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OPTIMIZATION OF THE ACQUISITION OF RISK MITIGATION SYSTEMS FOR A CONTINGENCY LOGISTICS NETWORK

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ABSTRACT

Contingencies are unexpected events or crises that cause a major threat for security and safety of a specific population. To cope with contingencies, logistics networks contain operational sites that are assigned to perform critical mission to recover back from the contingencies. In order to improve their mission capabilities, hence, overall reliability of a contingency logistics network, risk mitigation systems can pay significant role. This paper develops and presents risk mitigation systems acquisition model for a contingency logistics networks where sites are arranged in parallel and demand of sites as well as supplies to sites are assumed to have exponential distribution. The resulting nonlinear problem was solved through Excel solver and findings indicate that it is worthwhile to adopt risk mitigation systems in the contingency logistics network to improve its reliability.

Key words: contingency logistics, risk mitigation systems, mathematical models

1.Introduction

Studies on risk management and optimization for contingency logistics networks from the perspectireve of mission success emerged in 2000s in the literature. Thomas (2004) defines contingency as “unexpected event that creates a major threat to the safety and security of a population” and proposes first time modeling risk for contingency in terms of mission success based on interference theory between demand and supply to perform mission during contingency where operational site is mission capable when it has enough supply to perform the mission compared to demand required by the mission in the contingency logistics network (CLN). Under the inherent uncertainties of contingencies he suggests the use of probability distributions for the demand and suppliable material and maximum entropy principle in case of lack of information for demand and supply. Miman and Pohl (2008) extend Thomas (2004)’ preliminary work enabling operational sites to hold stocks before a contingency and considering risk attitudes of contingency logistic network planner towards the failure of operational sites through distorted risks modelling.

In a CLN design, the CLN planner may have multiple objectives, i.e., maximization of the reliability of the CLN in performing the mission to recover the contingency, cost and time for the plan. Miman and Pohl (2012) deals with this multi-objective decision problem using physical programming (PP) developed by Messac (1996), in context of selective maintenance where transportation links is assumed to have a Weibull life distribution and there are a set of maintenance alternatives (do-nothing, repair, replace with an original one and replace with a superior one) that effect the reliability of the links, hence the CLN. For the same selective maintenance context, Dağ and Miman (2014) proposes utopia-distance approach minimizing the distance between current solution and utopic point represented by the reliability of one and zero time and cost. Dağ and Miman (2015) in their another study proposes a multi-objective optimization modeling of the CLN as a weighted objective function of reliability of the network, where risk of bases were modelled through distortion (Offut et al., 2006) depending on the critically of the base for the mission, total cost of stock allocation and total number of stocks to allocate. They provide an Excel Solver illustration of their modeling of multi-objective paradigm for a CLN.

Risk mitigation systems are the ones that are aimed at reducing the risks for which they are working on. In supply chain, this can be achieved through mainly a proper flow of information, materials and funds (Faisal et al., 2006). Firms and corporations have been aware of the need for contingency logistics planning for a long time (Manuj and Mentzer, 2008). In these plans, organizational structuring and design, communication, culture and trust were determined to be four important concept for risk mitigation (Grabowski and Roberts, 1998). This study develops and presents a risk mitigation acquisition model for a CLN based on the work of Miman (2008). Following sections of the study were arranged as the model development, illustration, conclusion and discussion where contributions of this study and future research directions based on this study are highlighted.

2. Model Development

This section presents the model developed and analyzed for acquisition of risk mitigation systems under contingencies as a mathematical program. Below is the notation list necessary to build the mathematical model.

2.1. Notation list

CLN	Contingency Logistics Network
S_i	Random variable representing the supply at site $i = 1,\dots,n$
D_i	Random variable representing the demand at site $i = 1,\dots,n$
X_i	Probability distribution of the supply at site $i = 1,\dots,n$
Y_i	Probability distribution of the demand at site $i = 1,\dots,n$
f_i	Density (or probability mass) function of the supply at site $i = 1,\dots,n$
g_i	Density (or probability mass) function of the demand at site $i = 1,\dots,n$
G_i	CDF for the demand at site $i = 1,\dots,n$
μ_i	Exponential rate of the supply for Y_i
λ_i	Exponential rate of the demand for X_i
MD_i	Mean demand at site i ;$1/\lambda_i$
MS_i	Mean supply for site i; $1/\mu_i$
c_j	Unit cost of acquisition of risk mitigation system j
B	Available budget for acquisition of risk mitigation systems
m_{ij}	jth risk mitigation system's effect on percent reduction of risk faced on site i
z_j	Acquisition amount of risk mitigation system j , $0 \le z_j \le 1$ $j = 1,\dots,m$
ρ_i	Failure probability of site $i = 1,\dots,n$ based on interference between demand and supply
ρ_i^m	Mitigated risk of site $i = 1,\dots,n$ after acquisition of mitigating systems
R_i	Site reliability, $i = 1,\dots,n$
R	Reliability of the CLN
C	Cost of acquisition of risk mitigation systems in CLN

2.2. Problem Description

This study deals with *n* operational bases arranged in parallel redundancy, i.e. each of which can perform the dedicated mission, to perform contingency operations that are subject to inheriting risk of uncertainties. The operational site *i* is mission capable when it has enough supply to perform the mission compared to demand it requires. The associated risk of the site *i* is computed based on interference between demand and supply using their probability distributions according to Eq. (1)

$$\rho_i = \Pr\{D_i > S_i\} = \int_x \Pr\left(D_i > x\right) f_i(x)dx = \int_0^{\infty} (e^{-\lambda_i x})\mu_i e^{-\mu_i x} dx$$
$$= \int_0^{\infty} \mu_i e^{-(\mu_i+\lambda_i)x} dx = -\frac{\mu_i}{\mu_i+\lambda_i} e^{-(\mu_i+\lambda_i)x}\Big|_0^{\infty} = -\frac{\mu_i}{\mu_i+\lambda_i}(0-1) = \frac{\mu_i}{\mu_i+\lambda_i} \qquad \text{(Eq.1)}$$

It is assumed that there are *m* risk mitigating systems, *j*th of which, reduced the imposed risk at given by Eq. 2.

$$\rho_i^m = \rho_i \left(1 - \sum_{j=1}^{m} m_{ij} z_j\right) \qquad \text{(Eq.2)}$$

The site's reliability, R_i, then becomes equal to $(1-\rho_i^m)$. Eventually the CLN reliability for paralel arranged n sites are given by Eq. 3.

$$R = 1 - \prod_{i=1}^{n} (1 - R_i) = 1 - \prod_{i=1}^{n} \rho_i^m \qquad \text{(Eq.3)}$$

Overall mathematical program to allocate available budget to risk mitigation systems to enhance the CLN's reliability is expressed in P1.

$$Max \quad R = 1 - \prod_{i=1}^{n} \left\{ \frac{\mu_i}{\mu_i+\lambda_i} \left(1 - \sum_{j=1}^{m} m_{ij} z_j\right) \right\}$$
$$s.t.$$
$$\sum_{j=1}^{m} c_j z_j \le B$$
$$0 \le z_j \le 1 \qquad ,j = 1,..,m$$

(*P1*: Optimization Model for Acquisition of Risk Mitigation Systems in a CLN)

Note that model *P1* is nonlinear, non-separable, non-convex in terms of decision variables z_js. Therefore, in this study, Excel Solver with a nonlinear optimization option is investigated as a heuristic solution to the model and the results are provided to illustrate how risk mitigation systems acquisition can be modelled for a CLN.

3.Illustration

To illustrate the mathematical model described by P1, a CLN consisting of 5 operational bases arranged in parallel was considered along with 5 risk mitigation systems to acquire with a total budget of $300.000,00. Parameters of the model, i.e. mean demand rate, mean supply rate; percent reduction provided by each risk mitigation system to each operational site, and acquisition cost of each risk mitigation system are provided in Table 1 and Table 2 respectively.

Table 1. Parameters of the Model: Operational Sites

Site	MD	MS	λ	μ	ρ	Initial Capability
1	100	40	0,010	0,025	0,714	0,286
2	100	45	0,010	0,022	0,690	0,310
3	125	75	0,008	0,013	0,625	0,375
4	100	50	0,010	0,020	0,667	0,333
5	150	70	0,007	0,014	0,682	0,318
			System			**0,860**

Table 2. Parameters of the Model: Risk Mitigation Systems

mi,j			***j***		
i	**1**	**2**	**3**	**4**	**5**
1	0,032	0,045	0,031	0,062	0,080
2	0,058	0,013	0,025	0,058	0,011
3	0,007	0,044	0,012	0,064	0,032
4	0,007	0,044	0,041	0,052	0,050
5	0,082	0,072	0,034	0,003	0,003
c (1000s dollars)	150	125	100	80	130

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As seen in Table 1, before any risk mitigation system is acquired, the CLN has overall reliability, i.e. probability of being capable of performing assigned mission successfully, of 0,860.

Excel solver solution, and corresponding sites' reliabilities were provided in Table 3 and Table 4 respectively.

Table 3. Optimal Solution by Excel Solver: Risk Mitigation Systems

	j				
	1	2	3	4	5
zj	**0,000**	**1,000**	**0,950**	**1,000**	**0,000**
c (1000s $)	150	125	100	80	130
M	299,999996				
B (1000s $)	300				

Optimum solution requires the purchase of one unit of risk mitigation system 2 and 4 while 0,95 units of risk mitigation system 3 within the budget of $300.000,00.

Table 4. Optimal Solution by Excel Solver: CLN

Site	MD	MS	λ	μ	ρ	ρm	Initial Capability	Final Capability	% Change
1	100	40	0,010	0,025	0,714	0,617	0,286	0,383	34,11%
2	100	45	0,010	0,022	0,690	0,624	0,310	0,376	21,06%
3	125	75	0,008	0,013	0,625	0,550	0,375	0,450	19,90%
4	100	50	0,010	0,020	0,667	0,577	0,333	0,423	26,99%
5	150	70	0,007	0,014	0,682	0,609	0,318	0,391	22,99%
System							**0,860**	**0,926**	**7,62%**

Through the acquisition of risk mitigation systems 2 (one unit), 3 (0.95 units) and 4 (one unit) the corresponding operational sites capabilities (1 through 5) and overall the CLN reliability improved by 34,11%; 21,06%; 19,90%; 26,99%; 22,99%; and 7,62% respectively. These improvements can be regarded as significant depending on the criticality of the mission assigned to operational sites and overall CLN as well.

4. **Conclusion and Discussion**

This study develops and presents a risk mitigation systems acquisition model for a CLN, which is assigned a critical mission to perform to get rid of the contingencies. Although it assumes the operational sites are arranged in parallel, the rational behind the modelling paradigm can be applied to other structures as well without loss of generality.

Findings indicates that there is a great potential to improve the reliability of the CLN, its mission capability, through the acquisition of risk mitigation systems, which can be very significant for the CLN planner due to inheriting uncertainties in such systems. Therefore, it is worthwhile to invest on risk mitigation systems for contingency logistics networks to reduce risks and enhance its reliability.

Further studies can focus on the investigation of the use of other meta-heuristics such as genetic algorithm, tabu search, ant colony optimization etc. to improve the solution quality of the model proposed in this study.

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