Towards Secure & Green Two-stage Supply Chain Networks

CAMELIA-M. PINTEA, *Department of Mathematics and Informatics, Technical University of Cluj-Napoca, 430122 Baia Mare, Romania, E-mail: dr.camelia.pintea@ieee.org*

ANISOARA CALINESCU, *Department of Computer Science, University of Oxford, Oxford, OX1 3QD, United Kingdom, E-mail: ani.calinescu@cs.ox.ac.uk*

CORINA POP SITAR, *Department of Economics, Technical University of Cluj-Napoca, 430122 Baia Mare, Romania, E-mail: corina.pop.sitar@cunbm.utcluj.ro*

PETRICĂ C. POP, *Department of Mathematics and Informatics, Technical University of Cluj-Napoca, 430122 Baia Mare, Romania, E-mail: petrica.pop@cunbm.utcluj.ro*

Keywords: Security, Two-stage Supply Chain Network with Fixed-costs, Greenhouse Gas Emissions

Abstract

Modern supply chains security solutions need to also solve transport security. Greenhouse gas emissions (GHG) have a direct influence on the structure and behaviour of supply chains. The more complex the supply chains, the more critical these two dimensions become. This paper introduces a mathematical model for computing the risk associated with Greenhouse emissions, within the supply chain network context. The supply model chosen is a two-stage supply chain network, called the *Secure & Green Supply Chain Network (SGSCN)*. In the *SGSCN* a Manufacturer is directly connected to several Distribution Centers (DC), each of them connected to one or more Customers, (C). The objective of *Secure & Green Supply Chain Networks* is to minimise transportation costs whilst also maintaining a specified overall security level, including a specified GHG level. The applicability of the proposed model for several supply chain configurations and scenarios is illustrated and discussed.

1 Introduction

Global warming, earthquakes, floods and other natural disasters, and market uncertainties, computer attacks or other human-related threats represent significant negative influences and disruptions of various key dimensions of modern world, including the structure and behaviour of a wide range of Supply Chain Networks (SCN) [15]. A "secure freight system" should be created between supply chain partners, as Lee et al. [25] propose.

Network problems, in general, and transportation problems, in particular, are complex combinatorial optimization problems [1]. The complexity of SCN increases exponentially as the number of stages and constraints increases. The main objective of a supply chain is to satisfy the customers, in terms of delivering the right product, at the right time and of the right quality, with a minimum overall cost. These constraints are difficult to manage, as there are a large number of variables, and in addition most supply chains are affected by uncertainty and additional interdependent constraints.

Supply chain security threats could include internal factors, such as product design, manufacturing and poorly managed work-in-progress inventories [29, 30], and external factors, such as natural disasters or direct threats.

Ledwoch et al. used an agent-based model to investigate the effectiveness of risk management in specific topology complex supply networks [5]. The techniques they considered include inventory mitigation and contingent rerouting. Their results show that scale-free supply networks are more resilient, as they incur lower costs and need less inventory to recover from random disruptions than random networks. Contingent rerouting is only effective when sufficient alternative suppliers exist.

Qazi et al. considered the interdependence between supply chain risks and the manageability of risk mitigation strategies [6]. They proposed a Bayesian Belief Network-based method of prioritising strategies using three criteria: cost, effectiveness and manageability.

Aqlan & Lam proposed an approach based on Bow-Tie analysis and optimisation techniques to quantify and mitigate interdependent supply chain risks, under budget constraints [7].

Ivanov et al. performed an extensive literature review on disruption recovery in supply chains [9]. Disruption recovery is specified as the optimisation of the supply chain configuration, for given demand, supply and transportation levels, such as to minimise costs, whilst guaranteeing a given service level. They have identified and classified the state-of-the-art research using a matrix 'methods-contingency plans'.

Lee used a case study approach [25] to show that identification and measurement of both direct and indirect carbon footprint are critical for mitigating supply chain risks, and therefore need to be integrated into supply chain management.

The current work includes in particular Greenhouse gas emissions as a risk factor. In particular, Fixed-charge transportation problems [3, 4] are complex network problems that include distribution and transportation problems. This paper considers a two stage fixed-charge transportation problem with two supply chains: from Manufacturer to Distribution Centers, and from Distribution Centers to Customers.

Mainly heuristics-based algorithms are used to solve complex problems [4, 10, 12, 13], due to their computational efficiency when searching for feasible solutions. Hybrid algorithms could often give additional stability and confidence of a problems' solution [14].

The current work introduces a theoretic mathematical model of the new *Secure & Green Supply Chain Network (SGSCN)* problem. The problem is an extension of the *Secure Supply Chain Network (SSCN)* problem presented in [33]. In other previous works [22, 21] several heuristic-based approaches are presented. In [23] the Greenhouse gas emissions are also included in the two-stage supply chain with a fixed-cost problem.

The remainder of this paper is structured as follows. Section 2 describes the fixed-charged transportation *SSCN* problem including definitions, notations and the mathematical model. Section 3 presents the new security and greenhouse gas emission constraint model. Several numerical experiments are included in Section 4, followed by discussions of the benefits and limitations of the proposed model. The last section summarises the paper and discusses future work directions.

2 The Secure & Green Supply Chain Network (SGSCN) for a fixed-charged transportation problem

This section includes the problem formulation and the mathematical model based on the Secure Supply Chain Network for a fixed-charged transportation problem from [33] and on Greenhouse gas emissions approach from [23].

2.1 SGSCN problem formulation

In the *Secure & Green Supply Chain Network (SGSCN)* model there are two supply chains: the first one is the network from the main Manufacturer to a given set of Distribution Centers (DCs); the second supply chain is from Distribution centers to a given set of Customers (C). As an ideal theoretical problem, this model considers a Manufacturer with no capacity limitation in production. We also assume that each Distribution Center has sufficient space to store the products such as to satisfy the demands of all its customers [11]. This problem does not include time constraints. Figure 1 illustrates a schematic representation of the two-stage *Secure & Green Supply Chain Network (SGSCN)*.

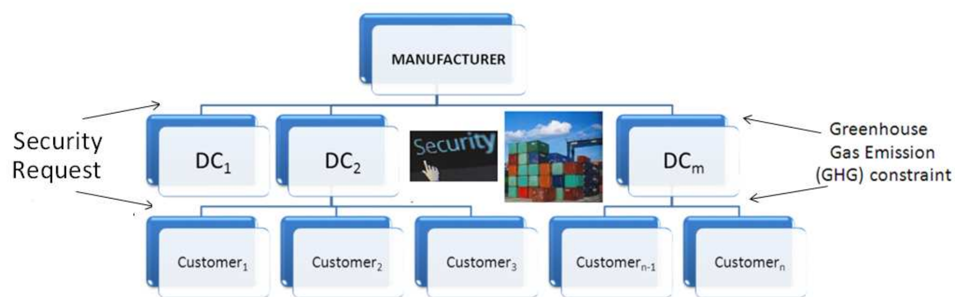

FIG. 1: An example of the two-stage *Secure & Green Supply Chain Network (SGSCN)*; it consist of an ideal case with an infinite capacity Manufacturer, m Distribution Centers (DCs) with infinite capacities, and with security and Greenhouse Gas Emission constraints.

We assume fixed-costs; these costs include transportation costs from both Manufacturer to Distribution Centers and furthermore from DCs to customers; the total cost also includes the opening cost of the Distribution Centers.

Figure 1 also illustrates the fact that each supply chain has a security risk coefficient. The security constraint SC is a pair of security demand and security rank values, denoted $SC = \{sd, sr\}$ as in [33]. The *SGSCN* problem's objective is finding a solution which satisfies all the customers, *i.e.* optimizing the overall supply chain cost whilst keeping the entire supply chain flow secure. The security probability captures the fact that a higher Greenhouse gas Emissions factor should correspond to a higher security risk.

2.2 Mathematical formulation of SGSCN

The mathematical model of the fixed-charged transportation problem with security and greenhouse gas emissions constraints is based on the *SSCN* mathematical model [33]. There are m Distributions Centers and n Customers. The other notations are included in Table 1.

Symbol	**Description**
Supply Chain Network parameters	
f_i	opening cost for Distribution Center DC_i
f_{ij}	fixed transportation cost from Distribution Center DC_i to Customer C_j
c_i	transportation cost from Manufacturer M to Distribution Center DC_i
c_{ij}	transportation cost from Distribution Center DC_i to Customer C_j
x_{ij}	demand of Customer C_j supplied by Distribution Center DC_i
x_i	quantity of the Manufacturer M supplied to a Distribution Center DC_i
y_i	binary variable (1/0); it has value 1 if DC_i is opened as potential location
a_i	capacity of Distribution Center DC_i
d_j	demands of Customer C_j
Z_{fc}	total fixed costs
Z_{tc}	total cost of transportation
Z	total cost includingZ_{fc} and Z_{tc} costs
Security parameters	
sd	the security demand of an operation
sr	the security risk of a unit in an activity
Greenhouse Gas Emission parameters	
α_i	GHG factor of a potential distribution center $i \in \{1, ..., m\}$ in tons per CO_2e (dioxide carbon equivalent) per unit demand
β_{ij}	GHG factor per unit demand and per unit distance between a potential distribution center $i \in \{1, ..., m\}$ and a customer $j \in \{1, ..., n\}$ in tons per CO_2e.
GHG	Greenhouse gas emissions
$GHGLimit$	Greenhouse gas emissions limits

TABLE 1: The description of the *Secure & Green Supply Chain Network (SGSCN) for a fixed-charged transportation problem.*

- **Fixed Cost**. Table 1 includes both considered **fixed costs** for the two-stages supply chain: f_i represents the opening cost for Distribution Center DC_i, and f_{ij} the fixed transportation cost from DC_i to Customer j.

- **Transportation Cost**. Table 1 also includes the transportation cost per unit from both stages of the network: c_i from Manufacturer to Distribution Center i, and c_{ij} from DC_i to Customer C_j.
- **Total Cost**. As it is already mentioned in Table 1, the overall cost, Z, includes both fixed Z_{fc} and transportation costs, Z_{tc}.
- **Objective problem**.The objective of the problem is to minimize the Z cost value when security constraints, including GHG, are satisfied.
- **Greenhouse Gas Emissions**. In [31] the *Greenhouse Gas* (GHG) emissions are determined by operation facilities and transportation activities used to fulfill demands. GHG emissions are proportional both with customers' demands and distance to travel. [32] introduced a model that captures the GHG emissions in a supply chain.

- **Main objective** is minimizing the function Z based on Eq. 2.1-2.2.

$$Z = Z_{fc} + Z_{tc} \tag{2.1}$$

$$Z_{tc} = \sum_{i=1}^{m} c_i x_i + \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij}, \qquad Z_{fc} = \sum_{i=1}^{m} f_i\ y_i + \sum_{i=1}^{m}\sum_{j=1}^{n} f_{ij} y_{ij}, \tag{2.2}$$

- Equation (2.3) includes constraints for the quantities to be transported.

$$x_{ij} \geq 0,\ \forall i = 1, \dots m,\ \forall j = 1, \dots n, \qquad x_i \leq a_i,\ \forall i = 1, \dots m, \tag{2.3}$$

where

$$y_i = \begin{cases} 1, & \sum_{j=1}^{n} x_{ij} \geq 0 \\ 0, & \sum_{j=1}^{n} x_{ij} = 0 \end{cases}, \forall i = 1 \dots m, \quad y_{ij} = \begin{cases} 1, & x_{ij} \geq 0, & \forall i = 1 \dots m, \\ 0, & x_{ij} = 0, & \forall j = 1 \dots n. \end{cases} \tag{2.4}$$

- The opened Distribution Centers are influenced by the risk probability ($P(risk)$) influenced by the security requirements: security demand, sd, and security rank, sr.

$$P(risk) = \begin{cases} 0, & sd - sr \leq 0 \\ 1 - e^{-\frac{1}{2} sd - sr}, & 0 < sd - sr \leq 1 \\ 1 - e^{-\frac{3}{2} sd - sr}, & 1 < sd - sr \leq 2 \\ 1, & 2 < sd - sr \leq 5 \end{cases} \tag{2.5}$$

- The factors affecting the risk probability also include the Greenhouse Gas emissions: the constraint $GHG \leq GHGLimit$ is used to limit GHG emissions (Eq. 2.6). The formulation is related to the facility location problem [31].

$$GHG(value) = \sum_{i=1}^{m} \alpha_i a_i y_i + \sum_{i=1}^{m} \beta_i a_i c_i y_i + \sum_{i=1}^{m}\sum_{j=1}^{n} \alpha_i d_j x_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} \beta_i d_j c_{ij} x_{ij}. \tag{2.6}$$

3 Novelty: Security Constraint Model with Greenhouse Gas Emissions

The security constraint model proposed at first in [33] was inspired by the security constraint model for data-intensive jobs running on distributed computing environments [16, 18, 19].

The current work makes a step forward, as it includes the Greenhouse Gas Emissions factor in the probability risk.

In the specific case of the supply chain network a distribution is assigned to an available Distribution Center based on the $sd \leq sr$ constraint. In this specific two-stage supply chain we consider both the Manufacturer and Distribution Centers as units with potential risk.

- **Security Modes.** The general security mode is the γ-*risky* mode. It includes a probability measure of risk. The mathematical formulation includes the **secure** ($\gamma = 0$) and **risky** ($\gamma = 1$) modes for particular values of γ. The centers are included in the supply chain flow based on the highest γ-risk. Further details are in [33].
- **Scale of Security for Supply Chain Networks** Based on the Song et al. [17], [33] introduced the scale of security levels for supply chain networks. The security levels scale a use qualitative/fuzzy scale with five scales: very high (5), high (4), medium (3), low (2), very low (1), described as follows.
  - For $sd - sr > 0$: in the security constraint model, the risk must be less than fifty percent when a distribution is assigned to a center with failure risk.
  - For $1 < sd - sr \leq 2$: the distribution should be made before deadline [20] if time is included as a supplementary constraint on the Two-stage Supply Chain network.
  - **Novel contribution:** When $GHG > GHGLimit$ (i.e. the Greenhouse Gas emissions of transportation units are not in the required limits), the security risk will be increased and considered the maximal risk type.
- **Risk Probability** The risk probability of the security constraint model uses Eq. (2.5).

  Including GHG factor in sr security risk: The security rank, sr, will be modified based on the GHG value as follows in Eq. 3.1.

  $$sr = sr - \lambda \cdot GHG, \tag{3.1}$$

  where λ is a coefficient chosen such that $sr - sd \leq 5$ when computing the probability risk (Eq. 2.5). In extreme cases when $P(risk) > 5$ then $P(risk)$ is considered the maximal value 5.

4 Solving proposal for SGSCN

The current section is based on the **efficient reverse distribution system** for solving the sustainable supply chain [23]. It uses the Nearest Neighbor technique to solve the two-stage supply chain problem. The technique is applied to minimize the transportation cost in the two-stage supply chain network with security constraints on Distribution Centers.

Security level	**Mathematical description**	**Risk description**
High	$sd - sr \leq 0$	The supply chain network is secure.
Medium	$0 < sd - sr \leq 1$	Distribution is possible through the considered center.
Low	$1 < sd - sr \leq 2$	The distribution will be delayed from the considered center.
Very Low	$2 < sd - sr \leq 5$	The distribution is not feasible from the considered center.

Table 2. Scale of Security representation based on [17, 33] in a supply chain.

The reverse perspective identifies the most promising and secure list (L) of Distribution Centers to optimize the transportation costs based on the fixed-charge transportation constraints. The second supply chain uses the reverse perspective from Customers to the identified list (L) of Distribution Centers influenced by quantities and security risks. Figure 2 illustrate the functions of the Nearest Neighbor for the first and second supply chains: from the Manufacturer to the secured Distribution Centers, and from a customer to the secure Distribution Centers.

Numerical experiments and discussions based on the influence of Greenhouse Gas Emissions on the probability risk follow. Different threats could act on either or both supply chains within the supply chain network. Some of these threats could be controllable, as in [15], via spare manufacturing capacity and/or transportation links, if contingency plans are in place. Similar approaches could be used to limit Greenhouse Gas Emissions, in order to reduce the security risks.

5 Numerical experiments and Analysis

This section includes several experiments for solving the sustainable supply chain network design problem, on a set of randomly generated configurations, as in [26], and as described in Table 3.

5.1 Numerical experiments

We consider six supply chain configurations, and each dimension has five different data sets. The ranges vary from 10 to 50 DCs, and from 10 to 100 customers.

Numerical experiments were conducted on an AMD 2600, 1.15 GHz and 1024MB RAM. Table 3 includes the data required for the SGSCN problem: the number of distribution centers m, the number of customers n, the total supply, the total demand, the variable costs, the fixed costs and the opening costs. Greenhouse gas emissions and GHG limitation for each test case are also included.

Table 4 provides results of Nearest Neighbor algorithm. sr' denotes the modified security risk factor when Greenhouse Gas emissions values are considered, as specified in Eq. 3.1.

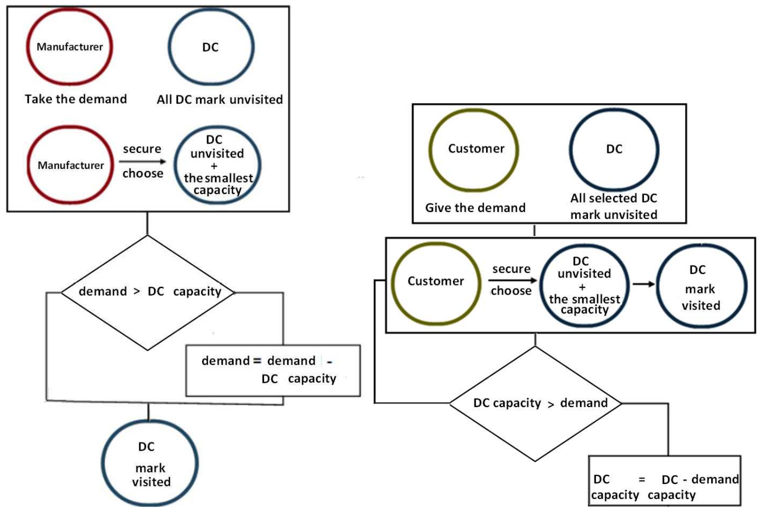

Fig. 2: The Nearest Neighbor algorithm for the first supply chain, from the Manufacturer to the secured Distribution Centers (Left) and for the second supply chain, from a customer to the secured Distribution Centers from the selected list(right).

Table 3: Test problem characteristics including the Lower (Low) and Upper (Up) Limitations.

Problem size $m \times n$	**Total supply**	**Total demand**	**Variable costs** Low	Up	**Fixed costs** Low	Up	**Opening costs** Low	Up	GHG Up
10×10	30000	10000	3	8	50	200	150	600	2000
10×20	45000	15000	3	8	100	400	300	1200	3000
15×15	45000	15000	3	8	200	800	600	2400	4000
10×30	45000	15000	3	8	400	1600	1200	4800	4000
50×50	150000	50000	3	8	400	1600	1200	4800	6000
30×100	90000	30000	3	8	400	1600	1200	4800	15000

5.2 Results analysis and Discussion

The results in Table 4 are discussed next. We will first consider the cases where the GHG **does not influence the final risk probability**.

- **High Security Level**: risk probability P(risk)=0 for 10x10.1, 10x10.5, 10x20.4, 10x30.5, 15x15.2, 50x50.3 and 30x100.5 cases.
- **Low Security Level** for 10x10.2, 10x20.3, 10x30.2, 15x15.4 and 50x50.2 cases.
- **Very Low Security Level** with the risk probability 1 for the majority of Table 2 cases: 10x10.3, 10x10.4, 10x20.1, 10x20.5, 10x30.1, 10x30.4, 15x15.1, 15x15.3, 50x50.1, 50x50.4, 30x100.1 and 30x100.2.

TABLE 4: Security risk values related to the Greenhouse Gas Emissions when compared with the initial corresponding values.

Problem	**Id**	**GHG**	**sr**	**sr'**	**sd**	P(risk)	P(risk1)
10x10	1	449.21	9	8.91016	7	0	0
	2	740.16	6	5.85197	7	0.39347	0.91313
	3	790.31	3	2.84194	7	1	1
	4	1064.50	4	3.78710	7	1	1
	5	1031.00	11	10.79380	7	0	0
10x20	1	1134.96	5	4.77301	8	1	1
	2	1136.36	6	5.77273	8	0.95021	1
	3	1132.32	7	6.77354	8	0.39347	0.84113
	4	1599.00	9	8.68020	8	0	0
	5	1247.00	4	3.75060	8	1	1
10x30	1	1744.92	5	4.65102	9	1	1
	2	1556.24	8	7.68876	9	0.39347	0.86011
	3	1618.44	7	6.67631	9	0.95021	1
	4	2523.00	6	5.49540	9	1	1
	5	2996.00	11	10.40080	9	0	0
15x15	1	759.56	7	6.84809	10	1	1
	2	833.32	11	10.83334	10	0	0
	3	793.04	6	5.84140	10	1	1
	4	1413.00	9	8.71740	10	0.39347	0.85396
	5	1346.00	8	7.73080	10	0.95021	1
50x50	1	2864.44	6	5.42711	10	1	1
	2	3196.56	9	8.36069	10	0.39347	0.91448
	3	3440.40	10	9.31192	10	0	0
	4	4516.00	7	6.09680	10	1	1
	5	4752.50	8	7.04950	10	0.95021	1
30x100	1	6964.36	7	5.60713	10	1	1
	2	6534.88	8	6.69302	11	1	1
	3	7114.52	10	8.57710	11	0.39347	1
	4	8833.50	9	7.23330	11	0.95021	1
	5	9527.50	11	9.09450	11	0	0

Based on Table 4, the distribution will be possible only on centers where the security risk is on **High security level**.

We now consider the cases where the GHG influences the final risk probability.

- **Decreasing Security Levels**: From **Low Security Level** to **Very Low Security Level** for 10x20.2; 10x30.3; 15x15.5; 50x50.5; 30x100.3 and 30x100.4 cases.

These results are based on Table 4 for the initial GHG Limits considered (10x10, 2000), (10x20,3000), (10x30, 4000), (15x15, 4000), (50x50, 6000) and (30x100, 15000), as in Table 3.

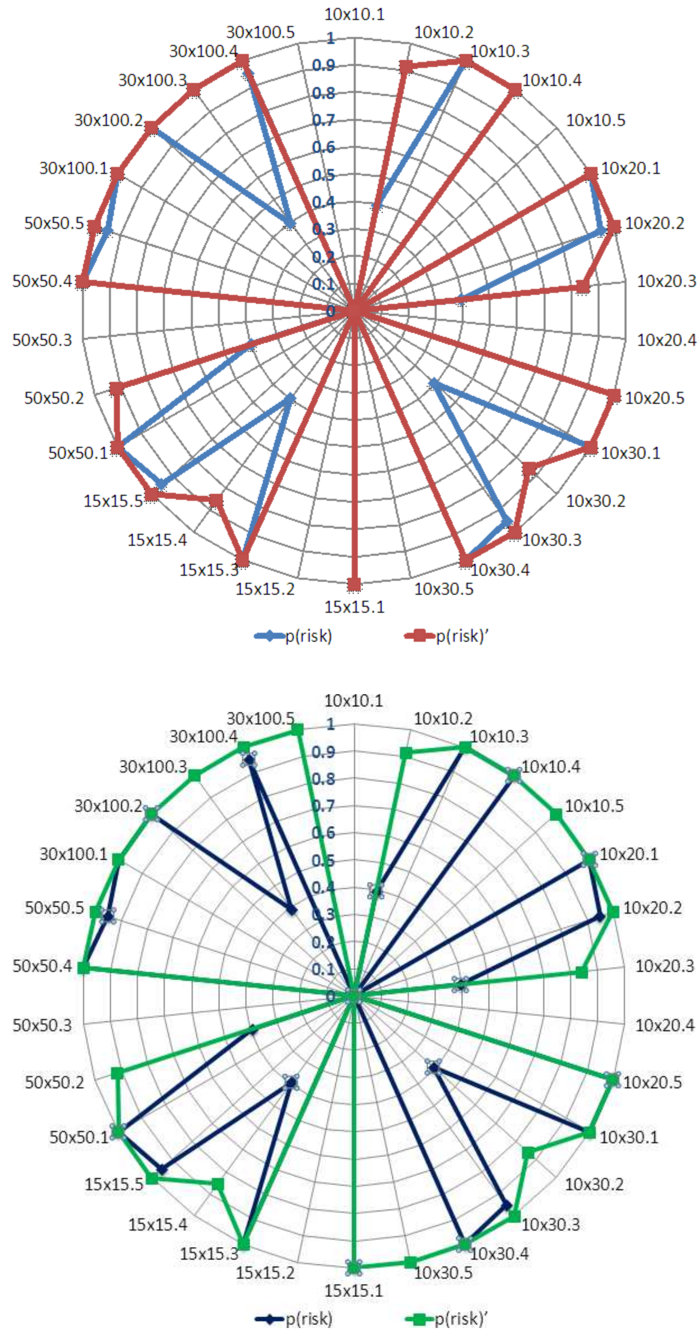

FIG. 3: Risk comparison between risk probabilities with (P(risk)') and without (P(risk)) considering explicitly Greenhouse Gas emissions. The second graph is for the case study with modified GHG Limits on 10x10, 10x30 and 30x100 considered cases.

5.3 Case Study

The GHG Limit directly influences the Security level. Furthermore we consider the case when just the **GHG value would directly influence the risk security level** - this would occur when the GHG value is higher than the $GHGLimit$, and thus the security level will be directly **Very Low Security Level**, with the risk probability P(risk)=1.

If, for example, the GHG Limits considered are modified for (10x10, 1000), (10x30, 2000) and (30x100, 9000), there will be also a change of the security levels:

- **Decreasing Security Levels**: From **High Security Level** to **Very Low Security Level**, therefore risk probability P(risk)=1, for 10x10.5, 10x30.5 and 30x100.5 when the $GHGLimit$ is modified and $GHG < GHGLimit$.
- **Stagnation of Security Level**: There will be a stagnation within the same security level, for 10x10.4 and 10x30.4, when the $GHGLimit$ is modified.

Figure 3 illustrates comparatively the considered case studies. The impact of changing the $GHGLimit$ on the 10x10.5, 10x30.5 and 30x100.5 cases is clearly illustrated. The **High Security Level** case of the *SGSCN* with fixed costs problem could be considered as the initial two-stage Supply chain problem without any secure constraints.

6 Conclusions and Further work

6.1 Conclusions

The security of supply chains is crucial, and it is therefore widely research by academics and governmental research institutions. The effective and efficient performance of supply chain networks could be disrupted by natural and human-based factors. This paper has extended the supply chain security parameters to simultaneously consider fixed costs, transportation costs, and greenhouse gas emissions. Several case studies that capture the impact of Greenhouse Gas emissions on the probability risk are designed, illustrated, and discussed. Discussions of the experiment results for a range of security levels are presented; specific cases where the GHG does not influence the final risk probability, and cases where GHG directly influences the risk security level, respectively, were considered. The analysis of the results provides preliminary insights that support the hypothesis that the GHG Limit could be a crucial factor in the risk probability of supply chain networks. In the future the time constraints and dynamism in the two-stage supply chain problem with security constraints could be considered.

6.2 Further work

Future work will include time constraints and models of dynamism in the supply chain problem with security constraints.

Time constraints could be included in either the first or the second supply chain or in the two-stage supply chain problem. This extension will provide additional insights into interdependencies between security and GHG constraints using a more realistic supply chain model, and will allow further investigations into means of mitigating and managing these risks delete could lead to a risky supply chain if the flow is not well organized.

Dynamism in the two-stage supply chain problem with security constraints could consider the following.

- Due to the security constraints influenced by a GHG factor over the limit, some distribution centers or customers could be blocked. In this case the transportation flow will ignore the blocked nodes.
- Due to the additional security constraints distribution centers or customers may refuse the distribution and as a result, the transport will have to be returned to the source. In this case the overall transportation cost will increase.

Acknowledgments. The study was conducted under the auspices of the IEEE-CIS Interdisciplinary Emergent Technologies TF.

References

[1] Hitchcock, F. L., The distribution of a product from several sources to numerous localities, J Math Physic, vol. 20, pp. 224–230, 1941.

[2] Diaby, M., Successive linear approximation procedure for generalized fixed charge transportation problems, J Oper Res Soc, vol. 42, pp. 991–1001, 1991.

[3] Adlakha, V., Kowalski, K., On the fixed-charge transportation problem. OMEGA: The International Journal of Management Science, vol. 27, pp. 381–388, 1999.

[4] Sun, M., et al., A tabu search heuristic procedure for the fixed charge transportation problem, Eur J Oper Res, vol.106, pp. 441–456, 1998.

[5] Ledwoch, A., Yasarcan, H., Brintrup, A., Multi-objective optimisation of reliable product-plant network configuration, International Journal of Production Economics vol.197, pp. 13–26, 2018.

[6] Qazi A., Quigley J., Dickson A., Cost-Effectiveness and Manageability Based Prioritisation of Supply Chain Risk Mitigation Strategies. In: Khojasteh Y. (eds) Supply Chain Risk Management. Springer, Singapore, pp. 23–42, 2018.

[7] Aqlan, F., Lam, S. S., Supply chain risk modelling and mitigation. International Journal of Production Research, 53(18), pp. 5640–5656, 2015.

[8] Lee, K.-H., Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry, Journal of Cleaner Production, vol. 19, no. 11, pp. 1216–1223, 2011.

[9] Ivanov, D., Dolgui, A., Sokolov B., Ivanova M., Literature review on disruption recovery in the supply chain, International Journal of Production Research, vol. 55, no. 20, pp. 6158–6174, 2017.

[10] Arya, S., et al., An Optimal Algorithm for Approximate Nearest Neighbor Searching in Fixed Dimensions, Jnl ACM, vol. 45, no. 6, pp. 891–923, 1998.

[11] Molla-Alizadeh-Zavardehi S. et al., Solving a capacitated fixed-charge transportation problem by artificial immune and genetic algorithms with a Prufer number representation, Expert Sys App, vol. 38, pp. 10462–10474, 2011.

[12] Chira C., Dumitrescu D., Pintea C-M., Learning sensitive stigmergic agents for solving complex problems, Computing and Informatics, vol. 29, no. 3,pp. 337–356, 2010.

[13] Pintea C-M., Matei O., Ramadan R.A., Pavone M., Niazi M., Azar A.T.: A Fuzzy Approach of Sensitivity for Multiple Colonies on Ant Colony Optimization. Soft Computing Applications. SOFA 2016, AISC, Springer, vol. 634 pp. 87–95, 2018.

[14] Pintea C-M., Crian G-C., Chira C., Hybrid Ant Models with a Transition Policy for Solving a Complex Problem, Logic Jnl IGPL, vol.20, no. 3, pp. 560-569, 2012.

[15] Xiangyang Li, Charu Chandra, Toward A Secure Supply Chain: A System's Perspective. Human Systems Management, 2008.

[16] Liu H., Abraham A., Snášel V., McLoone S., Swarm scheduling approaches for work-flow applications with security constraints in distributed data-intensive computing environments, Information Sciences, vol. 192, pp. 228–243, 2012.

[17] Song S., Hwang K., Zhou R., Kwok Y., Trusted P2P transactions with fuzzy reputation aggregation, IEEE Internet Computing, vol. 9, no. 6, pp. 24–34, 2005.

[18] Song S., Kwok Y., Hwang K., Security-driven heuristics and a fast genetic algorithm for trusted grid job scheduling, Int. Parallel & Distributed Processing, IEEE CS, vol. 65, pp. 4–12, 2005.

[19] Song S., Hwang K., Kwok Y., et al, Risk-resilient heuristics and genetic algorithms for security-assured grid job scheduling, IEEE Trans Comp, vol. 55, no. 6, vol. 703, 2006.

[20] Venugopal S., Buyya R., A deadline and budget constrained scheduling algorithm for eScience applications on data grids, LNCS vol. 3719, pp. 60–72, 2005.

[21] Pintea C-M., Pop P.C., An improved hybrid algorithm for capacitated fixed-charge transportation problem, Logic Jnl IGPL, vol. 23, no. 3, pp. 369–378, 2015.

[22] Pintea C-M., et al., A hybrid classical approach to a fixed-charged transportation problem, LNCS vol. 7208, pp. 557–566, 2012.

[23] Pop P.C., et al., An Efficient Reverse Distribution System for Solving Sustainable Supply Chain Network Design Problem. Jnl Applied Logic, vol. 13, no. 2, pp. 105–113, 2015.

[24] Rice, J. B., Caniato, F., Building a secure and resilient supply network. Supply Chain Management Review, vol. 7, no. 5, pp. 22–30, 2003.

[25] Lee, H.L., Wolfe M., Supply chain security without tears. Supply Chain Management Review, vol. 7, no. 3, pp. 12–20, 2003.

[26] S. Molla-Alizadeh-Zavardehi, M. Hajiaghaei-Kesteli and R. Tavakkoli-Moghaddam, Solving a capacitated fixed-cost transportation problem by artificial immune and genetic algorithms with a Prüfer number representation, Expert Systems with Applications, **38** (2011), pp. 10462-10474.

[27] Mes, M. et al., Comparison of agent-based scheduling to look-ahead heuristics for real-time transportation problems, Eur J Oper Res vol.181, no. 1, pp. 59–75, 2007.

[28] Sun, M., et al., A tabu search heuristic procedure for the fixed charge transportation problem, Eur J Oper Res vol. 106, no. 2, pp. 441–456, 1998.

[29] Calinescu, A., et al., Applying and assessing two methods for measuring complexity in manufacturing, J Oper Res Soc, pp. 723–733, 1998.

[30] Sivadasan, S., et al., Advances on measuring the operational complexity of supplier–customer systems, Eur J Oper Res, vol. 171, no. 1), pp. 208–226, 2006.

[31] Santibanez-Gonzalez, E. Del R., et.al., Solving a public sector sustainable supply chain problem: A Genetic Algorithm approach, Proc. of Int. Conf. of Artificial Intelligence (ICAI), Las Vegas, USA, pp. 507–512, 2011.

[32] Pintea, C-M., Pop P.C., Hajdu-Măcelaru,M., Classical Hybrid Approaches on a Transportation Problem with Gas Emissions Constraints. Advances in Intelligent and Soft Computing, vol. 188, pp. 449–458, 2013.

[33] Pintea C-M, Calinescu A., Pop P., Sabo C., Towards a Secure Two-stage Supply Chain Network: A Transportation-Cost Approach, Advances in Intelligent Systems and Computing, vol. 527, pp. 547–554, 2016.

Received March 2018.