A Flexible Period Multi-Objective Multi-Mode Networking Model for Post-Disaster Relief Goods Distribution

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Abstract The South East Asian region, including the Philippines, is vulnerable to various calamities due to its geographic location. These calamities such as typhoons and earthquakes result in the destruction of homes, buildings and significantly affects the livelihood of thousands of citizens within the affected area. Transportation of relief goods from storage facilities to local areas is critical as failure to deliver these goods on time could mean the loss of lives in the affected areas. From an analysis of related literature, a research gap was recognized that concerned the association of transportation costs, holding costs, and deprivation costs while considering the supply inventory and the number of periods taken for transporting goods using different modes of transportation. This paper proposes a flexible period multi-objective multi-mode networking model for post-disaster relief goods distribution to effectively and efficiently distribute the relief goods through the fastest transport means while minimizing the total costs incurred. Scenario analyses were then conducted to ascertain the validity of the model formulation and test the response of the model in different disaster conditions.

Keywords:Post-Disaster Relief Goods Distribution, Networking Model, Optimization, Disaster Response

1. INTRODUCTION

The region of the South and Southeast Asia, including the Philippines, is exceedingly susceptible to a variety of disasters, including but not limited to typhoons and hurricanes, earthquakes, tsunamis, and volcano eruptions (van der Keur et. Al., 2016; Roy et. Al., 2012). For instance, Typhoon Yolanda, otherwise known internationally as Haiyan, is one of the strongest storms known. It left Philippines with damages worth 360 billion Philippine Pesos, and deaths of more than 6,000 people (Holmes, 2014). Aside from these, several disasters have occurred worldwide that have spurred action and research on this area.

Relief efforts include a diverse collection of actors, specifically those of the host government, international organizations, military, national and regional relief organizations, and private organizations. Each of them have different goals, interests, constraints, and logistics know-how. Coordination mechanisms between these organizations have been well reviewed and analyzed.

The main factors that affect difficulty in disaster relief coordination involve the general chaotic environment after a disaster, the large number of organizations participating in the relief efforts with varying expectations and logistics structures, the influence of media, and the lack or oversupply of necessary resources. In addition, unpredictability is present in disaster relief, such as the location, timing, and intensity of the disasters, the demographics, the availability of certain infrastructures, and the political environment and available funding. Because of these, there have only been a few instances wherein coordination in disaster relief was a success. Improving coordination with planning is a must in post-disaster events due to the mentioned factors, as well as the increasing number of opportunities brought about by the advancements in information sciences. It was suggested that relief chains focus their strategies on the supply acquisition, prepositioning or warehousing, and transportation aspects of operations (Balcik et. Al., 2010).

Poor logistics preparedness is cited as a cause of failure in humanitarian relief after a large-scale disaster, it is suggested that a standardization of material handling and type of relief goods be achieved to minimize response time and improve efficiency of relief operations (Ito et. Al., 2014).

Developing a multi-transportation mode, and multi-period operations research model would allow organizations to quickly plan and execute relief efforts, with a decreased probability of failure. This model would prioritize minimizing total transportation, holding costs, and deprivation cost. With these objectives, the model would ensure that the delivery of relief goods would meet the most demand in the shortest time and cheapest cost possible, giving consideration to constraints such as transportation mode availability and inventory levels.

2. REVIEW OF RELATED LITERATURE

Operations research models are promising in helping relief agents to minimize cost, casualties, and distribution time while upholding fairness and maximizing the use of the scarce resources during the chaos post-disaster. Relief routing and distribution involves few studies concerning multiple periods, previous studies focused more on pre-positioning and initial deliveries, but beneficiaries require commodities even after the first delivery. Previous studies have revealed that significantly different routes resulted when changes in the main objective of the models are made. These changes include focusing on arrival time, cost, or service time (de la Torre et. Al., 2012).

Caunhye, Nie, and Pokharel (2012) reiterate the power of optimization modelling in handling emergency humanitarian logistics problems in pre- or post-disaster relief efforts. The major factors to be considered in pre-disaster preparations include short-notice evacuations, location of evacuation and warehouse facilities, as well as stock warehousing, while casualty rescue and relief distribution are the focus of post-disaster efforts. Prepositioning of stock warehouses for relief goods was found to be the best in maximizing effectiveness and efficiency of humanitarian relief operations (Roh, Jang, & Han, 2013). There are few research that discusses inventory management in disaster relief. The management of inventory includes every step of the process from their acquisition to their storage to their distribution (Whybark, 2007). According to Du and Sun (2011), emergency systems should be well-timed and quick, random and diverse, as well as multi-objective and effective. In relief distribution, it is reported by literature in a study by Roy, Albores and Brewster (2012) that several factors must be considered in disaster relief operations. These factors include the number, location, and capacities of the facilities, inventory types and policies, transportation and distribution policies.

Various operation research modeling techniques can be utilized to optimize and increase the efficiency of relief goods distribution post disasters. Liu, M., & Zhao, L. (2007, December) constructed a new composite weighted multi-objective optimal approach for distributing commodities. The model features a penalty function objective that considers the time taken to distribute the commodities and the total budget given as constraints in the equation. Fikar, C., Gronalt, M., & Hirsch, P. (2016) presented a paper based on a decision support system (DSS) that can facilitate coordination and decision making between private organizations and relief goods distribution centers. Dynamic programming allows interaction to different types of disasters and conditions through giving priority to certain commodities and requirements through goal programming (Lei, F., 2007, November).

Lin, Y. H., Batta, R., Rogerson, P. A., Blatt, A., & Flanigan, M. (2011) proposed a logistical model for delivery of prioritized items in relief operations. The multi objective integer model considered various commodities with multi vehicle modes in a period phased system that features a split delivery strategy scenario. Edrissi, A., Poorzahedy, H., Nassiri, H., & Nourinejad, M. (2013) proposed a multi agent optimization function that induces coordination.A three-echelon network model may also be utilized to integrate relief goods distribution (Pradhananga, R., Mutlu, F., Pokharel, S., Holguín-Veras, J., & Seth, D., 2016). Social cost can be minimized by identifying the potential supply points in the affected area where supplies can be sent to deliver to other facilities nearby. The deprivation cost, which refers to the amount of demand met by the system, is also considered. Na, L., & Zhi, L. (2009, October) show various types of emergency events considerations wherein multiple transportation nodes are considered to deliver to disaster ridden locations. The objective function of the model considers to minimize the total time taken to accomplish the distribution assuming that all the demand is met and the budget is set as a parameter to the function.

From the related literature discussing the various different operation research models utilized to optimize the distribution process of relief goods, conceptual and theoretical frameworks are formulated to determine the gap of research for the topic.

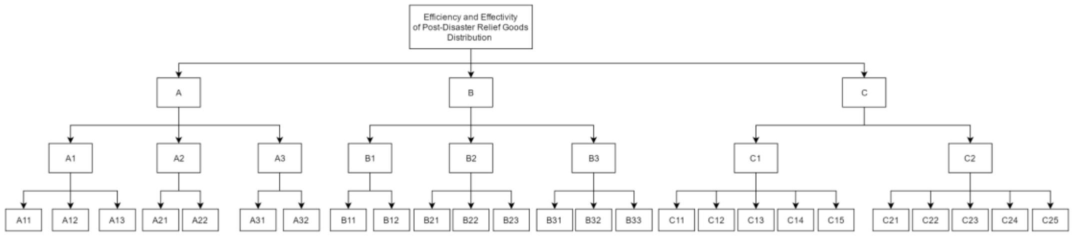

Figure 1. Conceptual Framework

3. FRAMEWORKS

Conceptual and theoretical frameworks are formulated to highlight the findings from the related literature and to depict the various factors that affect the efficiency and effectivity of post-disaster relief goods distribution. The conceptual framework, shown as a decision hierarchy, formulated is shown in Figure 1.

The overall objective is to increase the efficiency of the distribution by significantly reducing the time taken to deliver the relief goods from the source to the various facilities with respect to their location demand. From the main objective, there are three main decision branches: Facility Specifications, Inventory Management, and Distribution and Transportation.

Facilities are an essential element in any distribution activity. The facility specified here concerns the actual storage and distribution areas for each location. According to Roy, Albores, & Brewster (2012), the logistics and facility framework is highly dependent on the number of facilities that are available for use, the location of the facility, and its corresponding capacity. In the decision hierarchy, facilities specifications are subdivided into three branches: facility categorization, facility environment, and facility network. Facility categorization, which includes capacity, the number of facilities, and location, refers to the specific description and physical characteristics of the facilities (Luis, E., Dolinskaya, I. S., & Smilowitz, K. R., 2012). Facility environment refers to the external factors that affect the facility and its performance for the distribution, such as the demand in the location of the facility and the jurisdiction. Facility network is the interaction of the physical facility with other facilities that are also affected by the disaster. Under this are the actual interactions and the expanse or breach of control of each facility.

Inventory management, according to Silver, E. A., Pyke, D. F., & Peterson, R. (1998), is the supervision of non-capitalized assets, in this case the relief goods to be distributed, and the management of storing and facilitating the flow of these assets. In Figure 1, inventory management is broken down into inventory limitations, supply of resources, and inventory policies. Inventory limitations refer to the specifications of the inventory system and the limits these specifications impose. According to Buzacott, J. A., & Zhang, R. Q. (2004), the limitations can be defined as the inventory peak of the facility and the resource preferences in terms of demand for each category of goods. Supply of resources is categorized by the rate of supply of resources, frequency of supply of resources, and the aggregate demand of resources per time period (Chandraprakaikul, W., 2014). Inventory policies refer to the rules and regulations set in the inventory management system.

Distribution and transportation are important elements in any distribution process. This category is subdivided into: transportation modes and distribution network. According to Beamon, B. M., & Balcik, B. (2008), the speed of the mode of transportation, the route feasibility for each mode of transportation, the transport capacity, vehicle scheduling and sourcing, and the number of vehicles of each type available in a period of time are significant contributing factors to the transportation of relief goods. The distribution network consists of the distribution method to be implemented, the routes available to transport the goods from one location to another, the lot sizes for material handling, the number of available volunteers in the area, and the prioritization of certain areas in distribution (Ito, H., Wisetjindawat, W., & Yokomatsu, M., 2014).

Figure 2 shows the theoretical framework based on various compounded related literature. From the diagram above, previous studies were categorized into four classifications: Single Period Stochastic Model for Post-Disaster Relief Goods Distribution, Hierarchical Multi-Mode System, Bi-Objective Relief Distribution, Multi-Period Model for Post-Disaster Relief Goods Distribution, Logistics Focus Relief Goods Distribution (Multi-Mode Transportation), Multi Network Relief Distribution Model, Stock Inventory System, and Goal Programming Distribution System. The gap that is identified based on the review of related literature is a Flexible

Figure 2. Theoretical Framework

Period Stochastic Multi-Objective Multi-mode Transshipment Model for Post-Disaster Relief Goods Distribution with Consideration of Inventory Levels.

4. METHODOLOGY

A linear networking model is formulated to optimize the distribution process of the relief goods after a disaster. The model optimizes the time for the distribution, the total cost of the distribution process, and the unmet demand through a deprivation function. A networking approach is implemented, wherein the distribution process is conducted through a series of large nodes and small nodes which have their corresponding demands set by the area population. From a common source, the relief goods can be distributed to the large nodes, with a set inventory level and demand. Large nodes will then network these relief goods to their respective smaller nodes, which have their own respective demand levels. The model formulated can be used across multiple continuous periods and considers various relief mode alternatives. Scenario analysis is then conducted with varying conditions to ascertain the validity of the model formulated. In testing the model through scenario analysis, the MATLAB program is used to process the data. Implications from the analysis are then explicitly discussed.

5. MODEL FORMULATION

The network of this relief distribution model is composed of three tiers, specifically a source node, the depots, and the customers. The source node delivers goods to the depots to satisfy the depots and the customers' demand. Likewise, the depots deliver to any of the customers and may deliver to other depots as well. This is to allow the model to decide how many goods should be delivered to each node and at which node to deliver these goods to, to achieve minimum cost. This model assumes that a vehicle is blocked off for a specific number of periods each time it is used on a specific path. This number of periods is dependent on the transportation mode and route condition, and is a parameter that would be set by the user. Similarly, the initial inventories for the source node and depots, as well as the unit penalty cost for unmet demand, the projected demand in each depot and node, the fixed cost of using a specific transportation mode, the unit holding costs at the source and depots, the unit cost of a commodity using a transportation mode, and the capacity of each transportation mode are to be defined by the user prior to running the model.

This section shows the model developed for the distribution model. The tables below shows the indices, system variables, decision variables and their corresponding definitions that will be used in the formulation of the model.

Table 1. Indices

Indices	Definition
o	Source
i	Depot
m	Transportation mode
r	Vehicle number
k	Period
n	Customer Node

Table 2. System Variables

System Variables	Definition
I_{ok}	Inventory of source node at period k
I_{ik}	Inventory of depot i at period k
W_{nk}	Unmet demand of node n at period k

Table 3. Parameters

Parameters	Definition
P	Unit penalty cost for unmet demand (deprivation cost)
D_{nk}	Demand from node *n* at period *k*
F_m	Fixed cost of using transportation mode *m*
H_o	Unit holding cost at source
H_i	Unit holding cost at depot *i*
U_m	Unit cost of commodity using transportation mode *m*
C^m_{rk}	Capacity of mode *m* vehicle *r* at period *k*
$a_{ii'm}$	Number of periods needed to transport from depot *i* to depot *i'* using transportation mode *m*

Table 4. Decision Variables

Decision Variables	Definition
x_{imk}	Goods delivered from source to depot *i* using transportation mode *m* at period *k*
$y_{ii'mk}$	Goods delivered from depot *i* to depot *i'* using transportation mode *m* at period *k*
b_{inmk}	Goods delivered from depot *i* to customer node *n* using transportation mode *m* at period *k*
v^m_{rik}	1, if transportation mode *m* vehicle *r* of depot *i* is used at period k 0, otherwise

5.1 Objective Function

The objective function shown in (1) expresses the overall goal of the model formulate. The equation (1) seeks to minimize the total cost of transportation, the holding costs for inventory, and the total unmet demand for the periods.

$$Min\ Z = \sum_m \left\{ \sum_k \left[\sum_i x_{imk} + \sum_{i\neq i'} y_{ii'm(k-a_{ii'm})} + \sum_{i\neq i'} y_{ii'mk} + \sum_k \sum_i \sum_n \sum_m b_{inmk} \right] U_m \right\} + H_0 \left(\sum_k I_{ok} \right) + H_i \left(\sum_k I_{ik} \right) + \sum_k \sum_n PW_{nk} + \sum_k \sum_m \left[F_m \left(\sum_r v^m_{rik} \right) \right] \quad (1)$$

5.2 CONSTRAINTS

The objective function shown in the previous section is subjected to the constraints described below.

The constraint shown in equation (2) describes the inventory of the source through each period, specifically it is equal to the difference between the previous period's inventory and the total deliveries from the source.

$$I_{ok} = I_{ok-1} - \sum_i \sum_m x_{imk-1} \quad \forall k \neq 1 \quad (2)$$

Equation (3) illustrates the inventory count for each depot for each period. It is formulated by subtracting from the previous period's inventory the deliveries made from the depot for that period, and adding the deliveries made to the depot. The unmet demand is defined in equation (4) as the difference between the total demand and the total deliveries made to customers.

$$I_{ik} = I_{ik-1} - \sum_n \sum_m b_{inmk} + \sum_m x_{im\left(k-a_{ii'm}\right)} + \sum_m \sum_{i'\neq i} y_{i'im(k-a_{ii'm,})} - + \sum_m \sum_{i'\neq i} y_{ii'mk-1} \quad \forall i, k \neq 1 \quad (3)$$

$$\sum_n W_{nk} = \sum_n D_{nk} - \sum_i \sum_n \sum_m b_{inmk} \quad (4)$$

Equations (5) and (6) ensure that the goods to be delivered in each vehicle mode would not exceed its set capacity if used.

$$\textstyle\sum_i x_{imk} \leq C^m_{rk} [\sum_i \sum_r v^m_{rik}] \quad \forall mk \quad (5)$$

$$\sum_{i\neq i'} y_{ii'mk} + \sum_i \sum_n b_{inmk} \leq C^m_{rk} \left[\sum_i \sum_r v^m_{rik} \right] \quad \forall mk \quad (6)$$

Equation (7) makes sure that the usage of each vehicle would not overlap. As such, the equation below makes sure that when a vehicle is used in this period for the first time, the binary variable assigned to that vehicle must equal to zero for the succeeding periods that it is in use. In the same way, when that vehicle is not used in this period, the following periods may decide to use a vehicle or not.

$$v^m_{rik} + M(1 - v^m_{rik}) \geq \sum_k^{k+2a_{ii'm}-1} v^m_{rik} \quad \forall imr \quad (7)$$

The following notations (8) to (10) make sure that the model would assign non-negative integer values to the variables pertaining to goods delivered and either one or zero to the binary variables pertaining to the usage of a vehicle.

$$x_{imk}, y_{ii'mk}, b_{inmk}, I_{ok}, I_{ik}, W_{nk} \geq 0 \quad (8)$$

$$x_{imk}, y_{ii'mk}, I_{ok}, I_{ik}, W_{nk} \text{ are integers} \quad (9)$$

$$v_{rik}^{m} \in \{0,1\} \quad (10)$$

6. SCENARIO ANALYSIS

In order to test the validity of the model formulated, a base scenario was tested and optimized. The scenario contained the following parameters and system variable considerations. The model considers a total of three periods, one source, three depots, and three modes of transportation. Table 4 shows the information used in the hypothetical scenario used in this analysis.

Table 4. Information Used for Scenario Analysis

	Beginning Inventory
Source	6000
Depot 1	1500
Depot 2	3000
Depot 3	1500

Demand	Period 1	Period 2	Period 3
Depot 1	1500	1500	1500
Depot 2	1200	1200	1200
Depot 3	2100	2100	2100

Modes	**Units Available**	**Capacity**
1 - Plane	3	500
2 - Truck	8	200
3 - Ship	2	700

AIRPLANE			
Time From/To	Depot 1	Depot 2	Depot 3
Source	1	2	2
Depot 1	0	1	2
Depot 2	1	0	1
Depot 3	2	1	0

TRUCK			
Time From/To	Depot 1	Depot 2	Depot 3
Source	2	2	2
Depot 1	0	2	N/A
Depot 2	2	0	1
Depot 3	N/A	1	0

SHIP			
Time From/To	Depot 1	Depot 2	Depot 3
Source	1	2	2
Depot 1	0	N/A	2
Depot 2	N/A	0	2
Depot 3	2	2	0

	Unit cost	**Fixed cost/vehicle**
Air	2	2000
Truck	1	1000
Ship	1	1500

	Holding Cost/unit	**Penalty/unmet unit**
Source	5	30
Depot	0.5	

From the scenario given above, Table 5 shows the summarized results from the model. These reflect the deliveries from one location to different depots using one of the three modes of transportation.

Table 5. Optimal Delivery Schedule

Period	From	To	Mode Used	Units
1	Source	Depot 1	Airplane	1500
1	Source	Depot 2	Truck	1200
1	Source	Depot 3	Truck	400
1	Source	Depot 3	Ship	1400
2	Source	Depot 1	Airplane	100
2	Source	Depot 1	Ship	1400
1	Depot 1	Depot 2	Airplane	1000
1	Depot 2	Depot 3	Airplane	500
1	Depot 2	Depot 3	Truck	1600
2	Depot 2	Depot 3	Airplane	300

From this model, there is an unmet demand of 1000 in period one of depot one, 300 in period one of depot two, 600 of depot 3 in the same period, and 200 in period 2 of depot 2. The optimal minimum cost through this scenario is **100,100** monetary units.

6.1 Scenario: equal unit penalty cost for unmet demand and unit holding cost with low values compared to transportation costs

In this scenario, both the unit holding costs for the source and depots, as well as the penalty for each unit of unmet demand, are decreased to 0.5 monetary units, making it significantly cheaper for the model to avoid delivering goods and incurring transportation costs.

The scenario resulted to no transportation costs, and a total of 8,400 units of unmet demand. The breakdown of the unmet demand is shown in the table below. In the table below, the values in bold indicate the depots that have completely unsatisfied demands in each period; while those not in bold were either completely or partially satisfied demands. It can be inferred then that the depots distributed the inventory they were initially stocked with to its customers, as this does not incur any cost, while unmet demand still carries a cost of 0.5 per unit. This scenario resulted in an optimal minimum cost of 14,400 monetary units.

Table 6. Unmet demand

	Period 1	Period 2	Period 3
Depot 1	0	**1500**	**1500**
Depot 2	0	0	**600**
Depot 3	600	**2100**	**2100**

6.2 Scenario: increase in transportation costs for all modes with holding and deprivation costs remaining constant

In this scenario, the transportation costs of all modes increased to 50 for airplanes, 20 for trucks, and 50 for ships without changing the values of the holding and deprivation costs from the original scenario. As such, the transportation costs become relatively more expensive than holding costs and the assigned deprivation cost.

This scenario resulted to a total of 5,300 units of unmet demand, which is 3,200 units more than the original scenario. This is a result of the increased transportation costs, which caused the model to decrease the transportation of relief goods from various areas. Since the truck had the cheapest transportation cost, the model chose to use the truck mode the most often, The total optimal cost is **271,100** monetary units. Table 7 shows the unmet demand distribution and Table 8 shows the optimal delivery schedule.

Table 7. Unmet demand

	Period 1	Period 2	Period 3
Depot 1	0	1500	1100
Depot 2	0	1000	0
Depot 3	600	500	600

Table 8. Optimal Delivery Schedule

Period	*From*	*To*	*Mode Used*	*Units*
1	Source	Depot 1	Truck	400
1	Source	Depot 2	Truck	1200
1	Depot 2	Depot 3	Truck	1600
2	Depot 2	Depot 3	Airplane	1500

6.3 The source and depots are stocked with excessive amounts of initial inventory with costs and transportation times held constant

In this scenario, the initial inventories for the source and three depots are increased to 5,000 units each, without changing the demands of each depot and their customers, the holding, and deprivation costs of the original scenario. The transportation costs of all modes increased to 50 for airplanes, 20 for trucks, and 50 for ships as was done in the previous scenario.

This scenario resulted in no unmet demand, which is the result of the excessive initial inventories. Since each depot was stocked with 5,000 units each, there was no need for the source to deliver to the depots, and only a minimal need for the depots to deliver to another depot due to insufficient stocks. As such, only a few trips were made by the distribution efforts, the optimal delivery schedule is shown in Table 9. The optimal cost of the mode is **84,650** monetary units, which is 15,450 units below the original scenario's cost. The bulk of this scenario's cost, specifically 96.46%, is contributed by holding costs, the excess inventory is shown in Table 10.

Table 9. Optimal Delivery Schedule

Period	From	To	Mode Used	Units
1	Depot 1	Depot 2	Ship	100
1	Depot 2	Depot 3	Ship	1300

Table 10. Ending Inventory (in units)

	Period 1	Period 2	Period 3	Total	Cost/unit	Costs
Source	5000	5000	5000	15000	5	75,000
Depot 1	3400	1900	400	5700	0.5	2,850
Depot 2	2500	1300	100	3900	0.5	1,950
Depot 3	2900	800	0	3700	0.5	1,850
Total Holding Costs						**81,650**

7. CONCLUSION AND RECOMMENDATIONS

Calamities have recently been rampant in South East Asian countries, most especially in the Philippines, a country that is prone to typhoons and earthquakes. Several related literatures have been analyzed to formulate conceptual and theoretical frameworks and to assess the gaps of the literature. A model was formulated as means of alleviating the lives of people affected by disasters through the use of a flexible period multi-objective multi-mode networking model that considers inventory levels and can be used across multiple periods for post-disaster relief goods distribution. The model formulated minimizes transportation, holding and deprivation cost while considering the supply in each depot and the time taken to transport relief goods using different modes. Scenario analysis was conducted to show the possible situations that may occur in the distribution process for relief goods. In the scenario analysis, the situation wherein holding and deprivation costs were reduced resulted to a high unmet demand without any transportation occurring from different locations. The scenario in which the transportation costs for all modes were increased resulted to only a few transportation occurrences and a relatively high unmet demand rate. When the inventory levels of the depots are high relative to the demand for each depot, there is no unmet demand and only a few deliveries.

Future studies in relief goods distribution could explore on the distribution type wherein vehicles could leave a departure node and visit several depot or demand points until its stock turns to zero. The route the vehicle takes will be an optimal route in which the distance travelled is minimized at the same time satisfies the demand of depots. In this method, the sequence of depots to be visited will be critical. In addition, more transportation modes such as rail could also be included in the model if it is allowed in the situation. Transportation time uncertainties could also be considered in the model since in real world vehicles' traveling time will not arrive exactly as expected. The model may also consider accepting donations or gifts in commodity or monetary units on the first and second tiers of the network model.

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