the stability of network for simple supply chain case at l1.

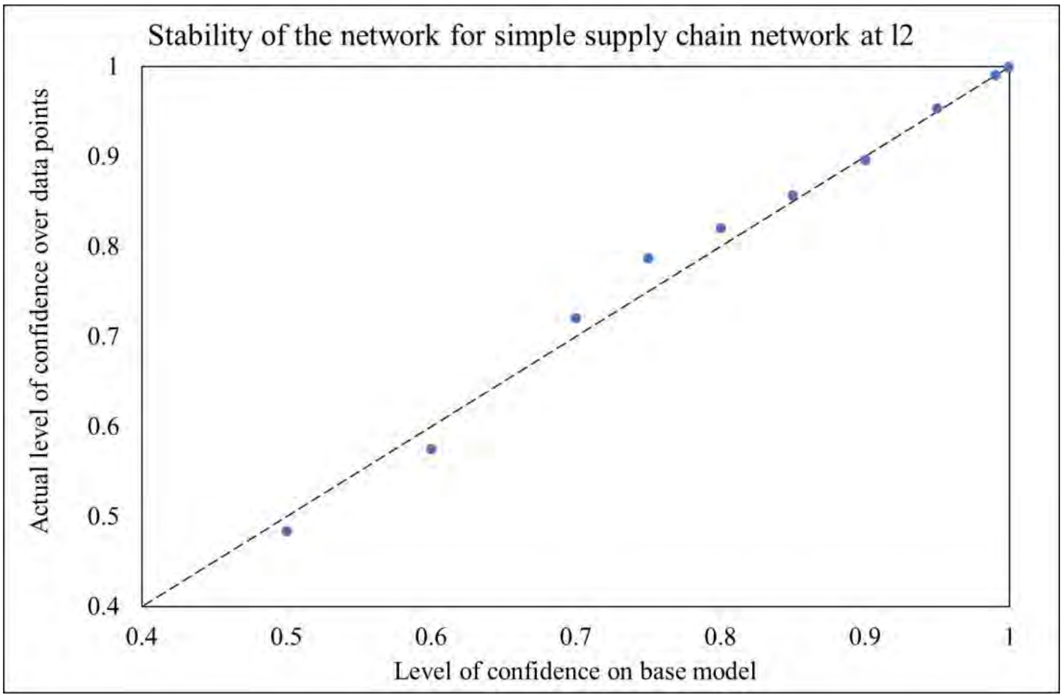

Figure 4.16 Result on the stability of network for simple supply chain case at l2.

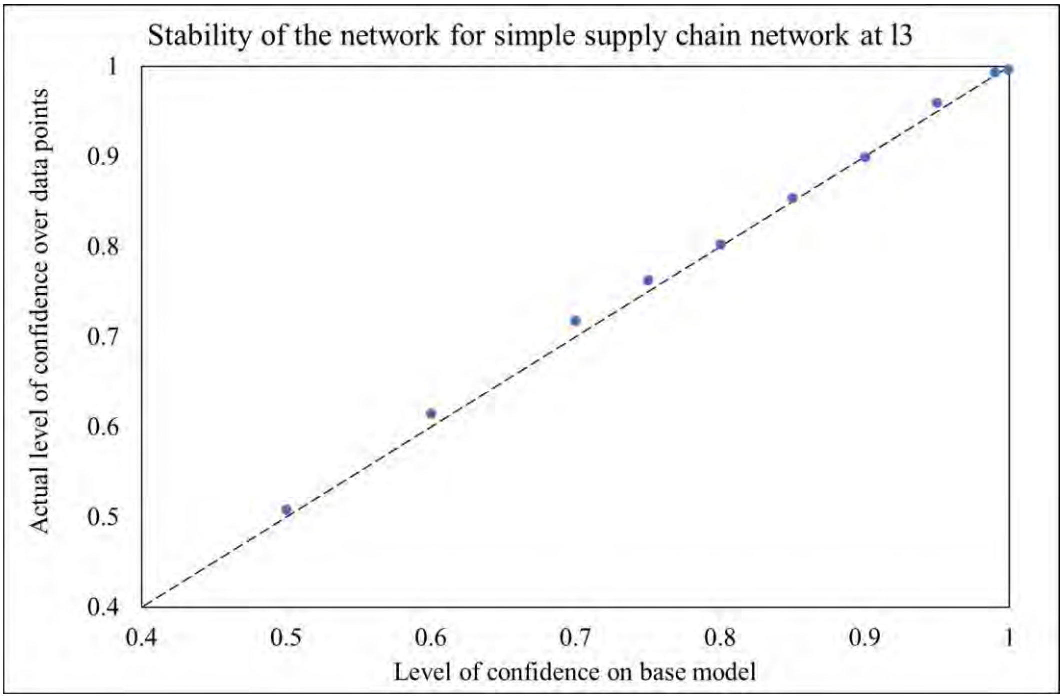

Figure 4.17 Result on the stability of network for simple supply chain case at l3.

Figure 4.18 to Figure 4.23 show the summary result of stability at 100,000 data points. The result shows that the calculated values of level of confidence are more precise meaning that the number of data points affect to precision of the model. In this study, only 3,300 data points are used to see the effect of optimized supply chain network under uncertainty in specific timeframe of 10 years (330 days/year). However, this is main concern when the validation model is used as supply chain network model synthesis.

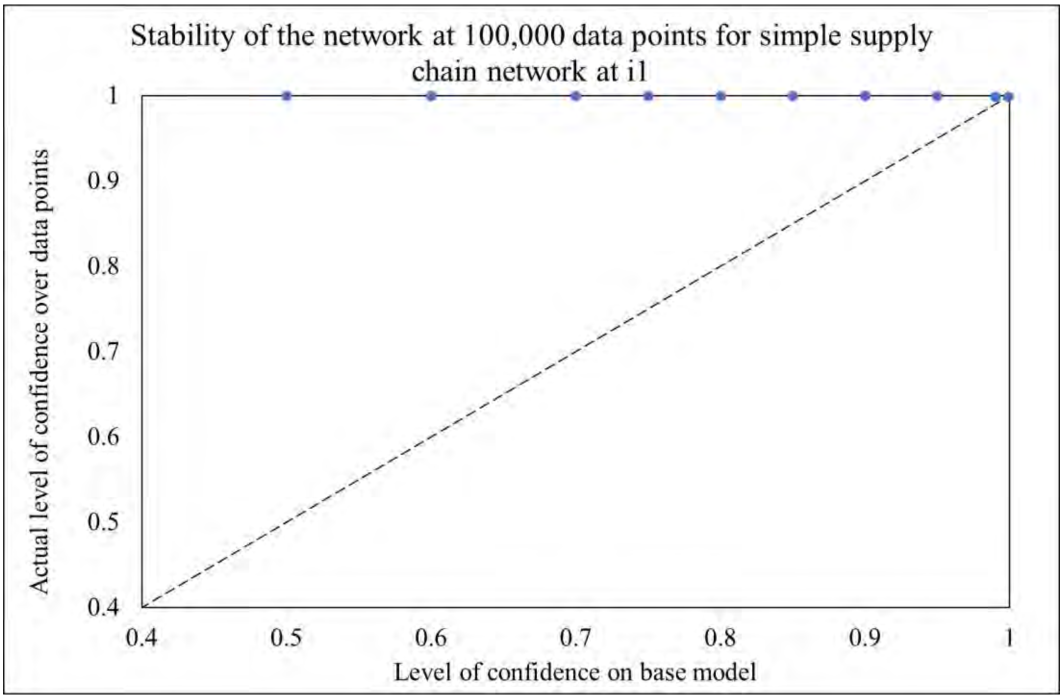

Figure 4.18 Result on the stability at 100,000 data points of network for simple supply chain case at i1.

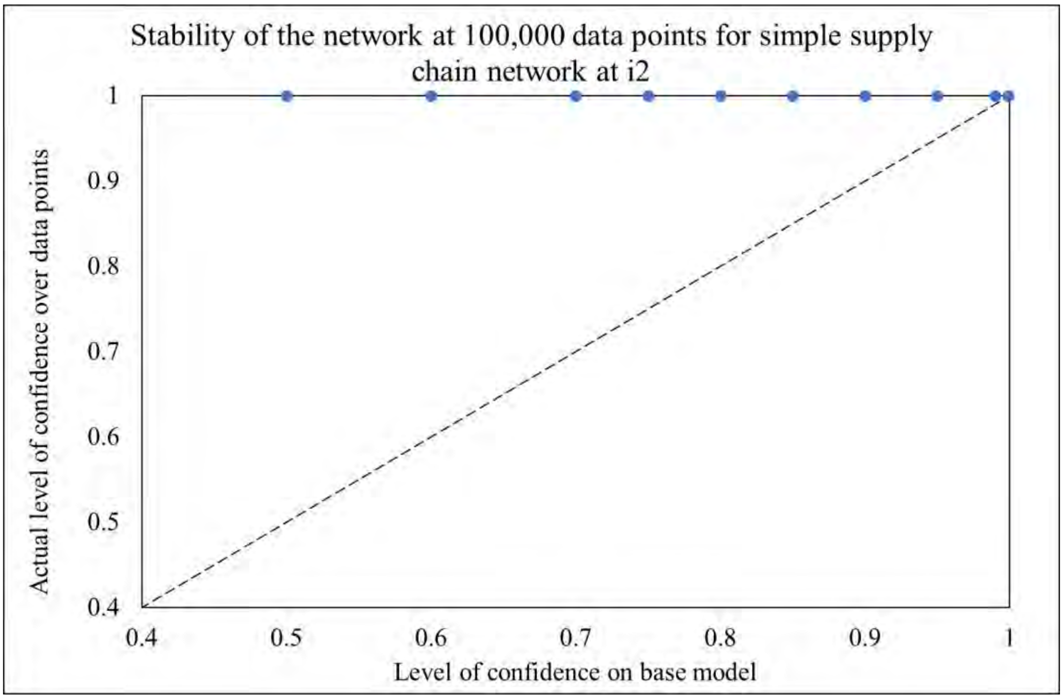

Figure 4.19 Result on the stability at 100,000 data points of network for simple supply chain case at i2.

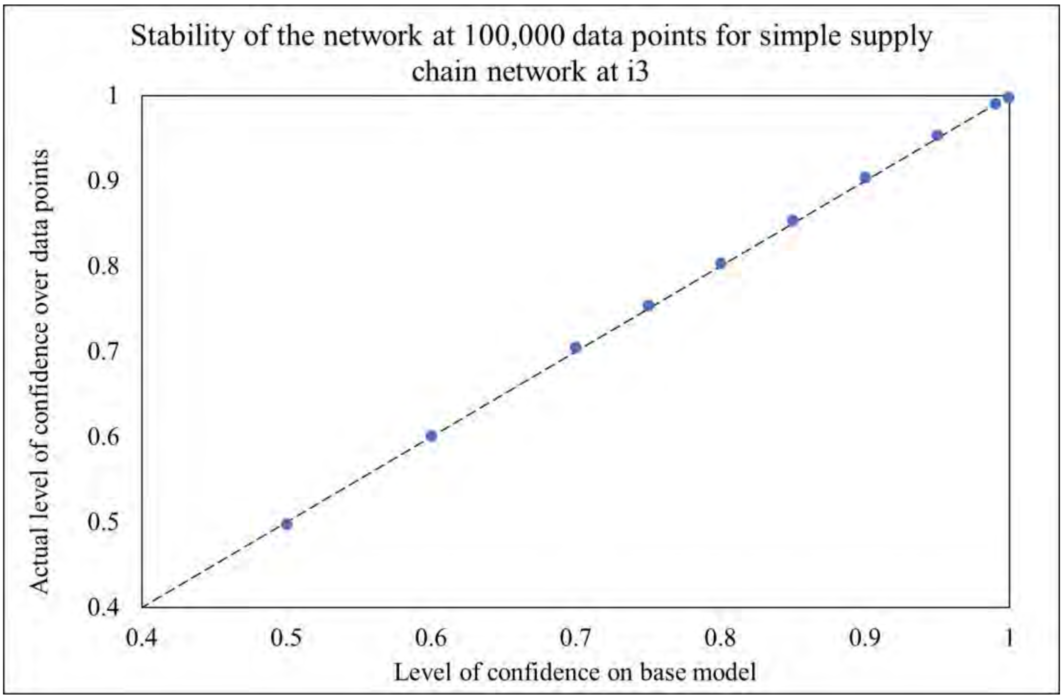

Figure 4.20 Result on the stability at 100,000 data points of network for simple supply chain case at i3.

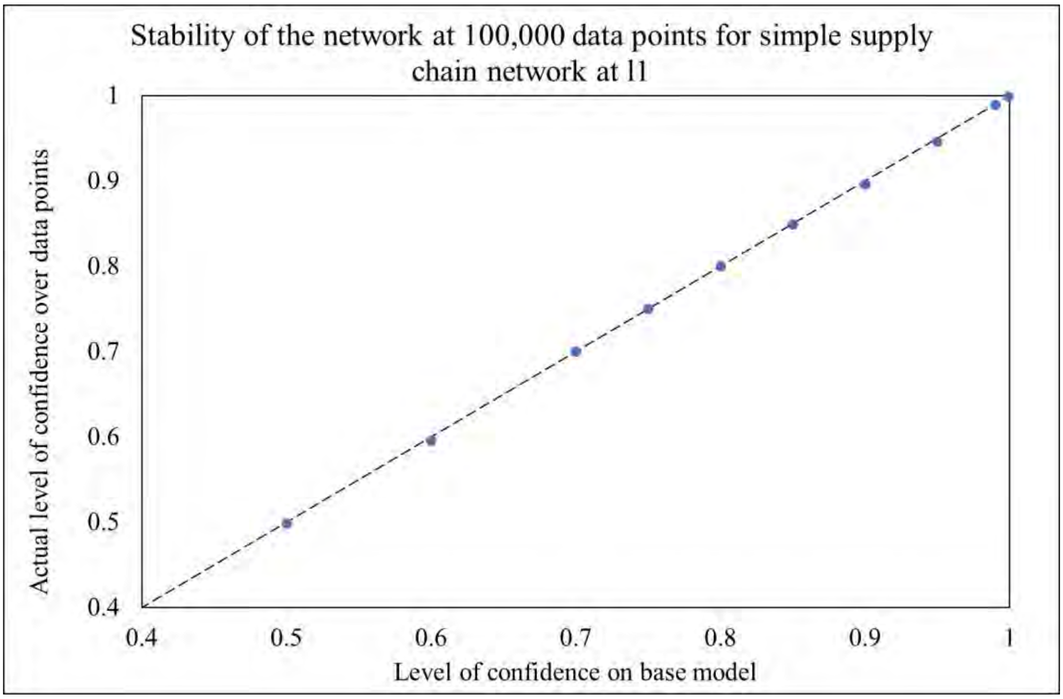

Figure 4.21 Result on the stability at 100,000 data points of network for simple supply chain case at l1.

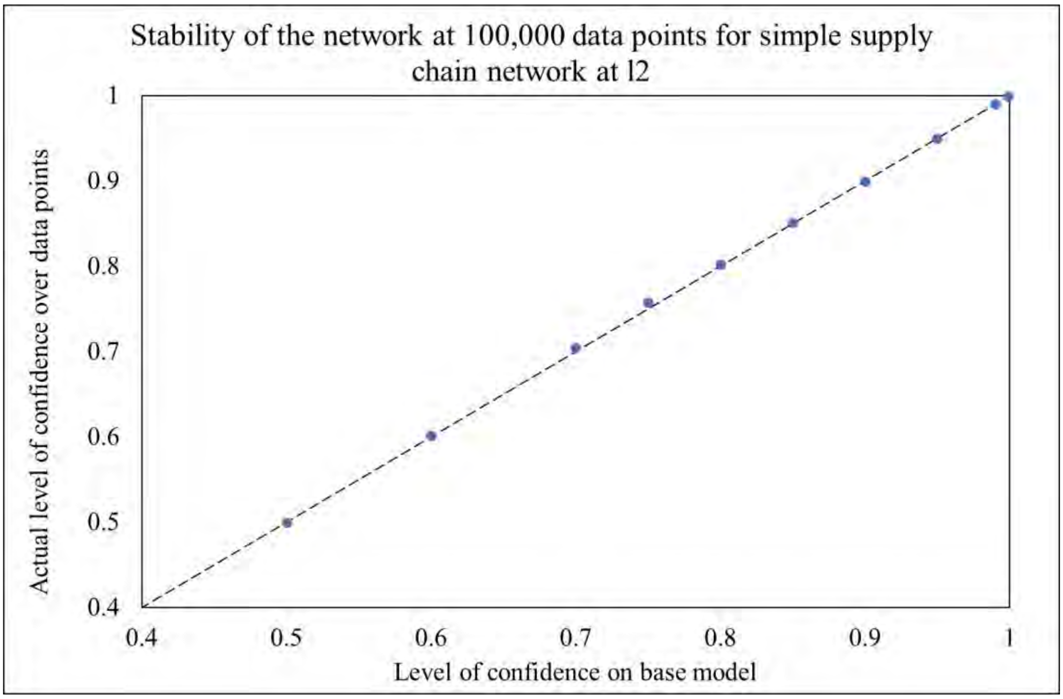

Figure 4.22 Result on the stability at 100,000 data points of network for simple supply chain case at l2.

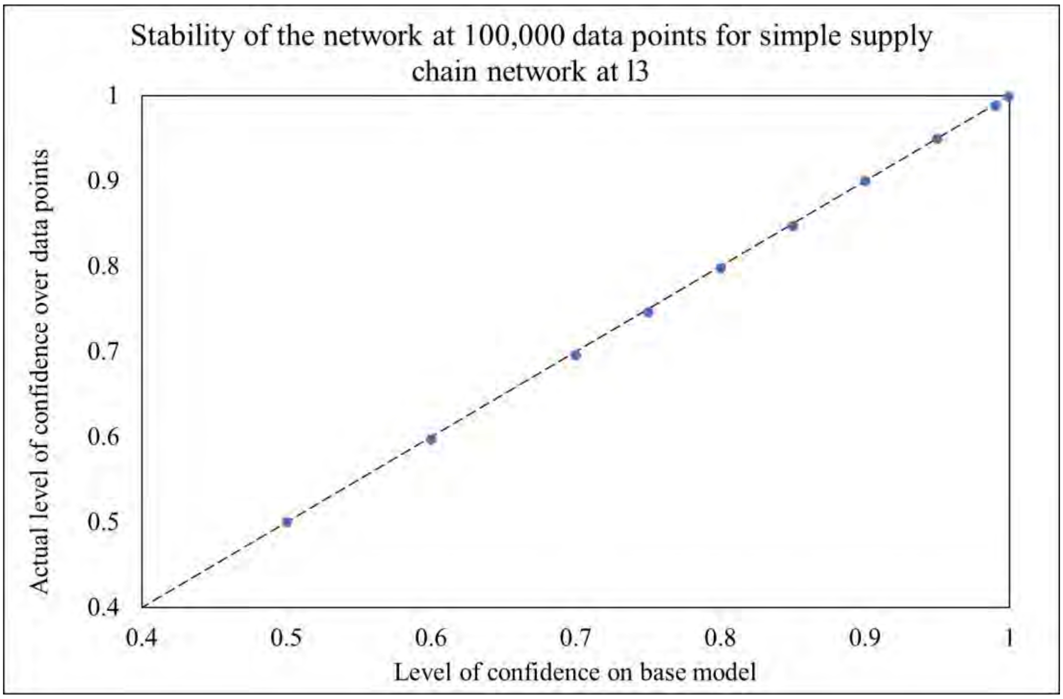

Figure 4.23 Result on the stability at 100,000 data points of network for simple supply chain case at l3.

4.2 Biodiesel Supply Chain Network

4.2.1 Simulation result for biodiesel plant

Figure 4.24 shows correlation results between steric acid feed rate and biodiesel production rate and the utilities requirement from simulation program PRO/II. The fitting coefficients used in the mathematical model for biodiesel supply chain network.

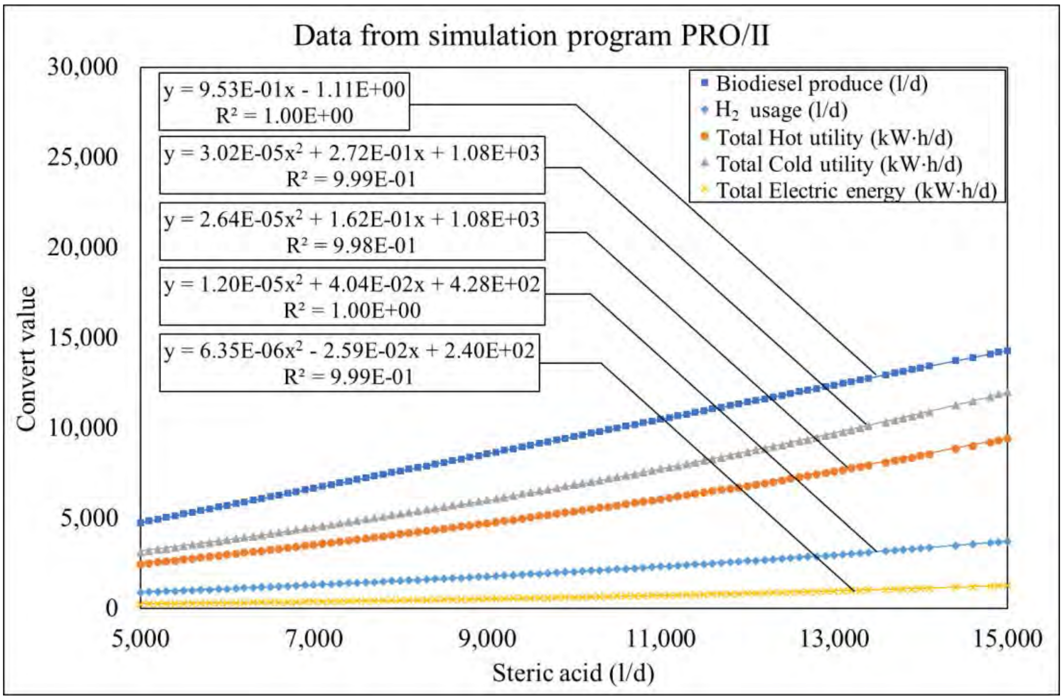

Figure 4.24 The results from simulation program PRO/II and the fitting coefficients.

4.2.2 Optimization results

The supply chain networks at levels of confidence of 0.50, 0.80 and 0.999 are shown in Figure 4.25 to Figure 4.27. All of the networks at different level of confidence can be found in appendix B.

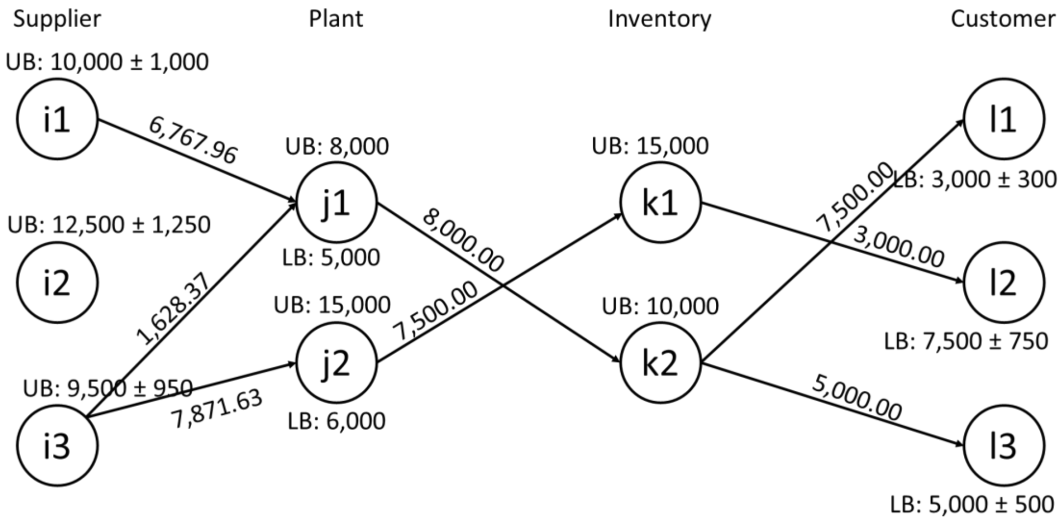

Figure 4.25 Supply chain network diagram for biodiesel supply chain case at 0.50 level of confidence.

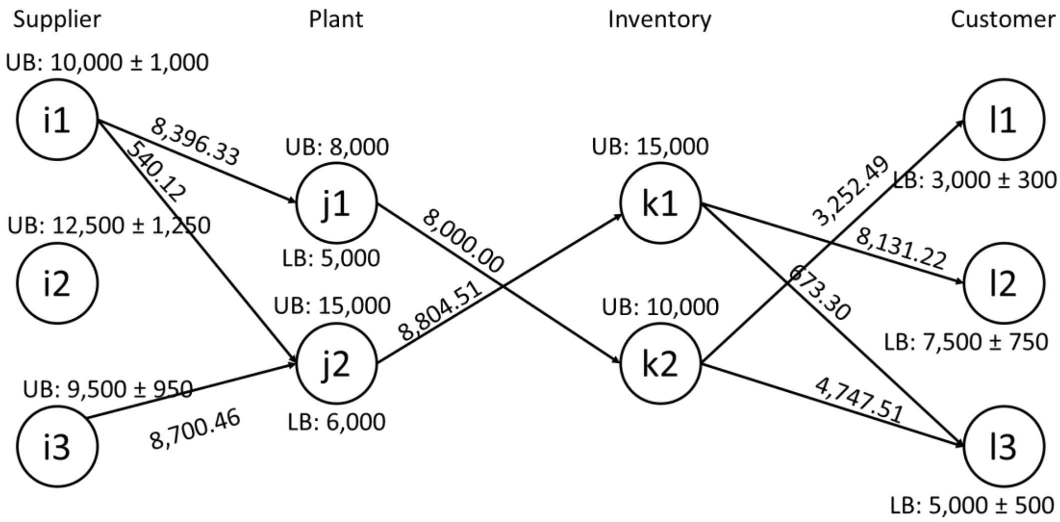

Figure 4.26 Supply chain network diagram for biodiesel supply chain case at 0.80 level of confidence.

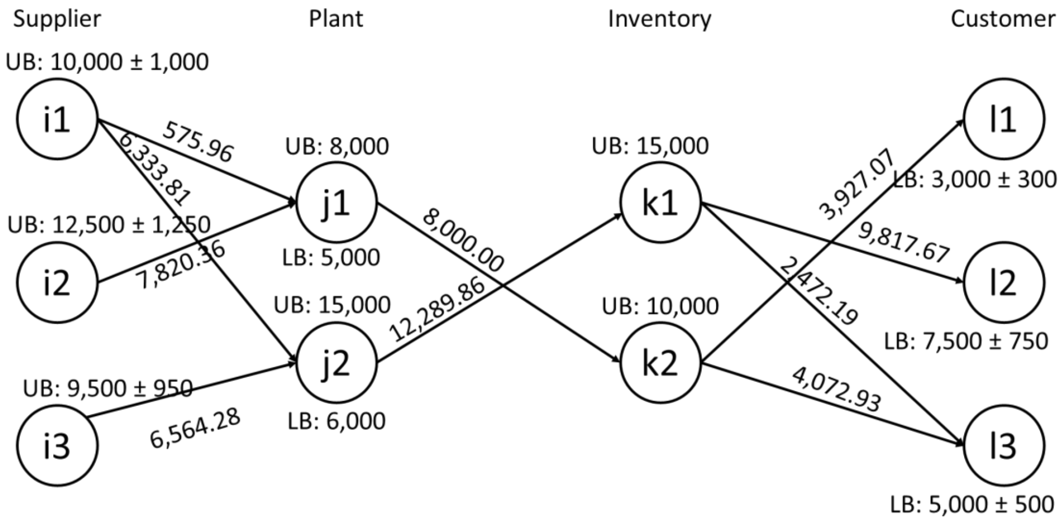

Figure 4.27 Supply chain network diagram for biodiesel supply chain case at 0.999 level of confidence.

Figure 4.28 shows the result of optimized network for biodiesel supply chain network by chance constrained optimization at different levels of confidence. The results show that the higher profit can be obtained at higher levels of confidence for each suppliers and customers. The same reason can be applied, the capacity for each supplier decreases below the average value but the BHD demand increases above the average value when using the deterministic equivalent form. Therefore, the required quantity of biodiesel in supply chain increases, resulting in increases of BHD revenue and total cost.

For the validation part of optimal supply chain, the average validated profit is lower than the optimized profit as shown in Figure 4.29. The same reason can be applied, the deterministic equivalent chance constrained model which does not calculate the penalty quantity (both of opportunity loss and over demand loss) in the system. Therefore, the model trends to satisfy the constraint at the new certain value does not have penalty quantity in the network.

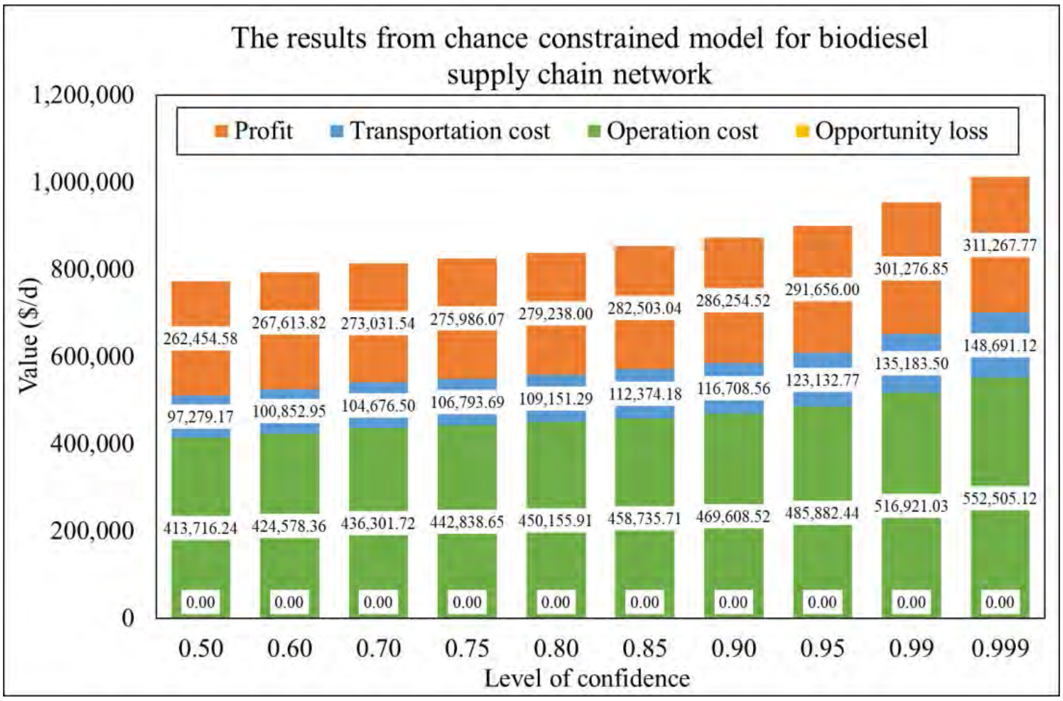

Figure 4.28 The results from chance constrained model for biodiesel supply chain network.

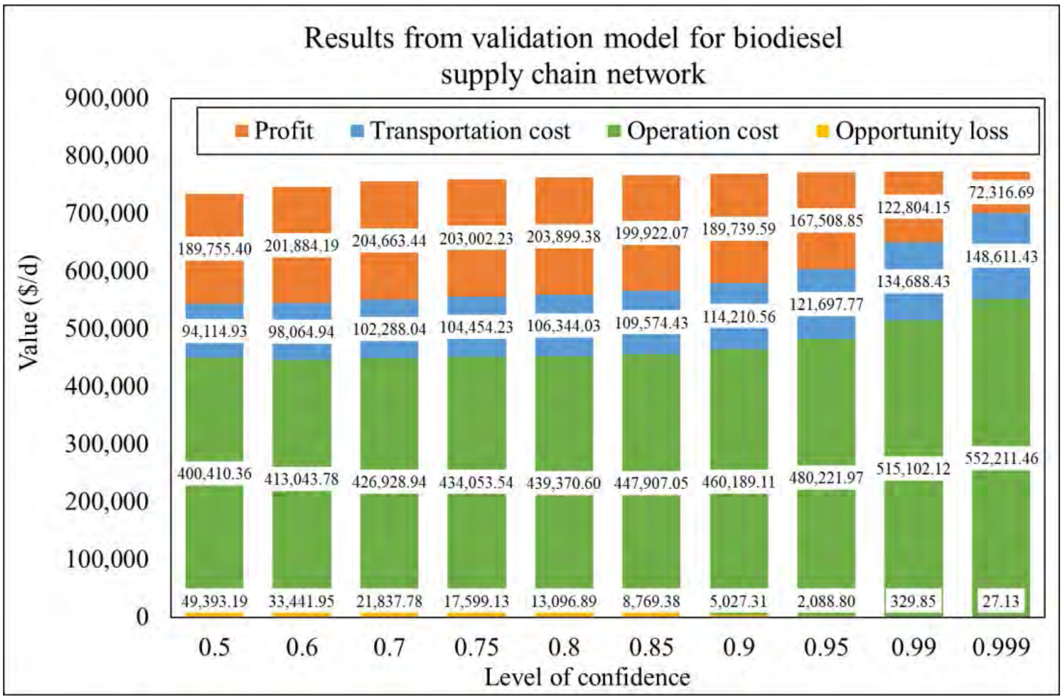

Figure 4.29 The results from validation model for biodiesel supply chain network.

Next, the trend of validated profit becomes lower at higher level of confidence. This comes from the over demand is affected the revenue even though the penalty cost for over demand is 0 $/l. At higher levels of confidence for each suppliers and customers, the total quantity of biodiesel in network increases as shown in Figure 4.30 to Figure 4.35. Therefore, more biodiesel is flowing through the network but the revenue stays the same due to the over demand products. The transportation and operation costs are higher in contrast of the penalty cost due to more biodiesel in the network. Although, the opportunity loss is lower but not trade-off with other costs. The trend of profit is going down at higher level of confidence. This case study shows that chance constrained programming gives lower opportunity loss than deterministic programming. The sensitivity analysis will be done to improve the profit.

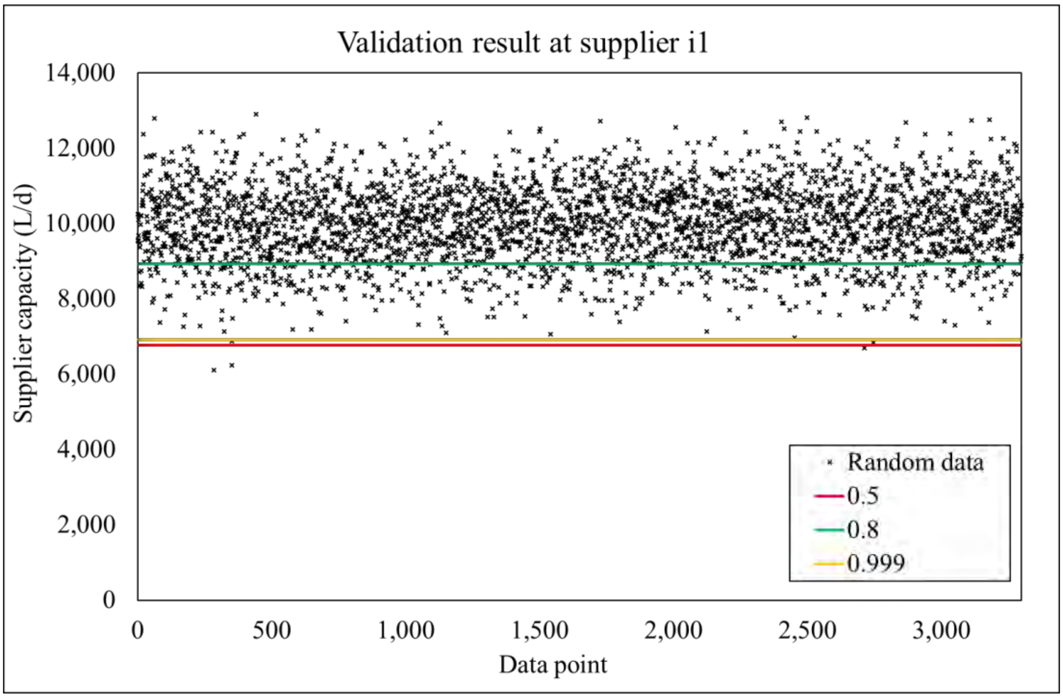

Figure 4.30 Validation result at supplier i1 for biodiesel supply chain network.

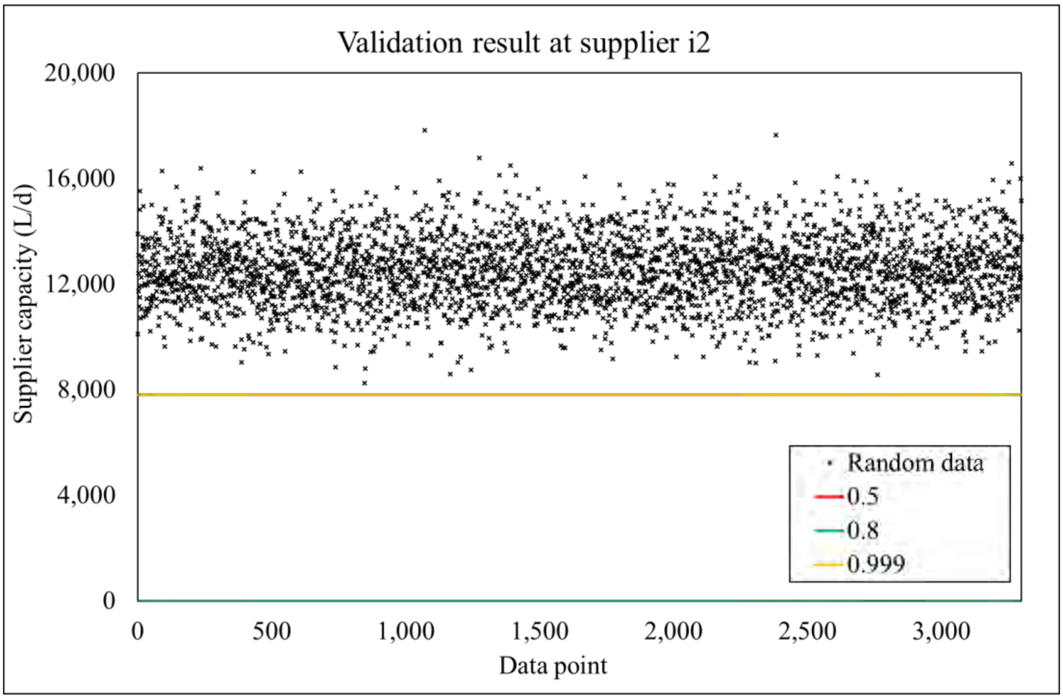

Figure 4.31 Validation result at supplier i2 for biodiesel supply chain network.

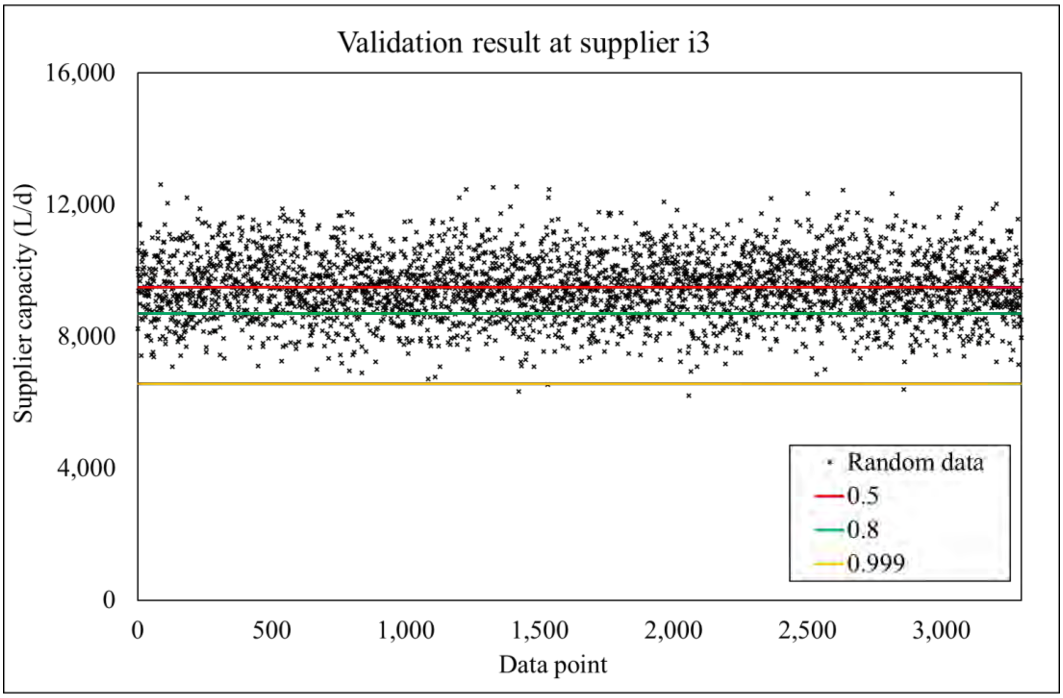

Figure 4.32 Validation result at supplier i3 for biodiesel supply chain network.

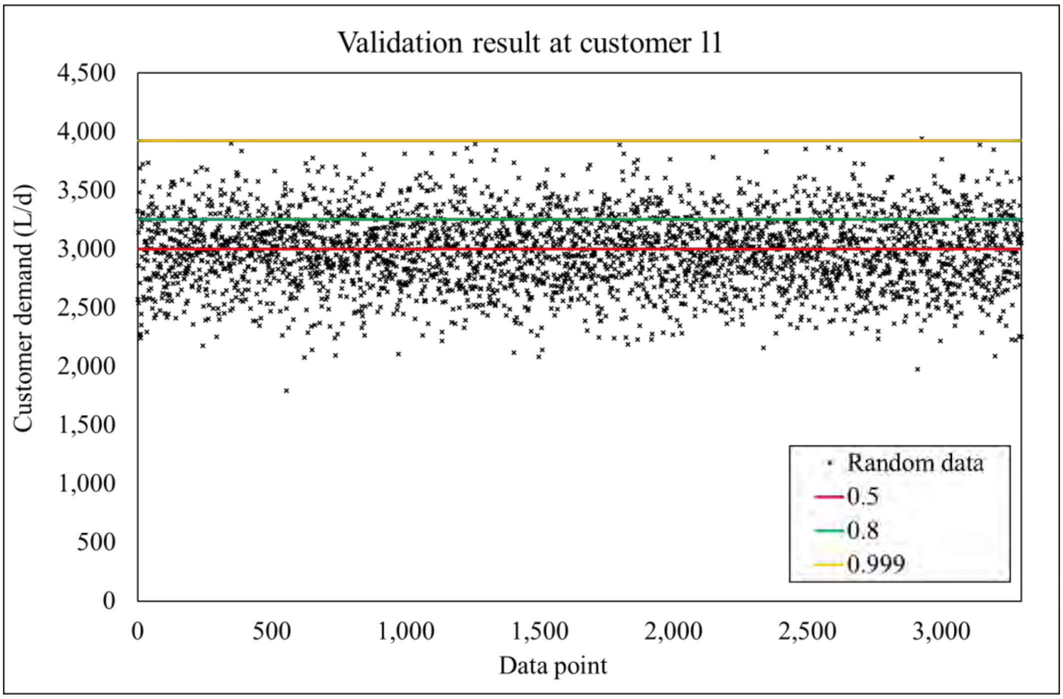

Figure 4.33 Validation result at customer l1 for biodiesel supply chain network.

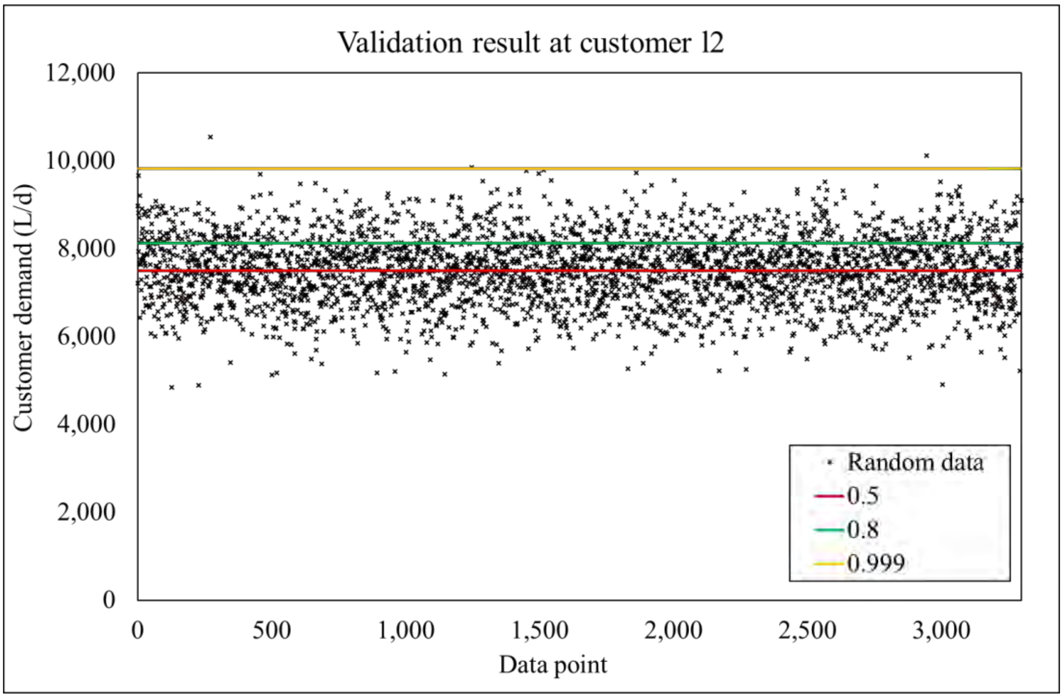

Figure 4.34 Validation result at customer l2 for biodiesel supply chain network.

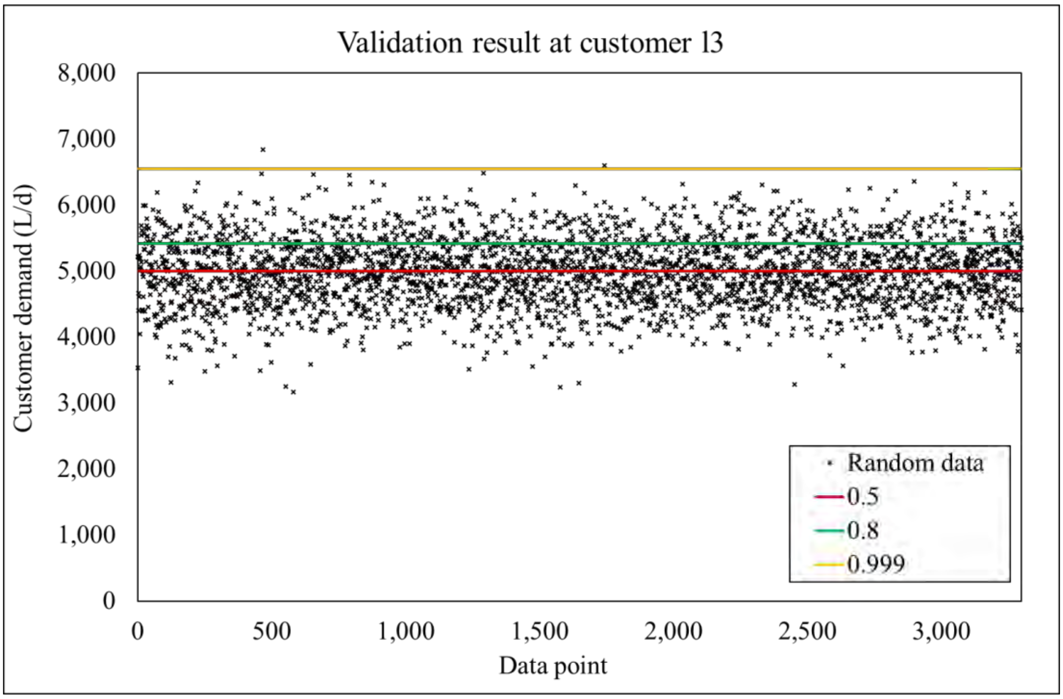

Figure 4.35 Validation result at customer l3 for biodiesel supply chain network.

The stability results are shown in Figure 4.36 to Figure 4.47. The same results as previous can be obtained. The result shows that the calculated values of level of confidence that obtain from violation model are around or above the diagonal line mean that observed events can satisfy under the level of confidence that use in chance constrained equations. Therefore, the chance constrained optimization gives the optimized network that did not violate the level of confidence.

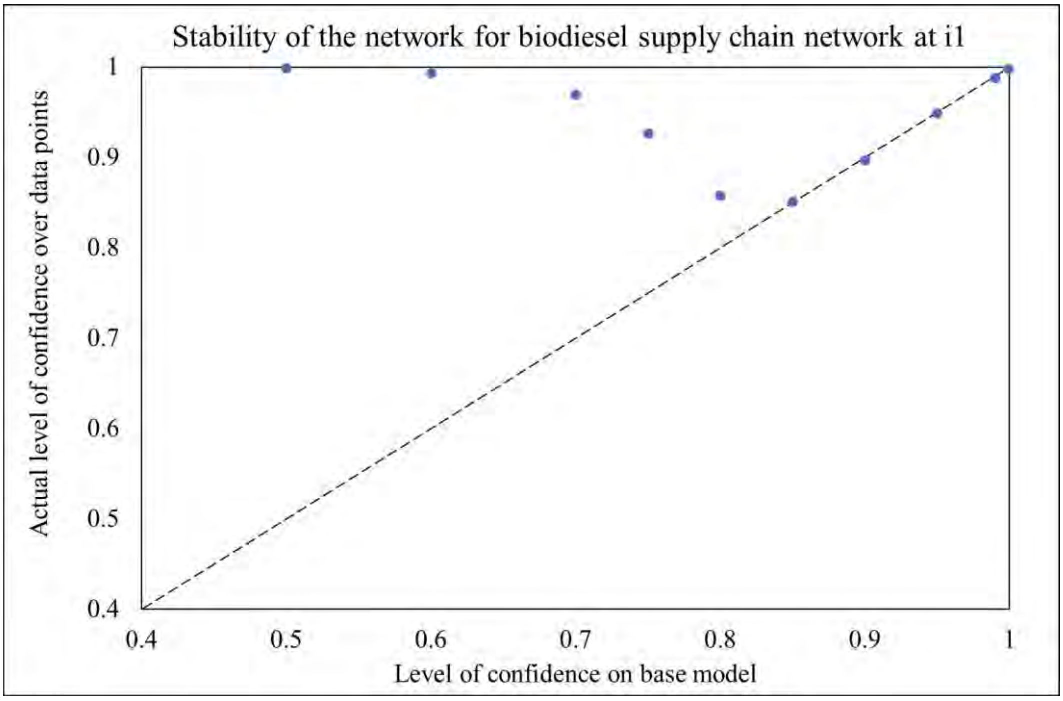

Figure 4.36 Result on the stability of network for biodiesel supply chain case at i1.

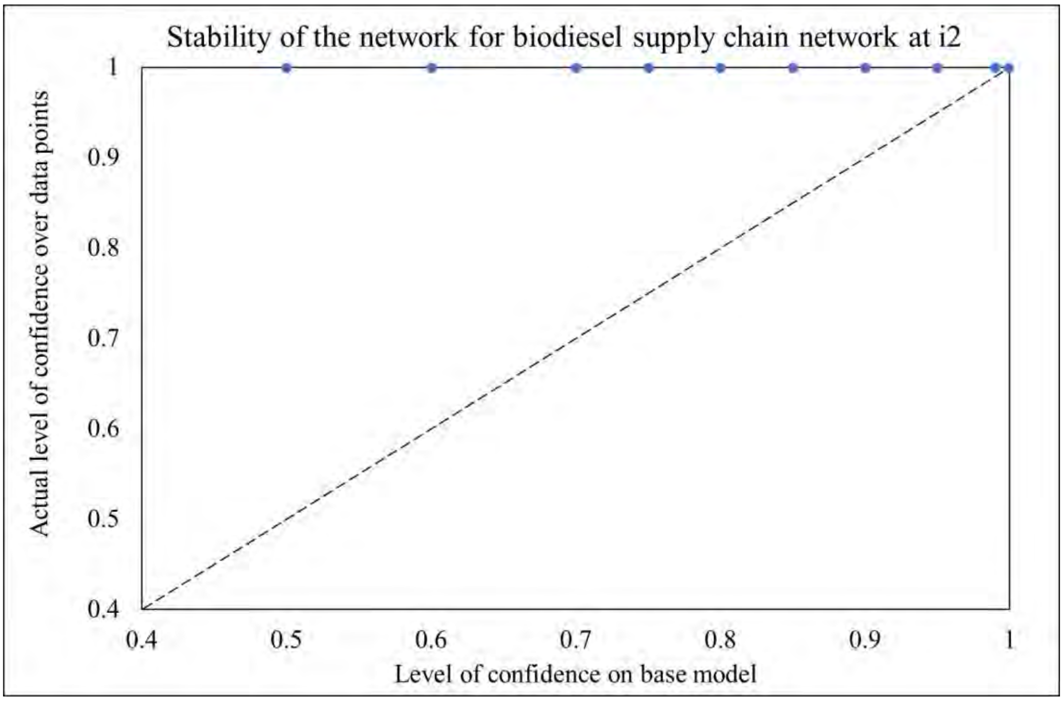

Figure 4.37 Result on the stability of network for biodiesel supply chain case at i2.

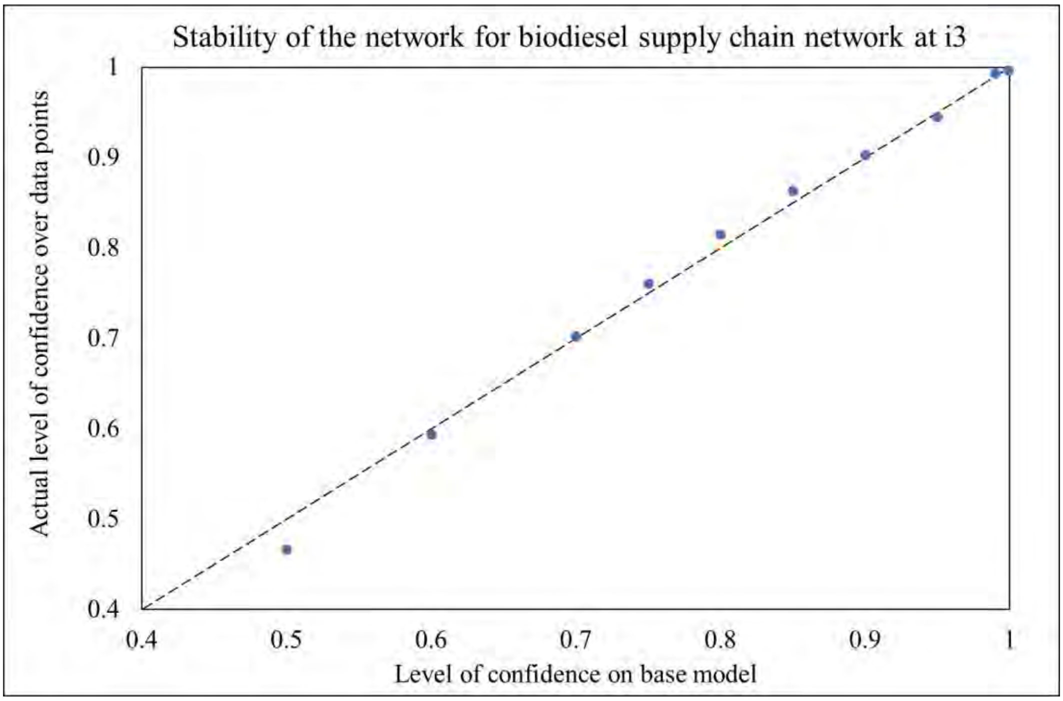

Figure 4.38 Result on the stability of network for biodiesel supply chain case at i3.

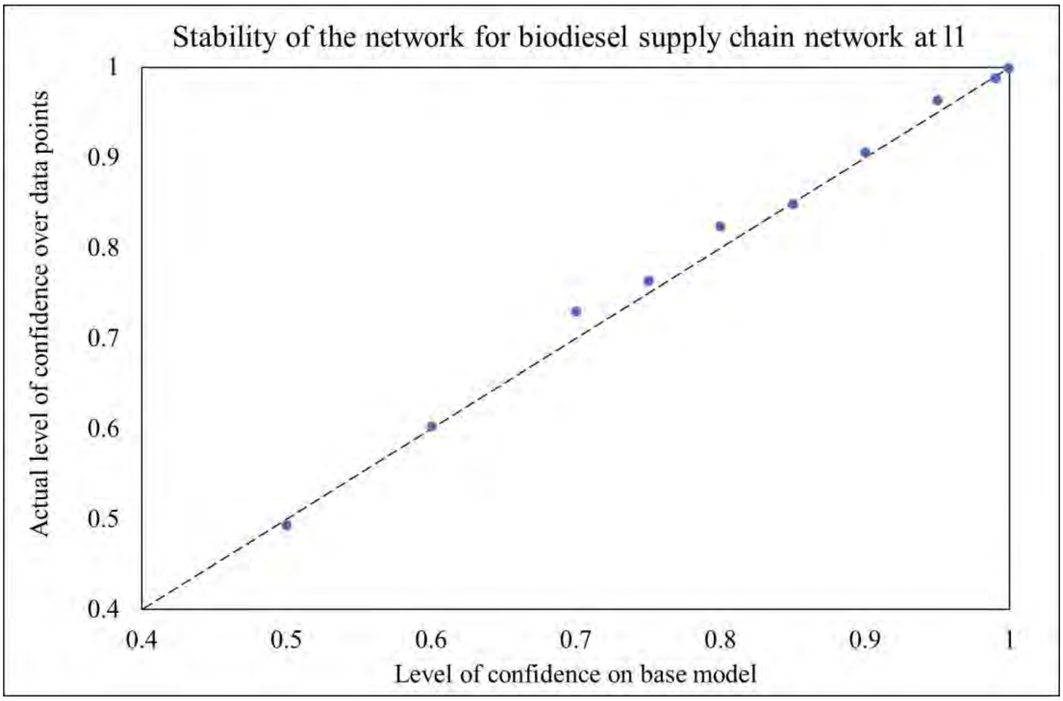

Figure 4.39 Result on the stability of network for biodiesel supply chain case at l1.

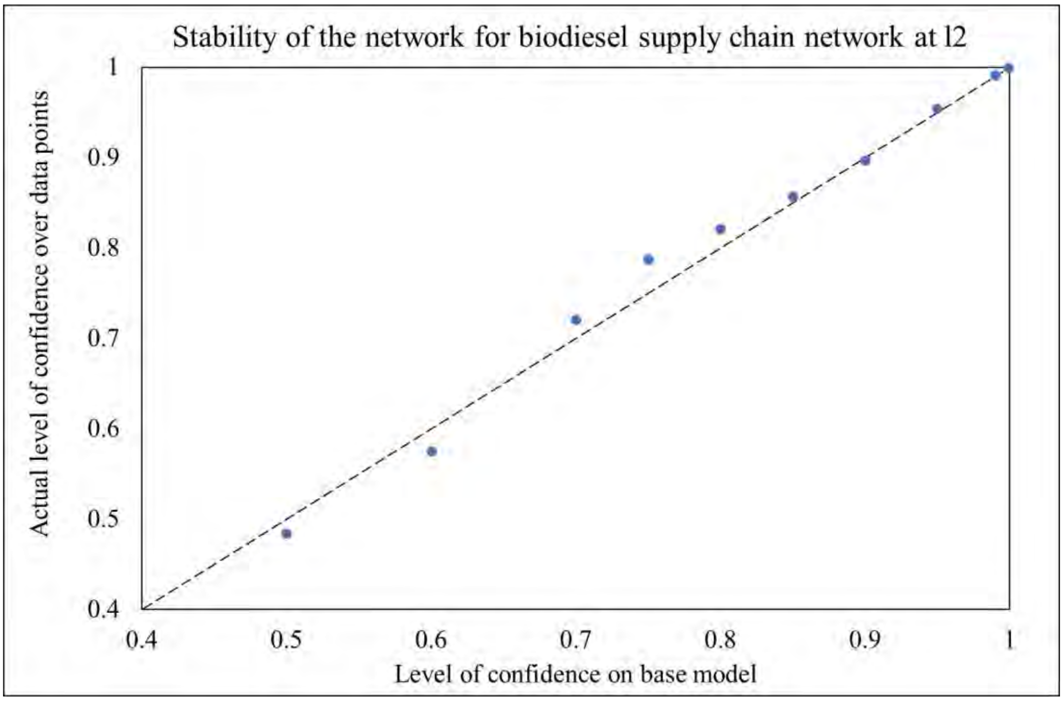

Figure 4.40 Result on the stability of network for biodiesel supply chain case at l2.

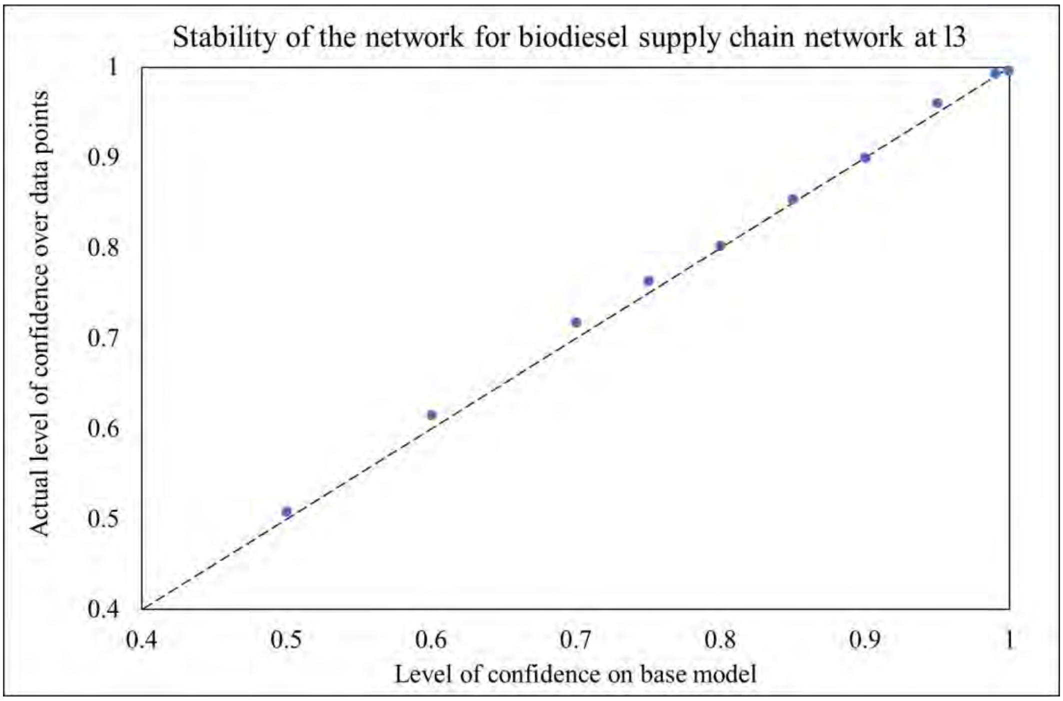

Figure 4.41 Result on the stability of network for biodiesel supply chain case at l3.

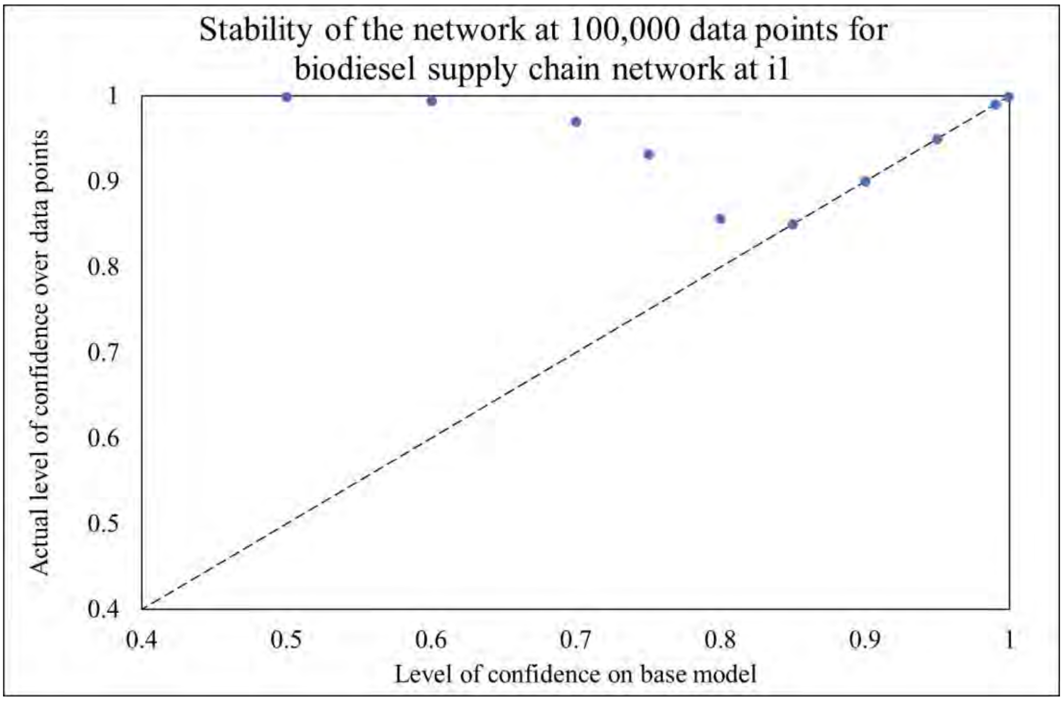

Figure 4.42 Result on the stability at 100,000 data points of network for biodiesel supply chain case at i1.

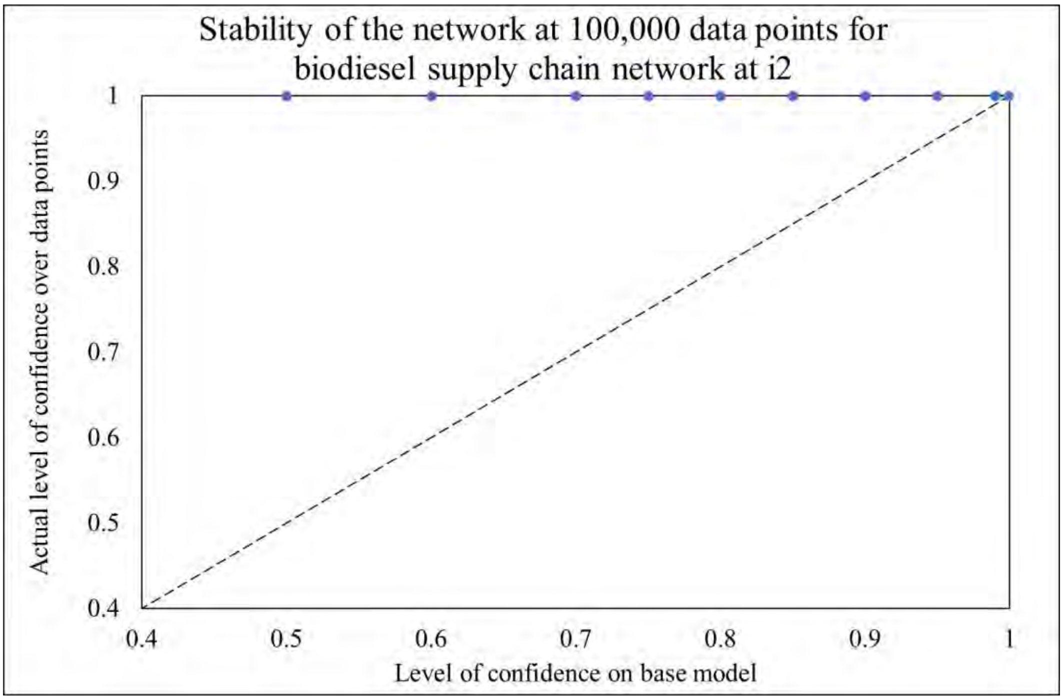

Figure 4.43 Result on the stability at 100,000 data points of network for biodiesel supply chain case at i2.

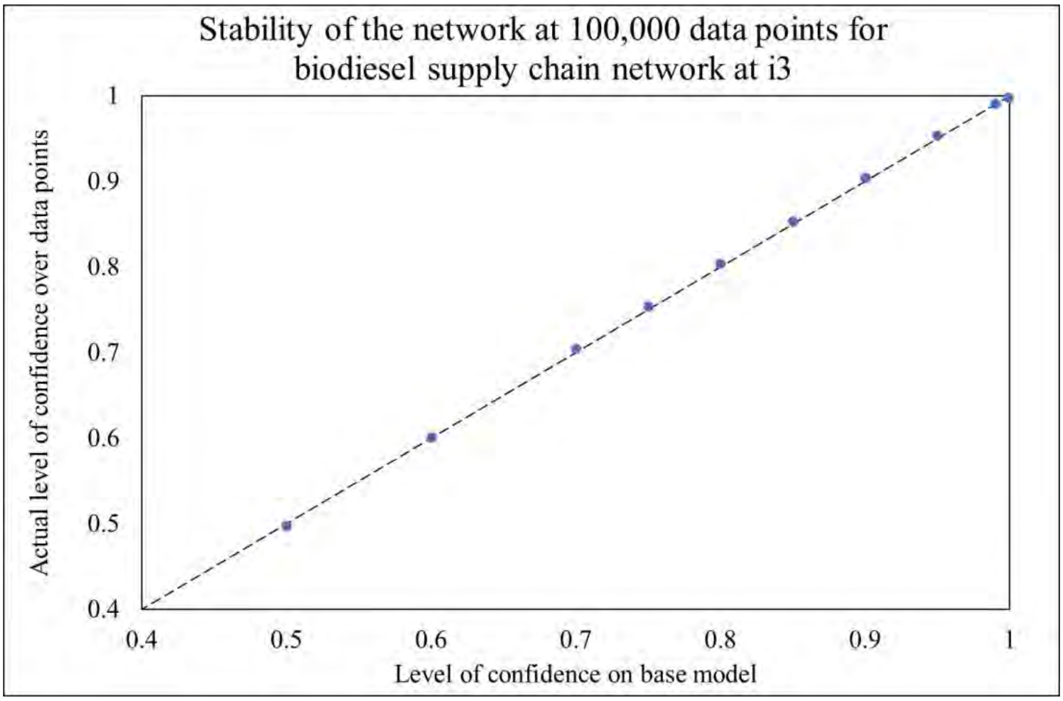

Figure 4.44 Result on the stability at 100,000 data points of network for biodiesel supply chain case at i3.

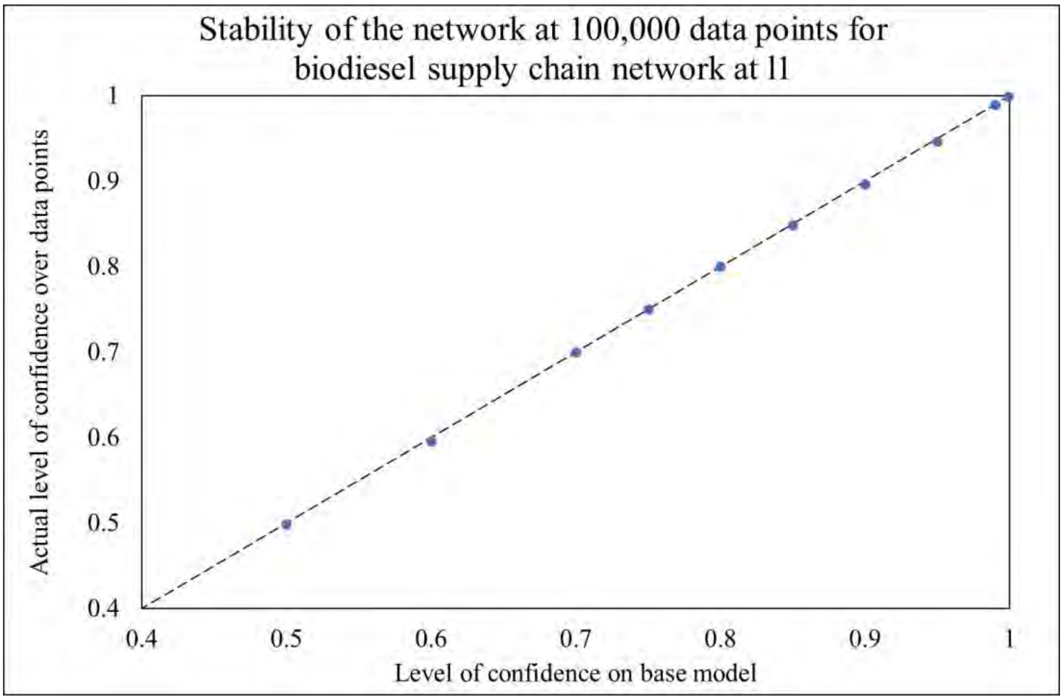

Figure 4.45 Result on the stability at 100,000 data points of network for biodiesel supply chain case at l1.

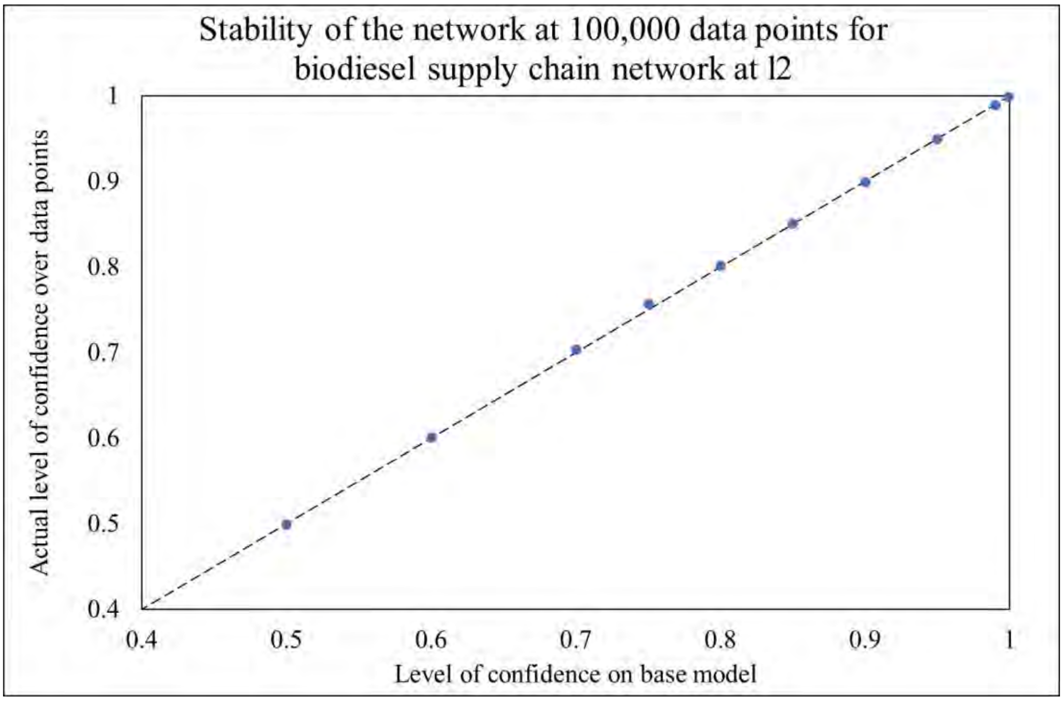

Figure 4.46 Result on the stability at 100,000 data points of network for biodiesel supply chain case at l2.

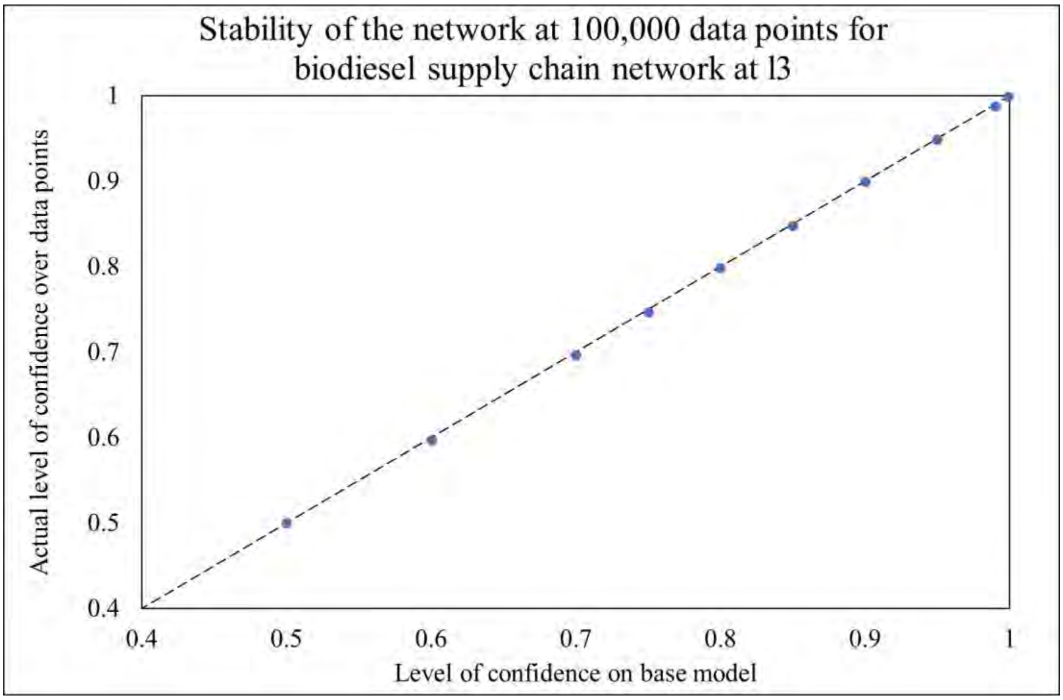

Figure 4.47 Result on the stability at 100,000 data points of network for biodiesel supply chain case at l3.

Figure 4.48 shows the result of sensitivity analysis on opportunity loss. The result shows that deterministic supply chain has higher magnitude of slope than chance constrained ones. The magnitude of slope for chance constrained decreases when level of confidence increases and when the opportunity loss becomes larger value, the deterministic supply chain will become less profitable than chance constrained ones. For the base case, at 62.375 $/l opportunity loss, the penalty cost is smaller than the other costs meaning that the decreases the quantity of opportunity loss by using chance constrained programming is meaningless. However, when the penalty cost for opportunity loss keeps increasing, the penalty cost and the decreased of the quantity of opportunity becomes more relevant.

The explanation is more opportunity loss occurs in the system at lower level of confidence. Therefore, the deterministic optimization has more opportunity loss in the system than the chance constrained optimization which has higher level of confidence. The opportunity loss is the main factor that affecting the sensitivity of penalty cost in this study so higher opportunity loss in the system means more sensitive to penalty cost.

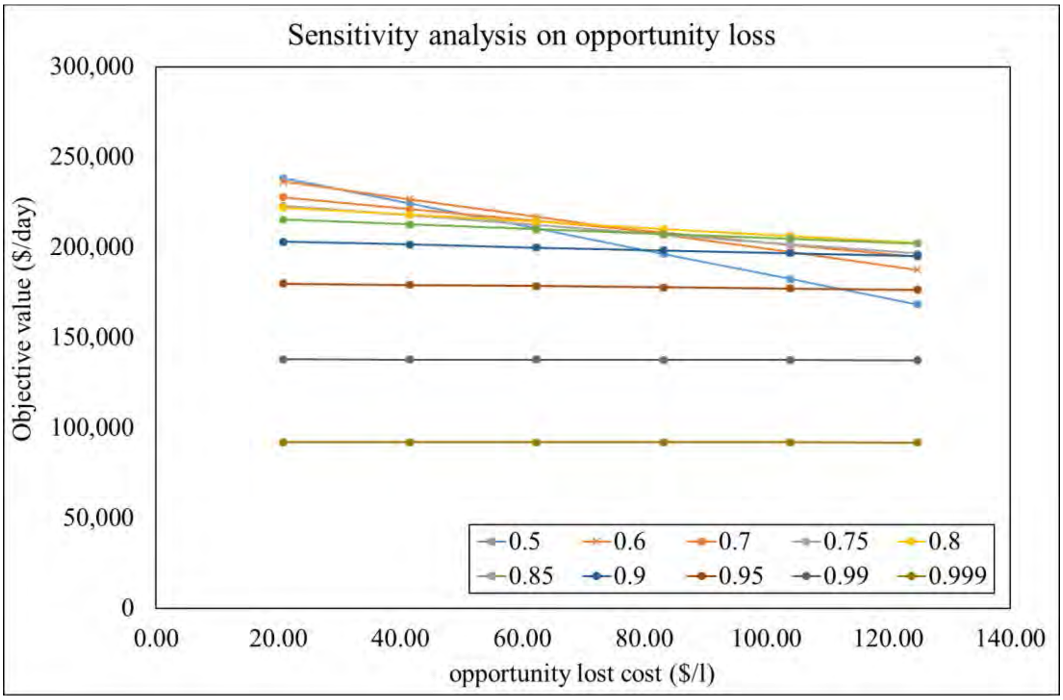

Figure 4.48 Results from sensitivity analysis on opportunity loss.

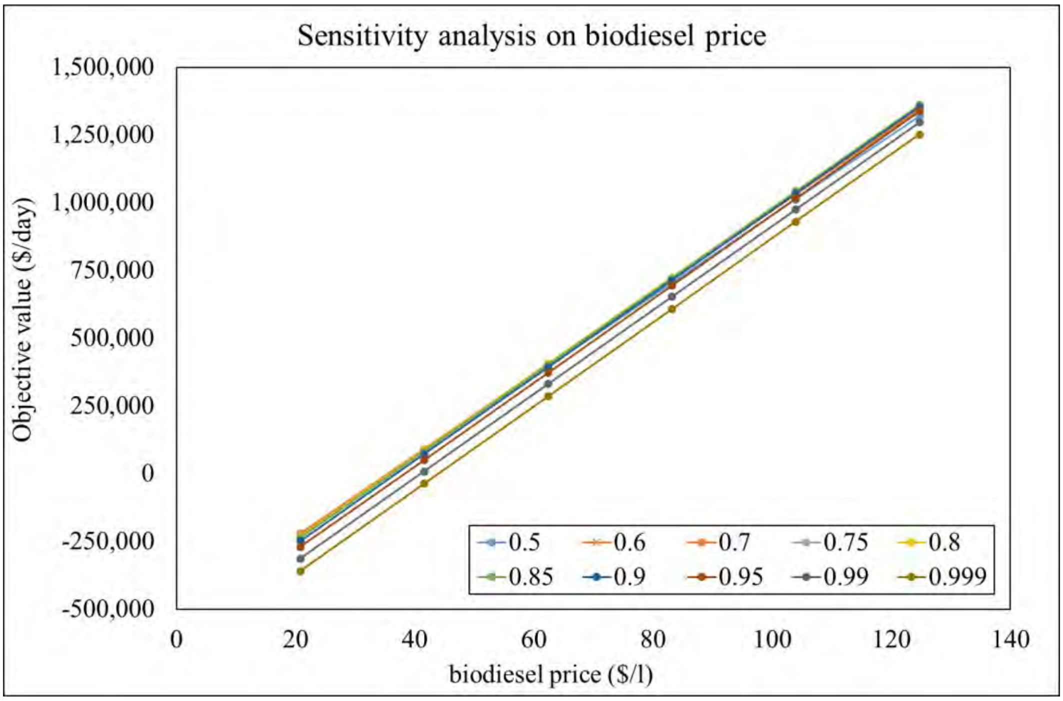

Figure 4.49 Results from sensitivity analysis on biodiesel price.

Figure 4.49 shows the result of sensitivity analysis on biodiesel price. The result shows that the slope of all graphs is around the same value. This can be explained by the quantity of selling product. Table B19 shows that the slope increases when level of confidence increases, meaning that more product is sold to customers at higher level of confidence. This gives the same conclusion as previous. However, the increment in slope is small. Figure 4.29 shows the height for each level of confidence is the same, meaning that the quantity of selling product is the same. Therefore, the profit increases at the same pace. It concludes that the biodiesel price is not the main factor that affecting profit under different level of confidence.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The basic concept of chance constrained programming can be used to design the supply chain network under the uncertainties within certain levels of confidence. However, the validation step is needed to reflect the real profit value by using the result from the deterministic equivalent solving method then transforms into the validated result under the uncertainties. The stability results show that more stable network is obtained when the level of confidence increases.

For the case of simple supply chain network, the chance constrained optimization gives more profit and stability than deterministic optimization because there are more of the flow of materials in the network to satisfy customers at higher level of confidence. Therefore, the less opportunity loss occur in the system and more revenue can be obtained.

For the case of biodiesel supply chain network, the deterministic optimization gives more profit than chance constrained optimization but less stability due to more opportunity loss occurs in the system. Finally, the sensitivity analysis shows that the chance constrained optimization is less sensitive to penalty cost due to the less opportunity loss occurs in the system. Therefore, the chance constrained optimization helps increase the profit of supply chain compared to one obtained from deterministic optimization when the opportunity loss has the significant value on the network.

The reason that chance constrained optimization of simple supply chain network case gives increasing profit but one of the biodiesel supply chain network case gives decreasing profit is that the price structure for both cases are not the same. In the simple supply chain network case, opportunity loss cost is insignificant due to its cost per unit smaller than the selling price of product. However, the opportunity loss cost in the biodiesel supply chain network is significant due to its cost per unit larger than the selling price of product. Therefore, the chance constrained optimization results are depended on case by cases.

5.2 Recommendation

Further research can be conducted by improving on the accuracy on the result of the chance constrained programming when compared with validation step. In this work assumed individual probability chance constraint. Further research can be done by using the joint probability chance constraint.

REFERENCE

Avhad, M. R. and Marchetti, J. M. (2015) A review on recent advancement in catalytic materials for biodiesel production. Renewable and Sustainable Energy Reviews, 50, 696-718.

Bilsel, R. U. and Ravindran, A. (2011) A multiobjective chance constrained programming model for supplier selection under uncertainty. Transportation Research Part B: Methodological, 45(8), 1284-1300.

Charnes, A. and Cooper, W. (1959) Chance constrained programming. Chance-Constrained Programming.

Chen, S., Zhou, G. and Miao, C. (2019) Green and renewable bio-diesel produce from oil hydrodeoxygenation: Strategies for catalyst development and mechanism. Renewable and Sustainable Energy Reviews, 101, 568-589.

Dubois, G. (2018) Modeling and simulation : challenges and best practices for industry. Boca Raton: Taylor & Francis, a CRC title, part of the Taylor & Francis imprint, a member of the Taylor & Francis Group, the academic division of T&F Informa, plc.

Gao, J. and You, F. (2017) Design a sustainable supply chain under uncertainty using life cycle optimisation and stochastic programming. Chemical Engineering Transactions, 61, 151-156.

Gentle, J. E., Härdle, W. and Mori, Y. (2004) Handbook of computational statistics : concepts and methods. Berlin ; London: Springer.

Gonela, V. (2018) Stochastic optimization of hybrid electricity supply chain considering carbon emission schemes. Sustainable Production and Consumption, 14, 136-151.

Harrison, A. and Hoek, R. I. v. (2008) Logistics management and strategy : competing through the supply chain. Harlow, England ; New York: Prentice Hall Financial Times.

Kim, J., Realff, M. J. and Lee, J. H. (2011) Optimal design and global sensitivity analysis of biomass supply chain networks for biofuels under uncertainty. Computers & Chemical Engineering, 35(9), 1738-1751.

Kumar, P., Yenumala, S. R., Maity, S. K. and Shee, D. (2014) Kinetics of hydrodeoxygenation of stearic acid using supported nickel catalysts: Effects of supports. Applied Catalysis A: General, 471, 28-38.

Li, P., Arellano-Garcia, H. and Wozny, G. (2008) Chance constrained programming approach to process optimization under uncertainty. Computers & Chemical Engineering, 32(1), 25-45.

Lin, Y.-S. and Wang, K.-J. (2018) A two-stage stochastic optimization model for warehouse configuration and inventory policy of deteriorating items. Computers & Industrial Engineering, 120, 83-93.

Miller, L. B. and Wagner, H. (1965) Chance-constrained programming with joint constraints. Operations Research, 13(6), 930-945.

Nagurney, A. (2006) Supply chain network economics : dynamics of prices, flows and profits. Cheltenham, UK ; Northampton, MA: Edward Elgar.

Nazemi, A. and Tahmasbi, N. (2013) A high performance neural network model for solving chance constrained optimization problems. Neurocomputing, 121, 540-550.

Shaw, K., Irfan, M., Shankar, R. and Yadav, S. S. (2016) Low carbon chance constrained supply chain network design problem: a Benders decomposition based approach. Computers & Industrial Engineering, 98, 483-497.

Steimel, J. and Engell, S. (2015) Conceptual design and optimization of chemical processes under uncertainty by two-stage programming. Computers & Chemical Engineering, 81, 200-217.

U.S. Energy Information Administration "Energy consumption by sector and source." 2019. 01.03 2019 <www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2019&cases=ref2019&sourcekey=0>

APPENDICES

Appendix A The Detail on Simple Supply Chain Network

– Chance constrained optimization detail results.

Table A1 Result for 0.50 level of confidence for simple supply chain network.

Confidence level					0.50
Profit ($/day)					3,550.00
Revenue ($/day)					5,250.00
Cost ($/day)					
- Transportation cost					1,700.00
- Penalty cost					-
Total cost ($/day)					1,700.00
Supply chain network (unit/day)					
i1-j1	50.00	j1-k1	50.00	k1-l1	-
i1-j2	-	j1-k2	300.00	k1-l2	50.00
i2-j1	-	j2-k1	-	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	100.00
i3-j1	300.00			k2-l2	100.00
i3-j2	-			k2-l3	100.00

Table A2 Result for 0.60 level of confidence for simple supply chain network.

Confidence level					0.6
Profit ($/day)					3,608.27
Revenue ($/day)					5,383.01
Cost ($/day)					
- Transportation cost					1,774.74
- Penalty cost					-
Total cost ($/day)					1,774.74
Supply chain network (unit/day)					
i1-j1	57.60	j1-k1	50.00	k1-l1	-
i1-j2	8.87	j1-k2	300.00	k1-l2	58.87
i2-j1	-	j2-k1	8.87	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	102.53
i3-j1	292.40			k2-l2	94.93
i3-j2	-			k2-l3	102.53

Table A3 Result for 0.70 level of confidence for simple supply chain network.

Confidence level					0.7
Profit ($/day)					3,670.61
Revenue ($/day)					5,525.31
Cost ($/day)					
- Transportation cost					1,854.70
- Penalty cost					-
Total cost ($/day)					1,854.70
Supply chain network (unit/day)					
i1-j1	65.73	j1-k1	50.00	k1-l1	-
i1-j2	18.35	j1-k2	300.00	k1-l2	68.35
i2-j1	-	j2-k1	18.35	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	105.24
i3-j1	284.27			k2-l2	89.51
i3-j2	-			k2-l3	105.24

Table A4 Result for 0.75 level of confidence for simple supply chain network.

Confidence level					0.75
Profit ($/day)					3,705.13
Revenue ($/day)					5,604.11
Cost ($/day)					
- Transportation cost					1,898.97
- Penalty cost					-
Total cost ($/day)					1,898.97
Supply chain network (unit/day)					
i1-j1	70.23	j1-k1	50.00	k1-l1	-
i1-j2	23.61	j1-k2	300.00	k1-l2	73.61
i2-j1	-	j2-k1	23.61	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	106.74
i3-j1	279.77			k2-l2	86.51
i3-j2	-			k2-l3	106.74

Table A5 Result for 0.80 level of confidence for simple supply chain network.

Confidence level					0.8
Profit ($/day)					3,743.57
Revenue ($/day)					5,691.85
Cost ($/day)					
- Transportation cost					1,948.28
- Penalty cost					-
Total cost ($/day)					1,948.28
Supply chain network (unit/day)					
i1-j1	75.25	j1-k1	50.00	k1-l1	-
i1-j2	29.46	j1-k2	300.00	k1-l2	79.46
i2-j1	-	j2-k1	29.46	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	108.42
i3-j1	274.75			k2-l2	83.17
i3-j2	-			k2-l3	108.42

Table A6 Result for 0.85 level of confidence for simple supply chain network.

Confidence level					0.85
Profit ($/day)					3,788.38
Revenue ($/day)					5,794.13
Cost ($/day)					
- Transportation cost					2,005.75
- Penalty cost					-
Total cost ($/day)					2,005.75
Supply chain network (unit/day)					
i1-j1	81.09	j1-k1	50.00	k1-l1	-
i1-j2	36.28	j1-k2	300.00	k1-l2	86.28
i2-j1	-	j2-k1	36.28	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	110.36
i3-j1	268.91			k2-l2	79.27
i3-j2	-			k2-l3	110.36

Table A7 Result for 0.90 level of confidence for simple supply chain network.

Confidence level					0.9
Profit ($/day)					3,844.76
Revenue ($/day)					5,922.81
Cost ($/day)					
- Transportation cost					2,078.06
- Penalty cost					-
Total cost ($/day)					2,078.06
Supply chain network (unit/day)					
i1-j1	88.45	j1-k1	50.00	k1-l1	-
i1-j2	44.85	j1-k2	300.00	k1-l2	94.85
i2-j1	-	j2-k1	44.85	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	112.82
i3-j1	261.55			k2-l2	74.37
i3-j2	-			k2-l3	112.82

Table A8 Result for 0.95 level of confidence for simple supply chain network.

Confidence level					0.95
Profit ($/day)					3,928.32
Revenue ($/day)					6,113.55
Cost ($/day)					
- Transportation cost					2,185.23
- Penalty cost					-
Total cost ($/day)					2,185.23
Supply chain network (unit/day)					
i1-j1	99.35	j1-k1	50.00	k1-l1	-
i1-j2	57.57	j1-k2	300.00	k1-l2	107.57
i2-j1	-	j2-k1	57.57	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	116.45
i3-j1	250.65			k2-l2	67.10
i3-j2	-			k2-l3	116.45

Table A9 Result for 0.99 level of confidence for simple supply chain network.

Confidence level					0.99
Profit ($/day)					4,085.06
Revenue ($/day)					6,471.33
Cost ($/day)					
- Transportation cost					2,386.27
- Penalty cost					-
Total cost ($/day)					2,386.27
Supply chain network (unit/day)					
i1-j1	119.79	j1-k1	50.00	k1-l1	-
i1-j2	81.42	j1-k2	300.00	k1-l2	131.42
i2-j1	-	j2-k1	81.42	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	123.26
i3-j1	230.21			k2-l2	53.47
i3-j2	-			k2-l3	123.26

Table A10 Result for 0.999 level of confidence for simple supply chain network.

Confidence level					0.999
Profit ($/day)					4,217.18
Revenue ($/day)					6,872.37
Cost ($/day)					
- Transportation cost					2,655.19
- Penalty cost					-
Total cost ($/day)					2,655.19
Supply chain network (unit/day)					
i1-j1	99.13	j1-k1	50.00	k1-l1	-
i1-j2	108.16	j1-k2	300.00	k1-l2	158.16
i2-j1	43.57	j2-k1	108.16	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	130.90
i3-j1	207.29			k2-l2	38.20
i3-j2	-		50.00	k2-l3	130.90

– Random data set for 3,300 days.

Table A11 Seed number for each year.

Year	Seed number
1	896
2	899
3	902
4	905
5	908
6	912
7	915
8	918
9	921
10	924

– Validation detail results.

Table A12 Validation detail results on profit for Simple Supply Chain Network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	3,105.84	3,244.20	3,345.44	3,385.67	3,420.75	3,449.35	3,470.36	3,481.89	3,472.45	3,405.74
2	3,165.15	3,288.11	3,372.79	3,404.02	3,430.60	3,451.31	3,466.03	3,473.49	3,464.48	3,399.34
3	3,117.37	3,258.90	3,361.73	3,400.32	3,432.61	3,458.27	3,477.95	3,490.05	3,480.89	3,414.40
4	3,121.35	3,254.48	3,352.81	3,390.59	3,423.04	3,449.46	3,468.39	3,481.75	3,476.15	3,410.86
5	3,112.54	3,247.69	3,345.35	3,385.06	3,418.24	3,443.94	3,461.39	3,470.61	3,463.41	3,398.62
6	3,126.36	3,261.05	3,356.91	3,395.43	3,427.44	3,453.55	3,471.74	3,478.27	3,467.12	3,401.00
7	3,137.63	3,263.45	3,358.18	3,395.61	3,426.23	3,450.30	3,467.37	3,476.42	3,465.48	3,398.10
8	3,163.86	3,285.03	3,372.37	3,406.12	3,434.12	3,457.42	3,476.61	3,486.47	3,477.38	3,411.44
9	3,139.94	3,270.43	3,367.60	3,401.84	3,430.95	3,454.10	3,468.60	3,472.42	3,457.95	3,391.68
10	3,105.97	3,242.90	3,343.95	3,384.25	3,418.65	3,446.74	3,469.38	3,482.87	3,477.19	3,410.47
AV	3,129.60	3,261.62	3,357.71	3,394.89	3,426.26	3,451.44	3,469.78	3,479.42	3,470.25	3,404.17

Table A13 Validation detail results on revenue for Simple Supply Chain Network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	4,989.06	5,138.28	5,272.81	5,338.77	5,407.03	5,479.69	5,562.03	5,672.46	5,859.37	6,060.40
2	5,029.28	5,168.11	5,292.35	5,352.83	5,415.40	5,482.27	5,559.58	5,666.31	5,851.79	6,051.94
3	5,003.30	5,152.69	5,287.28	5,351.74	5,417.48	5,487.61	5,568.97	5,679.48	5,867.56	6,069.59
4	5,007.10	5,152.50	5,283.33	5,347.09	5,412.77	5,483.36	5,564.03	5,675.38	5,863.46	6,066.07
5	4,986.89	5,135.24	5,268.54	5,334.32	5,401.66	5,472.60	5,552.85	5,661.71	5,850.52	6,053.65
6	5,002.21	5,147.95	5,279.39	5,344.05	5,410.52	5,481.34	5,561.20	5,668.83	5,854.82	6,056.23
7	5,007.78	5,147.32	5,276.11	5,339.73	5,404.49	5,473.58	5,553.71	5,663.22	5,851.15	6,053.06
8	5,040.26	5,178.02	5,302.36	5,363.28	5,426.03	5,493.36	5,572.20	5,678.74	5,864.69	6,066.63
9	5,000.42	5,145.52	5,277.77	5,340.53	5,405.06	5,473.74	5,552.41	5,659.86	5,844.50	6,045.73
10	4,995.62	5,144.24	5,278.45	5,343.77	5,410.78	5,482.66	5,564.98	5,675.93	5,864.37	6,065.66
AV	5,006.19	5,150.99	5,281.84	5,345.61	5,411.12	5,481.02	5,561.20	5,670.19	5,857.22	6,058.90

Table A14 Validation detail results on transportation cost for Simple Supply Chain Network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1,621.12	1,719.31	1,817.69	1,869.88	1,926.76	1,991.15	2,069.22	2,181.55	2,385.40	2,654.14
2	1,639.73	1,734.59	1,829.38	1,879.83	1,934.70	1,996.65	2,072.55	2,183.10	2,385.30	2,652.39
3	1,624.42	1,722.44	1,820.40	1,871.88	1,927.39	1,990.44	2,068.40	2,180.83	2,385.54	2,655.19
4	1,628.23	1,725.51	1,821.87	1,873.10	1,928.57	1,991.82	2,069.09	2,182.01	2,385.41	2,655.19
5	1,620.11	1,719.40	1,818.34	1,870.79	1,927.43	1,991.09	2,068.59	2,180.47	2,385.10	2,655.03
6	1,627.28	1,724.39	1,822.17	1,873.92	1,930.33	1,994.11	2,071.10	2,182.57	2,386.25	2,655.19
7	1,630.17	1,725.23	1,821.59	1,872.77	1,928.15	1,990.69	2,067.74	2,179.83	2,385.10	2,654.96
8	1,642.75	1,737.35	1,831.85	1,881.91	1,936.40	1,998.09	2,074.05	2,183.21	2,385.87	2,655.19
9	1,626.53	1,724.58	1,823.07	1,874.21	1,929.69	1,992.07	2,068.93	2,181.57	2,385.10	2,653.80
10	1,623.94	1,722.91	1,821.26	1,872.82	1,928.78	1,992.43	2,070.00	2,182.31	2,386.15	2,655.19
AV	1,628.43	1,725.57	1,822.76	1,874.11	1,929.82	1,992.85	2,069.97	2,181.75	2,385.52	2,654.63

Table A15 Validation detail results on opportunity loss for Simple Supply Chain Network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	262.09	174.77	109.69	83.22	59.52	39.20	22.45	9.02	1.52	0.52
2	224.40	145.42	90.18	68.98	50.10	34.31	21.01	9.72	2.01	0.22
3	261.51	171.35	105.14	79.54	57.48	38.90	22.63	8.60	1.13	0.00
4	257.52	172.51	108.66	83.40	61.16	42.07	26.55	11.62	1.90	0.02
5	254.24	168.14	104.85	78.47	56.00	37.58	22.87	10.64	2.00	0.00
6	248.57	162.51	100.32	74.70	52.76	33.67	18.36	7.98	1.45	0.04
7	239.97	158.64	96.34	71.35	50.11	32.58	18.59	6.97	0.57	0.00
8	233.66	155.64	98.14	75.25	55.51	37.84	21.54	9.06	1.44	0.00
9	233.94	150.51	87.10	64.49	44.42	27.58	14.88	5.87	1.45	0.24
10	265.71	178.43	113.24	86.70	63.36	43.50	25.59	10.74	1.03	0.00
AV	248.16	163.79	101.37	76.61	55.04	36.72	21.45	9.02	1.45	0.11

– Stability test detail.

Table A16 Detail of stability test at node i1 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9970	0.9970
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9970	0.9939
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9970	0.9939
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
AV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9991	0.9985

Table A17 Detail of stability test at node i2 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
AV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table A18 Detail of stability test at node i3 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4636	0.5606	0.6788	0.7242	0.7697	0.8364	0.8848	0.9515	0.9970	1.0000
2	0.5364	0.6424	0.7424	0.7879	0.8455	0.8909	0.9394	0.9606	0.9939	1.0000
3	0.4879	0.5879	0.7030	0.7515	0.8121	0.8545	0.9030	0.9485	0.9848	1.0000
4	0.4848	0.6121	0.7273	0.7667	0.8121	0.8545	0.9030	0.9485	0.9909	1.0000
5	0.4576	0.5667	0.6909	0.7242	0.7788	0.8515	0.8970	0.9545	0.9848	0.9939
6	0.5030	0.6000	0.7000	0.7485	0.7909	0.8697	0.9030	0.9545	0.9970	1.0000
7	0.5455	0.6485	0.7242	0.7697	0.8242	0.8606	0.8909	0.9455	0.9848	0.9970
8	0.5545	0.6667	0.7576	0.8152	0.8455	0.9121	0.9333	0.9697	0.9939	1.0000
9	0.4667	0.5939	0.7030	0.7606	0.8152	0.8636	0.9030	0.9455	0.9939	0.9970
10	0.4576	0.5848	0.6939	0.7545	0.7848	0.8424	0.9030	0.9485	0.9939	1.0000
AV	0.4958	0.6064	0.7121	0.7603	0.8079	0.8636	0.9060	0.9527	0.9915	0.9988

Table A19 Detail of stability test at node l1 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5182	0.6152	0.7212	0.7606	0.7970	0.8576	0.9091	0.9485	0.9939	1.0000
2	0.4364	0.5545	0.6939	0.7545	0.8152	0.8515	0.9000	0.9485	0.9879	1.0000
3	0.5030	0.6212	0.7121	0.7576	0.7970	0.8697	0.9121	0.9545	0.9909	1.0000
4	0.4939	0.5939	0.6939	0.7394	0.7970	0.8394	0.8909	0.9212	0.9818	1.0000
5	0.5000	0.6182	0.7303	0.7727	0.8121	0.8667	0.9212	0.9697	0.9909	1.0000
6	0.4727	0.5939	0.6939	0.7333	0.7788	0.8394	0.8970	0.9576	0.9848	1.0000
7	0.5242	0.6212	0.7424	0.8152	0.8606	0.9030	0.9333	0.9758	0.9939	1.0000
8	0.4939	0.6030	0.7303	0.7636	0.8242	0.8485	0.9061	0.9636	0.9879	1.0000
9	0.5333	0.6091	0.7000	0.7606	0.7970	0.8394	0.9061	0.9697	0.9909	0.9970
10	0.4939	0.5879	0.6939	0.7273	0.7848	0.8273	0.8909	0.9485	0.9909	1.0000
AV	0.4970	0.6018	0.7112	0.7585	0.8064	0.8543	0.9067	0.9558	0.9894	0.9997

Table A20 Detail of stability test at node l2 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4667	0.5455	0.6515	0.7061	0.7424	0.8121	0.8788	0.9152	0.9939	0.9970
2	0.5152	0.6152	0.7212	0.7606	0.8121	0.8727	0.9242	0.9636	0.9909	1.0000
3	0.4576	0.5333	0.6667	0.7424	0.7939	0.8303	0.8818	0.9424	0.9879	1.0000
4	0.4758	0.5879	0.7091	0.7515	0.8030	0.8333	0.8818	0.9364	0.9909	0.9970
5	0.4848	0.5939	0.6727	0.7273	0.7879	0.8333	0.8970	0.9455	0.9758	1.0000
6	0.4909	0.5909	0.7000	0.7424	0.8061	0.8424	0.8970	0.9515	0.9879	1.0000
7	0.4848	0.5758	0.7212	0.7879	0.8212	0.8576	0.8970	0.9545	0.9909	1.0000
8	0.4788	0.5818	0.7091	0.7515	0.7879	0.8303	0.8879	0.9333	0.9818	1.0000
9	0.5030	0.5848	0.7030	0.7727	0.8121	0.8818	0.9242	0.9788	0.9939	0.9970
10	0.4909	0.5788	0.6636	0.7121	0.7636	0.8030	0.8485	0.9273	0.9909	1.0000
AV	0.4849	0.5788	0.6918	0.7455	0.7930	0.8397	0.8918	0.9449	0.9885	0.9991

Table A21 Detail of stability test at node l3 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5030	0.6091	0.6636	0.7333	0.7788	0.8242	0.8818	0.9545	0.9909	1.0000
2	0.5394	0.6485	0.7273	0.7788	0.8242	0.8727	0.9182	0.9485	0.9879	0.9970
3	0.4848	0.5758	0.7000	0.7576	0.7970	0.8545	0.8848	0.9576	0.9818	1.0000
4	0.4727	0.5909	0.7000	0.7303	0.7848	0.8485	0.9000	0.9424	0.9939	1.0000
5	0.5121	0.6242	0.7212	0.7727	0.8303	0.8818	0.9061	0.9606	0.9970	1.0000
6	0.5091	0.6152	0.7182	0.7636	0.8030	0.8545	0.9000	0.9606	0.9939	0.9970
7	0.4970	0.6061	0.6818	0.7212	0.7848	0.8333	0.8818	0.9273	0.9939	1.0000
8	0.5273	0.6242	0.6758	0.7364	0.8030	0.8394	0.8970	0.9485	0.9909	1.0000
9	0.5091	0.6061	0.7273	0.7636	0.8061	0.8455	0.9121	0.9697	0.9879	1.0000
10	0.4970	0.6061	0.7212	0.7970	0.8273	0.8606	0.9091	0.9515	0.9909	1.0000
AV	0.5052	0.6106	0.7036	0.7555	0.8039	0.8515	0.8991	0.9521	0.9909	0.9994

Table A22 Detail of stability test with higher data points at node i1 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9998	0.9996
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9995	0.9983
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9998	0.9995
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9993
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9990	0.9985
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9995	0.9991
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9997	0.9995
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9997	0.9993
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9997	0.9995
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9991
AV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9997	0.9992

Table A23 Detail of stability test with higher data points at node i2 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
AV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table A24 Detail of stability test with higher data points at node i3 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4887	0.5917	0.6941	0.7448	0.7933	0.8423	0.8965	0.9443	0.9909	0.9990
2	0.4948	0.5922	0.6929	0.7415	0.7977	0.8458	0.8992	0.9510	0.9904	0.9988
3	0.5014	0.6006	0.6984	0.7457	0.7993	0.8501	0.8986	0.9497	0.9920	0.9993
4	0.4917	0.5908	0.6962	0.7473	0.7978	0.8485	0.9017	0.9527	0.9911	0.9995
5	0.4906	0.5986	0.7003	0.7472	0.7961	0.8493	0.8969	0.9488	0.9884	0.9985
6	0.5004	0.5995	0.6972	0.7462	0.7977	0.8503	0.8978	0.9485	0.9899	0.9988
7	0.4967	0.5990	0.7000	0.7541	0.8020	0.8498	0.8961	0.9483	0.9890	0.9992
8	0.5025	0.6015	0.6999	0.7541	0.8009	0.8468	0.8963	0.9496	0.9906	0.9994
9	0.4979	0.6016	0.7050	0.7548	0.8044	0.8541	0.9048	0.9540	0.9911	0.9986
10	0.4942	0.5937	0.6971	0.7508	0.7984	0.8493	0.8968	0.9477	0.9895	0.9992
AV	0.4959	0.5969	0.6981	0.7487	0.7988	0.8486	0.8985	0.9495	0.9903	0.9990

Table A25 Detail of stability test with higher data points at node l1 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5030	0.6016	0.6998	0.7495	0.8017	0.8533	0.9037	0.9490	0.9880	0.9989
2	0.4974	0.5985	0.7018	0.7505	0.7999	0.8449	0.8967	0.9494	0.9886	0.9987
3	0.4943	0.5929	0.6951	0.7439	0.7983	0.8512	0.8995	0.9505	0.9903	0.9993
4	0.5037	0.6046	0.7077	0.7548	0.8067	0.8552	0.9031	0.9501	0.9902	0.9992
5	0.5010	0.6037	0.7055	0.7523	0.8041	0.8538	0.9043	0.9527	0.9895	0.9987
6	0.4925	0.5926	0.6901	0.7415	0.7944	0.8444	0.8977	0.9542	0.9893	0.9993
7	0.5001	0.6019	0.6984	0.7462	0.7978	0.8454	0.8968	0.9491	0.9899	0.9996
8	0.4993	0.5962	0.7004	0.7505	0.8006	0.8492	0.8965	0.9467	0.9896	0.9991
9	0.5082	0.6027	0.7077	0.7572	0.8046	0.8504	0.9001	0.9503	0.9907	0.9991
10	0.4907	0.5981	0.7055	0.7539	0.8030	0.8524	0.9025	0.9534	0.9909	0.9993
AV	0.4990	0.5993	0.7012	0.7500	0.8011	0.8500	0.9001	0.9505	0.9897	0.9991

Table A26 Detail of stability test with higher data points at node l2 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5033	0.6007	0.7019	0.7533	0.8006	0.8493	0.8997	0.9493	0.9906	0.9994
2	0.4976	0.5959	0.6972	0.7481	0.7982	0.8483	0.8975	0.9491	0.9898	0.9987
3	0.4965	0.5896	0.6925	0.7455	0.7934	0.8411	0.8938	0.9459	0.9882	0.9993
4	0.5008	0.6028	0.7045	0.7549	0.8005	0.8515	0.9006	0.9513	0.9902	0.9984
5	0.4975	0.5944	0.6916	0.7437	0.7968	0.8502	0.8990	0.9486	0.9904	0.9994
6	0.5024	0.6008	0.6982	0.7518	0.7996	0.8484	0.8992	0.9482	0.9900	0.9986
7	0.5000	0.6016	0.7042	0.7577	0.8022	0.8512	0.9001	0.9501	0.9901	0.9995
8	0.4931	0.5946	0.7007	0.7490	0.7974	0.8473	0.8990	0.9498	0.9891	0.9982
9	0.5024	0.6001	0.6977	0.7481	0.7957	0.8461	0.8978	0.9492	0.9901	0.9986
10	0.4968	0.5947	0.7002	0.7516	0.7984	0.8501	0.9006	0.9492	0.9905	0.9992
AV	0.4990	0.5975	0.6989	0.7504	0.7983	0.8484	0.8987	0.9491	0.9899	0.9989

Table A27 Detail of stability test with higher data points at node l3 for simple supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4933	0.5908	0.6903	0.7406	0.7898	0.8407	0.8911	0.9465	0.9899	0.9993
2	0.5012	0.6059	0.7091	0.7594	0.8035	0.8489	0.8976	0.9502	0.9897	0.9994
3	0.4935	0.5921	0.6925	0.7418	0.7949	0.8475	0.8994	0.9495	0.9903	0.9996
4	0.4926	0.5984	0.6982	0.7471	0.8002	0.8515	0.9038	0.9492	0.9887	0.9987
5	0.5012	0.6022	0.6996	0.7459	0.7935	0.8459	0.8972	0.9485	0.9908	0.9989
6	0.5006	0.5978	0.6967	0.7468	0.7986	0.8483	0.9002	0.9497	0.9885	0.9993
7	0.5018	0.6099	0.7043	0.7522	0.8001	0.8501	0.8951	0.9494	0.9905	0.9991
8	0.5044	0.6052	0.7036	0.7514	0.8027	0.8515	0.9010	0.9498	0.9898	0.9993
9	0.5034	0.6048	0.7078	0.7565	0.8084	0.8569	0.9057	0.9518	0.9905	0.9992
10	0.5049	0.6049	0.7061	0.7566	0.8063	0.8522	0.9005	0.9510	0.9907	0.9989
AV	0.4997	0.6012	0.7008	0.7498	0.7998	0.8494	0.8992	0.9496	0.9899	0.9992

Appendix B The Detail on Biodiesel Supply Chain Network

– BHD plant simulation results

Table B1 Detail results of BHD plant simulation via PRO/II

Flow rate (L/d)			Hot utility usage (kWh/d)			Cold utility usage (kWh/d)				Electric energy usage (kWh/d)			
Steric inlet	Biodiesel produce	H2 usage	E1	E2	Reboiler	Condenser	E3	E6	Reactor	C1	C2	P1	P2
5,000.00	4,764.16	891.93	40.08	772.73	1,630.63	807.05	1,305.88	764.18	230.24	228.95	15.62	1.12	1.87
5,100.00	4,859.27	913.09	40.84	786.52	1,668.82	822.69	1,338.08	779.35	234.78	234.72	16.03	1.15	1.91
5,200.00	4,954.74	931.99	41.48	800.69	1,706.79	839.30	1,368.38	794.76	239.06	239.90	16.40	1.18	1.96
5,300.00	5,050.03	950.94	42.26	814.42	1,745.42	855.14	1,400.59	810.00	243.63	245.59	16.82	1.21	2.00
5,400.00	5,145.06	971.77	42.85	828.25	1,783.96	871.20	1,432.04	825.24	247.94	250.89	17.19	1.24	2.05
5,500.00	5,240.57	991.21	43.57	841.96	1,823.05	887.33	1,464.22	840.57	252.34	256.51	17.60	1.27	2.10
5,600.00	5,335.81	1,012.10	44.25	855.58	1,862.34	903.36	1,496.73	855.84	256.76	262.19	18.01	1.30	2.15
5,700.00	5,431.10	1,033.08	45.04	869.10	1,902.07	919.43	1,529.92	871.12	261.24	268.24	18.45	1.33	2.20
5,800.00	5,526.30	1,053.74	45.71	882.56	1,941.94	935.43	1,562.94	886.38	265.46	273.97	18.86	1.36	2.24
5,900.00	5,621.96	1,071.83	46.62	895.76	1,982.49	951.26	1,597.25	901.66	270.31	280.23	19.33	1.39	2.29
6,000.00	5,717.17	1,092.58	47.29	909.01	2,022.96	967.14	1,630.96	916.90	274.73	286.06	19.75	1.43	2.34
6,100.00	5,812.11	1,117.42	47.81	922.62	2,063.17	983.79	1,663.38	932.25	278.96	291.68	20.13	1.46	2.39
6,200.00	5,907.33	1,138.15	48.42	935.66	2,104.20	999.49	1,697.57	947.46	283.31	297.41	20.55	1.49	2.44
6,300.00	6,002.61	1,159.53	49.18	948.70	2,145.64	1,015.52	1,732.31	962.73	287.43	303.64	21.00	1.52	2.49
6,400.00	6,097.89	1,180.77	49.89	961.69	2,187.30	1,031.54	1,767.06	978.00	291.88	309.75	21.45	1.56	2.55
6,500.00	6,193.23	1,201.25	50.61	974.53	2,229.35	1,047.44	1,802.26	993.27	296.69	315.89	21.90	1.59	2.60
6,600.00	6,288.64	1,222.41	51.26	987.74	2,271.18	1,064.23	1,836.07	1,008.71	300.93	321.83	22.33	1.62	2.65
6,700.00	6,383.71	1,245.54	51.99	1,000.18	2,314.12	1,079.67	1,872.92	1,023.84	305.16	328.36	22.80	1.66	2.70
6,800.00	6,479.01	1,266.48	52.68	1,012.78	2,357.05	1,095.57	1,908.85	1,039.10	309.94	334.56	23.26	1.69	2.76

6,900.00	6,574.63	1,286.39	53.38	1,025.75	2,399.85	1,112.43	1,943.47	1,054.59	314.17	340.64	23.70	1.72	2.81
7,000.00	6,669.89	1,308.93	54.40	1,037.26	2,444.99	1,126.89	1,984.43	1,069.56	319.29	348.37	24.28	1.76	2.87
7,100.00	6,765.03	1,331.98	54.93	1,050.13	2,488.10	1,143.69	2,019.11	1,084.97	323.41	354.25	24.70	1.80	2.92
7,200.00	6,860.42	1,353.57	55.86	1,061.68	2,533.56	1,158.53	2,059.45	1,100.03	328.30	361.61	25.25	1.84	2.98
7,300.00	6,955.50	1,377.03	56.23	1,074.98	2,576.35	1,176.26	2,092.16	1,115.62	331.57	366.92	25.62	1.87	3.03
7,400.00	7,050.64	1,399.90	56.95	1,086.70	2,621.77	1,191.53	2,131.34	1,130.73	336.66	373.74	26.12	1.91	3.09
7,500.00	7,146.57	1,419.38	57.95	1,098.42	2,667.95	1,207.44	2,171.18	1,146.08	341.42	381.24	26.69	1.95	3.15
7,600.00	7,241.08	1,447.77	58.50	1,110.82	2,712.76	1,224.09	2,208.11	1,161.38	345.75	387.85	27.14	1.98	3.20
7,700.00	7,336.33	1,469.01	59.09	1,122.33	2,758.92	1,239.37	2,247.19	1,176.51	350.09	394.14	27.61	2.02	3.26
7,800.00	7,432.20	1,490.41	60.14	1,133.69	2,806.43	1,255.24	2,288.68	1,191.84	354.98	402.14	28.21	2.06	3.33
7,900.00	7,526.93	1,515.23	60.52	1,145.88	2,851.85	1,271.80	2,325.18	1,207.15	358.96	407.95	28.62	2.10	3.38
8,000.00	7,622.60	1,537.76	61.61	1,156.30	2,901.17	1,286.38	2,370.00	1,222.20	364.13	416.43	29.26	2.14	3.45
8,100.00	7,717.65	1,561.98	62.18	1,168.20	2,947.80	1,303.06	2,408.11	1,237.59	368.32	422.96	29.73	2.18	3.51
8,200.00	7,813.18	1,583.90	62.81	1,179.96	2,994.97	1,319.82	2,446.61	1,253.05	372.00	429.50	30.21	2.22	3.56
8,300.00	7,908.23	1,609.27	63.60	1,190.84	3,043.88	1,335.30	2,489.10	1,268.20	377.20	437.18	30.77	2.26	3.63
8,400.00	8,003.65	1,631.90	64.22	1,202.41	3,091.75	1,352.04	2,528.28	1,283.64	380.67	443.86	31.26	2.30	3.69
8,500.00	8,098.91	1,657.02	65.15	1,212.82	3,142.15	1,367.34	2,572.82	1,298.78	386.31	452.16	31.88	2.34	3.75
8,600.00	8,194.30	1,680.75	65.91	1,223.35	3,192.32	1,382.86	2,616.07	1,313.98	390.90	459.70	32.44	2.39	3.82
8,700.00	8,290.27	1,702.15	66.78	1,234.35	3,242.23	1,399.56	2,657.97	1,329.49	395.41	467.34	33.02	2.43	3.88
8,800.00	8,384.54	1,730.34	67.21	1,245.63	3,291.02	1,416.02	2,697.92	1,344.73	398.96	473.94	33.47	2.47	3.94
8,900.00	8,479.59	1,756.06	68.00	1,255.48	3,343.00	1,430.94	2,743.73	1,359.77	403.52	481.99	34.07	2.51	4.01
9,000.00	8,575.52	1,779.55	68.98	1,265.35	3,395.80	1,446.60	2,790.11	1,375.08	409.17	490.63	34.72	2.56	4.08
9,100.00	8,670.56	1,806.62	69.86	1,275.14	3,448.56	1,461.93	2,836.62	1,390.19	414.07	499.19	35.35	2.61	4.15
9,200.00	8,766.93	1,825.34	70.53	1,285.75	3,500.03	1,478.75	2,878.60	1,405.78	417.47	506.02	35.88	2.65	4.22
9,300.00	8,860.46	1,858.04	71.04	1,296.42	3,551.00	1,495.06	2,921.29	1,420.90	421.86	513.52	36.39	2.69	4.28
9,400.00	8,955.84	1,883.28	71.91	1,305.71	3,605.42	1,510.25	2,969.19	1,436.04	426.73	522.06	37.02	2.74	4.36
9,500.00	9,051.52	1,907.14	72.67	1,315.83	3,658.56	1,526.86	3,013.74	1,451.49	430.88	529.90	37.61	2.79	4.42

9,600.00	9,147.20	1,934.78	73.90	1,323.75	3,716.69	1,540.99	3,067.93	1,466.46	437.32	540.41	38.40	2.84	4.50
9,700.00	9,242.95	1,957.59	74.66	1,333.65	3,770.67	1,557.63	3,113.03	1,481.94	441.69	548.21	38.99	2.89	4.57
9,800.00	9,336.81	1,987.94	75.08	1,343.76	3,823.65	1,573.92	3,156.78	1,497.10	444.97	555.33	39.48	2.94	4.64
9,900.00	9,433.40	2,012.46	76.29	1,352.05	3,882.13	1,589.46	3,209.33	1,512.46	451.06	565.50	40.26	2.99	4.72
10,000.00	9,528.52	2,040.33	77.17	1,360.47	3,939.76	1,604.58	3,260.36	1,527.56	455.97	574.67	40.94	3.04	4.80
10,100.00	9,624.09	2,066.19	77.97	1,369.84	3,995.84	1,621.26	3,307.67	1,543.02	460.46	583.10	41.57	3.09	4.87
10,200.00	9,719.39	2,093.95	78.86	1,377.99	4,054.56	1,636.46	3,359.56	1,558.15	465.36	592.38	42.26	3.14	4.95
10,300.00	9,814.58	2,121.05	79.67	1,387.04	4,111.66	1,653.00	3,408.03	1,573.53	469.90	601.06	42.90	3.20	5.02
10,400.00	9,909.56	2,150.51	80.52	1,394.88	4,171.42	1,668.06	3,460.94	1,588.60	474.80	610.45	43.59	3.25	5.11
10,500.00	10,005.10	2,176.89	81.36	1,403.54	4,229.89	1,684.55	3,510.69	1,604.02	479.37	619.30	44.25	3.30	5.18
10,600.00	10,101.29	2,201.39	82.22	1,412.07	4,289.05	1,701.25	3,560.78	1,619.56	483.91	628.16	44.92	3.35	5.26
10,700.00	10,193.96	2,235.33	82.61	1,421.08	4,345.91	1,717.24	3,608.16	1,634.52	487.17	635.79	45.43	3.40	5.33
10,800.00	10,291.31	2,260.79	83.97	1,427.64	4,410.78	1,732.75	3,667.04	1,649.98	493.55	647.28	46.33	3.47	5.42
10,900.00	10,386.04	2,292.04	84.91	1,434.51	4,473.93	1,747.60	3,723.54	1,664.98	498.61	657.44	47.07	3.53	5.51
11,000.00	10,481.01	2,321.08	85.69	1,442.47	4,534.92	1,763.94	3,775.56	1,680.29	503.17	666.57	47.74	3.58	5.59
11,100.00	10,576.58	2,350.16	86.67	1,449.01	4,599.59	1,779.09	3,833.04	1,695.46	508.19	676.82	48.51	3.64	5.68
11,200.00	10,671.98	2,377.57	87.44	1,456.70	4,661.66	1,795.55	3,885.60	1,710.86	512.67	685.83	49.18	3.70	5.76
11,300.00	10,767.01	2,407.82	88.35	1,464.12	4,724.76	1,811.96	3,939.98	1,726.20	517.43	695.72	49.91	3.76	5.84
11,400.00	10,862.99	2,436.43	89.38	1,471.10	4,789.57	1,828.49	3,996.19	1,741.68	522.32	706.12	50.69	3.81	5.93
11,500.00	10,958.64	2,465.97	90.38	1,477.92	4,854.85	1,844.90	4,052.85	1,757.10	527.19	716.52	51.46	3.87	6.02
11,600.00	11,052.80	2,499.29	91.22	1,483.65	4,922.10	1,859.55	4,112.69	1,772.00	532.15	726.86	52.22	3.94	6.11
11,700.00	11,147.17	2,529.90	91.97	1,491.30	4,985.21	1,876.57	4,165.45	1,787.37	536.52	736.05	52.88	4.00	6.19
11,800.00	11,242.33	2,561.06	92.81	1,497.56	5,052.14	1,892.58	4,223.29	1,802.66	540.75	746.10	53.62	4.06	6.28
11,900.00	11,336.11	2,591.66	93.55	1,503.46	5,119.27	1,907.61	4,281.56	1,817.57	545.85	755.64	54.32	4.12	6.37
12,000.00	11,432.23	2,626.62	95.03	1,508.81	5,190.58	1,924.39	4,345.91	1,833.14	551.52	769.11	55.32	4.19	6.47
12,100.00	11,529.18	2,654.73	96.11	1,513.19	5,263.17	1,939.56	4,410.43	1,848.48	556.70	780.33	56.18	4.26	6.57
12,200.00	11,621.78	2,692.89	96.96	1,519.34	5,330.94	1,955.63	4,469.33	1,863.45	561.49	791.11	56.94	4.32	6.66

12,300.00	11,718.24	2,719.82	97.91	1,524.78	5,401.31	1,972.08	4,529.55	1,878.98	566.18	801.37	57.72	4.39	6.76
12,400.00	11,814.04	2,753.84	99.05	1,528.14	5,477.16	1,986.66	4,598.19	1,894.08	571.41	813.60	58.64	4.46	6.86
12,500.00	11,908.32	2,788.91	100.19	1,533.15	5,549.34	2,002.98	4,661.77	1,909.31	576.73	825.69	59.53	4.53	6.96
12,600.00	12,006.18	2,817.66	101.61	1,535.81	5,628.38	2,018.19	4,733.41	1,924.78	582.41	838.90	60.55	4.61	7.07
12,700.00	12,097.92	2,856.14	102.14	1,541.50	5,697.47	2,033.89	4,791.99	1,939.57	586.17	848.36	61.20	4.67	7.17
12,800.00	12,196.25	2,884.70	103.54	1,545.07	5,775.40	2,050.88	4,860.66	1,955.46	592.10	861.39	62.21	4.75	7.27
12,900.00	12,288.94	2,923.78	104.48	1,549.72	5,848.57	2,066.79	4,924.62	1,970.40	597.06	872.98	63.03	4.82	7.37
13,000.00	12,381.90	2,961.26	105.82	1,551.71	5,929.29	2,080.82	4,998.86	1,985.03	602.74	886.80	64.06	4.90	7.49
13,100.00	12,482.21	2,990.92	107.21	1,554.56	6,010.22	2,098.30	5,069.65	2,001.26	608.16	900.00	65.08	4.98	7.60
13,200.00	12,577.03	3,026.25	108.27	1,556.41	6,091.67	2,112.71	5,142.55	2,016.19	613.43	912.37	66.00	5.06	7.71
13,300.00	12,668.91	3,067.16	109.41	1,559.87	6,169.28	2,128.49	5,211.49	2,031.02	618.64	925.42	66.94	5.13	7.82
13,400.00	12,766.46	3,097.83	110.47	1,562.75	6,249.48	2,145.19	5,280.50	2,046.75	623.58	937.17	67.83	5.21	7.93
13,600.00	12,958.18	3,168.77	112.97	1,566.04	6,417.13	2,176.68	5,429.37	2,077.40	634.34	963.91	69.83	5.38	8.16
13,700.00	13,052.27	3,210.74	114.24	1,566.21	6,504.91	2,190.99	5,509.29	2,092.23	640.05	978.28	70.89	5.47	8.29
13,800.00	13,138.47	3,250.44	115.56	1,569.45	6,582.95	2,205.81	5,579.48	2,106.14	645.30	992.05	71.89	5.54	8.39
13,900.00	13,239.93	3,290.18	116.66	1,570.08	6,671.95	2,223.24	5,656.62	2,122.51	650.59	1,005.34	72.86	5.63	8.52
14,000.00	13,335.53	3,328.16	118.12	1,571.11	6,759.23	2,239.83	5,734.26	2,137.97	656.19	1,020.15	73.97	5.72	8.64
14,100.00	13,433.66	3,361.45	119.61	1,569.74	6,853.34	2,254.98	5,818.90	2,153.48	661.99	1,035.00	75.12	5.81	8.77
14,400.00	13,729.47	3,477.14	124.12	1,565.24	7,140.43	2,303.13	6,076.02	2,200.70	679.59	1,081.61	78.64	6.10	9.18
14,600.00	13,905.48	3,565.65	126.32	1,567.82	7,311.20	2,333.28	6,226.67	2,229.09	689.67	1,108.69	80.56	6.27	9.41
14,800.00	14,089.73	3,650.54	129.69	1,563.75	7,505.55	2,363.08	6,403.99	2,258.47	701.75	1,142.48	83.08	6.47	9.69
14,900.00	14,192.77	3,687.05	130.90	1,561.50	7,605.66	2,380.91	6,489.82	2,275.13	707.03	1,156.52	84.14	6.57	9.83
15,000.00	14,292.79	3,725.49	133.06	1,557.88	7,711.29	2,398.60	6,585.33	2,291.38	713.53	1,175.72	85.63	6.68	9.98

– Chance constrained optimization detail results.

Table B2 Result for 0.50 level of confidence for biodiesel supply chain network.

Confidence level					0.50
Profit ($/day)					262,454.58
Revenue ($/day)					773,450.00
Cost ($/day)					
- Transportation cost					97,279.17
- Penalty cost					-
- Operation cost					413,716.24
Total cost ($/day)					510,995.42
Supply chain network (unit/day)					
i1-j1	6,767.96	j1-k1	-	k1-l1	-
i1-j2	-	j1-k2	8,000.00	k1-l2	7,500.00
i2-j1	-	j2-k1	7,500.00	k1-l3	-
i2-j2	-	j2-k2	-	k2-l1	3,000.00
i3-j1	1,628.37			k2-l2	-
i3-j2	7,871.63			k2-l3	5,000.00

Table B3 Result for 0.60 level of confidence for biodiesel supply chain network.

Confidence level					0.6
Profit ($/day)					267,613.82
Revenue ($/day)					793,045.13
Cost ($/day)					
- Transportation cost					97,279.17
- Penalty cost					-
- Operation cost					413,716.24
Total cost ($/day)					510,995.42
Supply chain network (unit/day)					
i1-j1	7,420.72	j1-k1	-	k1-l1	-
i1-j2	-	j1-k2	8,000.00	k1-l2	7,690.01
i2-j1	-	j2-k1	7,892.69	k1-l3	202.68
i2-j2	-	j2-k2	-	k2-l1	3,076.00
i3-j1	975.61			k2-l2	-
i3-j2	8,283.71			k2-l3	4,924.00

Table B4 Result for 0.70 level of confidence for biodiesel supply chain network.

Confidence level					0.7
Profit ($/day)					273,031.54
Revenue ($/day)					814,009.76
Cost ($/day)					
- Transportation cost					104,676.50
- Penalty cost					-
- Operation cost					436,301.72
Total cost ($/day)					540,978.22
Supply chain network (unit/day)					
i1-j1	8,119.11	j1-k1	-	k1-l1	-
i1-j2	-	j1-k2	8,000.00	k1-l2	7,893.30
i2-j1	-	j2-k1	8,312.82	k1-l3	419.52
i2-j2	-	j2-k2	-	k2-l1	3,157.32
i3-j1	277.22			k2-l2	-
i3-j2	8,724.60			k2-l3	4,842.68

Table B5 Result for 0.75 level of confidence for biodiesel supply chain network.

Confidence level					0.75
Profit ($/day)					275,986.07
Revenue ($/day)					825,618.41
Cost ($/day)					
- Transportation cost					106,793.69
- Penalty cost					-
- Operation cost					442,838.65
Total cost ($/day)					549,632.34
Supply chain network (unit/day)					
i1-j1	8,396.33	j1-k1	-	k1-l1	-
i1-j2	109.49	j1-k2	8,000.00	k1-l2	8,005.87
i2-j1	-	j2-k1	8,545.46	k1-l3	539.59
i2-j2	-	j2-k2	-	k2-l1	3,202.35
i3-j1	-			k2-l2	-
i3-j2	8,859.23			k2-l3	4,797.65

Table B6 Result for 0.80 level of confidence for biodiesel supply chain network.

Confidence level					0.8
Profit ($/day)					279,238.00
Revenue ($/day)					838,545.19
Cost ($/day)					
- Transportation cost					109,151.29
- Penalty cost					-
- Operation cost					450,155.91
Total cost ($/day)					559,307.20
Supply chain network (unit/day)					
i1-j1	8,396.33	j1-k1	-	k1-l1	-
i1-j2	540.12	j1-k2	8,000.00	k1-l2	8,131.22
i2-j1	-	j2-k1	8,804.51	k1-l3	673.30
i2-j2	-	j2-k2	-	k2-l1	3,252.49
i3-j1	-			k2-l2	-
i3-j2	8,700.46			k2-l3	4,747.51

Table B7 Result for 0.85 level of confidence for biodiesel supply chain network.

Confidence level					0.85
Profit ($/day)					282,503.04
Revenue ($/day)					853,612.94
Cost ($/day)					
- Transportation cost					112,374.18
- Penalty cost					-
- Operation cost					458,735.71
Total cost ($/day)					571,109.90
Supply chain network (unit/day)					
i1-j1	8,158.89	j1-k1	-	k1-l1	-
i1-j2	804.68	j1-k2	8,000.00	k1-l2	8,277.33
i2-j1	237.44	j2-k1	9,106.47	k1-l3	829.15
i2-j2	237.39	j2-k2	-	k2-l1	3,310.93
i3-j1	-			k2-l2	-
i3-j2	8,515.39			k2-l3	4,689.07

Table B8 Result for 0.90 level of confidence for biodiesel supply chain network.

Confidence level					0.9
Profit ($/day)					286,254.52
Revenue ($/day)					872,571.61
Cost ($/day)					
- Transportation cost					116,708.56
- Penalty cost					-
- Operation cost					469,608.52
Total cost ($/day)					586,317.09
Supply chain network (unit/day)					
i1-j1	7,282.21	j1-k1	-	k1-l1	-
i1-j2	1,436.24	j1-k2	8,000.00	k1-l2	8,461.16
i2-j1	1,114.12	j2-k1	9,486.40	k1-l3	1,025.24
i2-j2	237.39	j2-k2	-	k2-l1	3,384.47
i3-j1	-			k2-l2	-
i3-j2	8,282.53			k2-l3	4,615.53

Table B9 Result for 0.95 level of confidence for biodiesel supply chain network.

Confidence level					0.95
Profit ($/day)					291,656.00
Revenue ($/day)					900,671.20
Cost ($/day)					
- Transportation cost					123,132.77
- Penalty cost					-
- Operation cost					485,882.44
Total cost ($/day)					609,015.20
Supply chain network (unit/day)					
i1-j1	7,282.21	j1-k1	-	k1-l1	-
i1-j2	1,072.94	j1-k2	8,000.00	k1-l2	8,733.64
i2-j1	1,114.12	j2-k1	10,049.52	k1-l3	1,315.88
i2-j2	1,536.76	j2-k2	-	k2-l1	3,493.46
i3-j1	-			k2-l2	-
i3-j2	7,937.39			k2-l3	4,506.54

Table B10 Result for 0.99 level of confidence for biodiesel supply chain network.

Confidence level					0.99
Profit ($/day)					301,276.85
Revenue ($/day)					953,381.38
Cost ($/day)					
- Transportation cost					135,183.50
- Penalty cost					-
- Operation cost					516,921.03
Total cost ($/day)					652,104.52
Supply chain network (unit/day)					
i1-j1	3,308.04	j1-k1	-	k1-l1	-
i1-j2	4,365.61	j1-k2	8,000.00	k1-l2	9,244.76
i2-j1	5,088.28	j2-k1	11,105.84	k1-l3	1,861.08
i2-j2	-	j2-k2	-	k2-l1	3,697.90
i3-j1	-			k2-l2	-
i3-j2	7,289.97			k2-l3	4,302.10

Table B11 Result for 0.999 level of confidence for biodiesel supply chain network.

Confidence level					0.999
Profit ($/day)					311,267.77
Revenue ($/day)					1,012,464.02
Cost ($/day)					
- Transportation cost					148,691.12
- Penalty cost					-
- Operation cost					552,505.12
Total cost ($/day)					701,196.24
Supply chain network (unit/day)					
i1-j1	575.96	j1-k1	-	k1-l1	-
i1-j2	6,333.81	j1-k2	8,000.00	k1-l2	9,817.67
i2-j1	7,820.36	j2-k1	12,289.86	k1-l3	2,472.19
i2-j2	-	j2-k2	-	k2-l1	3,927.07
i3-j1	-			k2-l2	-
i3-j2	6,564.28			k2-l3	4,072.93

– Random data set for 3,300 days.

Table B12 Seed number for each year.

Year	Seed number
1	896
2	899
3	902
4	905
5	908
6	912
7	915
8	918
9	921
10	924

– Validation detail results.

Table B13 Validation detail results on profit for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	187,096.31	200,192.86	203,599.03	202,776.18	205,251.18	202,121.21	191,857.45	169,808.48	124,708.90	73,167.69
2	193,588.88	203,174.79	204,244.49	201,971.99	202,518.44	198,907.54	188,203.79	164,527.62	120,028.29	70,327.62
3	188,275.73	202,700.17	207,293.80	205,929.66	206,995.72	203,252.31	192,494.85	171,950.96	126,641.33	75,348.07
4	189,286.32	201,836.87	203,823.28	202,440.55	203,055.14	199,429.86	189,442.88	168,998.31	125,030.65	73,789.04
5	188,899.96	201,081.42	202,827.77	201,525.60	203,270.10	198,932.80	188,094.66	165,617.19	121,160.59	71,185.23
6	188,549.65	201,463.11	205,397.06	203,861.35	204,999.41	199,898.02	190,089.57	166,577.11	120,702.94	70,583.01
7	190,215.23	201,655.54	204,449.60	202,333.78	201,194.40	197,867.82	188,158.79	166,592.35	121,945.89	70,991.64
8	191,285.16	201,860.40	204,907.90	202,224.15	203,344.16	198,473.58	187,691.08	166,254.68	124,329.85	74,260.52
9	193,773.03	205,324.46	207,367.77	205,928.23	205,737.35	201,448.92	192,562.36	166,974.59	118,925.94	69,448.85
10	186,583.70	199,552.31	202,723.71	201,030.83	202,627.95	198,888.63	188,800.50	167,787.22	124,567.11	74,065.26
AV	189,755.40	201,884.19	204,663.44	203,002.23	203,899.38	199,922.07	189,739.59	167,508.85	122,804.15	72,316.69

Table B14 Validation detail results on revenue for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	732,400.33	745,214.60	754,719.67	758,365.74	762,385.48	766,366.23	769,658.09	772,450.03	773,858.42	774,059.17
2	734,765.85	746,279.64	754,564.78	757,538.34	760,787.30	764,034.07	766,754.66	768,817.88	770,231.28	770,558.37
3	734,837.83	748,579.21	758,689.23	762,314.99	765,930.89	769,239.96	772,226.06	774,833.54	776,321.29	776,544.32
4	734,163.85	747,351.54	756,659.22	760,062.31	763,743.29	767,246.23	770,380.51	772,919.51	774,679.15	774,991.60
5	731,688.75	744,620.56	753,912.15	757,338.70	761,259.11	764,703.18	767,588.39	769,838.01	771,353.25	771,729.29
6	732,692.80	745,536.42	754,863.50	758,422.26	762,045.23	765,507.18	768,338.18	770,389.04	771,542.06	771,790.19
7	733,347.65	745,934.52	755,080.51	758,351.64	761,866.89	765,333.35	768,295.33	770,448.30	771,643.78	771,746.51
8	736,979.70	749,023.78	758,068.33	761,247.06	764,559.59	767,946.33	771,038.39	773,702.33	775,219.43	775,456.76
9	732,793.63	745,486.82	754,456.39	757,601.31	760,852.38	764,068.74	766,820.17	768,506.88	769,307.17	769,529.45
10	733,068.32	746,321.54	756,168.18	759,848.84	763,678.91	767,283.92	770,565.98	773,268.29	775,089.62	775,261.50
AV	733,673.87	746,434.86	755,718.20	759,109.12	762,710.91	766,172.92	769,166.58	771,517.38	772,924.54	773,166.72

Table B15 Validation detail results on transportation cost for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	93,928.29	97,676.96	101,806.01	103,912.72	105,677.87	108,968.11	113,769.66	121,439.96	134,470.64	148,595.15
2	94,511.22	98,387.95	102,502.16	104,634.44	106,428.69	109,471.16	114,055.60	121,730.11	134,672.48	148,464.26
3	94,085.95	98,016.11	102,256.66	104,461.90	106,319.13	109,426.76	114,195.62	121,445.66	134,602.64	148,691.12
4	93,993.77	98,044.62	102,429.39	104,548.96	106,494.16	109,672.12	114,358.66	121,557.09	134,577.53	148,691.12
5	93,761.78	97,763.88	102,188.60	104,284.69	106,167.48	109,470.17	114,176.40	121,677.11	134,673.88	148,557.12
6	94,200.68	98,058.09	102,092.70	104,319.59	106,175.22	109,653.60	114,117.35	121,732.68	134,836.14	148,691.12
7	94,196.65	98,230.04	102,397.26	104,580.13	106,851.80	109,938.06	114,487.64	121,750.46	134,641.34	148,599.24
8	94,654.54	98,636.14	102,750.20	105,023.01	106,761.25	110,148.68	114,929.74	122,382.67	134,858.67	148,691.12
9	93,848.07	97,866.24	102,084.56	104,116.51	106,057.77	109,230.78	113,478.24	121,354.53	134,749.03	148,442.92
10	93,968.32	97,969.36	102,372.82	104,660.29	106,506.91	109,764.84	114,536.73	121,907.39	134,801.92	148,691.12
AV	94,114.93	98,064.94	102,288.04	104,454.23	106,344.03	109,574.43	114,210.56	121,697.77	134,688.43	148,611.43

Table B16 Validation detail results on operation cost for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	399,166.04	411,152.93	425,004.12	431,923.92	436,728.18	445,524.60	458,393.49	479,054.03	514,291.80	552,160.19
2	401,868.55	414,311.93	427,769.60	434,600.33	439,569.78	447,443.44	459,684.08	480,327.99	515,065.11	551,709.93
3	400,343.04	412,906.54	426,819.93	434,136.77	439,349.26	447,430.45	460,137.76	479,298.46	514,798.53	552,505.12
4	399,842.77	412,913.67	427,484.76	434,404.87	440,127.30	448,456.22	460,808.80	479,767.70	514,674.09	552,505.12
5	398,976.32	411,889.33	426,624.35	433,540.18	438,733.80	447,517.58	460,141.19	480,179.61	515,048.74	551,986.95
6	401,059.81	413,187.08	426,204.47	433,520.50	438,678.47	448,090.88	459,805.33	480,316.90	515,681.89	552,505.12
7	400,937.20	413,783.95	427,401.15	434,694.14	441,471.15	449,511.01	461,334.92	480,482.73	514,928.14	552,155.64
8	402,943.66	415,486.01	428,674.70	436,237.76	440,832.72	449,936.03	462,894.61	482,871.94	515,734.24	552,505.12
9	399,191.38	412,181.43	426,101.35	432,585.00	438,149.54	446,501.78	457,331.58	478,838.16	515,292.97	551,576.31
10	399,774.82	412,624.91	427,204.99	434,891.89	440,065.83	448,658.48	461,359.35	481,082.16	515,505.73	552,505.12
AV	400,410.36	413,043.78	426,928.94	434,053.54	439,370.60	447,907.05	460,189.11	480,221.97	515,102.12	552,211.46

Table B17 Validation detail results on opportunity loss for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	52,209.69	36,191.85	24,310.51	19,752.92	14,728.25	9,752.31	5,637.49	2,147.56	387.08	136.14
2	44,797.20	30,404.97	20,048.53	16,331.58	12,270.39	8,211.93	4,811.18	2,232.16	465.41	56.55
3	52,133.10	34,956.38	22,318.85	17,786.66	13,266.78	9,130.44	5,397.83	2,138.47	278.78	-
4	51,040.99	34,556.38	22,921.78	18,667.93	14,066.70	9,688.02	5,770.17	2,596.42	396.88	6.31
5	50,050.68	33,885.92	22,271.43	17,988.24	13,087.73	8,782.64	5,176.13	2,364.10	470.05	-
6	48,882.67	32,828.14	21,169.28	16,720.83	12,192.13	7,864.68	4,325.93	1,762.35	321.09	10.93
7	47,998.58	32,264.99	20,832.50	16,743.60	12,349.53	8,016.46	4,313.98	1,622.76	128.42	-
8	48,096.33	33,041.23	21,735.54	17,762.13	13,621.46	9,388.04	5,522.97	2,193.04	296.67	-
9	45,981.16	30,114.68	18,902.71	14,971.56	10,907.72	6,887.26	3,447.98	1,339.60	339.23	61.38
10	52,741.48	36,174.95	23,866.65	19,265.83	14,478.24	9,971.97	5,869.40	2,491.52	214.86	-
AV	49,393.19	33,441.95	21,837.78	17,599.13	13,096.89	8,769.38	5,027.31	2,088.80	329.85	27.13

– Sensitivity analysis results

Table B18 Sensitivity analysis on opportunity loss detail results.

Level of confidence	Opportunity loss							
	20.79	41.58	62.38	83.17	103.96	124.75	Slope	%diff (from 0.5)
0.5	238,336.39	224,332.02	210,327.65	196,323.27	182,318.90	168,314.53	-673.5572	-
0.6	236,330.69	226,578.43	216,826.17	207,073.90	197,321.64	187,569.38	-469.0468	30.36 %
0.7	227,703.28	221,111.56	214,519.85	207,928.13	201,336.41	194,744.70	-317.0365	52.93 %
0.75	223,025.20	217,708.13	212,391.06	207,073.99	201,756.92	196,439.85	-255.7309	62.03 %
0.8	221,932.44	218,008.21	214,083.99	210,159.77	206,235.55	202,311.33	-188.7401	71.98 %
0.85	215,338.44	212,666.88	209,995.57	207,324.16	204,652.75	201,981.35	-128.4845	80.92 %
0.9	203,027.62	201,439.66	199,851.82	198,263.94	196,676.06	195,088.18	-76.3711	88.66 %
0.95	179,857.11	179,173.04	178,489.07	177,805.06	177,121.05	176,437.05	-32.8982	95.12 %
0.99	137,878.29	137,768.35	137,658.40	137,548.45	137,438.50	137,328.55	-5.2881	99.21 %
0.999	91,931.79	91,922.75	91,913.71	91,904.66	91,895.62	91,886.58	-0.4350	99.94 %

Table B19 Sensitivity analysis on biodiesel price detail results.

Level of confidence	Biodiesel price							
	20.79	41.58	62.38	83.17	103.96	124.75	Slope	%diff (from 0.5)
0.5	-221,107.37	87,039.75	395,186.86	703,333.98	1,011,481.09	1,319,628.21	14,820.71	-
0.6	-220,547.25	91,862.33	404,271.91	716,681.49	1,029,091.07	1,341,500.65	15,025.71	1.38 %
0.7	-227,278.33	88,291.79	403,861.92	719,432.05	1,035,002.17	1,350,572.30	15,177.72	2.41 %
0.75	-231,183.44	85,661.33	402,506.10	719,350.87	1,036,195.64	1,353,040.42	15,239.03	2.82 %
0.8	-231,448.60	86,788.94	405,026.57	723,264.19	1,041,501.88	1,359,739.50	15,306.02	3.27 %
0.85	-237,291.14	82,199.31	401,689.76	721,180.21	1,040,670.70	1,360,161.14	15,366.28	3.68 %
0.9	-248,629.57	71,944.39	392,518.36	713,092.33	1,033,666.29	1,354,240.26	15,418.39	4.03 %
0.95	-270,531.66	50,946.18	372,424.02	693,901.85	1,015,379.69	1,336,857.53	15,461.86	4.33 %
0.99	-313,214.25	8,837.64	330,889.53	652,941.43	974,993.32	1,297,045.21	15,489.47	4.51 %
0.999	-359,100.21	-36,947.41	285,205.39	607,358.19	929,510.98	1,251,663.78	15,494.33	4.55 %

– Stability test detail.

Table B20 Detail of stability test at node i1 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.9970	0.9848	0.9576	0.9152	0.8455	0.8424	0.8909	0.9333	0.9788	0.9970
2	0.9970	0.9879	0.9727	0.8939	0.8212	0.8091	0.8576	0.9333	0.9848	0.9939
3	1.0000	0.9970	0.9697	0.9303	0.8576	0.8485	0.8970	0.9424	0.9909	1.0000
4	1.0000	0.9909	0.9727	0.9273	0.8758	0.8727	0.9091	0.9515	0.9848	1.0000
5	1.0000	0.9970	0.9758	0.9364	0.8545	0.8485	0.9091	0.9485	0.9909	1.0000
6	1.0000	0.9970	0.9606	0.9333	0.8667	0.8576	0.9000	0.9485	0.9909	1.0000
7	1.0000	0.9970	0.9818	0.9394	0.8848	0.8788	0.9182	0.9636	0.9939	1.0000
8	1.0000	0.9970	0.9697	0.9455	0.8697	0.8606	0.9212	0.9636	0.9909	1.0000
9	0.9970	0.9939	0.9576	0.8970	0.8273	0.8212	0.8576	0.9364	0.9879	0.9939
10	1.0000	0.9909	0.9788	0.9485	0.8788	0.8727	0.9121	0.9667	0.9909	1.0000
AV	0.9991	0.9933	0.9697	0.9267	0.8582	0.8512	0.8973	0.9488	0.9885	0.9985

Table B21 Detail of stability test at node i2 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
AV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table B22 Detail of stability test at node i3 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4636	0.5606	0.6788	0.7242	0.7697	0.8364	0.8848	0.9515	0.9970	1.0000
2	0.5364	0.6424	0.7424	0.7879	0.8455	0.8909	0.9394	0.9606	0.9939	1.0000
3	0.4879	0.5879	0.7030	0.7515	0.8121	0.8545	0.9030	0.9485	0.9848	1.0000
4	0.4848	0.6121	0.7273	0.7667	0.8121	0.8545	0.9030	0.9485	0.9909	1.0000
5	0.4576	0.5667	0.6909	0.7242	0.7788	0.8515	0.8970	0.9545	0.9848	0.9939
6	0.5030	0.6000	0.7000	0.7485	0.7909	0.8697	0.9030	0.9545	0.9970	1.0000
7	0.5455	0.6485	0.7242	0.7697	0.8242	0.8606	0.8909	0.9455	0.9848	0.9970
8	0.5545	0.6667	0.7576	0.8152	0.8455	0.9121	0.9333	0.9697	0.9939	1.0000
9	0.4667	0.5939	0.7030	0.7606	0.8152	0.8636	0.9030	0.9455	0.9939	0.9970
10	0.4576	0.5848	0.6939	0.7545	0.7848	0.8424	0.9030	0.9485	0.9939	1.0000
AV	0.4958	0.6064	0.7121	0.7603	0.8079	0.8636	0.9060	0.9527	0.9915	0.9988

Table B23 Detail of stability test at node l1 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5182	0.6152	0.7212	0.7606	0.7970	0.8576	0.9091	0.9485	0.9939	1.0000
2	0.4364	0.5545	0.6939	0.7545	0.8152	0.8515	0.9000	0.9485	0.9879	1.0000
3	0.5030	0.6212	0.7121	0.7576	0.7970	0.8697	0.9121	0.9545	0.9909	1.0000
4	0.4939	0.5939	0.6939	0.7394	0.7970	0.8394	0.8909	0.9212	0.9818	1.0000
5	0.5000	0.6182	0.7303	0.7727	0.8121	0.8667	0.9212	0.9697	0.9909	1.0000
6	0.4727	0.5939	0.6939	0.7333	0.7788	0.8394	0.8970	0.9576	0.9848	1.0000
7	0.5242	0.6212	0.7424	0.8152	0.8606	0.9030	0.9333	0.9758	0.9939	1.0000
8	0.4939	0.6030	0.7303	0.7636	0.8242	0.8485	0.9061	0.9636	0.9879	1.0000
9	0.5333	0.6091	0.7000	0.7606	0.7970	0.8394	0.9061	0.9697	0.9909	0.9970
10	0.4939	0.5879	0.6939	0.7273	0.7848	0.8273	0.8909	0.9485	0.9909	1.0000
AV	0.4970	0.6018	0.7112	0.7585	0.8064	0.8543	0.9067	0.9558	0.9894	0.9997

Table B24 Detail of stability test at node l2 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4667	0.5455	0.6515	0.7061	0.7424	0.8121	0.8788	0.9152	0.9939	0.9970
2	0.5152	0.6152	0.7212	0.7606	0.8121	0.8727	0.9242	0.9636	0.9909	1.0000
3	0.4576	0.5333	0.6667	0.7424	0.7939	0.8303	0.8818	0.9424	0.9879	1.0000
4	0.4758	0.5879	0.7091	0.7515	0.8030	0.8333	0.8818	0.9364	0.9909	0.9970
5	0.4848	0.5939	0.6727	0.7273	0.7879	0.8333	0.8970	0.9455	0.9758	1.0000
6	0.4909	0.5909	0.7000	0.7424	0.8061	0.8424	0.8970	0.9515	0.9879	1.0000
7	0.4848	0.5758	0.7212	0.7879	0.8212	0.8576	0.8970	0.9545	0.9909	1.0000
8	0.4788	0.5818	0.7091	0.7515	0.7879	0.8303	0.8879	0.9333	0.9818	1.0000
9	0.5030	0.5848	0.7030	0.7727	0.8121	0.8818	0.9242	0.9788	0.9939	0.9970
10	0.4909	0.5788	0.6636	0.7121	0.7636	0.8030	0.8485	0.9273	0.9909	1.0000
AV	0.4849	0.5788	0.6918	0.7455	0.7930	0.8397	0.8918	0.9449	0.9885	0.9991

Table B25 Detail of stability test at node l3 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5030	0.6091	0.6636	0.7333	0.7788	0.8242	0.8818	0.9545	0.9909	1.0000
2	0.5394	0.6485	0.7273	0.7788	0.8242	0.8727	0.9182	0.9485	0.9879	0.9970
3	0.4848	0.5758	0.7000	0.7576	0.7970	0.8545	0.8848	0.9576	0.9818	1.0000
4	0.4727	0.5909	0.7000	0.7303	0.7848	0.8485	0.9000	0.9424	0.9939	1.0000
5	0.5121	0.6242	0.7212	0.7727	0.8303	0.8818	0.9061	0.9606	0.9970	1.0000
6	0.5091	0.6152	0.7182	0.7636	0.8030	0.8545	0.9000	0.9606	0.9939	0.9970
7	0.4970	0.6061	0.6818	0.7212	0.7848	0.8333	0.8818	0.9273	0.9939	1.0000
8	0.5273	0.6242	0.6758	0.7364	0.8030	0.8394	0.8970	0.9485	0.9909	1.0000
9	0.5091	0.6061	0.7273	0.7636	0.8061	0.8455	0.9121	0.9697	0.9879	1.0000
10	0.4970	0.6061	0.7212	0.7970	0.8273	0.8606	0.9091	0.9515	0.9909	1.0000
AV	0.5052	0.6106	0.7036	0.7555	0.8039	0.8515	0.8991	0.9521	0.9909	0.9994

Table B26 Detail of stability test with higher data points at node i1 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.9998	0.9953	0.9710	0.9276	0.8540	0.8478	0.8959	0.9495	0.9903	0.9996
2	0.9991	0.9927	0.9683	0.9293	0.8535	0.8459	0.8993	0.9462	0.9886	0.9983
3	0.9998	0.9955	0.9676	0.9326	0.8523	0.8455	0.9000	0.9478	0.9901	0.9995
4	0.9998	0.9952	0.9697	0.9307	0.8575	0.8522	0.9010	0.9490	0.9904	0.9993
5	0.9987	0.9953	0.9724	0.9347	0.8619	0.8546	0.9067	0.9514	0.9914	0.9985
6	0.9994	0.9951	0.9713	0.9345	0.8597	0.8547	0.9004	0.9521	0.9897	0.9991
7	0.9997	0.9952	0.9698	0.9349	0.8605	0.8554	0.9037	0.9510	0.9895	0.9995
8	0.9997	0.9948	0.9709	0.9357	0.8608	0.8538	0.9041	0.9528	0.9908	0.9993
9	0.9997	0.9955	0.9688	0.9288	0.8497	0.8434	0.8955	0.9484	0.9903	0.9995
10	0.9997	0.9948	0.9701	0.9354	0.8580	0.8517	0.9041	0.9516	0.9909	0.9991
AV	0.9995	0.9949	0.9700	0.9324	0.8568	0.8505	0.9011	0.9500	0.9902	0.9992

Table B27 Detail of stability test with higher data points at node i2 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9998
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
AV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999

Table B28 Detail of stability test with higher data points at node i3 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4887	0.5917	0.6941	0.7448	0.7933	0.8423	0.8965	0.9443	0.9909	0.9990
2	0.4948	0.5922	0.6929	0.7415	0.7977	0.8458	0.8992	0.9510	0.9904	0.9988
3	0.5014	0.6006	0.6984	0.7457	0.7993	0.8501	0.8986	0.9497	0.9920	0.9993
4	0.4917	0.5908	0.6962	0.7473	0.7978	0.8485	0.9017	0.9527	0.9911	0.9995
5	0.4906	0.5986	0.7003	0.7472	0.7961	0.8493	0.8969	0.9488	0.9884	0.9985
6	0.5004	0.5995	0.6972	0.7462	0.7977	0.8503	0.8978	0.9485	0.9899	0.9988
7	0.4967	0.5990	0.7000	0.7541	0.8020	0.8498	0.8961	0.9483	0.9890	0.9992
8	0.5025	0.6015	0.6999	0.7541	0.8009	0.8468	0.8963	0.9496	0.9906	0.9994
9	0.4979	0.6016	0.7050	0.7548	0.8044	0.8541	0.9048	0.9540	0.9911	0.9986
10	0.4942	0.5937	0.6971	0.7508	0.7985	0.8493	0.8968	0.9477	0.9895	0.9992
AV	0.4959	0.5969	0.6981	0.7487	0.7988	0.8486	0.8985	0.9495	0.9903	0.9990

Table B29 Detail of stability test with higher data points at node l1 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5030	0.6016	0.6998	0.7495	0.8017	0.8533	0.9037	0.9490	0.9880	0.9989
2	0.4974	0.5985	0.7018	0.7505	0.7999	0.8449	0.8967	0.9494	0.9886	0.9987
3	0.4943	0.5929	0.6951	0.7439	0.7983	0.8512	0.8995	0.9505	0.9903	0.9993
4	0.5037	0.6046	0.7077	0.7548	0.8067	0.8552	0.9031	0.9501	0.9902	0.9992
5	0.5010	0.6037	0.7055	0.7523	0.8041	0.8538	0.9043	0.9527	0.9895	0.9987
6	0.4925	0.5926	0.6901	0.7415	0.7944	0.8444	0.8977	0.9542	0.9893	0.9993
7	0.5001	0.6019	0.6984	0.7462	0.7978	0.8454	0.8968	0.9491	0.9899	0.9996
8	0.4993	0.5962	0.7004	0.7505	0.8006	0.8492	0.8965	0.9467	0.9896	0.9991
9	0.5082	0.6027	0.7077	0.7572	0.8046	0.8504	0.9001	0.9503	0.9907	0.9991
10	0.4907	0.5981	0.7055	0.7539	0.8030	0.8524	0.9025	0.9534	0.9909	0.9993
AV	0.4990	0.5993	0.7012	0.7500	0.8011	0.8500	0.9001	0.9505	0.9897	0.9991

Table B30 Detail of stability test with higher data points at node l2 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.5033	0.6007	0.7019	0.7533	0.8006	0.8493	0.8997	0.9493	0.9906	0.9994
2	0.4976	0.5959	0.6972	0.7481	0.7982	0.8483	0.8975	0.9491	0.9898	0.9987
3	0.4965	0.5896	0.6925	0.7455	0.7934	0.8411	0.8938	0.9459	0.9882	0.9993
4	0.5008	0.6028	0.7045	0.7549	0.8005	0.8515	0.9006	0.9513	0.9902	0.9984
5	0.4975	0.5944	0.6916	0.7437	0.7968	0.8502	0.8990	0.9486	0.9904	0.9994
6	0.5024	0.6008	0.6982	0.7518	0.7996	0.8484	0.8992	0.9482	0.9900	0.9986
7	0.5000	0.6016	0.7042	0.7577	0.8022	0.8512	0.9001	0.9501	0.9901	0.9995
8	0.4931	0.5946	0.7007	0.7490	0.7974	0.8473	0.8990	0.9498	0.9891	0.9982
9	0.5024	0.6001	0.6977	0.7481	0.7957	0.8461	0.8978	0.9492	0.9901	0.9986
10	0.4968	0.5947	0.7002	0.7516	0.7984	0.8501	0.9006	0.9492	0.9905	0.9992
AV	0.4990	0.5975	0.6989	0.7504	0.7983	0.8484	0.8987	0.9491	0.9899	0.9989

Table B31 Detail of stability test with higher data points at node l3 for biodiesel supply chain network.

Year	Level of confidence									
	0.50	0.60	0.70	0.75	0.80	0.85	0.90	0.95	0.99	0.999
1	0.4933	0.5908	0.6903	0.7406	0.7898	0.8407	0.8911	0.9465	0.9899	0.9993
2	0.5012	0.6059	0.7091	0.7594	0.8035	0.8489	0.8976	0.9502	0.9897	0.9994
3	0.4935	0.5921	0.6925	0.7418	0.7949	0.8475	0.8994	0.9495	0.9903	0.9996
4	0.4926	0.5984	0.6982	0.7471	0.8002	0.8515	0.9038	0.9492	0.9887	0.9987
5	0.5012	0.6022	0.6996	0.7459	0.7935	0.8459	0.8972	0.9485	0.9908	0.9989
6	0.5006	0.5978	0.6967	0.7468	0.7986	0.8483	0.9002	0.9497	0.9885	0.9993
7	0.5018	0.6099	0.7043	0.7522	0.8001	0.8501	0.8951	0.9494	0.9905	0.9991
8	0.5044	0.6052	0.7036	0.7514	0.8027	0.8515	0.9010	0.9498	0.9898	0.9993
9	0.5034	0.6048	0.7078	0.7565	0.8084	0.8569	0.9057	0.9518	0.9905	0.9992
10	0.5049	0.6049	0.7061	0.7566	0.8063	0.8522	0.9005	0.9510	0.9907	0.9989
AV	0.4997	0.6012	0.7008	0.7498	0.7998	0.8494	0.8992	0.9496	0.9899	0.9992

– Simulation result at plant j1 from chance constrained optimization result with 0.8 level of confidence

Stream Name		STERIC_FEED	BIODIESEL	H2_FEED
Phase		Liquid	Liquid	Vapor
Temperature	K	298.150	298.150	298.150
Pressure	BAR	1.000	1.000	1.000
Flowrate	kg-mol/hr	1.134	1.134	2.529
Total Std. Liq. Rate	liter/day	8804.510	8388.467	1733.910
Total Molar Comp. Fractions				
STEARIC		1.0000	0.0758	0.0000
H2		0.0000	0.0000	1.0000
H2O		0.0000	0.0000	0.0000
CO		0.0000	0.0000	0.0000
ETHANE		0.0000	0.0000	0.0000
PROPANE		0.0000	0.0000	0.0000
1OCDCNOL		0.0000	0.0106	0.0000
NC15		0.0000	0.0263	0.0000
NC16		0.0000	0.0526	0.0000
NC17		0.0000	0.8258	0.0000
NC18		0.0000	0.0089	0.0000

CSTR Name CSTR Description		R1
Duty	M*KW-HR/DAY	0.0004
DP	BAR	0.0000

Hx Name Hx Description		E1	E2	E3	E4
Duty	M*KW-HR/DAY	0.0001	0.0012	0.0027	0.0013
MTD	K	n/a	n/a	n/a	n/a

Column Name Column Description		T1
Condenser Duty	M*KW-HR/DAY	-0.0014
Reboiler Duty	M*KW-HR/DAY	0.0033

Pump Name Pump Description		P1	P2
Pressure Gain	BAR	7.0000	12.0000
Head	M	87.7829	150.8754
Shaft Work	KW	0.1029	0.1645

Compressor Name Compressor Description		C1	C2
Pressure	BAR	8.0000	10.0000
Temperature	K	600.9725	328.9943
Head	M	396749.9567	10557.4411
Shaft Work	KW	19.7784	1.3966
Isentropic coef., k		1.3995	1.8059

Appendix C Coding in GAMS langue

– The chance constrained optimization model.

```
set
     i    index of supplier   /i1*i3/
     j    index of plant      /j1*j2/
     k    index of warehouse  /k1*k2/
     l    index of customer   /l1*l3/;

parameter
     SP1_av(i) average specification of supplier
               /i1 300, i2 350, i3 300/
     SP2_av(j) average specification of plant
               /j1 350, j2 250/
     SP3_av(k) average specification of warehouse
               /k1 250, k2 300/
     SP4_av(l) average specification of customer
               /l1 100, l2 150, l3 100/
     SP1_sd(i) standard deviation of supplier
     SP4_sd(l) standard deviation of customer
     P         selling price      /15/
     C_P       penalty cost            /12/
     alpha(i)  probability factor of supplier
     beta(l)   probability factor of customer
;

SP1_sd(i) = SP1_av(i)/10;
SP4_sd(l) = SP4_av(l)/10;

Table    C_T1(i,j) Transportation cost
     j1   j2
```

```
i1   2    4
i2   3    5
i3   1    3
;

Table     C_T2(j,k) Transportation cost
     k1   k2
j1   3    1
j2   2    4
;

Table     C_T3(k,l) Transportation cost
     l1   l2   l3
k1   2    3    2
k2   1    4    2
;

*********Solver option*********
Option MIP           = CPLEX;
Option NLP           = CONOPT;
Option MINLP         = DICOPT;
Option optCR         = 0;
Option decimals      = 4;

*********Inverse value area*********
parameter
*CSND = cumulative standard normal distribution
*Only transfer value from inverse equation to calculation
     i_csnd_s(i)     inverse CSND of supplier
     i_csnd_d(l)     inverse CSND of factory
     p               ghost parameter;
variable
```

```
     ierfv;
equation
     ierrorf;
ierrorf .. errorf(ierfv) =e= 1-p;
model ierf /ierrorf/;

*********Model*********
variable
     x1(i,j)   quantity shipped from supplier to factory
     x2(j,k)
     x3(k,l)
     t_Tr_C    total transportation cost
     t_P_C
     t_Rev
     P1(i)
     P2_n(l)
     P2_p(l)
     z    Objective value                             ;

positive variable
     x1(i,j),x2(j,k),x3(k,l),P2_n(l),P2_p(l),P1(i);

equation
     t_cost         total cost
     Tr_cost        transportation cost
     P_cost
     Rev            revenue
     bal_j(j)
     bal_k(k)
     spec_i(i)
     spec_j(j)
     spec_k(k)
```

```
        spec_l(l)
        p_P1(i)
        p_P2(l)
        p_pP_f(l)
        p_nP_f(l)      ;

*Cost constrains
t_cost    ..   z =e= t_Rev-(t_Tr_C+t_P_C);

Tr_cost   ..   t_Tr_C   =e=   sum((i,j),x1(i,j)*C_T1(i,j))
               +sum((j,k),x2(j,k)*C_T2(j,k))
               +sum((k,l),x3(k,l)*C_T3(k,l));

P_cost    ..   t_P_C =e= C_P*(sum(l,P2_n(l)));
Rev       ..   t_Rev  =e=  sum((k,l),(x3(k,l)-P2_p(l))*Pr)
               +sum(l,P2_p(l)*h_Pr);

***Chance constrains
spec_i(i) ..   sum(j,x1(i,j)) =l=
                    (SP1_av(i)+i_csnd_s(i)*SP1_sd(i)) ;

spec_l(l) ..   sum(k,x3(k,l))+P2_n(l)-P2_p(l) =g=
                    (SP4_av(l)-i_csnd_d(l)*SP4_sd(l)) ;
p_pP_f(l) ..   sum(k,x3(k,l))-P2_p(l) =l=
                    (SP4_av(l)-i_csnd_d(l)*SP4_sd(l));
p_nP_f(l) ..   sum(k,x3(k,l))+P2_n(l) =g=
                    (SP4_av(l)-i_csnd_d(l)*SP4_sd(l));

*Mass balance
bal_j(j)  ..   sum(i,x1(i,j)) =e= sum(k,x2(j,k));
bal_k(k)  ..   sum(j,x2(j,k)) =e= sum(l,x3(k,l));
```

```
*Spec check
**Uper limit
spec_j(j) ..   sum(i,x1(i,j)) =l= SP2_av(j);
spec_k(k) ..   sum(j,x2(j,k)) =l= SP3_av(k);

model main /t_cost, Tr_cost, P_cost, Rev, spec_i, spec_l,
          p_pP_f, p_nP_f, bal_j, bal_k, spec_j, spec_k/

*begin_section @looping
set  alt  /ALT1*ALT10/;


parameter ALT_alpha(ALT) /alt1 0.5, alt2 0.6, alt3 0.7,
alt4 0.75, alt5 0.8, alt6 0.85, alt7 0.9, alt8 0.95, alt9
0.99, alt10 0.999/
          ALT_beta(ALT)  /alt1 0.5, alt2 0.6, alt3 0.7,
alt4 0.75, alt5 0.8, alt6 0.85, alt7 0.9, alt8 0.95, alt9
0.99, alt10 0.999/

;

File  out  /  D:\Google  Drive\PJ_PPC\Code\profit-main
\plant_add-on\part1\report2_.txt /;

out.ap=0;
out.nd=4;
out.ps=130;
put out;

loop(alt,
*open text export
```

```
put_utilities 'ren' / 'D:\Google Drive\PJ_PPC\Code\profit-
main\base_case\CCP_result\CSV_report_' :0 ALT.tl :0 '.csv'
:0;

*set input
alpha(i)=ALT_alpha(ALT);
beta(l)=ALT_beta(ALT);

loop(i,
     p=alpha(i);
     solve ierf max ierfv using nlp;
     i_csnd_s(i)=ierfv.l;
);

loop(l,
     p=beta(l);
     solve ierf max ierfv using nlp;
     i_csnd_d(l)=ierfv.l;
);

*solving
solve main max z using MIP;
*export file
**confidence level
put 'at confidence level', ',',',', ',' ALT_alpha(ALT)/;
**obj value
put 'objective value', ',', ',', ',' z.l//;
**detail price
put 'revenue', ',', ',', ',', t_Rev.l/;
put 'cost'/;
put ',','transportation cost', ',', ',', t_Tr_C.l/;
put ',','penalty cost', ',', ',', t_P_C.l/;
```

```
**network
put 'network'/;
***x1
put 'x1'/;
loop(j,
     put ',',j.te(j);
);
put /;
loop(i,
     put i.te(i);
     loop(j,
          put ',', x1.l(i,j);
     );
     put /;
);
put /;

***x2
put 'x2'/;
loop(k,
     put ',',k.te(k);
);
put /;
loop(j,
     put j.te(j);
     loop(k,
          put ',', x2.l(j,k);
     );
     put /;
);

```

```
put /;

***x3
put 'x3'/;
loop(l,
     put ',',l.te(l);
);
put /;
loop(k,
put k.te(k);
     loop(l,
          put ',', x3.l(k,l);
     );
     put /;
);
put /;

**penalty
put /'penalty detial'/;
put 'positive penalty'/;
loop(l,
     put l.te(l), ',', P2_p.l(l), ',';
);
put /;
put 'negative penalty'/;
loop(l,
     put l.te(l), ',', P2_n.l(l), ',';
);
put /;
put /'building block sum to validation'/;
*x1
put 'x1'/;
```

```
loop((i,j),
     put
'ALT_x1_s(',',',alt.te(ALT),',',i.te(i),',',j.te(j),',','
)=',',',x1.l(i,j) /;
);

*x2
put 'x2'/;
loop((j,k),
     put
'ALT_x2_s(',',',alt.te(ALT),',',j.te(j),',',k.te(k),',','
)=',',',x2.l(j,k) /;
);

*x3
put 'x3'/;
loop((k,l),
     put
'ALT_x3_s(',',',alt.te(ALT),',',k.te(k),',',l.te(l),',','
)=',',',x3.l(k,l) /;
);

);


*end_section
putclose out;
```

– The comparison chance constrained optimization model to the literature (Shaw *et al.* 2016).

The mathematical model from literature has been used to verify result from GAMS code for this work and the literature. The results show that the error from GAMS code and literature is insignificant. Overall the error comes from the round-off error.

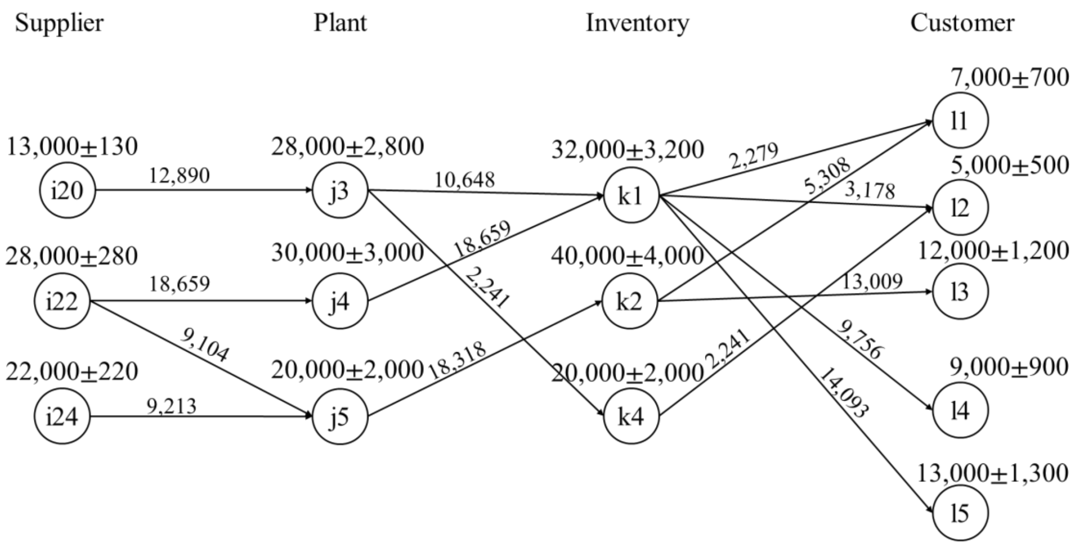

Figure C1 Supply chain network diagram from Shaw *et al.* (2016).

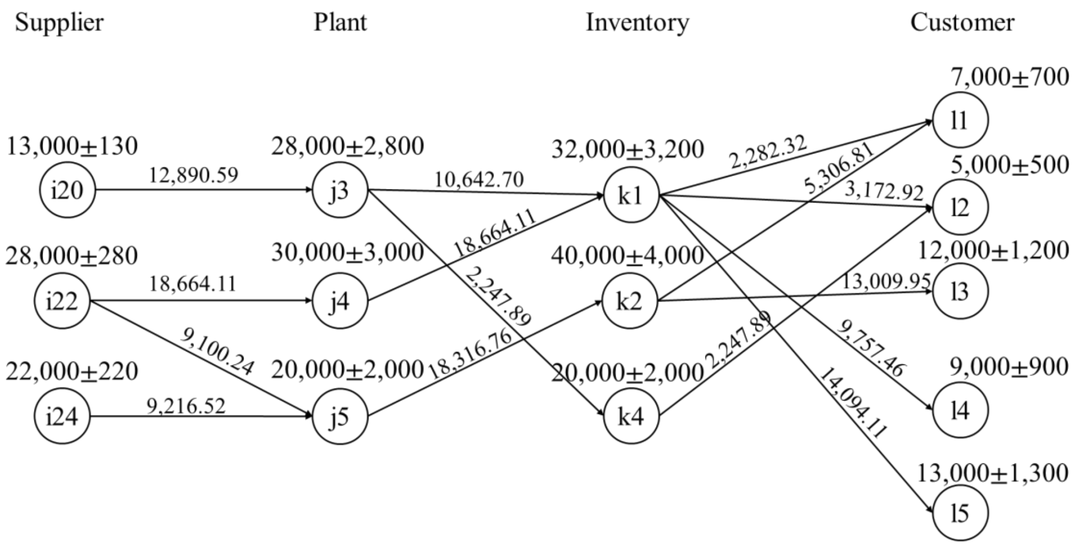

Figure C2 Supply chain network diagram from the model used in this thesis.

Table C1 The comparison result at 0.80 level of confidence.

Level of confidence			0.80
	Main model	Shaw *et al.* (2016)	%error
Total optimized cost (Rs)	9,084,851.32	9,084,300.00	0.0061%
Network (unit)			
i20-j3	12,890.59	12,890.00	0.0046%
i22-j4	18,664.11	18,659.00	0.0274%
i22-j5	9,100.24	9,104.00	-0.0414%
i24-j5	9,216.52	9,213.00	0.0382%
j3-k1	10,642.70	10,648.00	-0.0498%
j3-k4	2,247.89	2,241.00	0.3074%
j4-k1	18,664.11	18,659.00	0.0274%
j5-k2	18,316.76	18,318.00	-0.0068%
k1-l1	2,282.32	2,279.00	0.1458%
k1-l2	3,172.92	3,178.00	-0.1598%
k1-l4	9,757.46	9,756.00	0.0150%
k1-l5	14,094.11	14,093.00	0.0079%
k2-l1	5,306.81	5,308.00	-0.0224%
k2-l3	13,009.95	13,009.00	0.0073%
k4-l2	2,247.89	2,241.00	0.3074%

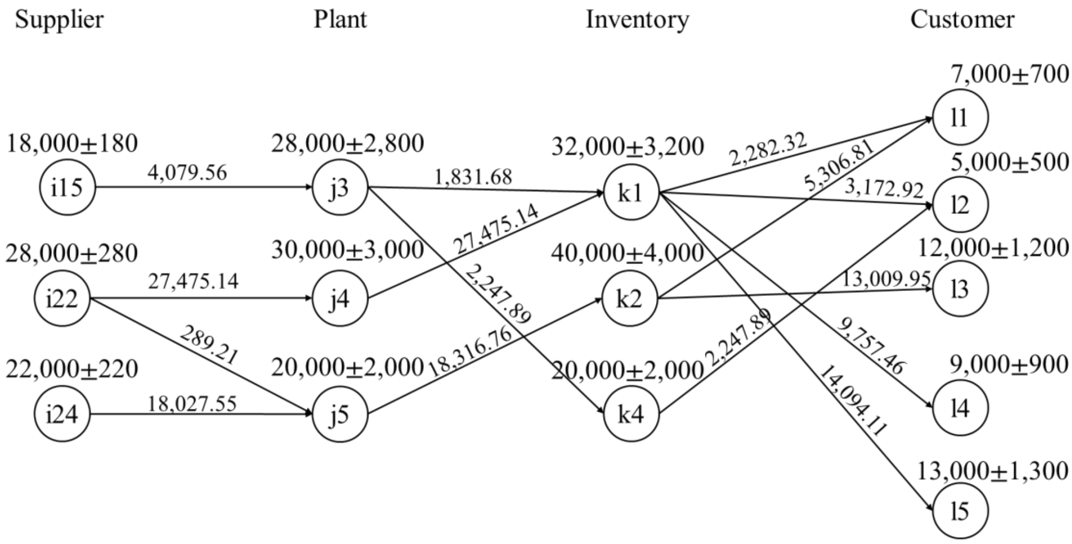

Figure C3 Alternative supply chain network diagram when fixed line i20-j3 to 0.

Table C2 Alternative design from chance constrained optimization result with 0.8 level of confidence when fixed line i20-j3 to 0.

Level of confidence	0.80
Fixed i20-j3 line to 0	
Total optimized cost (Rs)	9,103,325.00
Network (unit)	
i15-j3	4,079.56
i22-j4	27,475.14
i22-j5	289.21
i24-j5	18,027.55
j3-k1	1,831.68
j3-k4	2,247.89
j4-k1	27,475.14
j5-k2	18,316.76
k1-l1	2,282.32
k1-l2	3,172.92
k1-l4	9,757.46
k1-l5	14,094.11
k2-l1	5,306.81
k2-l3	13,009.95
k4-l2	2,247.89

Table C3 Alternative designs from chance constrained optimization result with 0.8 level of confidence: total cost result.

Level of confidence	0.80
	Total cost
Base case	9,084,851.32
Fixed 1 line from optimized network to 0	
i20-j3	9,103,324.81
i22-j4	9,157,820.67
i22-j5	9,158,553.34
i24-j5	9,185,112.64
j3-k1	9,225,749.75
j3-k4	9,245,160.24
j4-k1	9,877,541.14
j5-k2	10,176,243.00
k1-l1	10,176,243.00
k1-l2	10,176,243.00
k1-l4	10,176,243.00
k1-l5	10,176,243.00
k2-l1	10,176,243.00
k2-l3	10,306,343.00
k4-l2	10,306,343.00
Fixed 2 lines from optimized network to 0	
i20-j3 and i22-j4	10,306,343.00
i20-j3 and i22-j5	10,306,343.00
i20-j3 and i24-j5	10,306,343.00
i22-j4 and i22-j5	10,306,343.00
i22-j4 and i24-j5	10,306,343.00
i22-j5 and i24-j5	10,306,343.00
j3-k1 and j3-k4	10,306,343.00
j3-k1 and j4-k1	10,306,343.00
j3-k1 and j5-k2	10,306,343.00
j3-k4 and j4-k1	10,306,343.00
j3-k4 and j5-k2	10,306,343.00
j4-k1 and j5-k2	10,306,343.00
k1-l1 and k1-l2	10,306,343.00
k1-l1 and k1-l4	10,306,343.00
k1-l1 and k1-l5	10,306,343.00
k1-l1 and k2-l1	10,306,343.00
k1-l1 and k2-l3	10,306,343.00
k1-l1 and k4-l2	10,306,343.00
k1-l2 and k1-l4	10,306,343.00
k1-l2 and k1-l5	10,306,343.00
k1-l2 and k2-l1	10,306,343.00

k1-l2 and k2-l3	10,306,343.00
k1-l2 and k4-l2	10,306,343.00
k1-l4 and k1-l5	10,306,343.00
k1-l4 and k2-l1	10,306,343.00
k1-l4 and k2-l3	10,306,343.00
k1-l4 and k4-l2	10,306,343.00
k1-l5 and k2-l1	10,306,343.00
k1-l5 and k2-l3	10,306,343.00
k1-l5 and k4-l2	10,306,343.00
k2-l1 and k2-l3	10,306,343.00
k2-l1 and k4-l2	10,306,343.00
k2-l3 and k4-l2	10,306,343.00
i20-j3 and j3-k1	10,306,343.00
i20-j3 and j3-k4	10,306,343.00
i20-j3 and j4-k1	10,306,343.00
i20-j3 and j5-k2	10,306,343.00
i20-j3 and k1-l1	10,306,343.00
i20-j3 and k1-l2	10,306,343.00
i20-j3 and k1-l4	10,306,343.00
i20-j3 and k1-l5	10,306,343.00
i20-j3 and k2-l1	10,306,343.00
i20-j3 and k2-l3	10,306,343.00
i20-j3 and k4-l2	10,306,343.00
i22-j4 and j3-k1	10,306,343.00
i22-j4 and j3-k4	10,306,343.00
i22-j4 and j4-k1	10,306,343.00
i22-j4 and j5-k2	10,306,343.00
i22-j4 and k1-l1	10,306,343.00
i22-j4 and k1-l2	10,306,343.00
i22-j4 and k1-l4	10,306,343.00
i22-j4 and k1-l5	10,306,343.00
i22-j4 and k2-l1	10,306,343.00
i22-j4 and k2-l3	10,306,343.00
i22-j4 and k4-l2	10,306,343.00
i22-j5 and j3-k1	10,306,343.00
i22-j5 and j3-k4	10,306,343.00
i22-j5 and j4-k1	10,306,343.00
i22-j5 and j5-k2	10,306,343.00
i22-j5 and k1-l1	10,306,343.00
i22-j5 and k1-l2	10,306,343.00
i22-j5 and k1-l4	10,306,343.00
i22-j5 and k1-l5	10,306,343.00
i22-j5 and k2-l1	10,306,343.00

i22-j5 and k2-l3	10,306,343.00
i22-j5 and k4-l2	10,306,343.00
i24-j5 and j3-k1	10,306,343.00
i24-j5 and j3-k4	10,306,343.00
i24-j5 and j4-k1	10,306,343.00
i24-j5 and j5-k2	10,306,343.00
i24-j5 and k1-l1	10,306,343.00
i24-j5 and k1-l2	10,306,343.00
i24-j5 and k1-l4	10,306,343.00
i24-j5 and k1-l5	10,306,343.00
i24-j5 and k2-l1	10,306,343.00
i24-j5 and k2-l3	10,306,343.00
i24-j5 and k4-l2	10,306,343.00
j3-k1 and k1-l1	10,306,343.00
j3-k1 and k1-l2	10,306,343.00
j3-k1 and k1-l4	10,306,343.00
j3-k1 and k1-l5	10,306,343.00
j3-k1 and k2-l1	10,306,343.00
j3-k1 and k2-l3	10,306,343.00
j3-k1 and k4-l2	10,306,343.00
j3-k4 and k1-l1	10,306,343.00
j3-k4 and k1-l2	10,306,343.00
j3-k4 and k1-l4	10,306,343.00
j3-k4 and k1-l5	10,306,343.00
j3-k4 and k2-l1	10,306,343.00
j3-k4 and k2-l3	10,306,343.00
j3-k4 and k4-l2	10,306,343.00
j4-k1 and k1-l1	10,306,343.00
j4-k1 and k1-l2	10,306,343.00
j4-k1 and k1-l4	10,306,343.00
j4-k1 and k1-l5	10,306,343.00
j4-k1 and k2-l1	10,306,343.00
j4-k1 and k2-l3	10,306,343.00
j4-k1 and k4-l2	10,306,343.00
j5-k2 and k1-l1	10,306,343.00
j5-k2 and k1-l2	10,306,343.00
j5-k2 and k1-l4	10,306,343.00
j5-k2 and k1-l5	10,306,343.00
j5-k2 and k2-l1	10,306,343.00
j5-k2 and k2-l3	10,306,343.00
j5-k2 and k4-l2	10,306,343.00

CURRICULUM VITAE

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