Defining and measuring the network flexibility of humanitarian supply chains

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Defining and measuring the network flexibility of humanitarian supply chains: insights from the 2015 Nepal earthquake

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Abstract The efficient and effective response to disasters critically depends on humanitarian supply chains (HSCs). HSCs need to be flexible to adapt to uncertainties in needs, infrastructure conditions, and behavior of other organizations. The concept of 'network flexibility' is, however, not clearly defined. The lack of an unanimous definition has led to a lack of consistent understanding and comparisons. This paper makes a threefold contribution: first, it defines the concept of network flexibility for HSC in the context of sudden onset disasters. Second, it proposes a framework to measure network flexibility in HSCs. Third, we apply our framework to the 2015 Nepal earthquake case and provide evidence-based insights regarding how humanitarian organizations can improve network flexibility in HSCs. Our analyses for Nepal case show that delivery, IT support, and fleet criteria have the most influence on flexibility. Also, the application of our framework on the downstream network of nine humanitarian organizations shows low levels of network flexibility in all but one. This finding explains why several disruptions happened in relief distributions during the Nepal response.

Keywords Humanitarian supply chain · Network flexibility · Measurement framework · Field research · 2015 Nepal earthquake

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1 Introduction

Humanitarian disasters occur more frequently than ever before, and the demand for humanitarian assistance is expected to continue to increase (Guha-Sapir et al. 2015). Facilitated by the development of information technologies, humanitarian supply chains (HSCs) have become more transparent (Comes and Van de Walle 2016). However, the improved/improving information about HSC have not yet been translated into better response (Prasad et al. 2016), and some authors have argued that this is owing to a lack of flexibility (Scholten et al. 2010).

HSC literature often refers to network flexibility in terms of distribution (ability to provide access to aid) or responsiveness (ability to adapt to changing needs) (Fabbe-Costes and Jahre 2009; Pettit et al. 2013). However, a detailed definition of what 'network flexibility' is in humanitarian contexts and what it depends on, is lacking in HSC literature. Thus, there is no systematic approach for measuring network flexibility in HSCs.

Our paper aims at synthesizing the literature on 'network flexibility' and adapt the concept to the humanitarian response context. From the definition, we propose a flexibility measurement framework for HSCs that can be implemented by practitioners. Our research has a threefold contribution:

(i) we define HSCs network flexibility in the humanitarian response to sudden onset disasters;
(ii) we develop a framework to measure flexibility in HSCs;
(iii) we apply our theoretical framework to the 2015 Nepal earthquake case.

We follow an exploratory mixed-method research design in our study: we develop a theoretical framework which is informed by a field research after the 2015 Nepal earthquake. Then, we apply the framework to the Nepal case and conduct the quantitative analysis based on multi-criteria decision analysis. For the sake of brevity, we use 'flexibility' instead of 'network flexibility' throughout the paper.

The remainder of this paper is structured as follows: we review definitions of flexibility in HSCs in Sect. 2. Then, we describe our research design in Sect. 3. The development of the flexibility measurement framework is explained in Sect. 4. The analysis of applying our framework to the Nepal case and related results are described in Sect. 5. We discuss these results with some implications for theory and practice in Sect. 6. Eventually, we conclude with limitations of our study and directions for future research in Sect. 7.

2 Literature review

Flexibility has attracted much interest in commercial SC (CSC) management (Maria Jesus Saenz et al. 2015; Esmaeilikia et al. 2016). We focus here specifically on the humanitarian context but we complement our review with CSC findings if literature is sparse.

In CSC literature, flexibility is "the ability to respond to variations with little penalty in time, effort, cost or performance" (Christopher and Peck 2004). More recently, researchers highlight that considering flexibility is the key toward resilient and agile supply chain design (Kamalahmadi and Mellat-Parast 2015; Garcia-Herreros et al. 2014). Improving flexibility prepares SC to adapt to an environment with foreseen and unforeseen changes (Husdal 2010; Sheffi and Rice 2005).

2.1 Flexibility in humanitarian supply chains

In the chaotic environment of a response, HSCs are exposed to uncertainties that may cause serious disruptions (Perry 2007). Flexibility has therefore been recognized as one of the success factors of HSCs (Manoj et al. 2015; Bozorgi-Amiri and Asvadi 2015; Abounacer et al. 2014; Najafi et al. 2013; Yushimito et al. 2012; Afshar and Haghani 2012; Shen et al. 2009; Abidi et al. 2013). Flexibility impacts organizational structures, information systems, and logistics processes (Scholten et al. 2010). However, only few researchers propose definitions for 'flexibility in HSCs' (Scholten et al. 2010; Santarelli et al. 2013, 2015). Scholten et al. (2010) define flexibility in HSC through its dimensions, such as resources and distribution while Santarelli et al. (2013, 2015), define it as an ability to adapt to changing external conditions.

Combining these aspects, we define HSC flexibility as *a multi-dimensional ability to efficiently adapt to changing external and internal conditions in disasters to maintain or improve HSC performance*. Our definition supports HSC resilience and agility by improving SC's response to changes and disruptions.

Very few HSC papers admit how to consider flexibility when establishing HSCs. For instance, Oloruntoba and Gray (2006) note that in order to deal with unpredictable and turbulent contexts of response, HSCs require flexibility; however, the question of where and how remained unanswered. Without sufficient flexibility, HSCs are prone to several disruptions and hence, proposed quantitative models and simulations models in the literature (Anaya-Arenas et al. 2014) can not improve the work in the field. In this regard, measuring the state of flexibility is the first step toward benchmarking and then, further planning.

2.2 Measuring flexibility in humanitarian supply chains

Monitoring and measuring tools are designed to show the status of system features. These tools help to assess the current state and thus, enable developing plans for improvements. Two approaches can be distinguished: indirect and direct assessment (Santarelli et al. 2015; Abidi et al. 2014). There are several performance measurement tools in HSC literature that follow the first approach (Van Wassenhove 2006; Oloruntoba and Gray 2006; Jahre et al. 2007; Beamon and Balcik 2008; Perry 2007; Santarelli et al. 2013; Day 2014). These tools mainly measure the speed, effectiveness, responsiveness, and/or efficiency of HSC through key performance indicators (KPIs) such as delivery time, the number of saved lives, the quantity of distributed relief items, and operations' costs.

However, developing a systematic framework for measuring flexibility that follows the second approach has been rarely discussed. Direct assessment is considerably important because it enables more targeted (and detailed) improvement plans compared to indirect assessment with KPIs. Table 1 summarizes key points in contributions related to the second approach.

- Criteria: Beamon and Balcik (2008) and Charles et al. (2010) suggest measuring flexibility through 4 criteria: volume, delivery, mix, and product. If we compare these criteria with contributions in CSC literature, we find further criteria that have not been used for measuring flexibility in HSCs. For instance, Moon et al. (2012) discuss asset flexibility and its effects on material flow. Gong (2008) investigates information systems flexibility. Slack (2005) mentions fleet flexibility as one of the key performance indicators in commercial logistics.
- Aggregation: Only Charles et al. (2010) suggest the evaluation of all four flexibility criteria through an aggregation grid. The other papers neither propose any aggregation

Table 1 Overview of how flexibility is directly measured in HSC literature

Author(s)	Flexibility criteria	Aggregation method	Improvement proposal
Beamon and Balcik (2008)	Volume; delivery; mix; new-product	No	No
Scholten et al. (2010)	Resources; coordination	Unclear	Pre-positioning; investing in IT support
Chandes and Paché (2010)	Human resource	No	Partnership
Charles et al. (2010)	Volume; delivery; mix; new-product	Aggregation grid	No
Day (2014)	Sourcing	No	Developing monitoring systems
Santarelli et al. (2015)	Volume; mix	Unclear	No

method (despite having multiple criteria) nor explain how they aggregate their evaluation results. For instance, Beamon and Balcik (2008) propose that among the introduced criteria, it is sufficient to measure only one flexibility criterion given the case scope and context.

- Planning: Beamon and Balcik (2008) and Charles et al. (2010) suggest working on flexibility improvement proposals as the future research direction.
- Research design: Despite the demand for empirically grounded research in HSCs literature (Baharmand et al. 2015; Pedraza-Martinez and Van Wassenhove 2016), to the best of our knowledge, no paper use empirical evidence to develop, inform, and/or implement flexibility measurement framework for HSCs. Few papers apply their framework to real cases (Charles et al. 2010; Santarelli et al. 2013, 2015).

Table 2 shows a summary of analyzing flexibility measurement research in both CSC and HSC literature. This table shows domains and criteria that are relevant for measuring the flexibility in HSCs. The list is not exhaustive, and only includes the most common domains and criteria in the literature. We have tried to cover relevant aspects as far as we could.

In order to assess the level of flexibility through each criterion consistently, some metrics are required. An evaluation grid is also necessary to enable measuring each criterion by associated metrics (Charles et al. 2010). Level of flexibility in each criterion can then be referred by the corresponding score or grade from the evaluation grid.

2.3 Literature gaps and research statement

Flexibility in HSC is a prerequisite for dealing with the complexities and disruptions typical for sudden onset disaster response. However, flexibility is often assumed as a given and HSC literature lacks a specific, transparent analysis of flexibility with field driven insights. Without any applicable tool for measuring network flexibility in HSCs, practitioners are left with their intuition and experience to improve it.

In this paper, we translate our analysis of literature into a flexibility measurement framework which we use to support analysis of our field research. Our ambition is to develop a framework that can be used by practitioners. It should help to assess the flexibility of HSCs in the humanitarian response and to improve it by enabling targeted planning. To show this, we implement our framework on a real case, the 2015 Nepal earthquake response, and discuss the implications of results for both theory and practice.

Table 2 The outcome of literature analysis regarding flexibility domains and their criteria in SC

Flexibility domain in SC	Criteria	Definition
Product (PF)	Volume (V)	To provide large number of individual units of supplies (Beamon and Balcik 2008)
	Mix (M)	To provide mix of different type of supplies that the relief chain can provide (Beamon and Balcik 2008)
	Local sourcing (LS)	To change planned or assumed vendors to local sources (Chandes and Paché 2010)
Distribution (DF)	Assets (A)	To change or share planned or assumed assets (Moon et al. 2012)
	Fleet (F)	To change planned or assumed fleets (Slack 2005)
	Delivery (D)	To change planned or assumed delivery dates (Slack 2005)
	Trans-shipment (T)	To move stock between local supplier and demand locations where physical distances between them are small (Grigore 2007)
	Access and routing (AR)	To provide intensive distribution coverage (Naim et al. 2006)
Information systems (ISF)	IT support (IT)	To use IT as support for material and information flow control (Moon et al. 2012)
	Information databases (ID)	To have means to store and aggregate data (Moon et al. 2012)
	Decision support systems (DSS)	To have access to systems that can assist decision-making (Baharmand et al. 2015)
Resources (RF)	Human resources (HR)	To have access to human resources with relevant qualifications (Krajewski et al. 2005)
	Local partners (LP)	To have local NGOs as operational partners (Santarelli et al. 2015)

3 Research design

Our paper aims at developing a comparable quantitative measure of HSC flexibility which can help to identify improvement strategies. Our research design follows Bourne et al. (2000) who propose four steps for developing a performance measurement system: (a) system design; (b) implementation of measures; (c) use of measures to assess the implementation strategy; and (d) use of measures to challenge strategy. In this regard, we modified steps by adapting sub-parts in them and/or by allocating tasks to them when necessary. The proposed steps and corresponding research methods in our research design are shown in Fig. 1. In designing the system, step (a), we develop an initial catalogue of flexibility domains and related criteria as well as required metrics (cf. Sect. 4.1). In implementation of the system, step (b), we design our Nepal field research (interview guidelines and observation protocols) and after

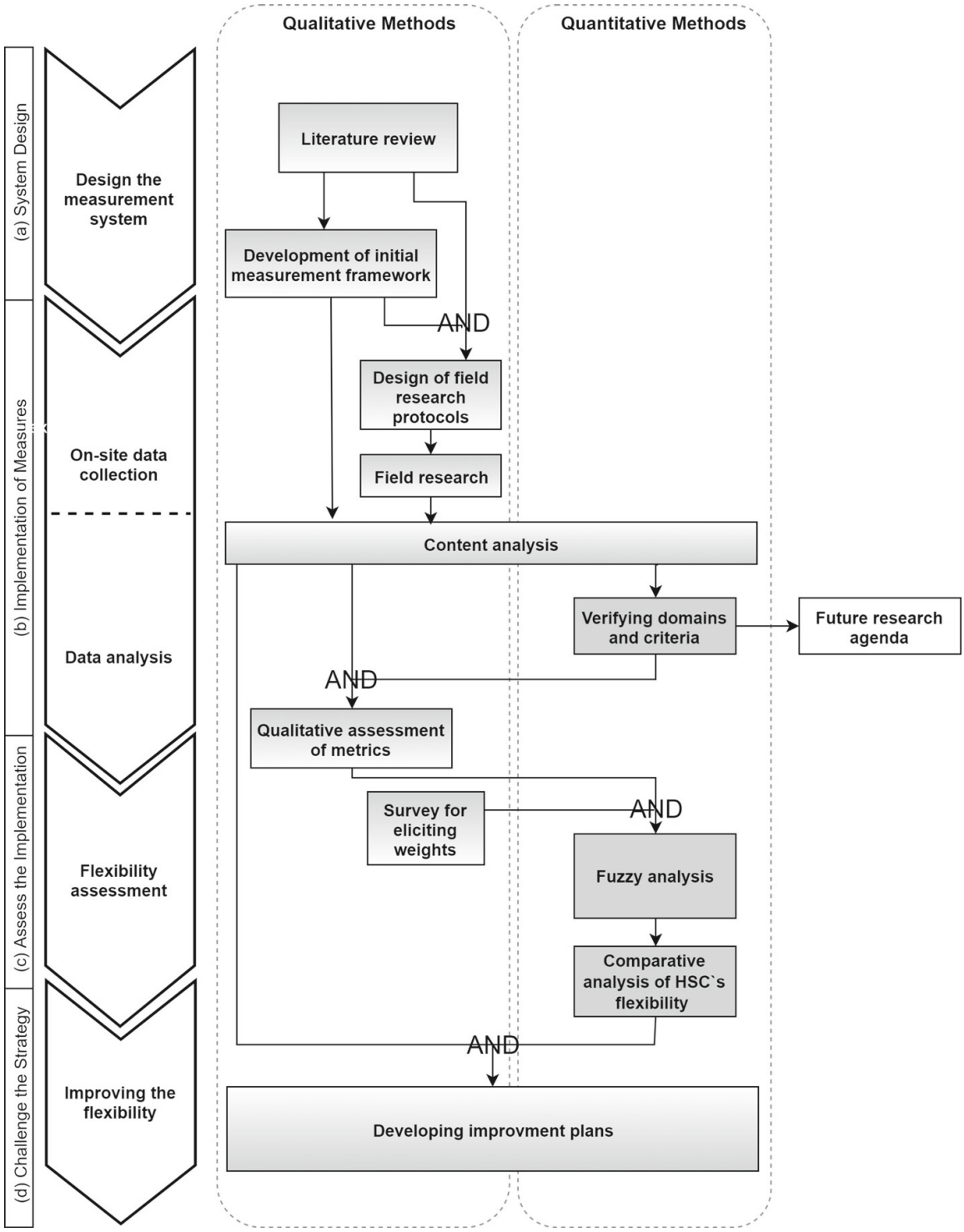

Fig. 1 Framework design and incorporated methodologies inspired by Bourne et al. (2000)

collecting data, we use content analysis to revise the primary catalogue of flexibility criteria for the Nepal case, cf. Sect. 4.2. In step (c), we use the empirical data to apply our flexibility measurement framework for the Nepal case. We carry out a critical evaluation of the flexibility assessment by combining the resulting weights of fuzzy analytic hierarchy process (AHP) with fuzzy technique for order preference by similarity and solution (TOPSIS), cf. Sect. 4.3. Finally, in step (d), we provide HOs with instructions on how to develop improvement plans, cf. Sect. 4.4. We explain these four steps in detail in Sect. 4.

4 Flexibility measurement framework for humanitarian supply chains

4.1 Designing the measurement system

Our proposed framework uses literature driven metrics for each criterion in Table 2. While metrics for volume, mix, local sourcing, assets, and fleet are shown in Table 3, the rest of metrics are provided in "Appendix A". Accordingly, an evaluation grid has also been prepared for the aforementioned metrics. This grid works with linguistic variables; poor, very poor, medium, good, and very good. Special care has been taken to keep the evaluation grid as robust and reproducible as possible.

4.2 Implementing the measurement system

This step comprises two parts: on-site data collection through a field research, and analyzing empirical data by content analysis.

4.2.1 On-site data collection

In order to collect relevant data, we propose conducting field research in the targeted humanitarian context. Field evidence strengthens the applicability of framework since field evidence enables researchers to provide more convincing insights for practitioners (Van de Walle and Comes 2015).

Developing practical data collection guidelines and protocols is of great importance for an effective field research (Holguín-Veras et al. 2014). Developing such protocols requires reviewing literature related to research objectives and questions. Our suggested methods for data collection in the field are in-depth semi-structured interviews and observations, which can be complemented by remote interviews. Using multiple methods helps to collect relevant information given the constraints in disaster contexts. For interviews, we suggest open questions because they enable acquiring much information without compromising research limits, such as time or number of key informants (Salvadó et al. 2015). Open questions also help to continue with more detailed questions when an interesting theme emerges during the interview (Baharmand et al. 2016). Also, we suggest eliciting quantitative data through targeted questions.

4.2.2 Data analysis

Our analysis approach has two sub-steps: (1) content analysis to verify criteria, and (2) assessment of metrics. Figure 2 illustrates the link between the qualitative field work and the framework that we are proposing in this paper.

Verifying domains and criteria Due to high dependency of HSCs' characteristics on the targeted context (Pedraza-Martinez and Van Wassenhove 2016), the criteria have to be verified. To this end, our approach aims at identifying those flexibility criteria which are frequently referred to during field interviews. Thus, we use literature driven criteria as keywords and then, we count the number of references in transcripts. Observations and field notes can effectively complement related findings. Besides, deep analysis of keyword 'flexibility' in field data enables finding attached concepts that may not be referred in the literature. Eventually, the verified list of flexibility criteria consists of: first, common criteria between the literature and the field data; and second, attached

Table 3 Some examples of metrics for flexibility criteria and related measurement grid

Flexibility criteria	Metrics	Very poor (score = 0)	Poor (score = 1)	Medium (score = 2)	Good (score = 3)	Very good (score = 4)
Volume	Number of households supported by relief operations, on average (Charles et al. 2010)	Less than 1000 households	Between 1000 and 5000 households	Between 5000 and 15,000 households	Between 15,000 and 30,000	More than 30,000 households
	Advocacy between local storage capacity and demands	Support max. 20% of targeted beneficiaries	Support max. 40% of targeted beneficiaries	Support max. 60% of targeted beneficiaries	Support max. 80% of targeted beneficiaries	Support more than 80% of targeted beneficiaries
	Assessment of volume criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$
Mix	Number of distinct relief item types being targeted for distribution	Only 1 type	1 or 2 Types	3 or 4 Types	4 or 5 Types	More than four types
	Number of distinct relief item types being shipped to different distribution centers, on average	Only 1 type	1 or 2 Types	3 or 4 Types	4 or 5 Types	More than four types
	Assessment of mix criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$
Local sourcing	Number of local suppliers selected per relief item, on average	No local supplier	Very few product types are bought from local market with no specific contract	Some products are bought from local market, but very few specific contract	Some products are bought from local market but not all through a contract based process	All products are bought from local market through a contract based process
Assets	Number of local storage or distribution centers	Only 1 place	1 or 2 Places	2 or 3 Places	3 or 4 Places	More than 4 places
Fleet	Number of accessible and available fleet types (including air delivery and outsourcing)	Only 1 type	1 or 2 Types	2 or 3 Types	3 or 4 Types	More than 4 types
	Number of carriers used for each type of transportation modes (except air delivery), on average	Less than 5	Between 6 and 10	Between 11 and 15	Between 16 and 20	More than 20
	Assessment of fleet criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$

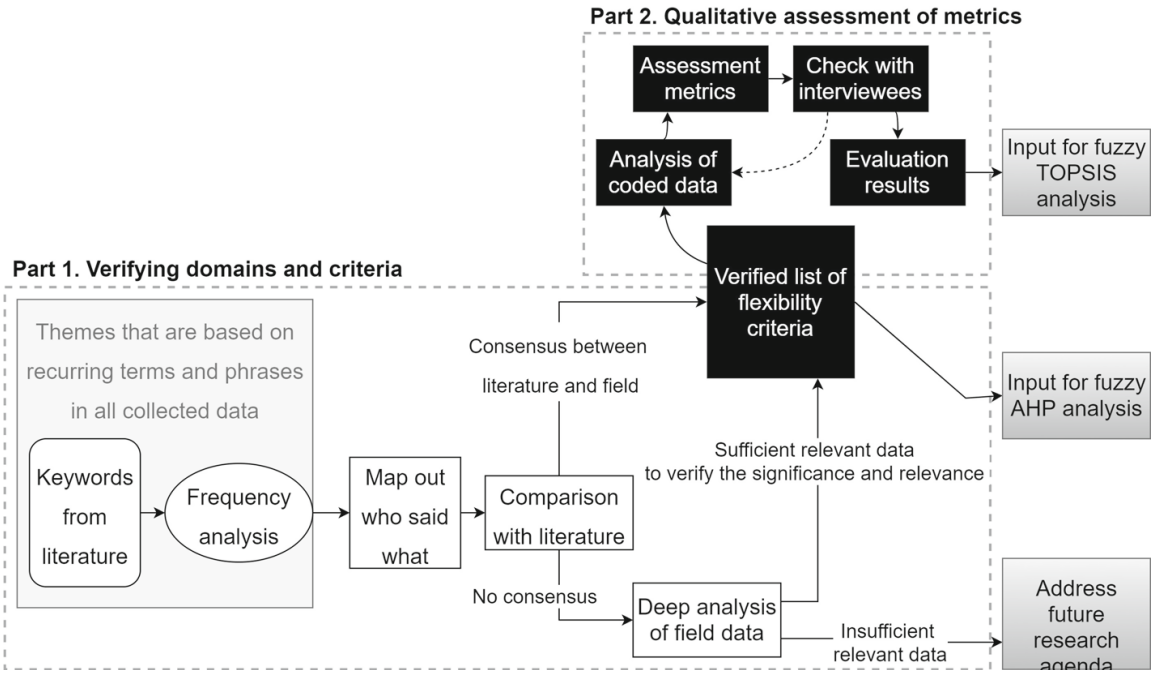

Fig. 2 Schematic illustration of how our field study informed model building

concepts to flexibility that their relevance can be confirmed through deep analysis of empirical data.

Qualitative assessment of metrics In this sub-part, we assess the coded categories through the literature-driven metrics (cf. Table 3) to provide the linguistic inputs of Kahraman et al.'s TOPSIS approach (2007). This part is composed of several iterations between collected data, assessment metrics, and checking the findings with interviewees to reduce biases as far as possible. The aim is to relate the status of each HO in every criterion to a corresponding linguistic variable (poor, very poor, medium, good, or very good).

4.3 Flexibility assessment

To ensure that HOs can benefit from a flexibility assessment tool, we develop a quantitative framework that enables benchmarking and continuous evaluation. In this step, we explain how to conduct such assessment with the collected and analyzed data.

4.3.1 Fuzzy analysis

Due to different scope of domains and criteria, they may not have the same impact on the overall flexibility. Therefore, the relative importance of each criterion has to be determined. We suggest using fuzzy AHP to determine the weights for verified criteria through pairwise comparison. Figure 3 illustrates the fuzzy analysis in our research.

AHP has been popular to determine weights across a wide range of disciplines (Oguztimur 2011). The strength of AHP lies in its ability to structure a complex, multi-domain, multi-criteria problem hierarchically. AHP scales the weights of attributes at each level of the hierarchy with respect to a goal using the experts' experience and knowledge in a pair-wise comparison of criteria.

There are several papers on fuzzy AHP; our research follows Chang's approach (1999) due to its simplicity and ease of use. In this approach, values are converted to triangular fuzzy

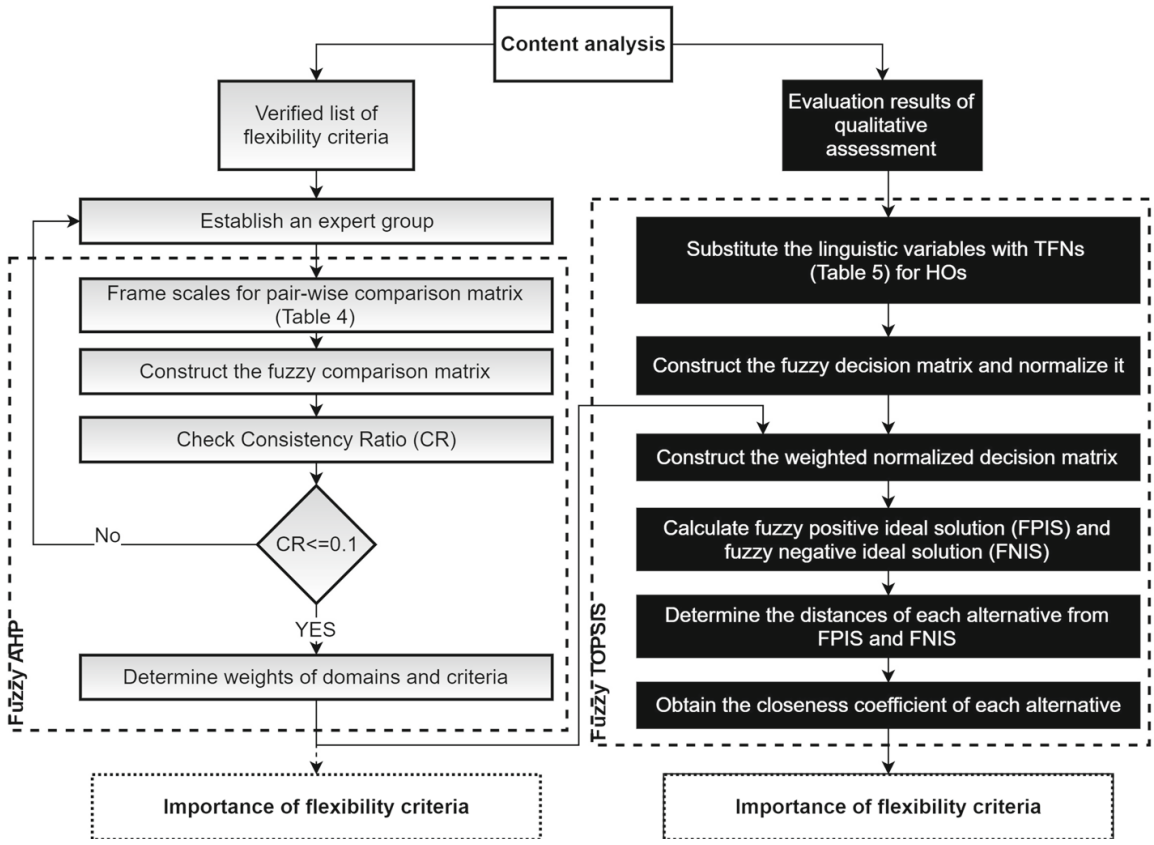

Fig. 3 Combination of Fuzzy AHP (Chang 1999) and fuzzy TOPSIS (Kahraman et al. 2007) for implementing flexibility measurement framework

Table 4 Linguistic values, their relative importance and equivalent TFN (Paksoy et al. 2012)

Relative importance	Definition	TFN
1	Equal importance	(1, 1, 1)
3	Moderate importance	(2, 3, 4)
5	Strong importance	(4, 5, 6)
7	Demonstrated importance	(6, 7, 8)
9	Extreme importance	(9, 9, 9)
2	Intermediate values	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

numbers (TFNs) and then, the geometric mean is calculated. Afterwards, fuzzy weights are normalized. We follow Paksoy et al. (2012) in the definition of linguistic values and their equivalent TFNs (see Table 4). All other calculations follow the original fuzzy AHP by Buckley et al. (1986). For a review of the complete formulations, we refer to Buckley et al. (1986), Chang (1999), and Paksoy et al. (2012).

Having linguistic variables (cf. Sect. 4.2.2) and normalized fuzzy weights, we use fuzzy TOPSIS for the assessment. For the fuzzy TOPSIS, we propose using the approach of Kahraman et al. (2007) since it is widely appreciated as effective and simple (Beskese et al. 2015).

As depicted in Fig. 3, Kahraman et al.'s fuzzy TOPSIS approach (1999) includes six steps. First, linguistic variables are substituted by their corresponding TFNs, as shown in Table 5, for

Table 5 Linguistic variables for evaluation (Kahraman et al. 2007)

Linguistic variable	Corresponding TFN
Very poor	(1, 1, 3)
Poor	(1, 3, 5)
Medium	(3, 5, 7)
Good	(5, 7, 9)
Very good	(7, 9, 9)

each alternative. Second, the fuzzy decision matrix is constructed using these TFNs and then normalized by a linear scale transformation. Third, a weighted normalized fuzzy decision matrix is constructed by multiplying the outcomes of fuzzy AHP with the normalized fuzzy decision matrix. Fourth, fuzzy positive and negative ideal solutions are determined. Fifth, distances of each alternative from these ideal solutions are calculated. Finally, the closeness coefficients to the ideals are obtained. For a complete list of formulas, see Kahraman et al. (2007). The result of this step is a ranking of HOs with respect to their flexibility level.

4.4 Improving the flexibility

This final step is designing and developing improvement plans, with the aim of achieving the desired level of flexibility. To design the improvement plans, HOs can follow two approaches.

First, they can focus on those criteria with highest weights that received the lowest scores. This enables HOs to carry out improvements based on their current status and available resources. Then, they can evaluate their status again with the provided metrics (cf. Sect. 4.1) to check if they achieved a satisfactory flexibility level.

The second approach refers to targeting a given profile of desired flexibility. A profile represents a set of pre-selected criteria (see Fig. 4). Our work for shaping aforementioned profiles is inspired by the work of Charles et al. (2010) on agility. In our framework, levels of flexibility are *not flexible*, *hardly flexible*, *semi flexible*, *flexible*, and *highly flexible*.

In order to develop practical plans, we propose complementing theoretical work with best practices and field driven insights. Developing plans based on only literature findings has three main problems: lack of relevant literature with respect to flexibility in HSCs, critical differences between CSC and HSC, and lack of confidence regarding the applicability of a solution without evidence. We suggest developing improvement plans based on best practices from those HOs with better flexibility rankings. These practices can be observed in the field or elicited through interviews.

5 Flexibility in the 2015 Nepal earthquake case

Bookman Old Style In this section, we illustrate the application of our framework in the Nepal case. We decided to focus on the downstream network of HSCs.

5.1 Case overview

Two major class earthquakes hit Nepal on April 25th and May 12th 2015. These earthquakes affected roughly 5.5 million people in 14 districts (out of country's 75 districts). They left nearly 9,000 casualties, and approximately 7.1 billion dollars in economic damages (GoN 2015).

The official request for international assistance was placed quickly after the first earthquake. Over time, emergency relief and humanitarian assistance to the affected population were provided by distinct HOs from over 60 countries including United Nations (UN) and other international agencies (GoN 2015).

5.2 On-site data collection

We conducted our field research June 21st–29th 2015, approximately 2 months after the earthquake. Representatives who took part in our research were from the following national and international HOs: International Federation of Red Cross and Red Crescent Societies (IFRC); two UN agencies; and eight international non-governmental organizations (iNGOs). All of these organizations deployed their response teams to Nepal a few days after the earthquake to distribute relief items. Some of these organizations planned to remain active during the recovery (for instance Cordaid). All interviewees had served in previous operations.

Our approach for on-site data collection is inspired by multi-disciplinary field research in sudden-onset disasters (Chan and Comes 2014; Holguín-Veras et al. 2014). Data collection followed the inductive approach and was designed to collect information regarding logistics challenges and bottlenecks. The framework that informed our field study was derived from a previous literature review regarding HSC challenges (Baharmand et al. 2015) and their relation to flexibility in downstream network. Data collection was done through:

(i) sixteen in-depth semi-structured interviews with representatives from eleven HOs active in relief operations with follow-up questions through email;
(ii) field observations in Kathmandu, Rasuwa, and Nowakut districts;
(iii) reviewing field notes, online resources (Reliefweb, LogCluster, HumData), cluster meeting minutes, and local newspapers.

We arranged most of our interviews before arrival through pre-existing contacts at iNGOs and the UN. The specific focus of selection was on logisticians. We also used online community platforms, especially LinkedIn and Reliefweb, to set up interviews. Additionally, we used snowballing to identify new participants. To avoid the limitations inherent in interviews, we used cross-validation whenever possible.

Our interview protocol was composed of questions regarding the structure of relief distribution network, needs assessment, decision-making process, collaborations with other HOs, and information sharing. Our questions also targeted HSC characteristics, e.g. flexibility, to identify the strengths and weaknesses of downstream networks.

We used open questions, asking interviewees to describe their downstream network and related problems in details. Interviews' durations were less than one and half hours and within the consent of interviewee, all conversations were recorded. We also asked interviewees for other relevant documents, maps, sheets, photos, and reports that they could share with us.

In addition to Kathmandu, which served as the central logistics hub, we conducted exploratory visits to field offices in remote and hard-to-reach areas (Rasuwa and Nuwakot districts). We spent 4 days observing interactions between humanitarians and local communities in these severely affected areas, with a specific focus on flexibility. We had interviews with two district managers mainly regarding relief operation performance. Our observation protocol also included logistics issues, needs assessment techniques, and collaboration among HOs.

We also collected documents including reports, maps, white papers, and meeting minutes from online sources. These resources provided us complementary information regarding relevant quantities, locations, and best practices in relief operations. Furthermore, we collected

articles from two newspapers (The Kathmandu Post and The Himalayan Times) that were published in English during our stay.

5.3 Data analysis

For verification and qualitative assessment (cf. Sect. 4.2.2), we analyzed our empirical data by content analysis (Elo and Kyngäs 2008). First, we converted the recorded interviews into transcripts and then, we added the supporting materials (field notes, operation reports, cluster meetings minutes, etc.). A coding sheet was used to assess and classify (Ritchie et al. 2013) the collected data regarding the flexibility domains/criteria (Table 2). We used the software NVIVO 11 for coding.

5.3.1 Verifying criteria: implications for flexibility theory

We first categorized findings with respect to flexibility domains and criteria. In most of our interviews, participants acknowledged the importance of flexibility, but they were struggling to indicate potential improvements. This was the main motivation from practice to measure HSC flexibility.

"We need more flexibility, and we are trying to."(23. 06. 2015, WVI, Kathmandu)

"You can talk about that [flexibility] easily but how can we reach it? Who knows?" (26. 06. 2015, UMN, Kathmandu)

The attributed importance and attention to flexibility criteria was highly diverse. Table 6 shows the list of flexibility criteria and their coverage in our interviews. According to this table, volume and delivery were mentioned most often, while DSS and local partners were referred to least. The biased distribution can, at least partly, be explained through the focus on operational decision-makers who we had access to in our field research. Furthermore, Table 7 shows a summary of insights from our field study with respect to each criterion. Details are provided in "Appendix B".

We did not include two categories of criteria in our investigations. The first category included trans-shipment flexibility and access/routing flexibility, that were not applicable in the context of Nepal case (downstream vs. upstream focus). The second category contained policy/strategy and donors flexibility that were not in the scope of our field study (strategic vs. operational focus).

5.3.2 Qualitative assessment of metrics

Using criteria metrics (cf. "Appendix A"), we assessed the classifications and scored HOs with corresponding linguistic variables (see Table 5). Then, results were checked with relevant interviewee. In cases that consensus was not achieved between our result and the interviewee's viewpoint, we re-conducted assessments and then, results were checked with the interviewee again. In our worst case, this iteration was carried out two times.

When we could not find related quantitative data in our classifications to compare with the metrics, we reached out to interviewees by emails and asked them to provide corresponding inputs. Subsequently, we had sufficient information to construct the fuzzy decision matrix for further fuzzy analysis (cf. Table 13).

Table 6 Number of references (percentage of coverage) in analyzed documents regarding the flexibility criteria

Current description	Volume	Mix	Local sources	Assets	Fleets	Delivery	IT support	Information databases	Decision support systems	Human resources	Local partners	Other criteria (total)
Transcripts of interviews Canadian Red Cross (and IFRC)	18 (0.27%)	13	11	17	13	15	18	21	23	14	22	3
Transcripts of interviews at UN WFP (and UNOCHA)	48 (0.68%)	28	39	37	35	28	38	38	35	31	31	8
Transcripts of interviews at Oxfam	19 (0.52%)	25	16	18	19	18	18	20	18	17	16	7
Transcripts of interview at IRW	10 (0.17%)	10	18	10	16	15	8	17	16	8	12	0
Transcripts of interview at WVI	13 (0.26%)	10	16	11	14	19	14	12	10	10	12	7
Transcripts of interviews at Cordaid	20 (0.33%)	20	26	21	20	28	24	32	28	17	30	2
Transcripts of interviews at UMN	18 (0.34%)	18	25	19	23	23	24	16	25	25	19	0
Transcripts of interview at Humedica	39 (1.24%)	40	35	40	32	40	37	25	26	32	34	0

Table 6 continued

Current description	Volume	Mix	Local sources	Assets	Fleets	Delivery	IT support	Information databases	Decision support systems	Human resources	Local partners	Other criteria (total)
Transcripts of interview at Handicap International	34 (0.61%)	23	24	19	30	26	21	21	25	28	18	7
Transcripts of interview at RI	21 (0.81%)	23	21	20	16	24	16	10	12	17	25	1
Field notes (Rasuwa)	45 (0.61%)	38	29	25	39	29	38	26	35	32	35	10
Field notes (Nowakut)	57 (3.02%)	28	24	17	13	26	17	26	12	13	30	5
Field notes (Kathmandu)	2 (0.18%)	0	10	3	9	7	8	9	4	8	9	6
Notes from other sources	26 (0.57%)	10	23	24	16	17	13	20	25	11	22	0
Sum	370	283	299	299	288	313	294	283	266	299	264	59

Table 7 Summary of field findings related to flexibility criteria

Criterion	Evidence	Flexibility status
Volume	We observed two types of HOs: first, those that focused on only one relief material in few village development committees (VDCs); second, those HOs who had establishments in Nepal prior to the earthquakes	The first showed more volume flexibility than the second (given assets constraints) but they were lacking mix criterion
Mix	Despite the variety of demands in different affected areas, majority of HOs worked on only one cluster in Nepal response. Besides, providing standardized relief packages was challenging due to procurement problems	Overall, majority of HOs had low levels of mix flexibility during immediate response and response
Local sourcing	Two observable impacts in this regard: first, prices of high priority relief items were almost doubled in the local market; second, it caused significant delays up to several weeks	Lack of local sourcing flexibility brought several challenges
Assets	We observed that asset flexibility is a constraint for volume flexibility. More effort invested in suitable assets meant less probability to change location during the response	Medium level of assets flexibility helped majority of HOs to position relief items effectively
Fleets and transportation	We observed that most HOs struggled with challenges in substituting fleets on short notice. These challenges along with problems in rescheduling resulted in delivery delays	Lack of fleet flexibility in majority of HOs impacted also their delivery flexibility
Delivery	We observed some cases that drivers refused to transport items. Besides, no alternative schedules were often pre-planned and very few HOs had systems for rapid rescheduling. Hence, delivery dates were frequently not met, causing backlogs and under-supplies	Low level of delivery flexibility observed in majority of HOs

Table 7 continued

Criterion	Evidence	Flexibility status
IT support	We observed that a few HOs had started to use IT tools for their assessments and data collection as opposed to paper-based systems. IT tools improved information sharing, decision making, and coordination considerably where there was appropriate database. Hence, information flow, IT support, and information database were interconnected flexibility criteria	Good level of IT flexibility in few HOs
Information database	We observed duplication of need assessment efforts. Due to common use of paper and lack of specifically developed databases, data collection was labor intense and prone to error	Most HOs were lacking information database flexibility
Decision Support System	The lack of technology support resulted in simplifying assumptions and the use of heuristics. These simplifications resulted some inefficiencies in operations such as congestions, loading/offloading problems, and delays	Lack of decision support system flexibility was observed in majority of HOs
Human resources	We observed that improving HR flexibility decreased high rotation of field workers. It decreased the complexity of management and resulted in more consistent decision-making during the response time-line. It also improved establishing local partnerships	Good level of human resource flexibility in those few HOs that adapted low rotation strategy
Local partners	Most of HOs managed to quickly establish a partnership or change it when necessary (for instance after changing their cluster)	Local partners flexibility was in good level in majority of HOs

5.4 Flexibility assessment: fuzzy analysis

The data for the pairwise comparison matrices was gathered from a survey of eight humanitarian logisticians with experience in four or more response operations. At the time of this research, they were working at UNWFP, Oxfam, IRW, WVI, Cordaid, UMN, Humedica, and Handicap International. We sent a questionnaire with pairwise comparisons to them via email with a brief explanation of included terms and concepts. The response rate was 100%.

Having received the pairwise matrices, we constructed the fuzzy comparison matrices by replacing linguistic values with alternative TFNs. Since all consistency ratio (CR) values were lower than 0.1, we concluded that our data was consistent. Thus, we continued to the next step: using fuzzy comparison matrices to calculate the weights of domains and related criteria. Tables 8, 9, 10, 11 and 12 illustrate our results regarding constructed fuzzy matrices, ratio weights, and overall weights.

According to Table 8, the dominant flexibility domains from the experts' viewpoints were distribution and information. Pairwise comparison results for criteria and their overall

Table 8 Fuzzy pairwise matrix for flexibility domains and their weights

Domain	PF	DF	ISF	RF	Normal weight
PF	(1, 1, 1)	(0.23, 0.29, 0.43)	(0.66, 0.84, 1.15)	(1.30, 2.13, 2.91)	0.22
DF	(2.33, 3.39, 4.41)	(1, 1, 1)	(0.66, 0.92, 1.32)	(1.41, 2.25, 3.02)	0.46
ISF	(0.87, 1.19, 1.51)	(0.76, 1.09, 1.51)	(1, 1, 1)	(1.30, 1.96, 2.54)	0.30
RF	(0.34, 0.47, 0.77)	(0.33, 0.44, 0.70)	(0.39, 0.51, 0.77)	(1, 1, 1)	0.01

Table 9 Fuzzy pairwise matrix for product flexibility criteria and their weights

PF criteria	V	M	LS	Ratio weight	Global weight
V	(1, 1, 1)	(1.30, 2.14, 2.91)	(1.09, 1.62, 2.06)	0.522	0.117
M	(0.34, 0.47, 0.77)	(1, 1, 1)	(1.41, 2.06, 2.63)	0.370	0.083
LS	(0.48, 0.62, 0.92)	(0.38, 0.48, 0.70)	(1, 1 ,1)	0.108	0.024

Table 10 Fuzzy pairwise matrix for distribution flexibility criteria and their weights

DF criteria	A	F	D	Ratio weight	Global weight
A	(1, 1, 1)	(0.58, 0.84, 1.32)	(0.42, 0.56, 0.92)	0.219	0.101
F	(0.76, 1.19, 1.73)	(1, 1, 1)	(0.47, 0.58, 0.84)	0.275	0.126
D	(1.09, 1.77, 2.36)	(1.19, 1.71, 2.13)	(1, 1, 1)	0.506	0.232

Table 11 Fuzzy pairwise matrix for information systems flexibility criteria and their weights

ISF criteria	IT	ID	DSS	Ratio weight	Global weight
IT	(1, 1, 1)	(1.09, 1.62, 2.06)	(1, 1.41, 1.73)	0.469	0.143
ID	(0.48, 0.62, 0.92)	(1, 1, 1)	(0.48, 0.62, 0.92)	0.165	0.050
DSS	(0.58, 0.71, 1)	(1.09, 1.62, 2.06)	(1, 1, 1)	0.366	0.112

Table 12 Fuzzy pairwise matrix for resource flexibility criteria and their weights

RF criteria	HR	LP	Ratio weight	Global weight
HR	(1, 1, 1)	(0.29, 0.41, 0.71)	0.125	0.002
LP	(1.41, 2.45, 3.46)	(1, 1, 1)	0.875	0.010

weights (Tables 9, 10, 11 and 12) depicted that delivery, IT support, and fleets criteria had the most influence on flexibility with 23.3, 14.2, and 12.6%, respectively. Product volume with 11.7% and DSS with 11.1%, were the next important criteria. The product mix was among the remaining five criteria with less influence as well as information database, local sources, local partners, and human resources.

This finding is not in line with the CSC literature where product mix is often referred to as one of the main criteria on flexibility (Siham et al. 2015; Sillanpää 2015; Nudurupati et al. 2011). The implications of results from our fuzzy AHP analysis are discussed further in Sect. 6.1.

After determining weights of domains and criteria with the fuzzy AHP, and constructing the fuzzy decision matrix (Table 13), the weighted fuzzy decision matrix was obtained and then normalized (Table 14). Following Kahraman et al.'s formulas (2007), we calculated the distances of each HO from fuzzy positive and negative ideal solutions. Table 15 shows the final results: gaps and satisfaction degree. These degrees indicate how far/close an alternative is from the desired satisfaction level, 1, respectively (Sun 2010).

Despite the importance of distribution and information in flexibility (see Table 8), our analysis shows studied HOs had low flexibility levels in mentioned domains, as shown in Table 13. For instance, with respect to information domain, we observed that information was treated as a product that HOs used for multiple purposes, including attracting funding. Thus, each HO had an interest in creating their own. However, decision makers often had to deal with information conflicts and redundancies in multiple products. Also, the problem with cluster meetings was that some HOs could not participate due to the lack of available human resource. Also, we did not observe any common tool that HOs used for sharing assessment information. Duplications in efforts for needs assessment confirmed this point. Similar evidence (cf. "Appendix B") in our analysis depicted that studied HOs had low levels of flexibility in most criteria, as also later confirmed by interviewees.

According to Table 15, flexibility SDs of all but one of studied HOs are surprisingly less than 0.5. This means the majority of studied downstream networks were far from flexible. Also, this implies that studied HOs need to improve their flexibility significantly if they want to experience less disruptions. Furthermore, difference between highest and lowest satisfaction degrees is remarkable; nearly 0.25. This shows the range of practices for flexibility in studied HOs. Also, the diversity of flexibility levels shows that more than 50% of studied HOs have fairly similar flexibility status (5 HOs with SD between 0.42 and 0.47). These results are further discussed in Sect. 6.

5.5 Improving the flexibility

Having the list of validated criteria for flexibility and their corresponding weights, we developed an aggregation grid, shown in Fig. 4. Within this aggregation grid, all conditions in each level must be met to assess the flexibility accordingly. For instance, if an HO has medium

Table 13 Fuzzy decision matrix by linguistic variables

HO name	Volume	Mix	Local supplier	Assets	Fleets	Delivery	IT support	Information database	DSS tools	Human resource	Local partner
Canadian Red Cross	(1, 3, 5)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)	(5, 7 ,9)	(1, 1, 3)
UNWFP	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)
Oxfam	(1, 3, 5)	(1, 1, 3)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)
Islamic Relief Worldwide	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 1, 3)	(3, 5, 7)	(1, 3, 5)
World Vision Int.	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)
Cordaid	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)	(3, 5, 7)	(3, 5, 7)
United Mission to Nepal	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)
Humedica	(3, 5, 7)	(1, 1, 3)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 1, 3)	(3, 5, 7)	(3, 5, 7)
Handicap Int.	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)

Table 14 Weighted normalized fuzzy decision matrix

HO name	Volume	Mix	Local supplier	Assets	Fleets	Delivery	IT support	Information database	DSS tools	Human resource	Local partner
Canadian Red Cross	(0.013, 0.037, 0.185)	(0.009, 0.009, 0.028)	(0.003, 0.003, 0.010)	…	…	…	…	…	…	…	(0.001, 0.001, 0.004)
UNWFP	(0.065, 0.432, 0.778)	(0.028, 0.046, 0.064)	(0.003, 0.010, 0.017)	…	…	…	…	…	…	…	(0.004, 0.007, 0.010)
Oxfam	(0.013, 0.037, 0.185)	(0.009, 0.009, 0.028)	(0.003, 0.010, 0.017)	…	…	…	…	…	…	…	(0.004, 0.007, 0.010)
Islamic Relief Worldwide	(0.013, 0.037, 0.185)	(0.028, 0.046, 0.064)	(0.003, 0.010, 0.017)	…	…	…	…	…	…	…	(0.001, 0.004, 0.007)
World Vision Int.	(0.013, 0.037, 0.185)	(0.028, 0.046, 0.064)	(0.010, 0.017, 0.024)	…	…	…	…	…	…	…	(0.001, 0.004, 0.007)
Cordaid	(0.013, 0.037, 0.185)	(0.028, 0.046, 0.064)	(0.003, 0.010, 0.017)	…	…	…	…	…	…	…	(0.004, 0.007, 0.010)
United Mission to Nepal	(0.039, 0.185, 0.432)	(0.028, 0.046, 0.064)	(0.003, 0.010, 0.017)	…	…	…	…	…	…	…	(0.004, 0.007, 0.010)
Humedica	(0.039, 0.185, 0.432)	(0.009, 0.009, 0.028)	(0.010, 0.017, 0.024)	…	…	…	…	…	…	…	(0.004, 0.007, 0.010)
Handicap Int.	(0.039, 0.185, 0.432)	(0.028, 0.046, 0.064)	(0.003, 0.010, 0.017)	…	…	…	…	…	…	…	(0.004, 0.007, 0.010)

Table 15 Flexibility satisfaction and gaps degrees of studied HOs

HO name	Satisfaction degree	Gaps degree
Canadian Red Cross	0.4700	0.5300
UN WFP	0.5843	0.4157
Oxfam	0.3959	0.6041
Islamic Relief Worldwide	0.3355	0.6645
World Vision International	0.4292	0.5708
Cordaid	0.4256	0.5744
United Mission to Nepal	0.4492	0.5708
Humedica	0.3432	0.6568
Handicap International	0.4493	0.5707

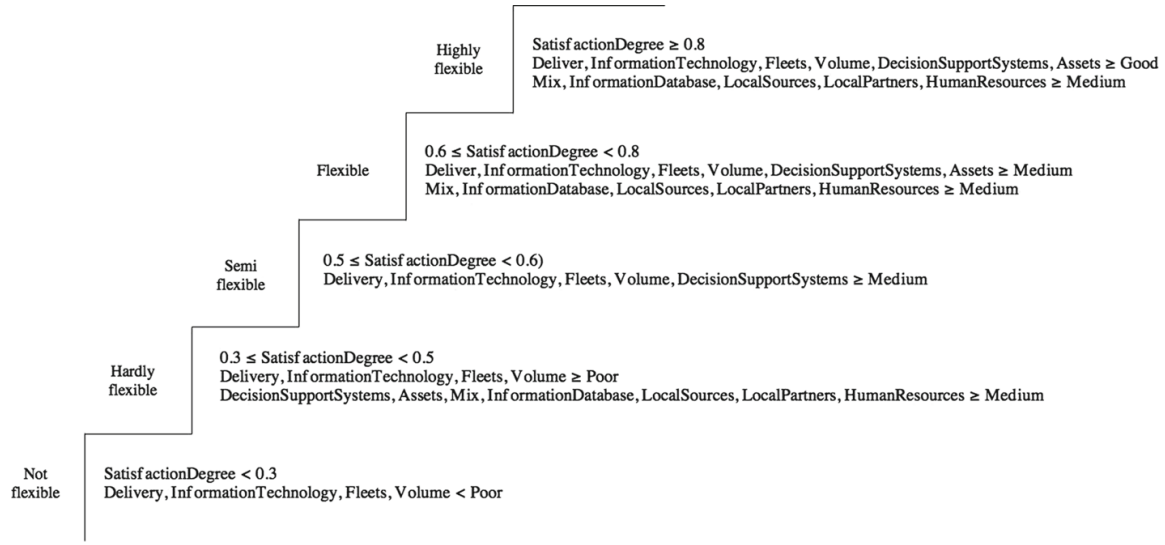

Fig. 4 Aggregation grid for flexibility in HSC downstream

score in delivery, information technology, fleets, volume, and decision support systems but poor score in assets, this means it is not flexible (but semi-flexible).

Comparing flexibility levels of Fig. 4 with our finding in Table 15, one can notice that the majority of our studied HOs had 'Hardly flexible' downstream SCs during the Nepal response. The only 'Semi flexible' downstream SC belonged to UNWFP (with a better flexibility SD in comparison to the other studied HOs). Hence, we continue the interpretation by focusing on UNWFP's best practices. This approach helps other HOs to develop improvement plans. Given the organizational size of UNWFP and their access to resources (monetary and non-monetary), other HOs may need to consider relevant constraints when reviewing UNWFP's practices.

Following best practices are mainly derived from comparing our key observations in the field for each criterion with relevant literature. We also selected those practices that improved relief operations in Nepal, in comparison to previous operations, according to interviews.

– Effective use of information and communication technology (ICT) tools for different processes including dispatching, warehousing, etc. (Van de Walle and Turoff 2007; Perego et al. 2011).

– Having access to a wide range of fleets. Other HOs can enable such access by establishing partnerships with logistics service providers (LSPs) that provide different fleet types (Vega and Roussat 2015; Baharmand et al. 2017).
– The number of UNWFPs' staging areas (SAs) and their geographical distribution. We noticed that UNWFP was the only HO with more than one SA. These SAs were located in different affected areas enabling quick access and remarkable storage capacity (Glenn Richey Jr et al. 2009).
– The use of DSS for operational decisions in the field which has shown the ability to improve the performance in critical situations (Baharmand et al. 2015).

To understand why UNWFP chose a different approach (and what constraints other HOs had) a deeper analysis of empirical data is required. Our observations showed that UNWFP invested partly in mobile storage units, IT tools, information database, partnerships, pre-stocking of highly demanded relief items, local procurement, and collaboration with local partners. Such efforts were not observed in any of other HOs due to policy issues and a lack of sufficient monetary resources, according to interviewees.

In addition, it is necessary to answer what UNWFP can do to improve. Further investigation of scores in Table 14 shows that UNWFP local procurement and collaboration with local partners can be improved. UNWFP tried to import pre-stocked items from their regional warehoused but problems with customs delayed the delivery. In this regard, some other HOs faced less problems mainly because they procured relief items from local markets, or through local partners that had surplus resources (Baharmand et al. 2016). Another improvement targets can be delivery and DSS tools. Although UNWFP established contracts with locals to supply required fleets, number of available helicopters was not sufficient for timely delivery during the immediate response. Also, according to our interviews, Logistics Cluster (ran by UNWFP) faced some challenges in adapting their delivery scheduling DSS tool to Nepal context. These two challenges decreased the timeliness of deliveries for UNWFP and other HOs who were working under the Logistics Cluster.

6 Discussion and implications

The Nepal case showed that the relevance and the impact of a criterion for measuring flexibility highly depends on the context. In our study, the list of criteria included volume, mix, local sourcing, assets, fleets, delivery, IT support, information database, DSS, human resources, and local partners. Having compared our lists with commercial literature (for instance Siham et al. 2015 or Sillanpää 2015), we noticed that verifying elements of our measurement framework before implementation is of great importance.

The chance to study HSC flexibility in the Nepal response offered some interesting insights for specific challenges. For instance, some severely affected areas with high demand were in remote and hard-to-reach areas. This entailed constrained access (also by helicopters) and challenged HOs' flexibility in some criteria like delivery significantly. Furthermore, due to governmental policies that restricted importing some relief items, HOs had to procure items from local markets while production volumes were limited. While for the former, HOs managed to adapt ad-hoc relief transportation modes (changing from trucks to trails of porters), for the latter, they looked for substitute relief items in the same cluster that could be procured in high volume from local markets (different shelter kits).

Our finding regarding the low levels of flexibility explains why many HSC disruptions occurred in the Nepal response. It refers to limited possibilities to efficiently respond to

environmental, political, and operational challenges. This is also in line with our observations that most HOs in the Nepal response were investing more efforts to respond to disruptions after they happened. Not having flexible SCs, HOs often had to re- organize, plan, and schedule relief operations which resulted in delays.

We also observed that HSCs' flexibility evolved considerably between immediate response and early recovery in Nepal. Our interviews confirmed that issues in some criteria, like volume, assets, and fleets, were resolved in the early recovery (partially or completely). This was due to capacities that corresponding HOs could establish.

To find out how HOs can enhance their SCs' flexibility, our framework offers practical solutions. Comparing the top HO from our fuzzy TOPSIS analysis, UNWFP, with others helped us to recommend best practices for enhancing flexibility. Among them, sharing assets, access to a good variety of fleets, and using IT support are promising enhancement criteria. Such comparisons can bring insights for HOs to challenge their strategies and/or adapt new ones in future response. Meanwhile, we note that the specific settings of Nepal case (for instance topography) have to be considered before generalizing the practices for other cases.

Although improving flexibility in some domains may not be the most efficient way to decrease disruptions, it is an effective one. Preparing alternative delivery plans, improving access to information and establishing information sharing platforms, enabling multi-modal transportation, sharing assets, and using IT solutions for more accurate demand estimation can be considered to improve flexibility. Resilience and agility in HSC cannot be reached without medium/high levels of flexibility (Charles et al. 2010; Heckmann et al. 2015). With respect to our framework, this means to have at least medium scores in delivery, IT, fleets, volume, and DSS flexibility criteria.

6.1 Implications for theory

Our study supports HSC literature regarding the impact of different domains and criteria on flexibility. For instance, it validates the positive influence of product mix (Vaillancourt 2016) and using IT (Kabra and Ramesh 2016) on HSCs' flexibility. Similarly, delivery and decision support systems, which ranked first and fifth in our fuzzy AHP analysis respectively, had been previously referred to as important factors for flexibility (Charles et al. 2010).

Our research has the following contributions to the theory.

- We provide a clear definition of HSC flexibility in the response given the characteristics of disaster settings.
- We introduce criteria for measuring flexibility in the context of HSC that were not considered in previous studies. For instance, we incorporated criteria related to information systems and resources in HSC context for the first time.
- We show that differences between CSCs and HSCs as well as the focusing scope (upstream vs. downstream) impacts flexibility criteria.

Surprisingly, our finding regarding the low levels of flexibility in the majority of studied HSCs is not consistent with literature. In their research, Santarelli et al. (2015) and Scholten et al. (2010) explain that HOs have high levels of flexibility in their SCs while we could not confirm this in Nepal case. The divergence can be explained by the differences between either the set of flexibility measurement criteria, corresponding weights for them, or the specific topography of Nepal. Hence, two other implications for theory can be suggested.

- Our study shows that the effective use of weights helps to account for the practitioners' preferences in the measurement system.

– Due to differences between distinct contexts (humanitarian vs. commercial, response vs. recovery, case A vs. case B, etc.), generalization of one framework to another context is hardly possible, if not impossible. This implies the need for studying the adaptation of measurement frameworks to other contexts.

6.2 Implications for practice

Our measurement framework has three main implications for practice.

– It helps HOs to assess their flexibility level without following all steps of the fuzzy analysis. They just need to use the evaluation and aggregation grids to measure their performance within each criterion (cf. "Appendix A") and then assess their level. However, special care is required since the criteria for the Nepal case may not be applicable in other contexts.
– Our non-compensatory approach can help HOs to design their improvement plans with respect to their desired flexibility level. To get the best of our framework for downstream of HSCs, our proposed aggregation grid can be of great help. Each desired flexibility level is addressed with a criteria profile. When practitioners decide what their desired level is, they can incorporate our grid to find out which criteria they have to concentrate on. Being able to design the improvement plan by using our grid, we suggest to incorporate other sources (best practices from literature or other HOs) to develop further detailed plans.
  For instance, we showed that improving flexibility in delivery, IT support, fleets, and volume impact the level of flexibility in HSC downstream significantly. In this regard, reviewing best practices for IT support in humanitarian contexts confirms that inclusion of ICT tools in different processes including planning, controlling, tracking, and monitoring improves HSC network performance (Tchouakeu et al. 2013). Similarly, using logistics service providers (LSPs) for managing fleets and other logistics activities enables better risk management and enhances relief distribution performance (Baharmand et al. 2017).
– Our framework can act as a prerequisite for implementing network design concepts that flexibility is among their key drivers, such as resilience and agility. Considering results of the framework, before recommending models or simulations for the design of the downstream network, leads to more convincing solutions.

7 Conclusions

In this paper, we aim at supporting humanitarian organizations (HOs) to improve their ability to deal systematically with disruptions in their supply chains (SCs). Planning towards agility and resilience in SCs helps to deal with potential disruptions, irrespective of when and where they occur.

Network flexibility is often referred as the primary driver of resilience and agility in commercial literature. However, in the humanitarian literature, network flexibility has not been adequately discussed. Furthermore, to the best of our knowledge, no framework has been developed to measure the network flexibility of humanitarian SC (HSC) with a concrete application case. Without tools for measuring network flexibility in HSCs, practitioners are left with their intuition and experience to improve it.

Given aforementioned gaps in the humanitarian literature, our paper has a threefold contribution. First, we define network flexibility in the context of humanitarian response after a sudden onset disaster. Second, we propose a framework for measuring network flexibility

in HSCs that covers a wide range of flexibility domains and criteria. Our framework uses linguistic variables and follows simple computational approaches. Therefore, it is easy to understand, implement and is based on experts' viewpoints. We suggest conducting field research as the main methodology for collecting relevant data for both verification and application of the framework. Third, we examine the proposed framework in the light of our findings based on a field research after the 2015 Nepal earthquake.

Our results show that delivery, IT support, fleets, and product volume have the most influence on overall flexibility level. Hence, dedicating more efforts on improving them can increase HSC flexibility significantly. We also found low levels of flexibility in the downstream network of majority of studied HOs. This finding explains why several disruptions happened in relief distributions during the Nepal response. To improve the network flexibility, we developed an aggregation grid based on the impact of each criterion in our study. Using the suggested grid through two proposed approaches helps HOs to improve the network flexibility of their SCs' effectively.

Our field study in Nepal imposed some limitations to this research. First, Nepal's topography, comparing to other earthquake-affected countries like Japan, is specific and this brought several logistics challenges to relief delivery. Nepal is located in Himalaya and thus, some affected areas could not be reached by trucks or even helicopters. Besides, high-capacity transportation infrastructures, like highways, were not available. Instead of effective and timely relief shipment with large 15mTons trucks, HOs had to revert to 3m Tons 4×4 trucks and tractors. Although road blockage can be common after disasters, narrow roadways and mountainous context of Nepal constrained relief support through air and ground considerably. This means the contextual characteristics should be considered carefully for practical implications of our framework. Hence, further empirical research on the application of our proposed framework on other cases across disasters is required. Second, due to the timeframe of our field research, we could not effectively investigate temporal evolution of flexibility within the response, which we leave for future work.

With respect to flexibility criteria, there are two criteria that we could not collect relevant information in our field research despite their importance; donors' flexibility and policies flexibility. Moreover, our Nepal field research focused only on downstream network. Therefore, routing/access and trans-shipment flexibility were not applicable, and a complementary research on upstream is needed. Also, evaluation of the framework with practitioners and implementation of the improvement system have to be further investigated. Another important research direction is to study the impact of flexibility on HSC resilience and/or overall HSC performance.

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A Evaluation grids

Table 16 shows the measurement grid for flexibility criteria.

Table 16 Metrics and measurement grid for flexibility criteria

Flexibility criteria	Metrics	Very poor (score = 0)	Poor (score = 1)	Medium (score = 2)	Good (score = 3)	Very good (score = 4)
Volume	Number of households supported by relief operations, on average (Charles et al. 2010)	Less than 1000 households	Between 1000 and 5000 households	Between 5000 and 15,000 households	Between 15,000 and 30,000	More than 30,000 households
	Advocacy between local storage capacity and demands	Support max. 20% of targeted beneficiaries	Support max. 40% of targeted beneficiaries	Support max. 60% of targeted beneficiaries	Support max. 80% of targeted beneficiaries	Support more than 80% of targeted beneficiaries
	Assessment of volume criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$
Mix	Number of distinct relief item types being targeted for distribution	Only 1 type	1 or 2 Types	3 or 4 Types	4 or 5 Types	More than four types
	Number of distinct relief item types being shipped to different distribution centers, on average	Only 1 type	1 or 2 Types	3 or 4 Types	4 or 5 Types	More than four types
	Assessment of mix criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$
Local sourcing	Number of local suppliers selected per relief item, on average	No local supplier	Very few product types are bought from local market with no specific contract	Some products are bought from local market, but very few specific contract	Some products are bought from local market but not all through a contract based process	All products are bought from local market through a contract based process
Assets	Number of local storage or distribution centers	Only 1 place	1 or 2 Places	2 or 3 Places	3 or 4 Places	More than 4 places
Fleet	Number of accessible and available fleet types (including air delivery and outsourcing)	Only 1 type	1 or 2 Types	2 or 3 Types	3 or 4 Types	More than 4 types

Table 16 continued

Flexibility criteria	Metrics	Very poor (score = 0)	Poor (score = 1)	Medium (score = 2)	Good (score = 3)	Very good (score = 4)
	Number of carriers used for each type of transportation modes (except air delivery), on average	Less than 5	Between 6 and 10	Between 11 and 15	Between 16 and 20	More than 20
	Assessment of fleet criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$
Delivery	Required time to change delivery plans	3 days or more	Between 2 and 3 days	between 1 and 2 days	Less than 1 day	Less than half day
	Number of alternative ready-to-implement delivery plans	No alternative plan	1	2	3	More than 3
	Assessment of delivery criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$
IT support	Using IT/ICT systems	No usage	For information gathering or sharing	For informations sharing + need assessment/material tracking	For information sharing + need assessment + material tracking	For information sharing + need assessment + material tracking + fleet/HR tracking
Information database	Having access to data storing facilities in the field	No access	For internally shared data	For internally shared and externally collected data	For internal and external data + real-time data from the people on the ground	For internal + external + real time data + capacity to integrate new data formats

Table 16 continued

Flexibility criteria	Metrics	Very poor (score = 0)	Poor (score = 1)	Medium (score = 2)	Good (score = 3)	Very good (score = 4)
Decision support tools	No specific DSS for field	DSS for operational decisions like scheduling	Web-based DSS for operational + tactical decisions like allocation	Local-based DSS for operational + tactical	Local-based DSS for all levels of logistics decisions	
Human resource	HR deployment to affected area	From own HR pool at the head quarters (HQ) office	From own pool at worldwide offices	From own HR pool at local or neighbor country office	From own pool + possibility to hire local workforce immediately	From own pool + local workforce + possibility to hire partners' workforces
Local partner	Partnership with local NGOs or international HOs who are active in current context	No partnership	In process of establishing partnership	Partner with 1 NGO or 1 HO	Partner with 1 or more NGO + 1 HO	Partner with more than 1 NGO and 1 HO
	Partnership with local logistics service providers (LSP)	No partnership	In process of establishing partnership	Partner with 1 LSP for warehousing or transportation	Partner with 1 LSP for warehousing and transportation	Outsourced logistics to 1 or more LSP(s)
	Assessment of local partner criteria	$(\sum Scores) < 2$	$2 \leq (\sum) < 4$	$4 \leq (\sum) < 6$	$6 \leq (\sum) < 7$	$(\sum) \geq 7$

B Details of field findings

B.1 Volume

Up 21st June 2015, nearly 8733 mt of relief items were sent to the affected areas by 110 different organizations (UNWFP 2015a). The share of relief items for distribution depended on the objectives of the HOs and changed over time: all interviewees mentioned that in the first days they primarily wanted to access the affected areas and distribute any relief item available to address the tremendous humanitarian needs. Therefore, the quantity of distribution was determined exclusively by available capacities and means for distribution. If standard items could not be sourced, some HOs replaced scarce standard items by entirely different products, e.g. food items instead of shelter sheets, that they could manage to procure in high volumes. However, we observed that volume and mix flexibility interrelate to each other and HOs often face trade-offs between these two criteria.

"So the government put restrictions in place which made [procuring and distributing shelter sheets] impossible and so we withdrew that and said: Okay, were not going to do it …we decided food items it was the right decision." (26. 06. 2015, UMN, Kathmandu)

"We had to stay in a long queue for sheets; then we decided to focus on kitchen items." (28. 06. 2015, Humedica, Kathmandu)

In the later response, almost 2 weeks after the major aftershock of 12th May, organizations targeted a service level of 80 to 85 percent across all affected areas within food, health, and shelter clusters. However, data uncertainties were a major barrier to planning: all interviewees confirmed that the estimated needs were incorrect, although initial assessments based on Government Census reports were replaced by the multi-cluster initial rapid assessment (MIRA) and assessments by country teams of some HOs (WVI, UMN, UNWFP).

"But both [assessments] didnt match, because it kept increasing, so we still dont know what the final number of households is." (24. 06. 2015, Cordaid, Kalikasthan)

"…in the beginning it was about 7,000 households and then it increased up to 9,000 households and by the time we are done it's been more than 10,000 households We are coming to the conclusion that it will be more than 11,000." (26. 06. 2015, UMN, Kathmandu)

Indeed, a lack of concrete information regarding the needs, and limitations due to government policies in procurement and customs control, hampered operations. HOs who had volume flexibility adapted their supply chains to fluctuations in demand and changes in policies. However, our observations in field trips revealed that these HOs with volume flexibility were either focusing on only one relief material in few village development committees (VDCs) (Humedica) or they had establishments in Nepal prior to the earthquakes (UMN).

B.2 Mix

All representatives mentioned that their product mix flexibility is relatively low in overall: except for the first days of the response, they prefer to focus on one category of relief items, typically linked to a specific cluster.

"…currently we are only involved in shelter cluster …we have already signed the contracts, and the local manufacturer is delivering the sheets to our warehouse." (24. 06. 2015, Cordaid, Kalikasthan)

"We couldn't wait in the long queue to provide sheets for shelter…we decided to focus on food items." (26. 06. 2015, UMN, Kathmandu)

"We wanted to provide something that can be procured easily from the local market. Therefore, we found some vendors for kitchen items" (28. 06. 2015, Humedica, Kathmandu)

In comparison to relatively low flexibility in overall, we observed that high levels of mix flexibility in one cluster brought some challenges to beneficiaries. Despite the available guidelines for kitted relief items, relief, packages were not standardized in terms of included items, size, and weight. Sometimes they were too heavy to be carried by beneficiaries and porters. For instance, a package that one organization was distributing weighed overall more than 50kg, and it required at least two persons to carry (2015b). Other packs only included 10Kg of rice which brought about criticisms:

"Two days, they needed to eat on the way. Now that 10kg is gone by the time they get home, so it wasnt worth coming. And not only that, all the bridges were affected, and there were so many landslides. They had to risk their lives to come and get those things, so it wasnt worth coming…It caused a few problems elsewhere because communities just said, no, we dont want yours, were going to wait for UMN to come and give us theirs." (26. 06. 2015, UMN, Kathmandu)

Despite the variety of demands in different affected areas, HOs preferred to work on only one cluster in Nepal response. Providing standardized relief packages was challenging due to procurement problems. For instance, active HOs in food cluster faced several challenges with respect to requirements for storage and transportation due to less flexibility in those domains. In this regard, we observed that sharing resources improved the situation considerably.

B.3 Local sourcing

Different affected areas had distinct priorities and needs. As the surge of demands exceeded the local market capacity, local sourcing for shelter items, specifically CGI sheets, was causing delays. Only two local manufacturers were present at the moment of our field research and all their products, were sold out for the next 4 months to the HOs who signed the first contracts.

"We contacted local manufacturer…they told us that their CGI sheets are sold out, and we have to wait in the queue…" (26. 06. 2015, UMN, Kathmandu)

"Currently, it is extremely hard to find CGI sheets, locals are sold out, and there is a long queue." (26. 05. 2015, IRW, Kathmandu)

"In cluster meetings, we found out that one organization has a lot of CGI sheets in their warehouses because they already had contracts with the manufacturer before the earthquake…We contacted them…We asked them to give us a part of their supplies…We will give them back when our own purchase arrives." (23. 06. 2015, WVI, Kathmandu)

These sheets were used in shelter roofing and therefore, other HOs who wanted to remain active in the shelter cluster needed to procure them internationally. The Nepalese Government, on the other hand, had put strict regulations on importing CGI sheets and some relief items.

"We brought several items to the Indian border, but we couldn't get them in after three weeks. It was a bad situation because of spoilage. Our trucks were kept there. Therefore, we decided to distribute items near the border and send the trucks back." (26. 05. 2015, IRW, Kathmandu)

"Our partners are trying their best to get customs clearance. It has been two weeks, I think." (23. 06. 2015, WVI, Kathmandu)

The lack of flexibility in local sourcing almost doubled prices for high priority relief items on the local market (28. 06. 2015, local newspaper) and caused significant delays up to several weeks. Therefore, some representatives mentioned that they changed their targeted relief items if they had enough mix flexibility (WVI and Humedica). As a result, these HOs also needed to change their coordination cluster as well (from shelter to food cluster). Some HOs (UMN and Oxfam) tried to procure relief items from the same category in the local market (tarpaulin instead of CGI sheets).

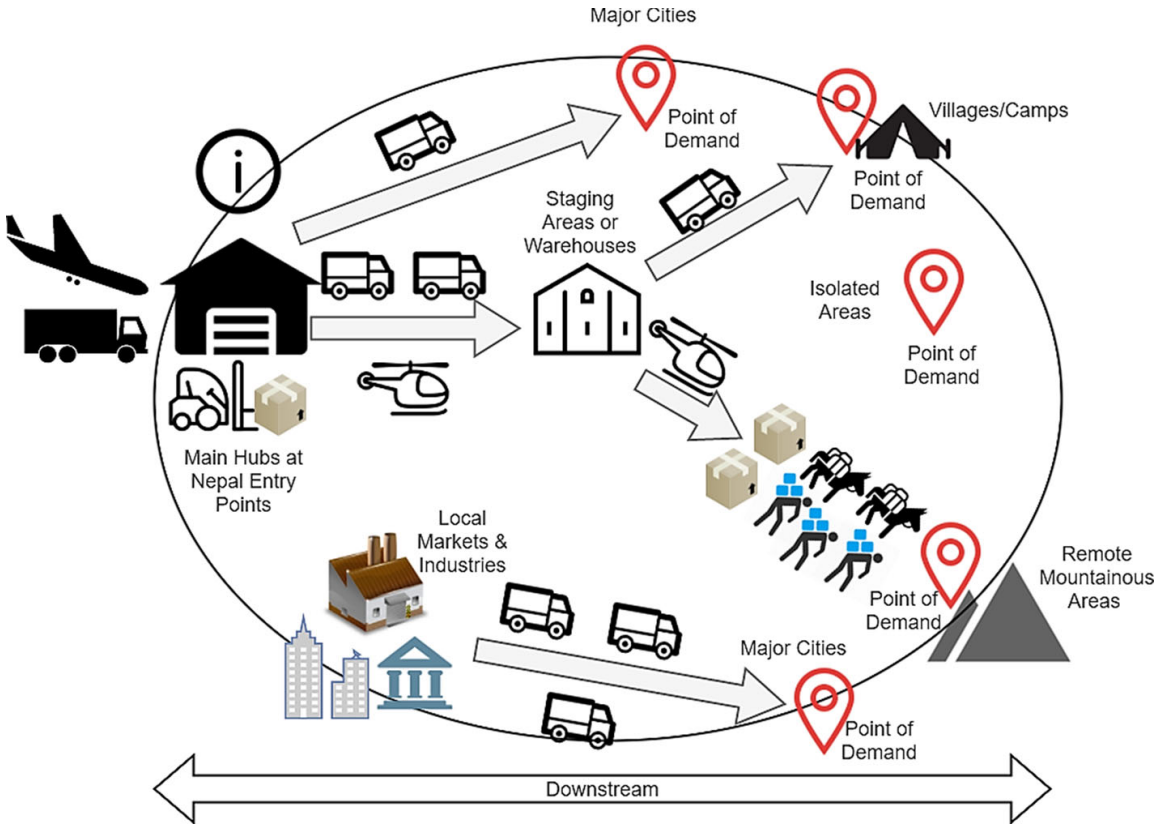

Fig. 5 Typical HSC downstream network in Nepal response

B.4 Assets

In terms of asset flexibility, we focus here on warehouses. The observed structure of HSC networks in Nepal differed from literature, which typically assumes a layered network of local distribution centers. The mountainous and hard to access areas outside the capital, however, implied that there were hardly any local distribution centers. After arrival at the international airport in Kathmandu or at the borders, the material was shipped to the central warehouse(s) of the HOs. From there, relief items were sent directly to the affected areas. Figure 5 depicts a HSC downstream scheme typical for the situation in Nepal.

Interviewees from iNGOs mentioned that the strategic facility locations decisions were made immediately upon arrival in Nepal based on availability and distance to affected areas (IRW, UMN, WVI, Cordaid, and Humedica representatives). Some of them already had pre-deployed assets due to their presence before the event of earthquakes (UMN and Cordaid) and few interviewees referred to the possibility to share assets with other HOs (UMN and WFP).

"I took the first place that I found because the cargo was coming and I didn't have enough time to look further!" (28. 06. 2015, Humedica, Kathmandu)

"By the time the disaster comes, our current warehouse was used for something else. And actually, it worked out quite well because it took us a couple of weeks to get a procurement coming in, goods coming in. …I mean even now I think were looking for another one because of the ongoing work." (26. 06. 2015, UMN, Kathmandu)

Our interviews and observations confirmed that there is a connection: asset flexibility is a constraint for volume flexibility. More effort invested in suitable assets meant less probability to change location during the response. Given time pressure, sharing assets or using portable

warehouses provided more flexibility. However, we observed only few HOs sharing their assets (WFP). Furthermore, not all HOs have the access and resources to deploy portable warehouses, e.g. big tents.

B.5 Fleet and transportation

The mountainous topography of Nepal brought many logistics challenges. Standard road transportation was often impossible, although HOs truck provision worked in general well. Some hired fleet delegates from local logistic service providers (Canadian Red Cross and IRW), and others did their road transportation themselves or through the Logistics Cluster. However, all interviewees mentioned that access to helicopters the only asset for air transportation to remote mountain areas - was difficult and required seven to ten days pre-planning. Because of the shortage of helicopters, air transport was dedicated to high priority relief items only, i.e. corrugated galvanized iron (CGI) sheets for shelter. Therefore, HOs who specialized on shelter, or those who were flexible in the product mix were able to request air transportation. Also, some of them took the benefit of a pre-established connection with the air transport service providers.

"We wanted to deliver NFI kits and Food packages, but also, we knew that we have to mention CGI sheets also in the forms to be in the queue. So we fill request forms with CGI sheets and after that with other items." (22. 06. 2015, WVI, Kathmandu)

"I prioritize [shelter] relief items and apart from that, I put the other food stuff items into one form so that we were in the queue." (23. 06. 2015, UMN, Kathmandu)

"When they first arrived [in Nepal] nobody really knew about them [MAF] but we, we used them. We were the first one on the list first day of operation." (23. 06. 2015, UMN, Kathmandu)

Because some affected areas were located in high altitudes and helicopters could not reach them, animal or human porters were used for last mile distribution (UNWFP 2015b). In this case, staging points to break bulks were set up, which could be reached by trucks or helicopters. From there, porters were responsible for the last mile delivery to beneficiaries which sometimes took 2–3 days (UNWFP 2015c). Overall, a combination of transportation modes was used by a few HOs among our participants (WFP, WVI, and UMN) since the others were not active in the most remote mountainous affected areas.

Due to delivery challenges (see Sect. B.6), most HOs struggled with challenges in substituting fleets in the last minutes or rescheduling (all representatives except Canadian Red Cross) that resulted in delivery delays. For instance, during our field trip to Rasuwa, we observed that delays in delivering shelter sheets combined with the start of the rainy season, forced several families to move together.

B.6 Delivery

Transportation planning was dominated by operations, and typically, plans were made and updated daily (interviews with UMN, Cordaid, and WVI representatives). Owing to the volatility of the situation, and the continuous risk of road blockage (e.g., by landslides), relief organizations had to update their plans every time new information was received (WVI and UMN representatives).

"Every five minutes! Whenever new information comes, we change the plan. For instance, the helicopter thing was really crucial, and we didnt know …I mean how many times we had to ask in those first days for the helicopter. We had no idea how long it would take." (26. 06. 2015, UMN, Kathmandu)

Because of those conditions, drivers frequently refused transports (IFRC representative). Since no alternative schedules were pre-planned (confirmed by all interviewees), and because there were no systems for rapid rescheduling, delivery dates were frequently not met, causing backlogs and under-supplies.

B.7 IT support

The use of computers, networking, cell-phone data and other physical devices to handle data were visible at headquarters level in Kathmandu. The logistics cluster supported other HOs with information products and maps (129 situation updates until the date of field research). Other HOs contributed by reporting their field observations during relief operations, like roads status.

We observed a similar information management set up at different coordination centres in Kathmandu. All interviewees indicated the important role of IT tools specifically for coordination and information sharing during their relief operations. Despite the lack of common data sharing system among HOs, cluster meetings acted as a coordination place where representatives could find answers for some of their questions. However, not all of HOs could participate in such meetings due to their human resource restrictions, and they prefer to read the meeting minutes that were shared online or were sent to registered email addresses.

"Cluster meetings are really helpful, and everyone tries to get information there…If we have a question or need something, we can go directly and ask." (23. 06. 2015, WVI, Kathmandu)

"We always have someone in cluster meetings we have to find what we need there…WFP helps us with updated information in cluster meetings…" (26. 06. 2015, UMN, Kathmandu)

"We are only three, and we cannot be at several places at the same time. I try to participate but since I have been here [4 weeks], I could go there only once…so I usually use minutes" (28. 06. 2015, Humedica, Kathmandu)

Our field observations confirmed that ICT helped significantly in coordinating relief operations. Since communication infrastructures in many affected areas were back to work quickly (in two to three days), HOs were able to establish their remote connection for coordination. According to local newspapers, access to cell-phone networks, radios, and satellites was effectively possible in Kathmandu two days after the earthquakes. However, not all affected areas experience the same. Up to the date of our field research, practitioners still had a lot of problems to contact their partners in mountainous areas.

"They have to go to the top of the hill, a certain hill, and there they get reception. Anywhere else they cant get reception…So sometimes it was so frustrating like when we needed information and […] or when we needed to communicate, like, "We have helicopter tomorrow," they wouldnt call us and its so frustrating. So it was challenging sometimes…" (26. 06. 2015, UMN, Kathmandu)

By improving the IT support, HOs could enhance their assessments, data collection, information sharing and coordination in Nepal response. Furthermore, they could compare the information through different sources (WFP) and verify them before sharing through online platforms (like Reliefweb). In this regard, access to reliable information was enhanced since the aftermath of disaster.

B.8 Information database

Despite the increasing availability of tracking and tracing technology, incoming and outgoing items in Nepal were counted manually. Related paper-based forms were completed by

warehouse managers and then transferred to Excel sheets. The lack of integrated inventory management software and human error resulted in the need for several inventory controls during the distribution operations for all interviewed organizations.

In the Rasuwa district, various HOs conducted surveys to assess the humanitarian needs and opportunities for local sourcing. During our visit, which coincided with the formal transition from the response to the early recovery phase, the majority of HOs were in the process of adding granularity to their data. As in other natural disasters (Altay and Labonte 2014; Van de Walle and Comes 2015) the Nepal case also followed a transition from initial high-level assessments to more granular information products as time passed. This information often composed of the number of current habitants/households, their personal information, belongings, losses, land/house status, and received financial assistance.

"It is like a newspaper. If you read about an area you do not know, its always informative and seems right, but if you read about your area, you always know its incomplete." (22. 06. 2015, Canadian Red Cross)

"Our partner in collaboration with our own staff do the need assessment …they went door-by-door and ask their needs." (23. 06. 2015, WVI, Kathmandu)

As we witnessed, the methods and detail at which such information was collected varied tremendously; for instance, door to door assessment, local representatives, and households documents. However, no database was developed to manage and store this information.

"International NGOs rarely had a database system that tracks the field updates from the beginning of response." (26. 06. 2015, UNWFP, Kathmandu)

We also observed duplication of need assessment efforts. International HOs and their partner NGOs were running various needs assessments to fulfill their data needs and hence, the ones operating in similar areas collected the same data. Therefore, due to common use of papers and lack of specifically developed database, the need of more experienced human resources was increased in HOs. In response, one HO (Cordaid) decided to develop an ad-hoc information database which could share assessments and beneficiaries information with the Nepalese Government as well. Linking information databases with inventory management systems in WFP, expanded more visibility in the downstream and enabled rapid adaptation. It also facilitated information sharing within other relief organizations.

B.9 Decision support system (DSS)

Interviewees confirmed the frequently reported skepticism against technology and computational decision support tools in the field (Crum et al. 2011; Kovács and Spens 2012; Comes and Van de Walle 2016). Arguments against the operational use of DSS include that the tools require time, processing capacity, computational resources, and specific expertise to enter data and interpret results. Among our interviewees, only the logistics cluster used a DSS [1] for transportation scheduling. In addition, we also found evidence of field staff trying to avoid the role of decision-maker.

"We are not deciding, but the partner is. The partner will come with the new plan so after the assessment, they have some documentation about what is the need for this VDC. After that, we will decide together." (24. 06. 2015, Cordaid, Kalikasthan)

"We don't have much time for that [DSS] I have some considerations myself for making decisions." (26. 05. 2015, IRW, Kathmandu)

The lack of technology support resulted in overly simplifying assumptions and the use of heuristics, which is well documented also for other cases (Comes 2016). In Nepal, typically,

[1] RITA system: http://www.logcluster.org/cargo-tracking.

few variables and parameters were considered in decision-making, although the underlying problems were complex, e.g. having numbers of warehouses with capacities $\leq 500\,m^2$ in different places instead of one with capacity $\geq 1500\,m^2$, the available parking space for trucks, or access to the helipad for decisions regarding warehouse locations.

This lack of structured support in addressing complex problems resulted in inefficiencies such as congestions, loading/offloading problems, and delays, which were reported by all interviewees.

B.10 Human resources

Human resources in HOs were keys to coordination and efficient use of assets, fleets, and materials. Since all studied HOs were international, most of their high and mid-level human resources were international. Operational levels were staffed with local human resources since they had the most interactions with local communities. HOs hired local human resources as fleet delegates, warehouse or procurement manager to strengthen the negotiation capacity and overcome language or cultural barriers.

Furthermore, through local staff, HOs accessed vital information during relief operations, e.g., regarding roads, bridges, and village status. Therefore, they improve the capacity of HO with new and reliable information.

"So I [as a local HR] can call the locals and know about the road conditions and every other thing that we want. We can call them in advance and ask like [whether the] road is OK or not? Sometimes there are landslides in Dhunche, and first, we have to know the road conditions and other related things, so I do that before the departure…on the highway, we also know all the police stations…because we cannot work if we don't have any connection." (22. 06. 2015, Canadian Red Cross, Kathmandu)

"Its quite difficult to verify the new information about the situation. You dont verify when youre trying to use it. You can waste several days taking goods on a path that doesnt exist. So I mean its a pretty big risk unless you had confidence that the source of the information was a good source [like local HR]." (23. 06. 2015, WVI, Kathmandu)

We observed only simple and inefficient mechanisms to organize volunteers in Nepal response, e.g. office registration, also pointing at a lack of database flexibility and IT support. Furthermore, HOs had started to replace their international staff with local human resources as they assumed the situation was becoming more stable. However, rainy season complicated the situation in some parts and new staff lacked experience. Therefore, increasing this criterion flexibility has some limitations that need to be considered.

Despite the challenges, we observed that improving HR flexibility decreased high rotation of field workers. This rotations added to the complexity of management due to diversity in viewpoints As a result of HR flexibility, some interviewees expressed more consistent decision-making (Canadian Red Cross and UMN) in addition to improvements in establishing local partnerships.

B.11 Local partners

The Nepalese Government required all international HOs, to partner with local organizations. Those partners were often local NGOs who distributed relief items to villages.

"We don't do the distribution, our local partner does. We just procure items, and they do the rest." (23. 06. 2015, WVI, Kathmandu)

They also assisted with finding local manufacturers, negotiations with customs control, and recruiting volunteers. Among the studied HOs, some had a pre-established partnership

with local NGO(s) and therefore, they could start their operations faster. Local partners also led operational decision-making.

"We are not deciding, but the partner is. The partner will come with the new plan so after the assessment, they have some documentation about what is the need for this VDC. After that, we will decide together." (24. 06. 2015, Cordaid, Kalikasthan)

However, a lack of flexibility to engage in new partnerships where necessary and insufficient HR flexibility to facilitate the situations delayed the processes and procedures:

"I have to go with them in distribution. I have to go myself and see how they do it It's our first partnership, and we don't know them well." (28. 06. 2015, Humedica, Kathmandu)

According to our observations, we found that this criterion flexibility was among the best practices of HOs. Most of them managed to quickly establish a partnership or change it when necessary (for instance after changing their cluster). Interviewees mentioned that they have defined partnership protocols. In addition to the support that local partner flexibility can provide for other criteria, it supports the community empowerment (Baharmand et al. 2017).

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