Problem definition

Considering the importance of providing scarce drugs due to their particular conditions, including sanctions that may exist for a particular country, or countries that live in poverty and are unable to provide these types of medicines to people, or because some of these drugs need special storage conditions that incur heavy costs on the government. Therefore, examining scarce drugs in crisis situations can be very effective in reducing mortality because many injured people have diseases that can cause serious problems for them if they do not find the desired drugs. In other words, in crisis situations due to the severity of various destructions, these types of drugs' storage conditions are extremely important because the government must pay a lot for these drugs. In order to ensure that these products reach injured people, the reliability of roads on different routes has been examined in this study. In order to prevent shortages and ensure proper storage of these products, backup distribution centers have been considered to ensure that pharmaceutical products can be stored before the crisis.

Another very important issue is the issue of the perishability of pharmaceutical products, which should be checked periodically before they expire due to their limited life span. If these products are about to expire, they should be replaced with new ones, and old ones can be sold at a lower price if they are nearing expiration. This study also examined the issue of domestic and foreign suppliers. The injured people will be supplied by foreign suppliers if domestic suppliers cannot satisfy the injured people's demands. In this study, two types of distribution centers are considered, which include primary distribution centers and backup distribution centers. In backup distribution centers, there is no possibility of destruction since fortification has been incurred, whereas, in primary distribution centers, there is a possibility of destruction.

This paper considers a multi-objective mixed-integer linear programming model to determine the optimal decisions regarding location-allocation, the distribution of drugs, substitutability of close-to-expiration drugs with new drugs to design a scarce drug supply chain network design (SDSCND) under disaster condition. This model determines the optimal pre-disaster preparedness policy, which includes where distribution centers should be located, how many commodities should be stored in each distribution center, how medicines should be stored in distribution centers, and how the commodities should be distributed to disaster areas. The considered objective functions minimize the average response time by considering maximizing route reliability and minimizing drug shortages. Moreover, a robust probabilistic programming approach is used to consider the uncertainty of input data, such as demand, and distribution centers' failure probabilities. In Fig. 1, an overview of SDSCND is presented for an understanding of the problem.

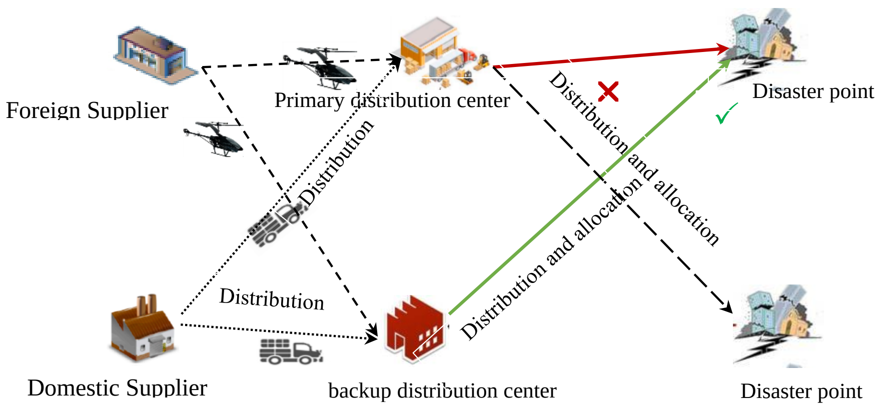

Fig. 1. Schematic diagram of the study problem.

3.1. Assumptions

Based on the proposed model, the following assumptions could be made:

- Drugs have expiry date.
- Two types of suppliers are considered: domestic suppliers and foreign suppliers.
- backup distribution centers that have been fortified are with high capacity, and the probability of failure of these centers is not exist.
- Among the model's parameters, the demand, probability of failure in primary distribution centers, and Inventory of distribution centers are considered uncertainty and all of them are expressed as occurrence probability of scenarios.
- Different routes of distribution may cause destruction.
- Each primary and backup distribution center is connected to each disaster point in only one unique way.
- It is not possible for suppliers to send drugs directly to disaster points.
-

3.2. Notations

Nomenclature

Sets

p	Set of pharmaceutical items, $p = \{1,\ldots,P\}$
i	Set of distribution centers, $i = \{1,\ldots,I\}$

k	Set of inner suppliers, $k = \{1,...,K\}$
kp	Set of external suppliers, $kp = \{1,...,KP\}$
b	Set of support centers, $b = \{1,...,B\}$
c	Set of disaster points, $c = \{1,...,C\}$
r	set of routes between distribution centers and disaster points, $r = \{1,...,R\}$
rp	set of routes between suppliers, $rp = \{1,...,RP\}$
t	Set of periods of times, $t = \{1,...,T\}$
s	Set of possible scenarios, $s = \{1,...,S\}$

Parameters

e_p	Production start date pharmaceutical item p
SC^s	Start time of crisis in scenario s
λ_{rt}	Failure rate of route r at period t
λp_{rpt}	Failure rate of route rp at period t
lp_{pt}	Perishable time pharmaceutical item p at period t
cx_{kipt}	Transportation costs pharmaceutical item p from inner supplier k to distribution center i at period t
cxp_{kpipt}	Transportation costs pharmaceutical item p from external supplier kp to distribution center i at period t
$Discount_{pts}$	the amount of discount for pharmaceutical item p at period t in scenario s
Czz_{icpt}	Transportation costs pharmaceutical item p from distribution center i to disaster point c at period t
Cq_{bcpt}	Transportation costs pharmaceutical item p from support center b to disaster point c at period t
ck_k	Fixed cost of establishing inner supplier k
ckp_{kp}	Fixed cost of establishing external supplier kp
ci_i	Fixed cost of establishing distribution center i
cb_b	Fixed cost of establishing support center b
ξk^s_{kpt}	Reduction rate of pharmaceutical item p in inner supplier k at period t
ξKP^s_{kppt}	Reduction rate of pharmaceutical item p in external supplier kp at period t
ξI^s_{ipt}	Reduction rate of pharmaceutical item p in distribution center i at period t
ξB^s_{bpt}	Reduction rate of pharmaceutical item p in support center b at period t

capb_{bpt}	The capacity of pharmaceutical item p in support center b at period t
capk_{kpt}	The capacity of pharmaceutical item p in inner supplier k at period t
$\text{capk}p_{kppt}$	The capacity of pharmaceutical item p in external supplier kp at period t
capi_{ipt}	The capacity of pharmaceutical item p in distribution center i at period t
CII^{s}_{ipt}	The cost of maintaining a unit of pharmaceutical item p in distribution center i at period t
Dem^{s}_{cpt}	Demand per unit of pharmaceutical item p at disaster point c at period t
pr^{s}	The occurrence probability of the scenario s
MM	A large number

Decision variables

x^{s}_{kipt}	Amount of pharmaceutical item p distributed from inner supplier k to distribution center i at period t under scenario s
xp^{s}_{kpipt}	Amount of pharmaceutical item p distributed from external supplier kp to distribution center i at period t under scenario s
zz^{s}_{icpt}	Amount of pharmaceutical item p distributed from distribution center i to disaster point c at period t under scenario s
q^{s}_{bcpt}	Amount of pharmaceutical item p distributed from support center b to disaster point c at period t under scenario s
ccz^{s}_{icpt}	The selling price of pharmaceutical item p distributed from distribution center i to disaster point c at period t under scenario s
II^{s}_{ipt}	The amount of inventory pharmaceutical item p in distribution center i at period t under scenario s
xxp^{s}_{rpt}	
xx^{s}_{rt}	
y_{k}	1 if an inner supplier k is constructed, 0; otherwise
yp_{kp}	1 if an external supplier kp is constructed, 0; otherwise
yz_{i}	1 if a distribution center i is constructed, 0; otherwise
yb_{b}	1 if a support center b is constructed, 0; otherwise
zs	time that is appropriate for pharmaceutical item should be sold under the price

The mathematical model can be formulated as follows.

$$Minz_1 = \sum_s pr^s \left[\sum_r \sum_{rp} \sum_t \exp\left(-\lambda_{rt}\,\mathrm{xx}_{rt}^s\right) \exp\left(-\lambda p_{rpt}\,\mathrm{xxp}_{rpt}^s\right) \right] \tag{1}$$

$$Minz_2 = \sum_s pr^s \left[\begin{array}{l} \sum_k \mathrm{ck}_k y_k + \sum_{kp} \mathrm{ckp}_{kp} yp_{kp} + \sum_i \mathrm{ci}_i yz_i + \sum_b \mathrm{cb}_b yb_b + \\ \sum_k \sum_i \sum_p \sum_t cx_{kipt} x_{kipt}^s + \sum_{kp} \sum_i \sum_p \sum_t cxp_{kpipt} xp_{kpipt}^s + \\ \sum_b \sum_c \sum_p \sum_t 1000\mathrm{Cq}_{bcpt} q_{bcpt}^s + \sum_i \sum_c \sum_p \sum_t ccz_{icpt}^s + \sum_i \sum_p \sum_t \mathrm{CII}_{ipt}^s II_{ipt}^s \end{array} \right] \tag{2}$$

$$\sum_i x_{kipt}^s \le \mathrm{capk}_{kpt} y_k \xi k_{kpt}^s \qquad \forall k, p, t, s \tag{3}$$

$$\sum_i xp_{kpipt}^s \le \mathrm{capk}p_{kppt} yp_{kp} \xi kp_{kppt}^s \qquad \forall kp, p, t, s \tag{4}$$

$$\sum_c zz_{icpt}^s \le \mathrm{capi}_{ipt} yz_i \xi i_{ipt}^s \qquad \forall i, p, t, s \tag{5}$$

$$\sum_c q_{bcpt}^s \le capb_{bpt} yb_b \xi b_{bpt}^s \qquad \forall b, p, t, s \tag{6}$$

$$\sum_c q_{bcpt}^s = 0 \qquad \forall b, p, s, t, t < SC^s \tag{7}$$

$$\sum_t zs_{tts} \le SC^s - 1 \qquad \forall s \tag{8}$$

$$\sum_{tp\,(tp \ge t,\, tp \le SC^s - 1)} zs_{ttps} = zs_{tts} \qquad \forall t, s \tag{9}$$

$$ccz_{icpt}^s \ge zz_{icpt}^s Discount_{pts} \mathrm{Czz}_{icpt} - MM\left(1 - zs_{ttps}\right) \qquad \forall i, c, p, t, tp, s \tag{10}$$

$$ccz_{icpt}^s \ge zz_{icpt}^s \mathrm{Czz}_{icpt} - MMzs_{ttps} \qquad \forall i, c, p, t, tp, s \tag{11}$$

$$II_{ipt}^s = II_{ipt-1}^s - \sum_c zz_{icpt}^s + \sum_k x_{kipt}^s + \sum_{kp} xp_{kpipt}^s \qquad \forall i, p, t, s \tag{12}$$

$$II_{ipt}^s + \sum_c zz_{icpt}^s = 0 \qquad \forall i, p, s, t, t > e_p + lp_{pt} \tag{13}$$

$$\sum_i zz_{icpt}^s + \sum_b q_{bcpt}^s = \mathrm{Dem}_{cpt}^s \qquad \forall c, p, t, s \tag{14}$$

$$x_{kipt}^{s}, xp_{kpipt}^{s}, zz_{icpt}^{s}, q_{bcpt}^{s}, ccz_{icpt}^{s}, II_{ipt}^{s} \geq 0 \qquad \forall k, kp, i, b, c, p, t, s \qquad (15)$$

$$\mathrm{xxp}_{rpt}^{s}, \mathrm{xx}_{rt}^{s}, y_{k}, yp_{kp}, yz_{i}, yb_{b}, zs \in \{0,1\} \qquad \forall r, rp, k, kp, b, i, t, s \qquad (16)$$

According to Eq. (1), the first objective function attempts to minimize the possibility of route failure in order to increase reliability. In Eq. (2), The second objective function minimizes the cost of whole chain. It includes costs of establishing the inner suppliers, the external suppliers, distribution centers, and support centers, the cost of transportation between inner suppliers and distribution centers, the cost of transportation between external suppliers and distribution centers, and the cost of transportation between support centers and disaster points, the selling price of pharmaceutical items, the maintenance costs of pharmaceutical items.

Constraint (3) relates to the capacity of inner suppliers. Constraint (4) relates to the capacity of external suppliers. Constraint (5) relates to the capacity of distribution centers. Constraint (6) relates to the capacity of support centers. Constraint (7) states that, prior to the crisis, sending from support centers to disaster points is not done. Constraint (8) defines the start time of the crisis. Constraint (9) specifies from which period pharmaceutical items can be sold at a lower price. Constraint (10) pertains to pharmaceutical items' cost decreasing as it approaches their expiration date. Constraint (11) associates with the period when the drug has an expiration date and no discount is offered. Constraint (12) represents the equilibrium constraint in distribution centers. Constraint (13) determines the time of perishability of pharmaceutical items. Constraint (14) associates with the fulfillment of demand by distribution centers or support centers.

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