Assessing Requirements for Decision Support Systems in Humanitarian Operations

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Abstract

Efficient and effective decision making in the chaotic environment of humanitarian relief distribution (HRD) is a challenging task. Decision makers, in such situations, are required to concentrate on numerous attributes classified by three decision factors: objectives, variables, and constraints. Recent HRD literature mainly focuses on optimizing procedures while neglecting the quantification of influential requirements (factors) for information systems to provide decision-making support. This article addresses this gap by accumulating those affecting attributes from the literature. It investigates their practical implications in HRD by measuring the preferences of a Delphi panel of 23 experts. The results quantify the importance of each attribute – along with the newly added ones by the experts – in the proposed process model for HRD in a large-scale sudden onset. Our work provides future researchers not only with a comprehensive set of practically feasible decision-making factors in HRD but also with an understanding of their influences or correlations.

Keywords: Natural disasters**,** decision support system, decision-making factors, relief distribution, humanitarian logistics, Delphi technique, expert preferences.

1. Introduction

Although saving life is the main aim of humanitarian relief operations, it is important to concentrate on minimizing social tension that increases due to imbalance (inefficiency) in relief distribution (RD). For example, if two distribution centers distribute different relief items, it may fuel tension among recipients. Hence, responders need to prepare standardize relief packages by coordinating with other responding groups and communicate with the recipients to disseminate a RD plan and the duration of response operations. However, to meet beneficiaries' necessities, responders must know *what* the demanded items are, and *where* and *when* they are needed. For rapid, effective, and efficient response, they also require knowing the accessibility (to transport relief items), warehousing (storing them), and distributing arrangements (to reduce social tension) [1]. Moreover, for successful relief operations, understanding and assessing the overall disaster situation (e.g., environment, vulnerabilities, coping mechanisms) is necessary. Thus, responders must acquire geographical, topographical and demographical knowledge before scheduling RD operations [7].

Identifying such influential decision factors in emergency management – especially in RD – is a complex task [47]. In the humanitarian logistics (HumLog) literature, we observed a surge of mathematical models and objective functions development by focusing on specific disasters as cases. Researchers utilized diverse variables and constraints in their models and functions for achieving targeted objectives. These factors need to be properly managed and utilized for rapid and effective decision making as their activities influence the success of the operation [46]. Failure to understand their importance for the information system will make the decision-making process more complex and time consuming, causing cause delayed and inadequate responses: an overall unsuccessful relief operation [29].

Following [15],[26] and [34], we rigorously and systematically reviewed and extensively analyzed humanitarian literature to develop a summarized list of decision factors for relief distribution. While sharing some common decision factors (objectives, variables, constraints), the review denoted that RD decision making is influenced by five other problem types (DPT): facility location (FL), inventory management (IM), relief supply chain (RSC), transportation (Trns.), and scheduling (Sch.). For achieving better performance in the complex decision-making operation, decision makers (DM) in RD need to concentrate on *shared* decision attributes as well and assist DMs in other DPTs to achieve their objectives.

However, there has been no structured attempt in RD to systematically identify comprehensive factors and their correlations, and to then prioritize them. This study addresses this gap by empirically testing decision support requirements with the help of the Delphi technique. A worldwide Delphi panel was formed with experts from academia, governments, and national and international NGOs. Their evaluations facilitated consensus and prioritization for each attribute and assisted us in answering the following research questions and contributing to rapid decision making for efficient and effective relief distribution in HumLog:

1. Do experts confirm decision support requirements identified from the scientific literature?
2. What attributes should be considered in the decision-making process of relief distribution?
3. How do the attributes influence each other or how are they correlated?

The remainder of this article is organized as follows. We provide the research background in Section 2. Section 3 describes our research design. The results are presented in Section 4. Section 5 synthesizes and discusses the Delphi study findings. Limitations and future research implications are presented subsequently. Section 6 concludes the article.

2. Research Background

To respond to disasters in a chaotic environment, practitioners conduct complex and challenging tasks. While making decisions on RD, they face uncertainty when identifying appropriate decision factors. Not much research concentrates on recognizing factors that influence decision making in relief distribution. Peres et al. [27] classify operational research (e.g. RD) in HumLog into three DPTs (FL, IM, and network flow and Sch.) without presenting influential decision-making factors. Gralla et al. [12] and Gutjahr and Nolz [14] respectively categorized and refined (into sub-groups) humanitarian aid operations into *efficiency* (refined into *cost efficiency*), *effectiveness* (refined into *response time*, *travel distance*, *coverage*, *reliability*, and *security*), and *equity* criteria. This classification, categorization and refinement lead towards identifying affecting decision factors and developing a comprehensive set of them. Although Roy et al. [37] listed some factors by dividing the RD process into four sub-processes (FL, IM, Trns., and RD decision), it was not investigated in detail to guide researchers on selecting decision variables and constraints for achieving targeted decision objectives. Safeer et al. [38] and Özdamar and Ertem [47] mapped constraints for specific objectives mainly for transportation and relief distribution, but lacked a comprehensive set of decision factors, their priorities and correlations. We know no research investigating the influences of other DPTs on the decision factors of RD.

However, to improve the disaster management process, adequate decision-making is the key, where prioritized and correlated decision factors play vital roles [4],[22],[43]. According to Li et al. [22], influential factors and their relationships need to be accumulated through proper investigation and experts' judgement. Instead of studying the entire system, current research mostly concentrates on optimizing certain procedures that are extensively case-specific and are rarely used (or unusable) in other cases. To get a holistic image, we accumulated the existing decision support models for humanitarian operations that were practically implemented in the contexts of sudden natural disasters, thereby collecting practical decision-making factors. The decision elements accumulated from academic literature are evaluated and utilized in this article to develop a practice-oriented RD process model are presented in Table 1.

Table 1. Relief distribution decision elements

Decision factors	Decision elements	Literature
10 decision objectives	maximize coverage (cov), maximize transport quantity (tq), minimize travel time (tt), minimize distribution time (dt), minimize travel distance (td), minimize total cost (tc), minimize resource cost (rc), minimize penalty cost (pc), minimize number of distribution centers (ndc), minimize practical length of emergency route (pler).	**[5,6],[12],[23],[32,33],[35],[42]**
13 decision variables	travel distance (td), inventory flow and capacity (ifc), penalty cost (pc), transport cost (trc), operational cost (oc), set-up cost (stc), supply unit (su), beneficiaries access cost (bac), transport quantity (tq), demand time (det), travel time (tt), distribution time (dt), resource need (rn).	
12 decision constraints	storehouse capacity (shc), road capacity (roc), inventory holding cost (ihc), number of storehouses (nsh), budget availability (ba), demand satisfaction (ds), replenishment cost (repc), load flow (lf), transport cost (trc), travel distance (td), operational cost (oc), resource availability (ra).	

3. Research Methodology

3.1. Method Selection

When Several techniques were advocated in the humanitarian literature for decision making in different problem areas. We used the Delphi technique to evaluate these factors and to identify new ones. It is suitable for this kind of exploratory research where researchers need to communicate with distantly located practitioners and field experts for dealing with complex and indispensable issues [24],[34]. Although, the Delphi technique was successfully utilized by MacCarthy and Atthirawong [15] for investigating and understanding decision-making factors, it was not widely exploited in humanitarian research. Cottam et al. [8] incorporated the Delphi technique to assess the potential benefit of outsourcing the trucking activities for relief distribution in developing countries. Richardson et al. [34] investigated affecting factors for global inventory prepositioning locations. The Delphi technique provides unbiased rating of the decision factors, which further go through ranking and consensus phases for identifying the importance and acceptance of each element for effective decision making in disaster-like uncertain situations [17]. Figure 1 illustrates the overall procedure for our Delphi study including panel formation and research design.

76 out of 96 identified experts were invited to participate in the survey and the questionnaire for the first Delphi round was sent to them for confirming their participation. Of those, 38 experts replied positively but 23 finally participated in the survey (formed the Delphi panel). 17 of the 23 participants completed and returned the questionnaire and rest preferred to go for interviews that were audio recorded the questionnaire for the second round was sent to the 17 who answered the questionnaire experts of whom 13 responded. The participating 23 experts are anonymized according to the agreement with Norwegian Center for Research Data (www.nsd.no) and the participants themselves. We exploited their assigned PIDs when refer them in Section 5.

3.2. Delphi Panel Formation

Initially, for their recency and severity, we targeted the Indonesia earthquakes of 2018 and the Nepal earthquake of 2015. While searching for involved experts having knowledge

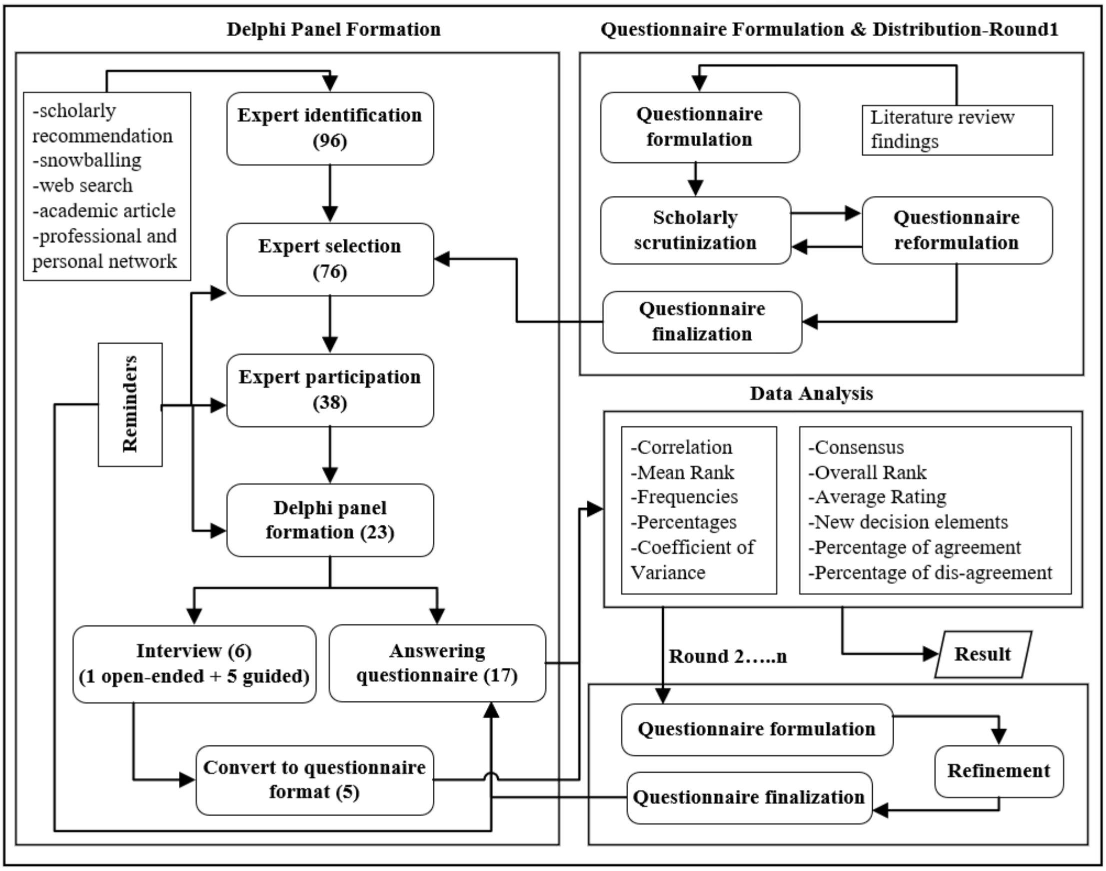

Fig. 1. The process model utilized in this Delphi Study (inspired by [21] and [25])

and interest in RD processes, we established contact with active practitioners and with their networks to gain updated knowledge on their usage of information systems (IS) for relief distribution. In addition, we utilized our personal contacts and the snowballing technique to bring more experts on-board. As a tentative list – including the anonymization for processing – of potential participants was ready, we sent a study plan including information on the aim of the Delphi and its rounds, the extent and timing of the expected involvement, expected outcomes, and the potential social benefit to the ones who replied affirmatively. Finally, a total of 23 experts from around the world were selected to participate in this Delphi study. With an adequate panel size according to Grim and Wright [13] and Okoli and Pawlowski [26], we proceeded to the next step. The first-round survey questionnaire was electronically distributed along with a consent form and a non-disclosure agreement.

3.3. Research Design

Data Collection Method

Instead of starting the process with an open-ended questionnaire or brainstorming sessions, as in traditional Delphi, to identify decision factors in RD [34], we approached participants with existing academic knowledge on such factors. These factors were accumulated, summarized, and clustered into three categories (decision objective, variable, and constraints) and added to the questionnaire for experts' evaluation. The factors were adequately explained in the questionnaire that facilitated respondents to rate each decision attribute on a six-point Likert Scale (inspired by [40]). Respondents were also given space to express their understanding for each of the factors and propose new factors from the practical field. However, if a participant found it complicated to answer the questionnaire, they had the opportunity to express their opinion through interview sessions (physical or online). As a result, our repository was enriched with qualitative data for the entire RD process (inspired by [44]). Additionally, to understand the depth of influences, participants were requested to mark the relationship of each decision factor of RD to other five problem types (FL, IM, RSC, Trns. and Sch.). This is how we incorporated relevant and in-depth information that was to be utilized in the first round (inspired by [18]).

Consensus and Stability

To decide on achieving consensus, we adopted the *Average Point of Majority Opinions* (APMO) technique by Kapoor [20]. A decision element would be considered as achieving consensus if its agreement or disagreement is above the cut-off rate of APMO. Instead of considering consensus achievement as a tool to decide on further Delphi rounds, we verified how a certain percentage of votes fall within a prescribe range, i.e. how the experts react to different decision elements. We identified no clear instruction on deciding on the number of Delphi rounds for studies. Hence, by following Dajani and Sincoff [9] and Strasser [41], we calculated the *coefficient of variance* (CV) to decide Delphi rounds and check their consistencies. Finally, we utilize SPSS software to calculated *Kendall's concordance coefficient* (W) to measure the degree of agreement among panel members ($W=0$ means perfect disagreement and $W=1$ means perfect agreement). $W=0.7$ is considered as an indication to achieve a higher level of general agreement in Delphi studies [39]. Consensus and stability are illustrated in Section 4 and discussed in Section 5.

Delphi Rounds

Round 1. After finalizing the list of experts, we started commencing the Delphi process by sending the questionnaire to each panel member in December 2018. Although an online survey is the typical mode for the Delphi technique [34],[40], emailing the questionnaire – e-Delphi – is also practical [2,3],[25]. In addition to survey questions, the questionnaire captured the professional background for each respondent. We collected responses until February 2019. Data accumulated from the first round of the Delphi survey were extracted for descriptive analysis for finding frequencies and percentages. We utilized tools from MS Excel and IBM SPSS software to find correlations among factors and different statistics, such as Mean rank and Kendall's W. Furthermore, we utilized APMO to determine whether consensus was achieved by each factor.

Round 2. The result generated from the collective feedback in first Delphi round was shared with all the panel members in March 2019. The questionnaire was re-designed to inform about the average rating, percentage of agreement and disagreement, overall ranking and achieving consensus for each decision element. The respondents were also provided their previous rating for each of the decision factors and given the opportunity to update it (inspired by [36]). The newly identified practical elements from round 1 for each decision factors were also added into the questionnaire to be evaluated. Although the newly identified practical elements were kept out of the scope of this article, the important ones were exploited in the proposed RD process model.

4. Results

4.1. Descriptive Information on the Participants

Most panel members have extensive working experience, partly of more than 25 years. They participated or are participating in the response operations for large-scale natural and man-made disasters worldwide, for example, the South Iceland earthquakes 2000 and 2008, the Haiti earthquake 2010, the Gorkha (Nepal) earthquake 2015, the Indonesia earthquake 2018, different devastating hurricanes and floods, the Ebola crisis in Africa, and the Syria crisis. Their heterogenous experiences on responding various crisis and disasters assist us in evaluating he influential decision-making factors.

4.2. Measurement of Stability and the Stopping Criterion of Delphi Rounds

To achieve stability and to stop further rounding, English and Kernan [11] quantified $0<CV\leq 0.5$. In the first Delphi round, we had four elements in three decision-making categories (one in decision objectives and constraints, and two in decision variables) that were in the border or out of the suggested range of achieving general agreement ($CV\geq 0.5$).

In addition, the Kendall's *W* value for each category was very low (for objectives *W= 0.181*, for variables *W=0.133*, and for constraints *W= 0.26*). Therefore, the second round was conducted, where those four decision elements achieved a good degree of consensus with *CV≤0.39*. Then, we measured the CV difference and defined the stopping rule as a CV difference of ≤0.3 (inspired by [41]). However, there were significant improvements (although still not high) in the degree of agreement in all categories in the second Delphi round: for objectives *W=0.194*, for variables *W=0.213*, and for constraints *W=0.470*. Finally, receiving an absolute CV difference of ≤0.26 for each element in every decision-making category and improved value for Kendall's *W* constituted stability, we decided to terminate conducting any additional Delphi round (inspired by [9,10]).

4.3. Results of the Delphi Rounds

Table 2 demonstrates the combined statistical results for two Delphi rounds. It illustrates the consensus and ranking for each decision element incorporated into three decision-making factors for relief distribution. From the table, we can easily compare the responses in both rounds and visualize the changes made by the respondents in the second round. For presenting the result in a convincing way, we clustered decision elements up to the third level of importance: achieving an average rating (AR) of ≥5.00 was considered as *highly important* decision-making element and placed in cluster 1, whereas elements satisfying *5.00>AR≥4.00* were considered in cluster 2 as *mediocre* and the rest with *AR<4.00* were in cluster 3 as *least affecting* elements.

Decision-Making Objectives

In Delphi round 1, 76.8% of the experts rated all listed decision objectives as important topics in the relief distribution decision making process, whereas 19.6% found them unimportant and 3.6% abstained to comment. Among those decision objectives, *travel time minimization* and *coverage maximization* were placed in cluster 1 as the most important objectives that responders try to achieve without considering *minimizing* different *costs* (*total, resource, penalty*) and *number of distribution centers*, hence placed in cluster 3. The mediocre category (cluster 2) encompassed elements that were mostly related to transportation and distribution. The result suggested *transporting maximum quantity* of relief items by choosing *practically short emergency route* that would *minimize travel distance* and *distribution time*. In Delphi round 2, 78.5% experts voted as important properties of decision making and 21.5% voted not to consider. However, a significant change was observed in this round, where *coverage maximization* was downgraded and all the topics from cluster 3 were upgraded to cluster 2. The only topic remained in cluster 3 was *resource cost minimization*.

If we inspect the consensus, we would observe that *transport quantity* from cluster 2 and all the topics in cluster 3 did not receive general agreement from the participants in the first Delphi round. However, they continued not to receive consensus in the second Delphi round as well, except the topic of *transport quantity*. Its AR was upgraded to 4.8 and secured its consensus with 92.3% vote in round 2. Except the down-graded topic of travel distance, all topics in cluster 1 and 2 gained their votes to be importantly considered in the relief distribution decision-making process. Finally, the voting for *total cost* was unstable (as *CV>0.5*) in round 1 and achieved its stability in round 2.

Decision-Making Variables

To find important decision-making variables in round 1, 74.8% panel members positively rated the elements in this category, whereas 21.3% finds them unimportant and 3.9% did not vote. In round 2, 81.1% voted to list them as important decision-making elements. However, by analyzing the voting result, we identified that *resource need* was placed in cluster 1 in both rounds, whereas *transporting quantity* of relief items accompanied it in round 2. All costing related topics (*penalty, transportation, operational, and set-up*) secured their places in cluster 3 in round 1, except *beneficiaries' access cost*. It was listed in cluster 2 along with *travel distance, inventory flow and capacity, supply unit,*

Table 2. Combined statistical results for Delphi rounds 1 and 2 (inspired by [8] and [41])

Acronyms: UAC: Unable to Comment; TO: Total Opinion; TP: Total Point; MP: Mean Point; SD: Standard Deviation; MR: Mean Rank; FR: Final Rank; CV: Coefficient of Variance; A.Total: Answering Total; C.Total: Consensus Total; **Please consult Table 1 for acronyms

SL	Attributes**	Round 1														Round 2												Stability(CV1-CV2)	Test Statistics
		Consensus (APMO)								Ranking						Consensus (APMO)						Ranking							
		UAC		Disagreed (1-3)		Agreed (4-6)		TO1	Consensus1	TP1	MP1	SD1	MR1	FR1	CV1	Disagreed (1-3)		Agreed (4-6)		TO2	Consensus2	TP2	MP2	SD2	MR2	FR2	CV2		
		#	%	#	%	#	%									#	%	#	%										
Decision Objectives																													
1	cov	0	0	3	13.6	19	86.4	22	Y	111	5.05	1.1	6.7	3	0.22	2	15.4	11	84.6	13	Y	62	4.8	1.1	5.73	5	0.23	-0.01	**Round 1: Kendall's W 0.181** **Round 2: Kendall's W 0.194**
2	tq	1	5	4	18.2	17	77.3	21	N	92	4.18	1.6	5.36	5	0.39	1	7.69	12	92.3	13	Y	62	4.8	1	5.96	4	0.21	0.176	
3	tt	0	0	1	4.55	21	95.5	22	Y	112	5.09	0.9	6.89	1	0.18	1	7.69	12	92.3	13	Y	66	5.1	1	6.88	2	0.19	-0.01	
4	dt	1	5	3	13.6	18	81.8	21	Y	109	4.95	1.6	6.89	2	0.31	2	15.4	11	84.6	13	Y	66	5.1	1.2	7.12	1	0.23	0.08	
5	td	0	0	6	27.3	16	72.7	22	N	90	4.09	1.3	4.68	7	0.31	5	38.5	8	61.5	13	N	52	4	1.5	4.19	9	0.37	-0.06	
6	tc	1	5	8	36.4	13	59.1	21	N	83	3.77	2	4.86	6	0.54	5	38.5	8	61.5	13	N	53	4.1	1.6	4.85	7	0.39	0.142	
7	rc	0	0	8	36.4	14	63.6	22	N	85	3.86	1.4	4.52	8	0.36	4	30.8	9	69.2	13	N	51	3.9	0.8	3.88	#	0.19	0.166	
8	pc	2	9	4	18.2	16	72.7	20	N	83	3.77	1.6	4.18	10	0.42	3	23.1	10	76.9	13	N	58	4.5	1.1	5.15	6	0.24	0.189	
9	ndc	2	9	5	22.7	15	68.2	20	N	83	3.77	1.7	4.34	9	0.44	3	23.1	10	76.9	13	N	56	4.3	1	4.73	8	0.24	0.201	
10	pler	1	5	1	4.55	20	90.9	21	Y	105	4.77	1.4	6.57	4	0.29	2	15.4	11	84.6	13	Y	62	4.8	1.2	6.5	3	0.24	0.044	
A.Total		8	4	43	19.6	169	76.8									28	21.5	102	78.5										
C.Total				0		169		212	80							0		102		130	78.5								
Decision Variables																													
1	td	0	0	7	31.8	15	68.2	22	N	93	4.23	1.4	6.59	10	0.33	3	23.1	10	76.9	13	N	59	4.5	1.3	7.12	7	0.29	0.033	**Round 1: Kendall's W 0.133** **Round 2: Kendall's W 0.213**
2	ifc	0	0	4	18.2	18	81.8	22	Y	98	4.45	1.1	6.86	7	0.24	2	15.4	11	84.6	13	Y	62	4.8	0.9	6.96	8	0.19	0.043	
3	pc	2	9	7	31.8	13	59.1	20	N	78	3.55	1.8	5.09	13	0.51	5	38.5	8	61.5	13	N	50	3.8	1.2	4.38	#	0.32	0.19	
4	trc	1	5	10	45.5	11	50	21	N	77	3.5	1.9	5.32	12	0.54	7	53.8	6	46.2	13	N	50	3.8	1.6	4.73	#	0.41	0.133	
5	oc	0	0	8	36.4	14	63.6	22	N	86	3.91	1.5	5.68	9	0.38	4	30.8	9	69.2	13	N	53	4.1	1.2	4.96	#	0.29	0.087	
6	stc	1	5	5	22.7	16	72.7	21	N	86	3.91	1.7	5.93	11	0.43	3	23.1	10	76.9	13	N	55	4.2	1	5.58	#	0.24	0.192	
7	su	1	5	4	18.2	17	77.3	21	Y	94	4.27	1.4	6.75	8	0.32	0	0	13	100	13	Y	63	4.8	0.7	7.92	5	0.14	0.174	
8	bac	1	5	5	22.7	16	72.7	21	N	94	4.27	1.6	6.91	6	0.38	2	15.4	11	84.6	13	Y	60	4.6	1.1	6.96	9	0.24	0.141	
9	tq	0	0	2	9.09	20	90.9	22	Y	104	4.73	0.9	7.86	5	0.19	0	0	13	100	13	Y	66	5.1	0.6	8.69	2	0.13	0.061	
10	det	1	5	4	18.2	17	77.3	21	Y	103	4.68	1.6	8.43	3	0.35	2	15.4	11	84.6	13	Y	64	4.9	1.3	8.58	3	0.27	0.083	
11	tt	1	5	2	9.09	19	86.4	21	Y	106	4.82	1.4	8.43	2	0.29	2	15.4	11	84.6	13	Y	64	4.9	1	8.31	4	0.21	0.08	
12	dt	2	9	1	4.55	19	86.4	20	Y	104	4.73	1.8	8.27	4	0.37	1	7.69	12	92.3	13	Y	63	4.8	0.9	7.81	6	0.19	0.185	
13	rn	1	5	2	9.09	19	86.4	21	Y	111	5.05	1.5	8.86	1	0.3	1	7.69	12	92.3	13	Y	67	5.2	1	9	1	0.19	0.111	
A.Total		11	4	61	21.3	214	74.8									32	18.9	137	81.1										
C.Total				10		203		275	77							7		131		169	81.7								
Decision Constraints																													
1	shc	1	5	4	18.2	17	77.3	21	Y	102	4.64	1.8	7.91	2	0.39	1	7.69	12	92.3	13	Y	66	5.1	1	8.12	5	0.19	0.198	**Round 1: Kendall's W 0.260** **Round 2: Kendall's W 0.470**
2	roc	0	0	4	18.2	18	81.8	22	Y	103	4.68	1.2	7.7	4	0.25	3	23.1	10	76.9	13	N	62	4.8	1.2	7.23	7	0.24	0.006	
3	ihc	1	5	10	45.5	11	50	21	N	78	3.55	1.5	4.43	11	0.42	6	46.2	7	53.8	13	N	49	3.8	1.1	3.81	#	0.29	0.134	
4	nsh	1	5	6	27.3	15	68.2	21	N	86	3.91	1.7	5.41	10	0.43	2	15.4	11	84.6	13	Y	55	4.2	0.9	5.04	#	0.22	0.213	
5	ba	2	9	1	4.55	19	86.4	20	Y	99	4.5	1.9	7.52	6	0.42	0	0	13	100	13	Y	67	5.2	0.8	8.62	1	0.16	0.26	
6	ds	2	9	1	4.55	19	86.4	20	Y	105	4.77	1.8	7.86	3	0.38	0	0	13	100	13	Y	65	5	0.9	8.19	4	0.18	0.194	
7	repc	1	5	12	54.5	9	40.9	21	N	68	3.09	1.4	3.18	12	0.47	8	61.5	5	38.5	13	N	42	3.2	0.9	1.96	#	0.29	0.18	
8	lf	1	5	3	13.6	18	81.8	21	Y	102	4.64	1.6	7.16	7	0.36	2	15.4	11	84.6	13	Y	64	4.9	1.3	7.54	6	0.26	0.101	
9	trc	0	0	7	31.8	15	68.2	22	N	87	3.95	1.6	5.55	8	0.42	3	23.1	10	76.9	13	N	56	4.3	1.3	5.58	8	0.29	0.126	
10	td	1	5	2	9.09	19	86.4	21	Y	102	4.64	1.4	7.59	5	0.29	1	7.69	12	92.3	13	Y	66	5.1	0.9	8.38	3	0.17	0.124	
11	oc	1	5	8	36.4	13	59.1	21	N	84	3.82	1.7	5.41	9	0.44	5	38.5	8	61.5	13	N	54	4.2	1.1	5.08	9	0.28	0.165	
12	ra	1	5	3	13.6	18	81.8	21	Y	106	4.82	1.6	8.27	1	0.33	2	15.4	11	84.6	13	Y	67	5.2	1.1	8.46	2	0.21	0.123	
A.Total		12	5	61	23.1	191	72.3									33	21.2	123	78.8										
C.Total				12		171		252	73							8		118		156	80.8								

transportation quantity, and *demand*, *travel*, and *distribution time*. There was no such significant change in round 2. *Operational* and *set-up cost* upgraded to cluster 2 and as already mentioned, *transportation quantity* joined *resource need* in cluster 1.Although *travel distance* was a mediocre affecting decision element, it did not achieve general agreement along with all elements from cluster 3 in the first round. However, all the non-consensus elements in the first round remained unchanged in the second round, except *beneficiaries' access cost*. It secured its consensus with 84.6% of general agreement in the final round. Lastly, the rating for *penalty cost* and *transportation cost* were unstable (as *CV>0.5*) in round 1 that became stable in round 2.

Decision-Making Constraints

The decision elements in this category already achieved stability as *CV<0.5* for each of them in Delphi round 1 and this stability became higher in round 2 as *CV≤0.29*. However, the analysis found no highly important decision element for cluster 1 in the first round. Seven out of 12 decision-making constraints were considered as mediocre and placed in cluster 2, where rest were encompassed in cluster 3. The elements constituted this category gained their maximum percentage of general agreement in round 1, which remained the same in round 2 as *road capacity* and *number of storehouses* switched their places in achieving consensus. However, five decision constraints (*storehouse capacity, budget availability, demand satisfaction, travel distance, and resource availability*) from cluster 2 gained higher importance in the second round and moved to cluster 1, which was the maximum content of this cluster. 72.3% of the panel members agreed to consider the listed elements as important decision-making constraints in round 1, whereas 23.1% were not convinced and 4.6% were unable to comment. In round 2, 78.8% voted for enlisting these elements as decision-making constraint in the DSS, whereas 21.2% voted against.

Final Ranking

All 35 elements in three decision-making categories (objectives, variable, and constraints) gained an overall accepting vote of ≥76.8% in the first and a vote of ≥81.1% in the second round. This confirms the influence of these elements in the decision-making process. Hence, they need to be considered as importance requirements in the intended DSS for relief distribution. Decision making is typically highly contextual, and DMs face severe uncertainty in information gathering, processing and implementation [31]. Hence, instead of suggesting simply the top decision elements in all categories, we preferred to finally rank them by generating the *mean rank* in SPSS and present their consensus at the same time. This will support DMs to identify appropriate decision elements and utilize them for rapid decision making. However, to provide a general understanding of outcomes to the participants in round 2, we calculated consensus and ranking for the decision elements in round 1 as well. This will also provide them the opportunity to visualize the changes happened after the second round of the survey. A complete overview can be found in Table 2.

5. Synthesis and Discussion

In this section, we synthesize our findings from the Delphi process and category-wise discuss them. Afterwards, by exploiting the result, we draw a correlational matrix and propose a relief distribution process model. Finally, we conclude this section by discussing the challenges and portraying our future research directions.

Firstly, distributing maximum relief items within a short period is the main objective of the humanitarian operations undertaken in response to any natural disasters [5]. For successful humanitarian operations, DMs always try for faster response and meet as many demands as possible [16]. In doing so, the operation must be forecasted with adequate data for need assessment. Participant (P)12 exemplified the context of the Indonesian Earthquake 2018 to point out that the process should prioritize acquiring and assessing demand data before focusing on serving maximum needs. According to the participant, this is sometimes absent in the process operated in the field. To speed up the process, P44 and P52 suggested focusing on fulfilling the basic needs with quality relief items instead of quantity of relief demand. P24 came with a unique idea of publicly forecasting the need information to serve maximum demand by incorporating the concept of *social capital*. After sudden-onset, initial responses come from the people inhabiting in neighboring communities when organizational support is still unavailable (P41, P42, P57). So, if they can be forecasted with frequently updated need information, more demands can be served to save more lives. By monitoring communal services, national or international responders can avoid allocating funds for relief items that may stay unused or become surpluses (P24, P25). This will provide flexibility to responders for meeting important demands that are still missing. However, P40 recommended to *"...prioritize remote regions for relief operations as small and mediocre organizations keep those regions out of their distribution plans to minimize expenditure"* though *operational cost* and *social tension* may increase. According to P20 and P71, the success of any relief operation largely depends on the instructions from the sourcing organizations (e.g., hosting government, United Nations) and their mission objectives and capacity.

Speed is one of the critical success factors of relief distribution [29]. When a responding team is planning to serve maximum demands, it needs to find its way(s) for faster mobilization of maximum relief items (*transport quantity*) to the affected population [16]. According to P26, *minimizing travel time* would ensure timely relief distribution (*distribution time minimization*) by increasing the potential number of sorties of shipments. Although it is important to *shorten travel time,* the access constraints need to be considered during emergencies (P58). For example, extreme weather condition made the relief operation challenging in the East part of Indonesia, where P12 participated. Hence, P24 suggested to place demand notation into a map, so that central DMs can select *shortest practical length of emergency route*(s) (hence, *shorter travel distance*) and calculate *minimum travel time* to the demand points from the nearest distribution center(s). However, participants identified *minimizing travel time* is more important than *coverage maximization*. Thus, the later element was re-evaluated in Delphi round 2 and listed cluster 2. It would make the entire operation unsuccessful, if maximum coverage is planned without minimizing travel time. Hence, P41 remarked *"...do well in one area rather than poorly in all areas"*. Furthermore, the cost related elements are theoretically important (P58), but practically *"...saving lives and providing basic needs and medical treatment are of paramount importance as compared to the cost involved"* (P3). However, although some participants were in favor of having reasonable (or more) distribution centers for serving affected people, others were not concentrating on this issue as this topic is directed to central logistic hub.

Secondly, for achieving the objectives on humanitarian assistance and successfully distributing relief items, DMs are required to control some variables [37]. Among the 13 listed decision variables, panel members considered, at the first place, balancing *resource need* and relief *transportation quantity* for demand meeting at targeted point of distribution (POD). In doing so, multiple panel members suggested to categorize and prioritize peoples' needs before dispatching relief vehicles, whereas P24 and P40 emphasized to share the distribution plan beforehand to gain beneficiaries' satisfaction. For example, the relief packages can be standardized by categorizing the recipients by age, gender, location, households, family member, etc. and if they are informed earlier about the package (food/non-food, heavy/lightweight), they would ensure their arrangements (*beneficiaries' access cost*) to receive relief package(s) and return home safely. This will ensure the reduction of *social tension*, which is one of the most critical and complex issues to tackle in the disaster-arisen chaotic field (P40). Furthermore, to face such challenges it is also necessary to maintain reduced travel and distribution time that can be done by establishing *supply unit(s)* with *sufficient storing capacities* in shorter *travel distance*, accelerating inventory flow for shortening *demand meeting time*.

However, none of the cost related issues (*penalty, transport, operational, and set-up cost*) gained ultimate consensus and hence, ranked lowest. According to the participants, achieving cost benefit may be important in business logistics, not in HumLog. P3 expressed that *"...importance should be given to the mechanism to transport the relief materials as quickly as possible and not the cost involved"*. Nonetheless, P40 criticized the hidden cost benefit issue in humanitarian operations that restricts NGOs to support remote communities. The participant suggested to prioritize those communities while planning for deployment as they are not covered in most of the cases and if necessary, this can be negotiated with the donors for supporting responding operations in better ways.

Thirdly, to operate an effective and efficient relief distribution, DMs need to satisfy some limiting constraints that are not directly controlled by them. For example, *budget* and *resource availability*, *travel distance,* and *storehouse capacity* gained the highest attention. Humanitarian operations largely depend on donors [19] and humanitarian organizations have no credit (P40). Although it is expected to have adequate budget to support the entire relief distribution mechanism (P3), it is always difficult to convince donors to increase budget, even if it is needed to cover more survivors in remote areas (P19, P41). Additionally, if the required items (resources) are unavailable in the hosting area (e.g., local market), the logistical costs become higher and affect the entire operation (P24). On the other hand, *number of storehouses* and their *capacities* are centrally controlled and always face space unavailability to the upcoming shipments waiting in the port to be unloaded (P57, P58). Although, P71 were mentioning to arrange mobile storages, it would, however, increase *operational cost* and relief *distribution time*. Furthermore, unavailable access points would delay the distribution process by limiting *road capacity* or *traveling longer distance* (P40, P44). This results in an irregular *load flow; inventory holding cost* and *replenishment cost* would increase significantly.

Moreover, geographical location, security, political instability, and weather of the hosting area(s) always bring uncontrollable situations to the operations. Besides, having support from the hosting government and military, responding teams must be careful while tackling such situations. P19 and P41 suggested to incorporate local informants for continuous situational updates on further sections of a distributing network and local transport provides as they have knowledge on the local road-links. Hence, P24 was envisioning a technological system where local communities can post information on certain issues that are further refined by system analysts and graphically presented into a distribution network map. This would help DMs to find alternatives.

Fourthly, after getting a clear understanding of decision-making elements and their influences on the relief distribution process, it is important to know how each element of decision objectives is correlated with that of decision variables and constraints. Table 3 illustrates details of positive and negative correlations. For positive correlation, we considered a correlation coefficient of ≥ 0.3, whereas for negative correlation, we notated all of them though some values were insignificant. By doing so, we warn DMs, in case they intend to consider these elements for the process. The presented correlation matrix guides DMs to select and tackle appropriate variables and constraints for achieving certain objectives. By consulting the correlational values in the matrix, DMs can rapidly decide the elements that are necessary to be considered in the intended decision support systems (DSS) and can thus produce decision alternatives for efficient and effective relief distribution.

Table 3. Correlational matrix of decision-making elements

*Please consult **Table 1** for acronyms

Rank	**Decision Objectives**	**Cons-ensus**	**Highly correlated Decision Variables***		**Highly correlated Decision Constraints***	
			Positive Correlation ≥ 0.3	**Negative Corr.**	**Positive Correlation ≥ 0.3**	**Negative Corr.**
1	Distribution time **(minimize)**	Yes	rn(0.48), td(0.34), dt(0.29)	pc(0.15), trc(0.01)	ds(0.66), repc(0.53), trc(0.46), shc(0.4), ba(0.35), ihc(0.32), lf(0.29)	
2	Travel time **(minimize)**	Yes	ifc(0.45), td(0.4), tq(0.38), tt(0.38), rn(0.37)		lf(0.5), ra(0.4), trc(0.38), rc(0.3), td(0.3)	
3	Practical length of emergency route **(minimize)**	Yes	oc(0.43), tq(0.34), rn(0.3)	pc(0.13), bac(0.013)	trc(0.5), rc(0.4), shc(0.37), repc(0.35), lf(0.32), ihc(0.32), oc(0.31)	
4	Transport quantity **(maximize)**	Yes	oc(0.78), trc(0.57), ifc(0.45), stc(0.44), dt(0.34), su(0.32), tq(0.3)	det(0.2), rn(0.1), td(0.04), bac(0.002)	oc(0.6), shc(0.57), nsh(0.53), ba(0.53), rc(0.49), trc(0.45), lf(0.38), repc(0.34)	ds(0.12)
5	Coverage **(maximize)**	Yes	det(0.51), tt(0.47), rn(0.4), bac(0.31)	oc(0.06), su(0.01)	td(0.59), ra(0.47)	ba(0.18), shc(0.06), repc(0.03)
6	Penalty cost **(minimize)**	No	su(0.67), pc(0.58), tq(0.56), ifc(0.54), stc(0.49), oc(0.43), td(0.37), bac(0.32)	rn(0.09)	nsh(0.75), shc(0.62), ba(0.61), ihc(0.61), trc(0.52), rc(0.52), oc(0.41)	ds(0.04)
7	Total cost **(minimize)**	No	oc(0.71), trc(0.4), stc(0.4)	det(0.28), tt(0.23), rn(0.2), td(0.03)	trc(0.71), shc(0.6), nsh(0.4), ba(0.55), repc(0.58)	td(0.05), ds(0.002)
8	Number of distribution centers (DC) **(minimize)**	No	tq(0.58), det(0.55), su(0.52), tt(0.45), rn(0.4), pc (0.35), oc(0.34), dt(0.34), bac(0.32), ifc(0.33)		td(0.74), oc(0.58), ra(0.47), nsh(0.47), trc(0.47), ds(0.46), rc(0.43), shc(0.42), ihc(0.3)	
9	Travel distance **(minimize)**	No	pc(0.36), oc(0.36), trc(0.3)	rn(0.03)	ihc(0.5), trc(0.48), repc(0.36), lf(0.31)	
10	Resource cost **(minimize)**	No	trc(0.68), oc(0.67), su(0.6), stc(0.6), tq(0.4), td(0.4), pc(0.38), ifc(0.37)	det(0.23), rn(0.2)	nsh(0.71), oc (0.62), rc(0.62), trc(0.58), ba(0.58), shc(0.55), ihc(0.4), lf(0.35), repc(0.3)	ds(0.2)

Although most of the cost related topics did not achieve consensus and were ranked low, some of them show high correlational significance. For example, *operational cost* has the highest impact when practitioners intend to transport maximum relief items to different PODs. It scored highest in both decision variables (0.78) and decision constraints (0.6) categories. This justifies that DMs working in the down-stream of the humanitarian supply chain are not fully independent while budgeting operational costs. They are controlled (to some extent) by donors and central authorities of respective organizations. They may face similar situations when deciding on *transport cost* and *travel distance*. However, DMs must be cautious while deciding on variables and constraints because some elements have high positive impacts to achieve certain objectives, whereas the same element(s) affect other objective(s) to be accomplished. For example, *operational cost* and *supply unit* have high influences on transporting maximum relief items, whereas they negatively impact covering maximum demands. Hence, DMs should evaluate the applicability and impacts of those elements in their targeted context(s).

Fifthly, according to [26] and [45], instead of studying separately, all DPTs should be dealt jointly and concurrently for effective disaster response. Therefore, by utilizing findings from this Delphi study and from personal experiences, we have proposed a RD process model in Figure 2. The model encompasses two distinct portions: information flow (denoted in solid arrows) and material flow (denoted in dotted arrows). To demonstrate processes more clearly, we assumed each DPT as an individual operational entity. The process starts by receiving (continuous) need information from the field that DMs analyze in the distribution centers. The assessed demand information is publicly forecasted immediately for informing neighboring communities to meet initial demand and to maximize coverage. The information on *social capital* is continuously assembled while preparing the responses by exploiting decision-making factors evaluated in this research. By understanding the achieving objectives, DMs concentrate on utilizing necessary variables and constraints along with contextual ones. They consult and negotiate with other DPTs (if related) and plan for deployment.

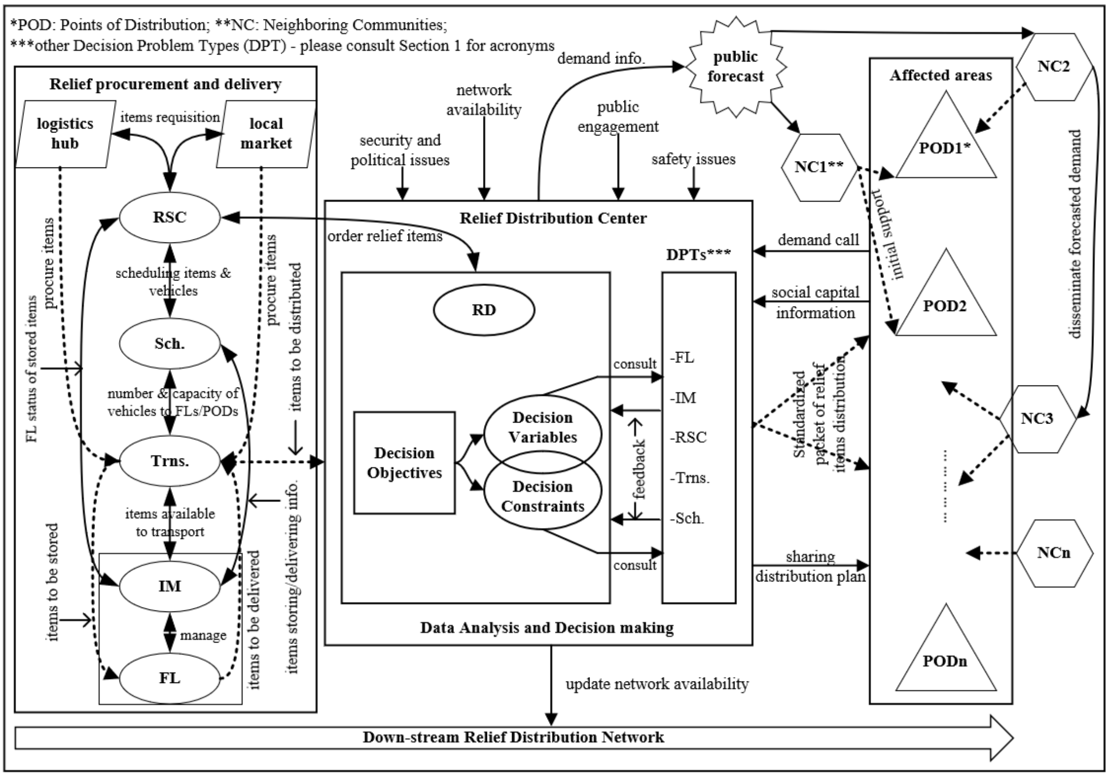

Fig. 2. The proposed relief distribution process model (inspired by [4],[28] and [37])

RSC receives initial demand notes and establishes communication with the logistic hub or local market for procuring necessary items. Parallelly, RSC communicates with IM for updates of FL status and Sch. for scheduling items to be transported and vehicles to be utilized. Then, Sch. contacts with Trns. and IM for finalizing the shipment(s) to be stored in FL or sent to the distribution centers (DC). As soon as deploying arrangement(s) is finalized, DC shares the distribution plan in the PODs. After dispatching relief items either directly from the procurement or from the selected FL(s), DC monitors the entire shipment(s) and continually communicates with responsible ones for updating the safety and security of selected the distribution network (DN). Along with official informants, DC may increase public involvement for faster update on DNs (i.e., blocked road, collapsed bridge), political instability in the network, safety and security.

Considering limitations, our study faced the typical weaknesses summarized by Hsu and Sanford [18]: low response rates and large span of time consumption. Our study also faced the challenge of discontinuing the future round(s) despite participants being properly motivated by providing information about the survey topic, method, rounds, outcomes, and the overall research theme. Since we exploited emails to communicate geographically dispersed experts, it was always difficult to reach them as we had no indication whether we were using the right addresses until participants replied. The conducted interviews were informative, but it was laborious for us to convert them to a questionnaire-like format.

After tackling all these difficulties, this summarized our findings allows to identify paths for future research. Decision-making factors learned from our work can be translated into requirements for developing future IS artifacts (e.g., DSS), where the prioritization by the experts can form the basis of a typical *Must-Should-Could* assessment. In fact, the step following this article will be a design-oriented pragmatic approach that would effectively support rapid decision making for efficient relief distribution in large-scale disasters [30]. Our own research will focus on proposing an information ecosystem (IE) for RD by examining the influences that it receives from other problem types introduced in Section 1. This IE could feedback DSS to produce effective and efficient support.

6. Conclusion

Relief distribution is the core task of HumLog operations. To be completed successfully, it depends on qualified decision making in FL, RSC, IM, Trns., and Sch. Except for a few of them, decision factors in relief distribution (RD) are shared by different problem types. Thus, it is important for decision markers (DMs) to know the list of decision objectives and how and to what extent they are influenced by decision variables and constraints. In this article we have identified and developed a generalized list of decision-making elements that academic researchers exploited in their objective functions and models to solve case or scenario specific RD problems. We evaluated the elements with experts in HumLog and the RD process and prioritize them basing on experts' rating. Furthermore, to quantify the influences of decision variables and constraints over each decision objective, we generated a correlational matrix, from which DMs can understand and select decision elements basing on their respective context(s).

The findings in this research have various implications. Empirically evaluating the decision-making factors has extended the current body of knowledge on RD process in large-scale sudden onsets. Based on our findings, we have contributed to the HumLog literature by clearly extending the existing models to accelerate decision making in disaster-like deeply uncertain situations, where information is infrequent and incomplete. Our research findings, along with the proposed a process model, will support field-based decision making in the down-stream of humanitarian (relief) supply chain, as well as in the center. Moreover, it serves as input to information – specifically decision support – system development. Additional research is needed to refine the findings and extend the process model to prototype and develop a DSS to support DMs with alternatives, from which they would choose the suitable one for implementation.

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