A Bi-objective Disruption Recovery Plan with Integrated Production and Distribution Decisions

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Abstract. We integrate production and distribution decisions in a recovery planning model for a disrupted production system to minimize the negative impacts of disruption on its profit and customers' satisfaction. The problem is originally motivated by the real-life case of an explosion disaster occurred in September 2015 in a leading producer of household consumer goods in Iran. Multiple recovery policies as using the reserve line, production outsourcing and inventory transshipment are adopted to the firm's multi-product three echelon network of production resources, depots and classified customers. Considering a practical setting for customers' approach to the shortage, production contractors' quantity discounts and the availability limitations on the dispatching area caused by the disruption makes the model more adoptable to the real life problems. Epistemic inherent uncertainty of demands and recovery progress are addressed with triangular fuzzy numbers. The model's two objective functions are aggregated with a weighted sum formulation and helpful insights are derived from numerical experiments.

Keywords: Disruption Recovery, Production, Distribution, outsourcing, Transshipment

1 Introduction

Increasingly competitive business environment has made firms to carefully investigate their supply chain's capability in anticipating and managing risks. Tang [1] considers two categories of risks: operational and disruption risks. The first one refers to inevitable uncertainties in supply and demand related parameters and the latter refers to low-likelihood man-made or natural disasters which can have significant short or long-term impacts on the system's economic and competitive performances. Two types of approaches can be applied to manage disruptions: proactive and reactive ([2], [3]). Although investment in pro-active disruption management strategies mitigates the negative impacts of disruption, reactive recovery approaches as quick adoption of plans and policies are essential for business continuity and avoiding long-term effects on its economic performance ([4], [5], [6], [7]). Despite of unavoidable necessity of recovery strategies, less efforts have been put into post-disruption planning as compared with pre disruption activities ([8]).

This paper presents a bi-objective fuzzy recovery planning model with integrated production and distribution decision-making in the disruption recovery phase of a multi-product manufacturing company. The proposed work is inspired by an explosion disaster in a leading producer of personal and home care products in Iran. The network consists of one disrupted production site which should serve multiple distribution depots and customers. The presented model seeks to provide support for four groups of decisions over a multi-period recovery time to optimize the sales performance of the company: (1) selecting the best production contracts to back up the production during the recovery phase, (2) the optimal production delivery flows from the contractors as well as the production plans in the plant's reserve and disrupted lines, (3) the optimal transshipment flows between depots and (4) the optimal transportation flows (i.e. shipment lots) between different echelons.

Furthermore, the overall performance of supply chain planning models is affected by chaotic and complex business environment which leads to uncertainty in the demand and supply parameters i.e. operational. Therefore, in order to make the model closer to the reality, demand as well as the production and dispatching capacity recovery progress are assumed to be imprecise and estimated in the form of triangular fuzzy numbers.

The following paper which extends the previous work of authors ([9]) who considered depots' transshipment optimization in a location inventory problem for a three echelon distribution network under normal undisrupted circumstances. Products were grouped into seasonal and unseasonal with lost sales for pick seasons and backorder under other states. The current work adopts the transshipment as one of the disruption recovery mechanism in a disrupted production distribution problem. The main contributions of this paper can be summarized as follows:

- Modeling a new integrated production distribution recovery problem for post-disruption stage in a three echelon network while considering supply/demand epistemic uncertainty (i.e. operational risks).
- Accounting for a realistic customer-dependant shortage situation in which each customer bears a maximum due time for receiving his/her backlogged order after which the sales is lost.
- Incorporating multiple disruption recovery policies including activating reserve production line, inventory transshipment and production contracting in a bi-objective.
- Accounting for quantity discount structure in each contractor's set of offers to optimize outsourcing selection.

A recent complete review on disruption in design (pro-active stage) and execution (re-active stage) could be found in Snyder et al. [10] and Ivanov et al. [7]. Eisenstein [11] presented a dynamic produce-up-to recovery policy for a single disruption in cyclic production systems. Yang et al. [12] developed a recovery plan for production disruption. Klibi and Martel [13] investigated the design of resilient supply network under depots disruption. During the recovery periods, while the capacity of the disrupted depot improves to its normal level according to a piecewise linear function, the depot satisfies a subset of its primary customers and transfers the remaining ones. They also modeled the backup depot, multiple sourcing and enhancing the network coverage as the operational response policies which will improve the network resilience if considered in the design stage. Wang et al. presented a recovery model for combinational disruptions in logistics delivery. Shao and Dong [14] studied selection of reactive strategies to respond to supply disruption in an assemble-to-order supply chain. Baghalian et al. [15] proposed a reactive robust supply chain design model for multi products in a three echelon network with manufacturers' disruption probabilities. Ahmadi-Javid and Seddighi [16] considered a location routing problem with production and distribution disruption. They minimized the total cost of location, distribution and disruption under three risk-measurement policies. Hishamuddin et al. [17] developed a recovery model for production disruption in a single product single supplier-single retailer setting. They minimized the costs (including the disruption-related shortage costs) by adjusting the production lot size after the disruption down time within the recovery time window. Torabi et al. [18] considered several pro-active disruption management strategies in a bi-objective mixed possibilistic stochastic supplier selection and order allocation model. Chen and Xiao [19] investigated a manufacture's outsourcing strategy in presence of production disruption risks as well as demand and capacity uncertainties in his relationship with a retailer in different leadership settings.

2 Problem Description

This study is inspired by a real-world case of explosion disaster in a leading household products manufacturer in Iran. The company owns the leading brands of insecticide and hair styling sprays in the national market as well as well-known brands for other various home and personal care goods including spray products in body deodorants, air fresheners and dashboard polish families. The products are distributed among retailers/mega stores by national-wide depots.

The Explosion which occurred in September 28th 2015, seriously damaged one of the spray production halls and risked the company's economic performance and cash flow. Therefore, the firm needed a re-planning for its production and distribution activities in order to cost-effectively minimize the negative impacts of its production line disruption on its profit and customers' satisfaction and consequently its market share until the disrupted line would be fully recovered.

We propose a new mixed integer linear formulation to model integrated production distribution decisions for a multi-period production disruption recovery plan in a three echelon distribution network as depicted in figure 1. The first echelon consist of the disrupted plant as well as candidate production contractors. The second echelon includes the depots and the third one covers the customers. The plant might use its non-disrupted production line as a reserve resource while counts on updated recovered capacity of its disrupted line. The damaged hall recovery project proceeds according to an initial Gant chart and its accomplishments are reflected in the plant's production capacity. Due to the uncertainty of estimated planned progress rates, it is formulated as a possibilistic distribution in the form of triangular fuzzy parameters. The production contractors offer quantity discounts in their contract structure. They might send their finished production either to the plant for stocking or consolidation purposes or might send them directly to the distribution centers in the second stage. Transportation in the first echelon and from the production sources to depots are to be done by the company's own capacitated vehicle fleet and by unlimited third-party fleet to cover the capacity gap. Explosion disruption might prevent the full availability of dispatching area due to safety risks and/or damages. So transportation flow to/from the plant is subject to available capacity which is also treated as fuzzy recovery progress rates. Lateral inventory transshipment between depots are to be planned as another alternative source of supply for each distribution center to timely satisfy unmet high-priority demands while keeping the transportation economy-of-scale. Each depot in the second stage is assigned to a set of customers in the third echelon which it should directly serve. Each customer has got a maximum waiting time for receiving each of demanded products. That is backorder becomes lost sales if the depot does not satisfy the demand during the customer's backlog time window. This assumption not only is realistic in aspect of different market position of various products of the company and different expectations of various classes of customers but also enables the model to account for seasonal and non-seasonal products' different shortage behavior in peak seasons (please refer to Ahmadi et al. [9] for more explanations on seasonal shortage behavior).

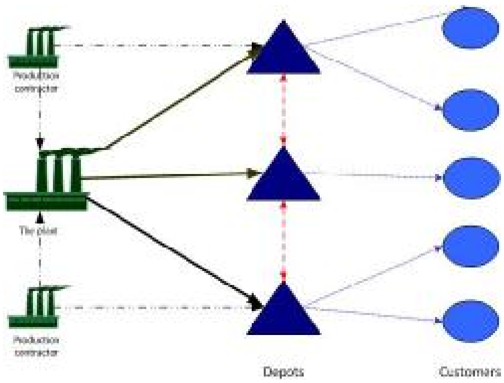

Figure 1. Recovery distribution network

Indices and parameters

$i, i' \in \{1,2,..,Pr\}$	Products
$j \in \{0,1,2,..,R\}$	Temporary production resources (0 denotes the plant)
$k, k' \in \{0,1,2,..,D\}$	Depots (0 denotes the plant)
$r \in \{R_1,..,R_k,..,R_D\}$	Retailers (Customers) assigned to depot *k*
$t, t' \in \{1,2,..,Z\}$	Time periods in the recovery horizon
$l_j \in \{1,..,\Omega_j\}$	Contract types for resource *j* ($j \neq 0$)
$\tilde{d}_{irt} = (d^l_{irt}, d^m_{irt}, d^u_{irt})$	Demand of customer *r* to product *i* in period *t*, where $d^l_{irt}, d^m_{irt}, d^u_{irt}$ are respectively the most pessimistic value, the most possible value and the most optimistic values of imprecise parameter $\tilde{d}_{irt}$
g^0	The plant's disrupted line's production capacity in each period in normal state
g^1	The plant's reserve line's production capacity in each period
g_j	Maximum allocatable total capacity of resource *j*
$\tilde{\mu}_t = (\mu^l_t, \mu^m_t, \mu^u_t)$	The disrupted line's recovery progress percentage in period *t*, where $\mu^l_t, \mu^m_t, \mu^u_t$ are respectively the most pessimistic value, the most possible value and the most optimistic value of imprecise parameter $\tilde{\mu}_t$
$A^{l_j}_j$	Minimum order quantity required by resource *j* in contract type l_j ($j \neq 0$)
c_k	Stocking capacity of depot *k*
γ	The plant's receive/dispatch capacity in each period in normal state
α_t	Receive/dispatch recovery progress percentage at period *t*
ρ_t	Available number of vehicles in the first echelon at period *t*
n	Capacity of each vehicle in the first echelon
θ_i	Sales price of each unit of product *i*
f_{jk}	Fixed cost for each vehicle of the first echelon's fleet transporting goods from node *j* to *k*
e_{jk}	variable cost of transporting each unit of product from resource *j* to depot *k* by third-party fleet
$f^2{}_{kk'}$	Fixed cost of coordination the transshipment between depots *k* to *k'*

$e^2{}_{kk'}$	variable cost of transshipment of each unit of product between depots k to k'
h_k	Holding cost of each unit of product for one period at depot k
$u^0{}_i$	Production cost of each unit of product in the plant's main line
$u^1{}_i$	Production cost of each unit of product in the plant's reserve line
$u_{ij}^{l_j}$	Production cost of each unit of product by resource j in contract type l_j ($j \neq 0$)
w_r	Weight (priority) score of customer r
L_{ir}	Time window for satisfying backorders of product i in customer r

Decision variables

$p^0{}_{it}$	Production amount of product i in the plant's main line at period t
$p^1{}_{it}$	Production amount of product i in the plant's reserve line at period t
$Q_{ij}^{l_j}$	Ordered quantity to resource j for product i in contract type l_j
s_{ijkt}	Transportation flow of product i from resource j to depot k at period t by the plant's in-house fleet
δ_{jkt}	Number of vehicles assigned between resource j and depot k at period t
$s^o{}_{ijkt}$	Transportation flow of product i from resource j to depot k at period t by third party fleet
q_{ikrt}	Transportation flow of product i from depot k to customer r ($r \in R_k$) at period t ($k \neq 0$)
$m_{ikk't}$	Transshipment flow of product i from depot k to k' at period t $(k, k' \neq 0)$
I_{ikt}	Inventory of product i in depot k at the end of period t
b_{irt}	backorder of product i for customer r at the end of period t
$\beta_{irt}, \beta_{irt}^-$	Lost sales and delivery surplus amounts for demand of product i at t^{th} period for customer r
σ_r	Dissatisfaction measure of customer r
$x_j^{l_j} = \begin{cases} 1 \\ 0 \end{cases}$	If resource j and its contract type l_j is chosen in t ($j \neq 0$) Otherwise
$y_{kk't} = \begin{cases} 1 \\ 0 \end{cases}$	If transshipment occurs from depots k to k' at period t $(k, k' \neq 0)$ Otherwise
$v_t = \begin{cases} 1 \\ 0 \end{cases}$	If third part fleet is used at period t Otherwise

Proposed mathematical model

$$\begin{aligned}\text{Max} \sum_i \sum_k \sum_r \sum_t q_{ikrt}\,\theta_i - \sum_j \sum_k \sum_t \delta_{jkt}\, f_{jk} \\ - \sum_j \sum_k \sum_i \sum_t s^o{}_{ijkt}\, e_{jk} - \sum_t \sum_{k'} \sum_k y_{kk't}\, f^2{}_{kk'} \\ - \sum_i \sum_t \sum_{k'} \sum_k m_{ikk't}\, e^2{}_{kk'} - \sum_k \sum_i \sum_t I_{ikt}\, h_k \\ - \sum_i \sum_t p^o{}_{it}\, u^o{}_i - \sum_i \sum_t p^1{}_{it}\, u^1{}_i - \sum_i \sum_j \sum_{l_j} u_{ij}^{l_j} Q_{ij}^{l_j}\end{aligned} \tag{1}$$

$$\text{Min} \sum_r \sigma_r w_r \tag{2}$$

S.T.

$$I_{i0t-1} + p^0{}_{it} + p^1{}_{it} + \sum_{j \neq 0} \left(s_{ij0t} + s^o{}_{ij0t}\right) - \sum_{k \neq 0} \left(s_{i0kt} + s^o{}_{i0kt}\right) = I_{i0t} \qquad \forall i, t \tag{3}$$

$$I_{ikt-1} + \sum_j \left(s_{ijkt} + s^o{}_{ijkt}\right) - \sum_{r \in R_k} q_{ikrt} - \sum_{k' \neq 0} m_{ikk't} + \sum_{k' \neq 0} m_{ik'kt} = I_{ikt} \qquad \forall i, k \neq 0, t \tag{4}$$

$$\sum_i m_{ikk't} \leq M y_{kk't} \quad M = \min\,(c_k, c_{k'}) \qquad \forall k, k', t \quad k \neq k' \tag{5}$$

$$x_j^{l_j} A_j^{l_j} \leq \sum_i Q_{ij}^{l_j} \leq x_j^{l_j} A_j^{l_j+1} \qquad \forall j, 1 \leq l_j < \Omega_j \tag{6}$$

$$x_j^{l_j} A_j^{l_j} \leq \sum_i Q_{ij}^{l_j} \leq x_j^{l_j} g_j \qquad \forall j, l_j = \Omega_j \qquad (7)$$

$$\sum_{l_j} x_j^{l_j} \leq 1 \qquad \forall j \qquad (8)$$

$$\sum_k \sum_t \left(s_{ijkt} + s^o{}_{ijkt}\right) = \sum_{l_j} Q_{ij}^{l_j} \qquad \forall i, j \qquad (9)$$

$$b_{ir0} = \tilde{d}_{ir0} - q_{ikr0} \qquad \forall i, k, r \in R_k \qquad (10)$$

$$b_{irt} = \sum_0^t \tilde{d}_{irt'} - \sum_0^t q_{ikrt'} - \sum_0^{t-L_{ir}} \beta_{irt'} \qquad \forall i, k, t, r \in R_k,\ 0 < t \qquad (11)$$

$$\beta_{irt} - \beta_{irt}^{-} = \sum_0^t \tilde{d}_{irt'} - \sum_0^{t+L_{ir}} q_{ikrt'} - \sum_0^{t-1} \beta_{irt'} \qquad \forall i, k, t, r \in R_k,\ t \leq Z - L_{ir} \qquad (12)$$

$$\sum_{t'=0}^{t} q_{ikrt'} \leq \sum_0^t \tilde{d}_{irt'} \qquad \forall i, k, t, r \in R_k \qquad (13)$$

$$\sum_i s_{ijkt} \leq n\delta_{jkt} \qquad \forall j, k, t,\ j + k > 0 \qquad (14)$$

$$\sum_j \sum_k \delta_{jkt} \leq \rho_t \qquad \forall t \qquad (15)$$

$$\sum_k \sum_j \sum_i s^o{}_{ijkt} \leq \sum_r \sum_i \tilde{d}_{irt}\, v_t \qquad \forall t \qquad (16)$$

$$v_t \leq \frac{\sum_k \sum_j \delta_{jkt}}{\rho_t} \qquad \forall t \qquad (17)$$

$$\sum_i \left(\sum_{j\neq 0} s_{ij0t} + \sum_{j\neq 0} s^o{}_{ij0t} + \sum_{k\neq 0} s_{i0kt} + \sum_{k\neq 0} s^o{}_{i0kt} \right) \leq \alpha_t \gamma \qquad \forall t \qquad (18)$$

$$\sum_i I_{ikt} \leq c_k \qquad \forall k, t \qquad (19)$$

$$\sum_i p^0{}_{it} \leq \tilde{\mu}_t g^0 \qquad \forall t \qquad (20)$$

$$\sum_i p^1{}_{it} \leq g^1 \qquad \forall t \qquad (21)$$

$$\sigma_r \geq \frac{\sum_i \sum_t \beta_{irt}}{\sum_i \sum_t \tilde{d}_{irt}} \qquad \forall r \qquad (22)$$

$$y_{kk't}, x_j^{l_j} \in \{0,1\}$$
$$\sigma_r, \beta_{irt}, I_{ikt}, b_{irt}, m_{kk't}, q_{ikrt}, s^o{}_{ijkt}, \delta_{jkt}, s_{ijkt}, Q_{ij}^{l_j}, p^1{}_{it}, p^0{}_{it} \geq 0 \qquad (23)$$

The first and the second equations compute cost maximization and dissatisfaction minimization objective functions respectively. Total cost function consists of the production at all production resources, inventory costs, fixed costs of shipments by the in-house fleet, variable costs of shipments by third-party in the first and second echelon, and transshipments' fixed and variable costs. Due to the crisis environment, only the aggregated proportion of lost sales are taken into account for measuring each customer's dissatisfaction. Inventory balance in the plant and depots are stated in constraint (3) and (4). Equation (5) state the integrality constraint for transshipment flow of goods between depots. Constraints (6) to (9) decide on the ordered quantities to the contractors and their contract type. Backlog and lost sales amounts are computed in equations (10) to (12). Equation (13) limits the cumulative amount of sales to retailers to their cumulative demands in the previous periods. Constraint (14) and (15) guaranty that transportation flows with the in-house vehicle fleet do not violate the capacity limitation. Equation (16) and (17) ensures that third-party fleet not called if the owned transportation capacity is not fully realized. Dispatching area capacity constraint is treated in equation (18). Equation (19) deals with the stocking capacity in depots and equation (20) and (21) limit the production quantities in the reserve and under-recovery line to available capacity. Each customer's dissatisfaction measures is computed in equation (22). Sign constraints are stated in (23).

3 Solution Procedure

3.1 Crisp Formulation

To deal with possibilistic constraints, the efficient method presented in Jimenez et al. [20] is applied. The expected interval and expected value for ambiguous/imprecise parameters, is shown in Table 1. Defining α as the least level of satisfying of each possibilistic constraint, the crisp reformulations to replace the equations (10) and (20) are presented as examples. The same should be done for constraints (11) to (13).

Table 1: Required computations fro imprecise parameters.

Fuzzy parameter	Fuzzy triangular membership function	$EI(.) = [E_1, E_2]$	EV(.)
$\tilde{\mu}_t$	$(\mu_t^l, \mu_t^m, \mu_t^u)$	$\left[\frac{\mu_t^l + \mu_t^m}{2}, \frac{\mu_t^m + \mu_t^u}{2}\right]$	$\frac{\mu_t^l + 2\,\mu_t^m + \mu_t^u}{4}$
$\tilde{d}_{irt}$	$(d_{irt}^l, d_{irt}^m, d_{irt}^u)$	$\left[\frac{d_{irt}^l + d_{irt}^m}{2}, \frac{d_{irt}^m + d_{irt}^u}{2}\right]$	$\frac{d_{irt}^l + 2d_{irt}^m + d_{irt}^u}{4}$

$$q_{ikr0} + b_{ir0} \geq \left(\frac{\alpha}{2}\right) E_2^{\tilde{d}_{ir0}} + \left(1 - \frac{\alpha}{2}\right) E_1^{\tilde{d}_{ir0}} \qquad \forall i, k, r \in R_k \qquad (24)$$

$$q_{ikr0} + b_{ir0} \leq \left(1 - \frac{\alpha}{2}\right) E_2^{\tilde{d}_{ir0}} + \left(\frac{\alpha}{2}\right) E_1^{\tilde{d}_{ir0}} \qquad \forall i, k, r \in R_k \qquad (25)$$

$$\sum_i p^0{}_{it} \leq g^0 \left((1-\alpha) E_2^{\tilde{\mu}_t} + (\alpha) E_1^{\tilde{\mu}_t}\right) \qquad \forall t \qquad (26)$$

3.2 Bi-Objective Approach

To Deal with the presented bi-objective model after its reformulation to a crisp version, a weighted sum of dimension-less objective functions is used. In order to map each objective to a unified vector, the membership function introduced by Pishvaee and Torabi [21] is adopted. The crisp formulation is solved optimally for each objective function to gain α-positive ideal solutions. The α-negative ideal solutions are the corresponding values of the other objective in each run. $W_h^{\alpha-NIS}$ and $W_h^{\alpha-PIS}$ state the α-negative and α-positive ideal solutions and W_h represent the objective function value. The unified objective function variable is stated in equation (27). OW_h represents the weight of h^{th} objective function and consequently, the weighted sum of objective functions is as equation (28).

$$\frac{W_h^{\alpha-NIS} - W_h}{W_h^{\alpha-NIS} - W_h^{\alpha-PIS}} \qquad \forall h \qquad (27)$$

$$max \sum_h \frac{W_h^{\alpha-NIS} - W_h}{W_h^{\alpha-NIS} - W_h^{\alpha-PIS}} OW_h \qquad (28)$$

4 Numerical Experiments

The CPLEX solver in GAMS on a 2.1 GHz AMD Athlon II P320 Dual-Core processor was used to test the applicability of the model. Due to privacy reasons, input data and results in the motivating case could not be elaborated and a randomly generated numerical example of two production contractors, three depots, 12 customers and 8 product in a recovery planning horizon of 6 months was investigated. The

instance has 2,903 constraints, 6,262 continuous variables and 111 binary variables. All presented instances were solved optimally in less than 10 seconds.
While setting the importance of profit objective function as 0.6 according to the decision maker input, three different values for feasibility degree of fuzzy parameters were tested as shown in table 2. Fixing the α at 0.7, the impact of different importance weights of objective functions on the performance measures are presented in table 3.

Table 2: Compromise solutions' objective functions.

α	profit ideal negative	profit ideal positive	dissatisfaction ideal negative	dissatisfaction ideal positive	profit value	dissatisfaction value
0.5	5,051,250,000	21,734,000,000	0.868	0	18,899,000,000	0.024
0.7	-5,785,396,000	19,445,000,000	1.104	0	15,399,000,000	0.025
0.9	-5,329,483,000	17,155,000,000	1.301	0	12,597,000,000	0.074

Table 3: Sensitivity analysis on objective functions' weights.

OW_1	profit ideal negative	profit ideal positive	dissatisfaction ideal negative	dissatisfaction ideal positive	profit value	dissatisfaction value
0.1					7,815,190,000	0.000
0.2					14,523,000,000	0.000
0.4					15,018,000,000	0.004
0.5	-5,785,396,000	19,445,000,000	1.104	0.0	15,150,000,000	0.010
0.6					15,399,000,000	0.025
0.8					16,236,000,000	0.112
0.9					18,883,000,000	0.888

To provide managerial insights on potential improvement areas and identifying determining factors on the company's performance, sensitivity analysis were tested on the speed of production hall recovery progress, the possibility of transshipment flows as well as loosening the minimum quantities in contractors' discount scheme. α and profit weight was set to 0.7 and 0.6 respectively. The results are presented in table 4.
Three scenarios were generated: 1) recovery progress were assumed to benefit from a 15% improvement, 2) minimum order quantities were decrease by 25%, and 3) the first and the third scenarios were activated together. As shown due to the higher importance of profit objective functions, actualizing all improvement potentials positively affect the company's profit performance.

Table 4: Performance measure's average performance in sensitivity analysis

Performance measures	Base scenario	First Scenario	Second Scenario	Third Scenario
Profit value	15,399,000,000	15,985,000,000	15,984,000,000	15,707,000,000
Dissatisfaction value	0.025	0.072	0.072	0.049

4 Conclusion

In this study, a new recovery planning model for disruption in a production firm, motivated by a real-world explosion disaster, is presented. To address the trade-off between resulting recovery cost and customers' satisfaction, two objective functions of maximizing profit and minimizing customer dissatisfaction are taken into account. To optimally reduce the destructive effects of the disruption on the firm's normal status, advantaging from the producer's reserve line, production contractors and transshipment between the distribution centers are modeled. Several real-life constraints on classified customers, their waiting threshold for satisfaction of backlogged orders, possible effects of disruption on

dispatching capacity and inherently uncertain demands and recovery progress are taken into account. The model was solved for a randomly generated instance was solved and investigated for different range of possiblistic parameters' feasibility degree and objective functions importance weights. Sensitivity analysis was performed for different potential improvements. Using the method introduced in [20], the crisp formulation is developed which thereafter will be transformed to a single objective optimization model by weighted summation of dimension-less objectives. The model is capable of providing helpful managerial insights on the recovery decisions as well as being used as a simulation tool in pre-disruption stage.
Future researches may be directed to incorporating soft constraints on customers' backlogging threshold, incorporating more practical contract terms and conditions by production contractors and developing heuristic or meta-heuristic solution methods.

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