Towards a sustainable humanitarian supply chain: characterization, assessment and decision-support

Laura Laguna Salvadó

THÈSE

en vue de l'obtention du

DOCTORAT DE L'UNIVERSITÉ DE TOULOUSE

délivré par
IMT – École Nationale Supérieure des Mines d'Albi-Carmaux

---

présentée et soutenue par

Laura LAGUNA SALVADÓ

le 9 avril 2018

Towards a Sustainable Humanitarian Supply Chain
Characterization, Assessment and Decision-support

École doctorale et discipline ou spécialité :
EDSYS : Génie industriel et informatique

Unité de recherche :
Centre Génie Industriel, IMT Mines Albi

Directeur(s) de Thèse :
Matthieu Lauras, Maître-Assistant, HDR, IMT Mines Albi
Tina Comes, Professeur, University of Agder (UiA)

Autres membres du jury :
Gyöngyi Kovács, Professeur, Hanken School of Economics Helsinki, *(Rapporteur)*
Valérie Botta-Genoulaz, Professeur, INSA Lyon, *(Rapporteur)*
Chihab Hanachi, Professeur, IRIT Toulouse, *(Président)*
Dubey Rameshwar, Professeur Associé, Montpellier Business School, *(Examinateur)*

Contents

Remerciements

C’est Matthieu qui m’a poussée à transformer ma curiosité pour le domaine de la logistique humanitaire en travaux de recherche. Merci Matthieu, merci beaucoup pour ton soutien depuis la minute 0, pour m’avoir donné ta confiance. J’ai appris énormément de ta persévérance et optimisme.

Thank you, Tina. You have been a great source of inspiration and challenge. It has been a pleasure to be part of your research team. Thank you also for all the opportunities you offered all along this way (Norway, the Triplex, Delft, …) All those experiences have been completely amazing and have shaped me as researcher and person.

Merci aussi à Mathieu Grenade, et donc la Fédération International de la Croix Rouge, pour avoir cru à ce projet et avoir joué le jeu. Spécialement pour l’accueil de toute l’équipe au Panama, qui a beaucoup contribué à construire ce projet.

Je remercie les rapporteurs et membres du jury d’avoir accepté et accompli cette tâche si critique. C’était un vrai challenge et plaisir de discuter avec vous tous.

J’aimerais remercier aussi Arnaud Cabal (MSF), qui m’a ouvert les portes dans le domaine passionnant de la logistique humanitaire.

Merci à tous les collègues du Centre de Génie Industriel de l’IMT Mines Albi. Merci à vous tous pour tous les bons moments partagés.

Hossein, it was a pleasure to share this adventure with you, the best practitioner ever ;-)

Isabelle, tu étais l’âme du CGI tel que je l’ai connu. Merci pour ton amitié, pour avoir partagé ta joie de vivre, tu me manques.

Merci Nico… Gracies als amics i la familia que heu seguit aquest projecte des de la distancia. Sense vosaltres tot seria molt més dificil!

RESUM EN CATALÀ

Per una cadena de subministrament d'ajuda humanitària sostenible: caracterització, avaluació i suport a la presa de decisions

Paraules clau. Cadena de subministrament humanitària, presa de decisions, planificació tàctica, gestió de crisi, sostenibilitat.

La cadena de subministrament humanitària (CSH) és un element clau per millorar la resposta davant les crisis humanitàries. Les organitzacions humanitàries (OH) han rebut pressions tant internes com externes que han conduit a una millora substancial de la gestió dels recursos (eficiència i eficàcia) durant els darrers anys.

Tot hi així, com que la diferència entre les necessitats de finançament i els recursos disponibles tendeix a créixer, i els mecenes demanen cada cop més transparència i justificació de les despeses, el coneixement i gestió del rendiment segueix essent cabdal. D'altra banda, la pressió de l'opinió publica empeny les OH a integrar els reptes de sostenibilitat, més enllà dels resultats econòmics.

A l'inici d'aquest projecte de recerca, gràcies als resultats de la investigació de camp, es van identificar les dificultats per considerar la sostenibilitat en la presa de decisions de la CSH. A part de la manca de coneixement generalitzat sobre què és la sostenibilitat i com mesurarla, alguns dels frens majors per planificar operacions humanitàries sostenibles son la manca de sistemes de suport per la presa de decisió i una cultura de sostenibilitat específica a la CSH.

La tesi aborda diferents aspectes per facilitar l'introducció de la noció de rendiment sostenible en la gestió de la CSH. En aquest sentit, s'han investigat tres pistes de recerca que han permès de desenvolupar un sistema de suport a la presa de decisió per a la planificació d'operacions de la CSH durables:

(a) Com es pot obtenir un coneixement exhaustiu d'una CSH?, La contribució proposada és una Meta-Model de la CSH, basat en la definició d'un sistema col·laboratiu, útil tant per a la investigació sobre el terreny com per al desenvolupament de sistemes de suport a la decisió.

(b) Què significa sostenibilitat en el context de la CSH? A partir de la recerca bibliogràfica contrastada amb la investigació de camp, s'estableix un marc per definir el rendiment sostenible de la CSH basat en la TBL (Tripple Bottom Line) que considera les dimensions econòmica, mediambiental i social.

(c) Com prendre decisions sostenibles en el context de la CSH? Aquesta contribució es basa en un algoritme d'investigació operativa que permet d'integrar el rendiment sostenible en la presa de decisions de manera interactiva. El procés de decisió estudiat és el de la planificació tàctica (selecció de proveïdors, mitjans de transport, magatzems) per la distribució d'ajuda humanitària en una zona geogràfica continental.

Les tres contribucions han estat aplicades a casos pràctics basats en l'activitat de la Federació Internacional de la Creu Roja (FICR).

RÉSUMÉ LONG EN FRANÇAIS

Introduction

Des Chaîne Logistiques Humanitaires pourquoi ?

La Chaîne Logistique Humanitaire (CLH) a pour but d'acheminer, au bon endroit et au bon moment, les articles de première nécessité appropriés aux personnes touchés par des crises humanitaires.

Ce qu'on appelle une crise humanitaire, est la conséquence d'un ou une suite d'évènements d'origine naturel et/ou humain qui menacent la survie d'un grand nombre de personnes.

En cas de crise, la première réponse vient toujours de la population et d'organisations locales. Ce n'est que quand les besoins dépassent la capacité du territoire que la communauté internationale se mobilise. Depuis des décennies, les Organisations Humanitaires (OH) telles que les ONGs et les agences des Nations Unies travaillent - souvent en coordination avec les autorités locales, militaires ou encore le secteur privé - pour porter assistance aux populations affectés par les crises majeures en suivant les principes d'humanité, impartialité et neutralité. Les OH sont capables de fournir de l'aide humanitaire à plusieurs crises en parallèle avec des CLH très réactives même si les ressources dont elles disposent sont souvent insuffisantes, le turnover des « humanitaires » est élevé, et les Systèmes d'Information (SI) utilisés sont plutôt rudimentaires.

Dans les dernières années on a constaté une poussée des besoins d'aide humanitaire. Les évènements (dangers) causent de plus en plus d'impacts due à l'augmentation de leur récurrence et magnitude. L'exposition de la population aux dangers augmente plus vite que descends la vulnérabilité, ce qui conduit à un incrément du risque.

La CLH, de plus en plus professionnalisée, a été identifié comme un élément clé pour garantir le succès des opérations de réponse aux crises humanitaires. Dans cette thèse on a commencé pour s'intéresser à l'évolution de la CLH pour mieux comprendre les défis à venir.

Evolution de la Chaîne Logistique Humanitaire

Si l'on considère le cycle de la gestion d'une crise (préparation, réponse, récupération, atténuation), les décideurs de la CLH ont tendance à focaliser les efforts dans la gestion de la phase de réponse. En effet, et en contraste avec la chaîne d'approvisionnement industrielle, le moteur principal de la CLH a été typiquement la réactivité et l'efficacité depuis le début (s. XX).

Cependant, plusieurs « échecs » dans la réponse à des crises humanitaires majeures on mit en cause l'approche. L'un des exemples le plus frappant est l'ouragan Mitch, en 1998, où les problématiques d'approvisionnement ont été suivies avec une couverture médiatique sans précédents. Dû à cette médiatisation, l'opinion publique et grands donateurs ont exercé une forte pression vers les OH qui a poussé à investir des ressources sur les phases de préparation, en amont des crises.

Dès lors, même si les fonds disponibles ont bien augmenté, les ressources sont toujours insuffisantes dû à l'augmentation des besoins. L'écart entre les besoins et le financement a tendance à se creuser. De plus, les donateurs exigent de plus en plus de transparence et de responsabilité dans l'utilisation des fonds. Par conséquent, la maîtrise de la performance de la CLH est un facteur clé et concerne tant l'efficacité que l'efficience des opérations.

Le terme « durabilité », ou performance durable, a été utilisé dans un large éventail de disciplines et de contextes, mais il a reçu peu d'attention dans le domaine de la réponse aux crises humanitaires. Cela n'est pas surprenant car toute CLH contribue à sauver des vies et à améliorer les conditions de vie de la population et donc ceci semble tout justifier.

Néanmoins, certaines OH se sont déjà engagées pour développer des activités plus durables, même si aujourd'hui il s'agit d'une déclaration de haut niveau. Tant la recherche sur le terrain comme la littérature scientifique soulignent que les décideurs dans le contexte de l'aide humanitaire n'ont pas les outils adéquats pour évaluer l'impact de leurs décisions en termes de durabilité.

Plus encore, l'évolution dans les attentes de l'opinion publique (et donc les donateurs) suggère que la durabilité de la CLH, en termes de performance, devra être prise en compte dans les années à venir pour assurer la compétitivité, et donc le maintien de l'activité.

La Figure 10, dans le chapitre d'introduction de ces travaux de thèse, synthétise l'évolution dans les attentes liées à la performance depuis le début de la CLH jusqu'à nos jours.

C'est donc dans ce contexte que ces travaux de recherche se positionnent, avec l'hypothèse que maitriser la performance durable dans les années à venir sera incontournable pour les décideurs de la CLH.

Défis de la Chaîne Logistique Humanitaire durable

Pour maitriser la performance durable des opérations dans la CLH, trois défis majeurs ont été identifiés d'après la littérature scientifique et les données/observations au terrain.

- Difficultés à mesurer la durabilité

  La performance durable est souvent définie par le biais de la TBL, pour *Tripple Bottom Line* en anglais, qui se compose des dimensions économiques, environnementale et sociale. La TBL est une approche systémique qui souligne la nécessité d'atteindre un minimum de performance pour les trois dimensions, mais il n'existe pas de consensus sur les compromis et les synergies entre les trois.

  La définition macro-économique de la durabilité et les trois dimensions peuvent expliquer le développement durable d'un point de vue conceptuel, mais ne fournissent pas assez d'indications sur la manière dont la durabilité doit être abordée dans le contexte des opérations de la CLH.

- Planification insuffisante

  Pour maîtriser la performance il faut être capable d'anticiper l'impact des décisions, ce qui relève de la planification. Cependant, le contexte des CLH est caractérisé par un manque de planification structurée (Haavisto et Kovács, 2014). De plus, le réseau de logistique humanitaire est de plus en plus complexe à gérer, avec des entrepôts dits de « pre-positionnement » localisés tout autour du Globe, des partenariats avec des industriels ou encore des organismes de coordination inter-organisation comme les Clusters des Nations Unies.

Ce manque de planification lié à la complexité du réseau, entraîne des défaillances dans la gestion de l'approvisionnement (*i.e.* gestion des stocks, mode de distribution, choix des fournisseurs), et donc des inefficacités et inefficiences telles que l'effet coup de fouet ou les retards de distribution, et constitue un obstacle à l'alignement des opérations sur des objectifs durables.

- Absence de systèmes d'aide à la décision adéquats

  Dans les chaînes d'approvisionnement commerciales, les processus de planification sont de plus en plus pris en charge par des systèmes d'aide à la décision (ERP, TMS, APS). Un système d'aide à la décision est généralement défini comme « un système d'information interactif basé sur ordinateur conçu pour prendre en charge des solutions aux problèmes de décision » (Liu et al. 2010). Dans la gestion des opérations, les systèmes d'aide à la décision reposent souvent sur des approches de recherche opérationnelle (RO).

  En matière de gestion des crises humanitaires, il est de plus en plus reconnu la nécessité d'étudier l'applicabilité de la RO. Bien que de nombreuses recherches aient été menées sur la mise au point de modèles de RO pour appuyer la prise de décision dans la CLH, très peut ont un impact réel sur le terrain (Laguna Salvadó et al. 2015).

Problématique scientifique et terrain

La littérature souligne que la durabilité est toujours négligée dans les contextes humanitaires, même si elle est essentielle pour aligner les objectifs opérationnels sur les objectifs à long terme de l'action humanitaire. Plusieurs auteurs ont appelé à davantage de recherches pour intégrer la durabilité aux prises de décision humanitaires (Haavisto et Kovács 2014; Klumpp et al. 2015; Kunz et Gold 2017).

Il est fondamental de bien comprendre le contexte de la CLH et de concevoir des solutions reposant sur une hypothèse forte, basée sur le terrain. Par conséquent, l'objectif de ce travail de recherche est d'aborder les questions de recherche suivantes :

Question de recherche 1 : Comment conceptualiser formellement ce qu'est un CLH ?

Le CLH est un système collaboratif dans lequel de nombreux acteurs et parties prenantes interagissent pour atteindre l'objectif ultime de « alléger la souffrance humaine ». Pour améliorer la performance globale d'un système, il est essentiel d'en avoir une connaissance suffisante. Des travaux de recherche antérieurs ont proposé des modèles pour définir ces connaissances, mais aucun de couvre totalement la CLH en tant que système collaboratif.

La difficulté donc, reste de disposer d'une conceptualisation partagée et suffisamment explicite de la CLH pour, d'une part, comprendre, puis pour améliorer le comportement du système. Cette question de recherche est intéressante à la fois pour l'académique et les praticiens de terrain, car elle devrait contribuer au partage des connaissances et à la communication entre les praticiens eux-mêmes, ainsi qu'entre les praticiens et les universitaires. Il peut également contribuer à la recherche en facilitant la conception et analyse de la recherche sur le terrain.

Question de recherche 2 : Que signifie la durabilité des opérations de la CLH et comment peut-on l'évaluer ?

Compte tenu de l'augmentation du nombre de publications scientifiques qui s'intéressent au concept de « durabilité » dans de nombreuses disciplines, on peut considérer la durabilité comme un sujet à la mode. Ceci n'empêche pas les difficultés pour définir qu'est-ce que la performance durable dans le cadre de la CLH.

Déjà, la durabilité est un concept multidimensionnel. De plus, on remarque que le niveau de granularité des mesures de la durabilité proposées dans la littérature sont généralement contraires à la transférabilité de ces mesures. C'est-à-dire, il semble que l'évaluations de la durabilité corresponds souvent à des objectifs de haut niveau (petite granularité) qui ne sont pas transférables (et donc n'appuient pas) les niveaux de décision tactiques et opérationnels (petite granularité). Ainsi, à ces niveaux de décision, chaque secteur d'activité doit trouver un moyen fiable de quantifier la durabilité.

Même si les OH ont déjà souscrit au programme de développement durable, il est encore difficile de concrétiser ce qu'est une performance durable aux différents niveaux de décision. Cette question de recherche est pertinente pour les académiques car elle vise à contribuer à combler le fossé entre les concepts généraux de durabilité et le domaine de recherche, ainsi que pour les praticiens car elle vise à permettre l'évaluation de la durabilité dans les processus décisionnels en matière de CLH.

Question de recherche 3 : Comment aider les décideurs à faire des compromis en matière de durabilité et à en explorer les conséquences de manière consciente et systématique ?

Pour améliorer la durabilité des opérations, les décideurs peuvent tirer parti de l'évaluation *a priori* de la durabilité dans le processus de planification. Pour planifier des opérations durables, les décideurs doivent faire des compromis sur la durabilité de manière transparente, sur la base de leur connaissance de la situation (objectifs et intérêts organisationnels, expertise, etc.) et de la prise de conscience de leurs conséquences.

Cependant, les systèmes d'aide à la décision qui traitent des compromis ne sont pas alignés sur les exigences des praticiens en termes de compétences et de temps. Les utilisateurs doivent généralement gérer des pondérations et des dépendances abstraites et complexes, ce qui peut constituer un obstacle à l'acceptabilité des systèmes d'aide à la décision sur le terrain. Le défi consiste alors à concevoir et à développer une approche de système d'aide à la décision qui contribue à réduire l'écart entre les propositions académiques et la convivialité sur le terrain.

Cette orientation de recherche est intéressante pour les universitaires car elle vise à utiliser des méthodes pour des non-experts et, partant, à améliorer systématiquement les processus de planification des CSS.

La Figure 17, dans le chapitre d'introduction aux travaux de recherche, montre une synthèse des grandes problématiques abordées dans ces travaux. L'objectif finale étant de proposer un système d'aide à la décision pour une CLH durable, trois étapes sont abordées :

- la description du système CLH, afin de structurer la connaissance,
- la description des objectifs de durabilité, pour ainsi pourvoir évaluer la durabilité dans le contexte de la CLH, et
- la prise de décisions qui prennent en compte la durabilité du système, et donc pour pouvoir proposer un système pour aider à la planification tactique (Master Planning) de la CLH.

Méthodologie de recherche

Pour répondre aux questions de recherche, et réduire l'écart entre la pratique et la recherche (fortement critiquée), nous avons suivi une approche de recherche inductive. Inductive, car le problème et les solutions sont tous deux fondés sur des recherches sur le terrain, dans le but de créer une hypothèse générale.

Dans ce sens, on a suivi la philosophie de la recherche-action. Nous avons donc collaboré tout au long du projet avec la branche logistique de la Fédération Internationale de la Croix Rouge (FICR), plus précisément avec le Centre Logistique Régional de l'Amérique et des Caraïbes, située au Panama.

La force des propositions repose sur la capacité d'identifier un problème pertinent pour les OH. La méthode utilisée est la collecte de données sur le terrain, avec une analyse et des retours sur les résultats vers les OH. Nous avons utilisé des données secondaires et primaires de la FICR, et d'autres ONGs et agences humanitaires.

Les données secondaires se trouvaient principalement sur Internet et sont constitués notamment de rapports annuels et communications sur les opérations. Le site reliefweb.net a été utilisé comme point de départ.

Pour les données primaires, nous avons mené une campagne de recherche sur le terrain au Panama, au Centre Logistique Régional de la FICR, et utilisé des entretiens semi-structurés, des observations et un accès aux documents.

Recherche terrain avec la FICR au Panama

Où? Centre Logistique Régional de la FICR en Amérique (Panama). Bureaux et entrepôts.

Quand? 10 jours en septembre 2015

Qui? Un chercheur sur le terrain et deux dans le « back office »

Quoi? Formaliser les processus opérationnels de la CLH. L'objectif était d'identifier les défis du système et opportunités pour les décideurs.

Les résultats des recherches sur le terrain (enjeux métiers), associés à la revue de la littérature, ont permis de formuler les trois questions de recherche (enjeux scientifiques) développées dans ce manuscrit.

Pour construire des contributions scientifiques, des travaux approfondis ont permis de mettre au point des méthodes originales, ou ont adapté les méthodes existantes permettant de répondre aux questions de recherche et aux enjeux de l'organisation, la FICR.

De plus, un démonstrateur de chaque contribution a été développé et validé avec une preuve de concept basée sur des données de recherche sur le terrain.

1ère contribution : Métamodèle de la CLH

Pour faciliter la formalisation et la compréhension de la CLH, le chapitre 2 du manuscrit présente un métamodèle du système CLH. La contribution s'appuie sur les travaux de Benaben et al. (2016), qui ont proposé de définir tout système collaboratif à partir de quatre briques : le contexte, les partenaires, les objectifs et le comportement. Ces quatre briques forment le cœur du métamodèle, sur lequel des concepts correspondants a un domaine donné peuvent être structurés.

Dans ce chapitre il est décrit la couche du métamodèle correspondante au système CLH. La Figure 34 montre une synthèse de cette contribution. Cette approche repose sur l'hypothèse que le CLH est un système collaboratif qui peut être décrit par des concepts spécifiques au domaine, mais assez génériques pour être transposables d'une CLH à une autre. Nous avons construit et organisé le métamodèle à partir des concepts retrouvés dans la littérature ainsi que grâce aux recherches terrain.

Cette proposition est originale étant donné qu'aujourd'hui, il n'existe pas de conceptualisation formelle standard d'un système CLH. Elle permet donc d'organiser les informations relatives à une CLH d'une manière structurée. Les utilisations potentielles d'un tel métamodèle sont multiples, et nous mettons donc en avant :

- le développement de supports pour la recherche terrain : le métamodèle est un outil qui permet de structurer l'information pour générer de la connaissance. Pendant les explorations de terrain, il peut faciliter la recollecte d'information d'une manière structurée, ainsi que la réutilisation de résultats (modèles).
- le développement de systèmes d'information spécialisés de la CLH : le métamodèle permettrait à des SI d'intégrer et d'interpréter l'information et générer donc de la connaissance et notamment de l'aide a la décision.
- soutenir des étapes concrètes d'amélioration continue pour les aspects logistiques : pour identifier les points faibles d'une CLH donnée, il faut maitriser l'état actuel (cartographie ASIS). Le métamodèle permettrait de faciliter cette tâche et d'assurer l'intégrité des éléments nécessaires pour analyser.

Nous avons validé et démontré l'intérêt du métamodèle de la CLH en construisant des supports pour la recherche terrain. Ces outils ont été utilisées dans le cadre du cas d'étude de la FICR et on permit un recueil exhaustif et reproductible d'information.

Limites : L'application pratique (et donc la validation) du métamodèle pour d'autres utilisations suggérées telles que la définition des spécifications d'un système d'information, ou pour faciliter la coordination et interopérabilité des OH, n'a pas été mise en œuvre.

2ème contribution : la maison des opérations de la CLH durable

Les objectifs de cette seconde contribution sont doubles :

(1) clarifier le concept de la CLH durable,

(2) créer un cadre pour évaluer la performance des opérations.

Tout d'abord, on a défini un cadre de mesure de la performance : La Maison des opérations de la CLH durable. Ce cadre traduit les concepts de durabilité en opérations concrètes de la chaîne d'approvisionnement (achats, entreposage, transport) et souligne la nécessité de prendre en compte les trois dimensions du TBL pour améliorer la durabilité opérations. Les critères ont été définis en tenant compte de l'analyse de la littérature sur la durabilité de la chaîne d'approvisionnement et de l'impact des processus (achats, stockage et transport) sur les différentes sous-dimensions.

Ensuite, un modèle et une méthode pour évaluer la maturité de performance de la CLH durable sont proposés. Pour illustrer l'utilisation du modèle d'évaluation de la maturité, une preuve de concept a été construite avec une étude de cas de là FICR. La Figure 49 et la Figure 53 montrent la Maison des opérations de la CLH durable et le modèle pour mesurer la maturité d'un système de CLH en termes de durabilité respectivement.

Ce chapitre contribue de manière significative à la discussion naissante sur la durabilité des CLHs. Il amène des éléments de discussion et pour l'évaluation concrète de la durabilité des opérations de la CLH, qui semble encore difficile dans de nombreuses disciplines.

Le cadre de performance présenté dans le chapitre 3 constitue donc la base de l'élaboration d'un système d'aide à la décision permettant d'optimiser la planification des opérations de la CLH en ce qui concerne les impacts du TBL. Toutefois, la durabilité étant un concept multidimensionnel aux objectifs contradictoires, le défi consiste maintenant à maitriser les compromis et synergies au travers des dimensions économique, environnementale et sociale.

Limites : le cadre a été mis au point grâce aux contributions des recherches sur le terrain avec la FICR, ainsi qu'aux grilles d'évaluation de la maturité. Une validation plus large devrait être menée avec des experts de différents OH, afin de consolider un point de repère permettant de comparer les organisations.

3ème contribution : un système d'aide à la décision pour le Master Planning (comment ?)

Enfin, la dernière contribution (chapitre 4) développe une approche pour intégrer de manière concrète la prise en compte de la performance durable lors de la planification des opérations de la CLH.

À partir des recherches sur le terrain et de la littérature, le niveau de planification tactique est identifié comme un bon catalyseur pour introduire la durabilité dans le processus de prise de décision.

Par conséquent, le problème de la planification tactique (Master Planning) de la CLH durable a été abordé. Sur la base du réseau de la FICR en Amérique, un ensemble de critères de performance durable (social, économique et environnemental) ont été sélectionné et définis à fin d'être mesurables.

Ensuite, le réseau logistique dit amont (des fournisseurs jusqu'aux points d'entré aux endroits géographiques affectés par des crises) et les indicateurs sont modélisé mathématiquement avec les outils de recherche opérationnelle déterministes. Il est proposé de résoudre le système avec un algorithme d'ordonnancement lexicographique interactif qui permet de prendre en compte l'expertise des décideurs dans le processus de planification. La Figure 59 montre le diagramme logique de l'algorithme qui a été développé dans cette contribution.

Limites : le cas d'utilisation de la FICR en Amérique couvre le processus décisionnel interne et en amont, qui ne représente qu'un périmètre limité de l'ensemble de la CLH (des fournisseurs aux utilisateurs finaux). L'application pratique à un périmètre plus large et à d'autres OH reste à faire. De plus, beaucoup de données sont nécessaires pour exécuter le modèle. La capacité de collecte de ces données doit donc être étudiée en amont, de même que la sensibilité des résultats.

Perspectives

Le chapitre 5 du manuscrit présente les contributions, résultats et conclusion de ces travaux, que nous avons déjà évoqué dans ce résumé.

Pour synthétiser, les trois grandes questions qu'ont été abordées pour aller vers une CLH durable sont donc :

- la modélisation du système CLH en tant que système collaboratif,
- la définition de la performance durable dans le contexte de la CLH, et
- le développement d'un outil pour aider à planifier les opérations tactiques d'une CLH.

Nous présentons ici une feuille de route visant à consolider les propositions et à proposer de nouvelles orientations de recherche.

Perspectives à court terme (validation)

i. **Validation plus large avec scénario réel :**

Pour démontrer la validité des propositions, toutes les contributions ont été validées via le cas d'utilisation de la FICR en Amérique. Néanmoins, chacune des contributions a été construite avec un ensemble de données limité étendu par des hypothèses. Bien que les hypothèses aient été discutées avec les praticiens ou fondées sur des observations sur le terrain et / ou la revue de la littérature, il serait pertinent de définir un scénario basé sur un ensemble complet de données réelles.

ii. **Validation en temps réel** :

Pour construire un scénario réel, il serait approprié de s'engager avec la FICR sur une campagne de recherche sur le terrain dédiée à la collecte et exploitation de données en temps réel. En outre, les praticiens pourraient effectuer une étape de validation en comparant les résultats de performance avec et sans utiliser le système d'aide à la planification de la CLH.

iii. **Hypothèses du modèle contrastés avec d'autres OH :**

Les hypothèses ont été construites sur les spécificités de la CLH amont de la FICR. Il s'agit d'une limitation et l'une des perspectives serait donc d'étendre la validation à un plus grand nombre d'OH, tels que le Plan Alimentaire Mondial (PAM) ou même Médecins sans Frontières (MSF), qui gèrent des réseaux de CLH similaires. La portée des autres CLH peut différer en termes de contexte (i.e. conflits armés) et, par conséquent, l'hypothèse et les contraintes du modèle de flux de réseau CLH peuvent différer.

iv. **Une évaluation plus approfondie de la sensibilité :**

La sensibilité du modèle doit être examinée plus en profondeur avec un jeu de données réel. L'objectif est d'aider les utilisateurs à interpréter et à anticiper les conséquences de leurs choix au cours du processus de décision.

Perspectives à moyen terme (mise en œuvre)

v. **Interaction homme-machine**

Dans la troisième contribution, nous nous sommes concentrés sur l'algorithme et le modèle permettant d'évaluer la durabilité et de résoudre le problème décisionnel lié à la planification durable. Bien que nous ayons pris en compte le savoir-faire des utilisateurs pour hiérarchiser les objectifs de performance, l'utilisation du système reste complexe pour les non-initiés. Pour renforcer l'approche de la recherche appliquée, des travaux supplémentaires doivent être menés pour concevoir et développer des interactions ergonomiques homme-machine. Développer des interfaces utilisables (efficaces, performantes et satisfaisantes) est une question interdisciplinaire qui concerne l'ingénierie informatique et qui bénéficierait également d'une perspective des sciences sociales (conception d'interaction) (Dix 2009).

vi. **Transfert technologique**

Une fois le prototype mis en œuvre, il est important d'envisager la diffusion du système d'aide à la décision parmi les utilisateurs potentiels (accès à la connaissance). L'intégration avec les systèmes d'information existants (par exemple, ERP) est une question connexe importante à prendre en compte. Cela peut notamment révéler des problèmes d'interopérabilité.

Perspectives à long therme (évolutions)

vii. **Évaluations du cycle de vie**

Une approche standard pour évaluer les impacts d'un produit sur les différentes dimensions de la durabilité consiste à effectuer une analyse du cycle de vie (ACV). Cette évaluation a généralement été réalisée pour la dimension environnementale, mais certains auteurs envisagent également de réaliser une ACV sociale. C'est une perspective intéressante à suivre car elle peut permettre d'identifier, dans une perspective d'amélioration continue, les étapes de la CLH qui ont l'impact le plus négatif.

viii. Vers un système de planification avancée humanitaire

Le but ultime de la CLH est de générer un comportement décisionnel synergique avec toutes les parties prenantes de la réponse humanitaire en amont et en aval. Ce travail de recherche a abordé une première étape, avec le développement d'un module de planification de base, pour la CLH en amont. Cependant, la question de savoir comment les décisions prises en amont ont un impact sur la durabilité globale des CLH reste posée. Comment les décideurs peuvent-ils acquérir une perspective holistique ?

Par conséquent, pour améliorer les opérations de la CLH, deux perspectives intéressantes se dégagent :

(1) l'intégration des différents niveaux de planification et

(2) l'intégration des parties prenantes en amont et en aval.

Pour les Chaînes Logistiques commerciales, les APS (*Advanced Planning Systems*) sont considérées comme la solution pour intégrer tous les processus de décision en utilisant une approche hiérarchique. Cependant, le contexte des opérations humanitaires soulève des difficultés supplémentaires : les réseaux en aval sont déployés de manière ad-hoc, les collaborations entre les parties prenantes peuvent être sporadiques et la prise de décision peut être décentralisée.

- Est-il alors possible de développer une SAP humanitaire agile et/ou flexible ?
- Comment aborder la dynamique et l'incertitude du système ?

Néanmoins, de nombreuses études ont déjà été menées sur la prise de décision au niveau stratégique, avec par exemple la conception du réseau (Aurélie Charles 2010; Vargas Florez et al. 2015), ou au niveau opérationnel avec des problèmes de prise de décision concernant la distribution du dernier kilomètre (Burcu Balcik. et al 2008). Des questions restent à résoudre :

- Comment introduire la perspective durable dans les différents niveaux de décision et
- Comment assurer l'interopérabilité des différents systèmes ?

L'utilisation du métamodèle CLH peut être un facteur facilitant le développement de l'APS humanitaire durable, si elle est utilisée comme référence commune pour définir le réseau.

ix. Agilité (détection, adaptation)

Enfin, les opérations de la CLH durable doivent faire face à un degré d'incertitude élevé. Par conséquent, le processus de prise de décision requiert des méthodes qui s'adaptent à la dynamique de l'environnement. Notre contribution se limite à la conception d'un processus (le schéma directeur) et, pour faire face à l'incertitude, nous avons proposé une approche de planification à horizon glissant. Un système agile peut détecter les écarts entre le plan et la réalité et s'adapter à la nouvelle situation. Un processus décisionnel agile peut être mis en œuvre en ajoutant les deux dimensions : détection et adaptation.

Chapter I. INTRODUCTION

> "When a humanitarian disaster hits, affected communities frequently require essential, appropriate and timely humanitarian assistance."
>
> (Humanitarian Coalition 2015)

1. Humanitarian Supply Chain Context

We introduce in this section the concepts of humanitarian disasters and the response to them to obtain an overview of what a Humanitarian Supply Chain (HSC) is and what the main challenges to be solved in the future will be.

1.1. Humanitarian Disasters

1.1.1. Disaster terminology

For the moment, there is no consensus on the definition of a "**humanitarian disaster**". In the academic literature, Pearce defined it as "a non-routine event that exceeds the capacity of the affected area to respond to it in such a way as to save lives; to preserve property; and to maintain the social, ecological, economic, and political stability of the affected region" (Holguín-Veras et al. 2012; Pearce, 2000). The United Nations International Strategy for Disaster Reduction (UNISDR) defines a disaster as a "serious disruption of the functioning of a community or a society (due to hazardous events interacting with conditions of vulnerability and exposure) leading to widespread human, material, economic or environmental losses and impacts" (UNISDR, 2009). This second definition stresses the fact that disasters are always the consequence of a hazard.

A hazard is defined as "something that is dangerous and likely to cause damage" (Cambridge dictionary, 2017). Therefore, the disaster's severity depends on how much impact a hazard has on a society and the environment. The UNISDR highlights that the impact of a hazard depends on population vulnerability[1] and exposure[2] (UNISDR, 2017). This approach is in line with the academic literature that studies how to mitigate the risk and impact of hazards. Exposure emphasizes that the location of the hazard influences its impact. For example, the same magnitude earthquake that hits a city or that hits a desert will not have the same consequences. The impact also depends on the standards of living in the area. If the city is in a developing country the damage may be more severe. Vulnerability emphasizes that some groups are more prone to damage. Poor populations are more likely to be vulnerable than rich populations. Within affected communities, typically vulnerable groups include children, pregnant and nursing women, migrants, and displaced people

[1] Vulnerability is the characteristics determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UNISDR, 2017).

[2] Exposure is the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas (UNISDR, 2017).

1.1.2. Humanitarian disaster typologies

Humanitarian disasters are often classified by the origin of the hazard: either natural, caused by physical or biological hazards; or man-made (Van Wassenhove, 2006). The speed of the hazard onset is also a relevant characteristic. Sudden-onsets refer to disasters that impact a community within a short period of time. A typical example of a natural sudden-onset is an earthquake. Slow-onset disasters are the humanitarian disasters that evolve progressively over time, for example droughts. The main difference is that slow-onset disasters can be mitigated by early response. Unfortunately, as stated by the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), the response to most slow-onset disasters often ends up resembling the response to sudden-onset disasters (United Nations, 2011). Moreover, some disasters are recurrent due to the cyclical frequency of natural hazards such as hurricanes or floods. An example is the "El Niño" phenomenon, which generates both heavy rains and droughts in irregular cyclical patterns (every 2 to 7 years), and affects especially the South American Pacific coastal areas (Vargas Florez et al. 2015).

The combination of several or prolonged hazards may lead to "complex disasters". These are characterized by extensive violence, displacement of populations, severe damage to societies and economies and even more challenging: the potential prevention of the arrival of humanitarian assistance because of political and military constraints. This complex disaster context is a risk for humanitarian responders, as illustrated by the MSF (Médécins Sans Frontières) and ICRC (International Committee of the Red Cross and Red Crescent) hospital attacks during the on-going Syrian conflict.

In Table 1, a few recent examples are classified by origin of the hazard occurrence. The lines between types of disaster are often blurred. Thus, this classification is illustrative, but non-exhaustive, and may be controversial.

Table 1 Examples of Humanitarian Disaster classification by hazard typology

	Natural	**Man-Made (and complex emergencies)**
Sudden-onset	Nepal Earthquake (2015) Ecuador Earthquake (2016) Irma and Maria Hurricanes (2017) Pakistan recurrent floods	Central African Republic, South Sudan political conflict escalation (2016) Earthquake, Tsunami and Fukushima nuclear disaster (2011) Samarco dam collapse (2015)
Slow-onset	Sahel droughts (recurrent) Zika outbreak (2016) Ebola Outbreak (2013)	Syrian conflict (ongoing) South Sudan chronic political crisis

1.1.3. Impact

Disaster impacts may include loss of life, injury, disease, and other negative effects on human physical, mental, and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption, and environmental degradation.

A positive trend is that the number of casualties due to natural disasters has tended to decrease since the beginning of the 20th century. Thanks to the improvement of early warning and planning systems, disasters such as floods have became less deadly, while in contrast, earthquakes have became more dangerous with the growth of cities and their vulnerability. However, statistics show a significant rise in the number of affected people (Figure 1), particularly during the last ten years.

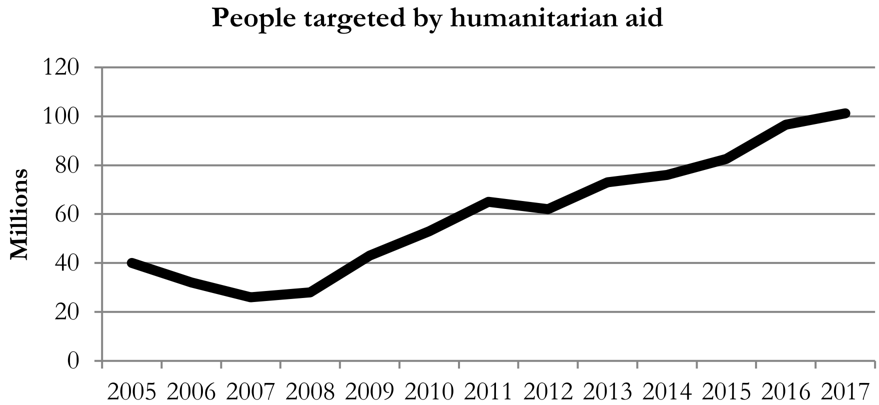


Figure 1 People targeted by humanitarian aid in the last decade (OCHA, 2017)

Evidence indicates that the exposure of persons and assets in all countries has increased faster than vulnerability has decreased, as highlighted by the Sendai framework for disaster risk reduction (United Nations, 2015).

Natural disasters are exacerbated by climate change and are increasing in frequency and intensity. The United Nations Development Program (UNDP) highlighted that there has been a substantial increase in heavy precipitation events, that droughts have become more common and more intense in tropical and sub-tropical regions and that intense tropical cyclone activity has been on the rise since the 1970s (UNDP, 2008). A clear example is the occurrence of increasingly severe hurricanes: Sandy (2012), Matthew (2016), and Harvey, Irma, Jose & Maria (2017) illustrate this trend. The data from the last 40 years shows that that the intensity is becoming stronger for Atlantic hurricanes (Figure 2).

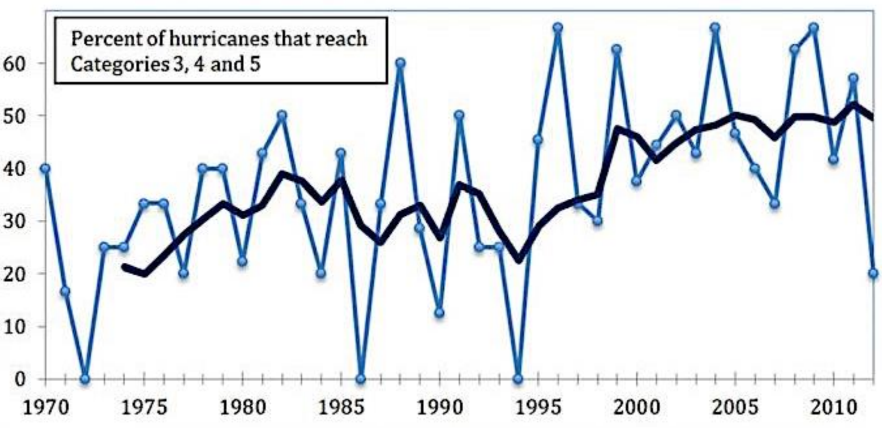


Figure 2 Atlantic hurricane trends (UCSUSA, 2016)

Man-made disasters, mainly armed conflicts, have become a driver of prolonged humanitarian needs. The main consequences are the increase in the number of populations forcibly displaced: refugees and Internally Displaced People. The Syrian conflict has contributed substantially to these records, especially in 2015, along with conflicts in neighboring countries such as Iraq and Yemen, and in many other African crises. The total number has doubled from 1997, to attain 65.6 million people in 2016, as shown in Figure 3.

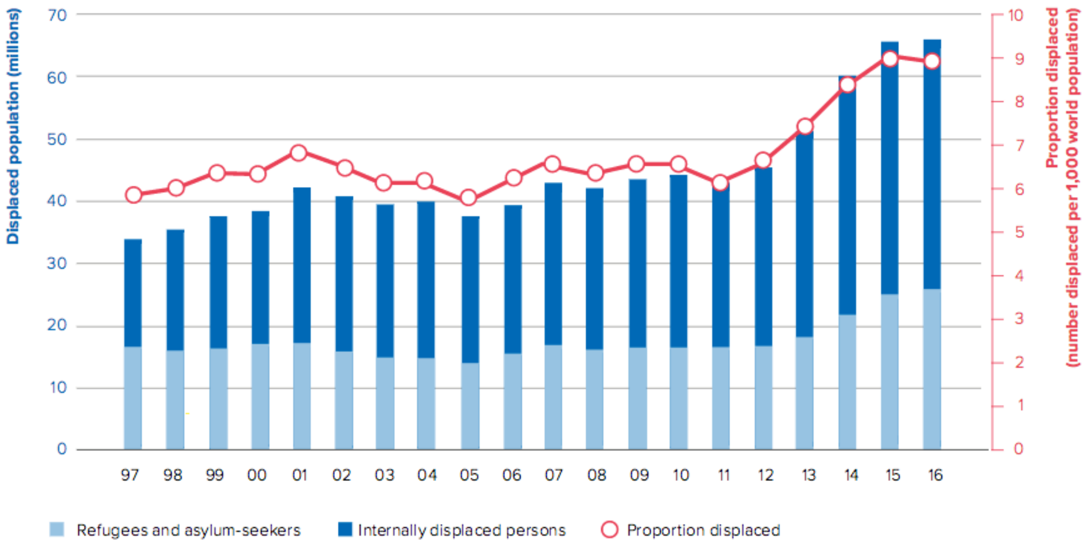


Figure 3 Trend of global displacement & proportion displaced 1997-2016 (UNHCR, 2017)

Even though the proportion of newly displaced people has decreased, the problem now for the long-term displaced population is that "many people remain in limbo for years in Internally Displaced People camps, urban slums or other areas of refuge, a situation defined as protracted displacement. "Lacking a permanent home or sustainable livelihoods, they often have little prospect of reaching a durable solution" (UNHCR, 2017).

To sum up, the trends show an increase in both natural and man-made disaster occurrences and impacts. Therefore, there is also an increase in the short- and long-term humanitarian needs. Professionalization of humanitarian operations is more than ever a critical issue.

1.2. Humanitarian aid

1.2.1. The Disaster Management Cycle

Humanitarian disaster management is described as a four-phase cycle: preparedness, response, recovery and mitigation phases (Figure 4).

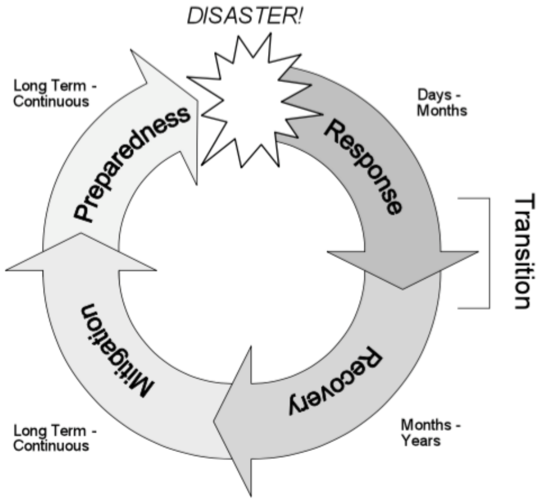


Figure 4 Disaster Management Cycle (Haddow and Bullock, 2004)

In the short term, affected communities need external interventions to maintain and improve the quality of life of the affected population. Such assistance may range from providing specific but limited aid, such as transport, temporary shelter, and food, to establishing semi-permanent settlements in camps and other locations, before coming back to a "normal" situation. Providing such relief aid is the role of humanitarian responders during the response phase. Before a disaster happens, efforts are put on the preparedness of the areas and populations at risk. Humanitarian Organizations (HOs) have developed disaster preparedness initiatives during the past decades, which have provided quicker and more effective responses to humanitarian crises. As an example, the Inter-Agency Standing Committee (IASC) proactively anticipates the coordination of international responders with the Emergency Response Preparedness approach.

In the long term, humanitarian responders work on the recovery of the affected communities to come back to a "normal" situation and on the development of community's resilience[1] to mitigate the impacts of future disasters. Mitigation is typically addressed by the scope of development projects, which addresses systematic problems of developing countries, with a focus on economic, social and political development.

This separation between short and long-term humanitarian aid is blurred, because it is not clear when the relief is finished and the recovery begins. This thesis focuses, however, on relief assistance delivery (short-term humanitarian needs coverage), so therefore on the preparation and response phases exclusively.

1.2.2. Humanitarian Actors

In the aftermath of a disaster, the first responders are local or national. They can belong to many different actors such as the authorities, civil defense, communities (e.g. churches), local or

[1] Resilience is defined as: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions", United Nations Office for Disaster Risk Reduction (UNISDR), "2009 UNISDR Terminology on Disaster Risk Reduction", Geneva, May 2009 (http://www.unisdr.org/we/inform/terminology).

international Non-Governmental Organizations (NGOs), which are already in the field. When the authorities of a country/region are overwhelmed by a humanitarian crisis, the international community is mobilized. The IASC, for example, activates exceptional response mechanisms when an emergency requires a system-wide response (so-called Level 3 emergencies). For the designation of an L3 emergency, the IASC protocol establishes the analysis of five criteria: scale, complexity, urgency, capacity, and reputational risk.

The international response includes a large variety of HOs (NGOs, UN agencies, humanitarian agencies, etc.), which interact with other stakeholders: governments, militaries, media, donors (public/private), etc. Figure 5 gives an overview of the variety of organizations that are part of the humanitarian response.

Our focus is on HOs, which include Humanitarian Agencies such as the World Food Programme (WFP), the International Federation of the Red Cross (IFRC), the ICRC and local and international NGOs (i.e. MSF, Save the Children, Care). HOs are supposed to provide relief assistance while following humanitarian principles: humanity, neutrality, impartiality and independence. The UN General Assembly formally established these core principles in 1991 (humanity, impartiality and neutrality) and 2004 (independence) was inspired and reiterated by the IFRC/ICRC. Nonetheless, each HO has its own mandates in accordance with the HO's objectives. The common characteristics of HOs are (Charles and Lauras 2011):

- They are under-resourced, with limited skills availability and high employee turnover that limits institutional memory and efficiency.
- Ineffective leverage of technology (i.e. non-robust equipment) and in particular, Information Systems that are relatively basic.
- Decision-making tends to be distributed and does not follow command/control approaches.
- HOs deal with several disasters at the same time, including both relief assistance and development projects.

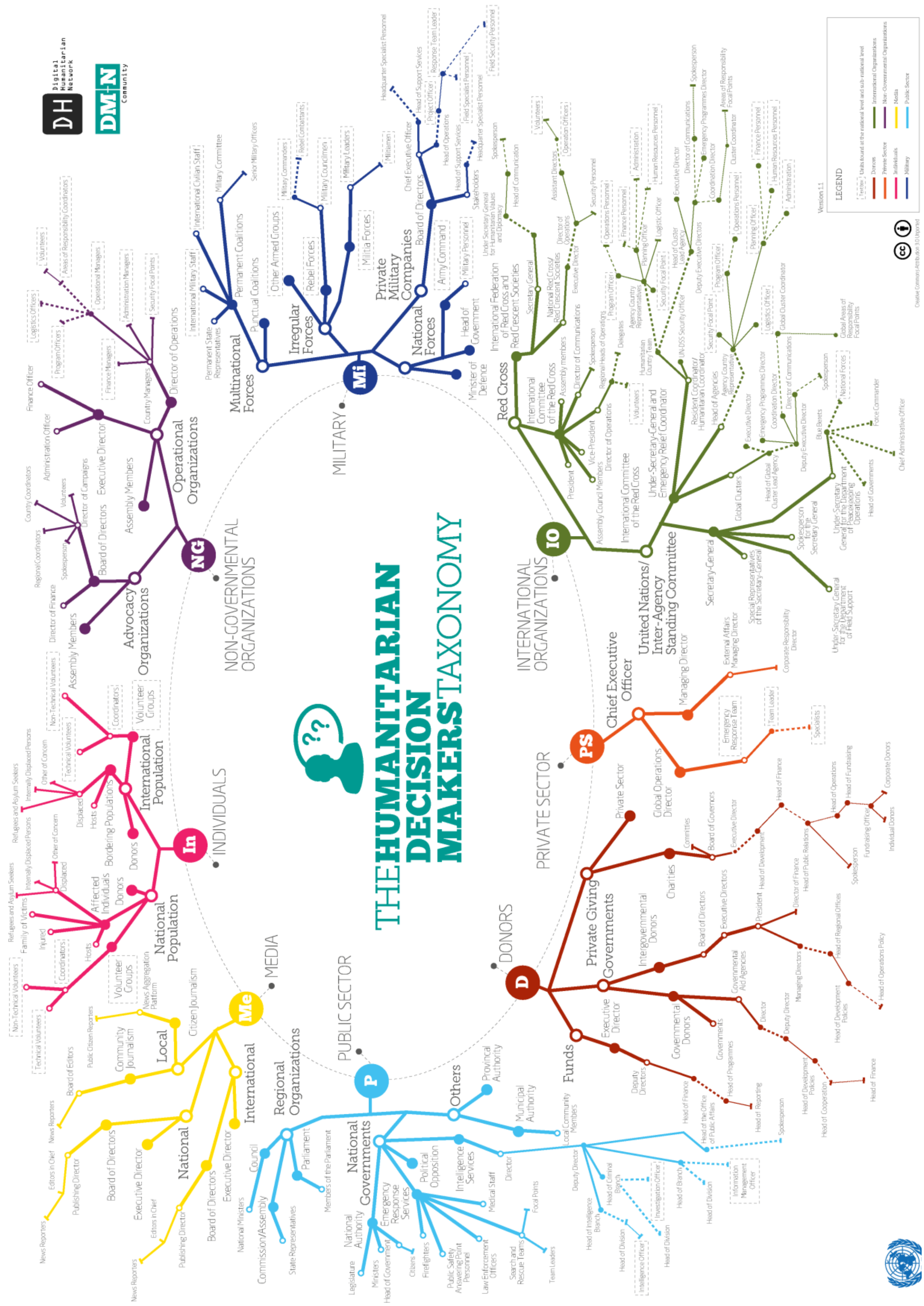


Figure 5 The Humanitarian Decision-makers Taxonomy (Gralla et al. 2013)

1.2.3. Humanitarian Organization coordination

Coordination in a humanitarian disaster context can be defined as the relationship and interactions among different actors operating within the relief environment (Balcik et al. 2010). HO coordination is an important issue, as experience has demonstrated that a lack of coordination within or between HOs leads to inefficiencies and ineffective relief operations. Coordination, still considered a weakness of the humanitarian sector, can take place at different granularity levels (local, global) and in different forms (Laguna Salvadó et al. 2015).

- Intra-Organizational Coordination concerns the internal relationships and interactions within an organization. The organizational structure is a key element (e.g. field teams with Head Quarters). This can be difficult due to the lack of "command and control" hierarchical approaches in organizations such as the IFRC, where the National Societies are autonomous.
- Inter-Organizational Coordination concerns the coordination between organizations at local and global levels. This coordination is difficult, variable, and rather low (Charles et al. 2010). The main difficulties and enablers at the local (Table 2) and global level (Table 3) were summarized by Charles et al. (2010):

Table 2 Coordination barriers and enablers to implement collaboration networks involving humanitarian organizations at a local level (Charles et al. 2010)

Barriers	Enablers
Lack of mutual understanding due the diversity of actors	Choice of the right ecosystem of actors
Lack of transparency and accountability	Incentives for shared information on mutual experiences and existing initiatives
Insufficient commitment on all levels	Involvement of key actors of the value chain
Lack of clarity on roles and responsibilities	Develop clear and jointly agreed roles and responsibilities to encourage commitment of actors
Lack of change management	Participatory approach
Lack of funding for activities that have no direct, visible and dedicated field application	Support of adequate Information Management tools and services

Table 3 Barriers and enablers to implement collaboration networks involving HOs at a global level (Charles et al. 2010)

Barriers	Enablers
In-country NGOs vary widely in their ability and willingness to partner UN or International NGO bodies	Most organisations are connected to one another in principle through their desire to provide aid effectively
Most organisations are tied to each other only episodically	General awareness of the aims and competencies of principals actors
Accurate data, for need assessment, logistics management and many other critical part of operations is vital but typically difficult to obtain	Specific shared IT tools are developed to improve data capture and analysis
All humanitarian organisations are poor in lessons learnt and need structure to prepare knowhow, knowledge rules/pools, to clarify what they need in specific fields	Score Cards are under development in most major International NGOs
The humanitarian community has many serious weaknesses in managing human resources, from recruitment to training to appraisal	

Nonetheless, efforts have been made to improve this challenging coordination. The foundations of the current HO international coordination system were set by UN General Assembly resolution 46/182 in December 1991. Almost 15 years later, in 2005, a major reform of the humanitarian coordination approach, known as Humanitarian Reform, introduced a number of new elements to enhance predictability, accountability and partnership. The Cluster Approach, a coordination facilitator mechanism, was one of these new elements.

Figure 6 UN cluster coordination approach

In the Cluster Approach, HOs (both UN and non-UN) are represented in one (or several) of the 8 main clusters of humanitarian action: Food and Security, Early Recovery, Education, Water Sanitation & Hygiene, Logistics, Health & Nutrition, and Shelter and Protection. The lead organization is designated by the IASC and has clear responsibility for coordination. The main objective of the system is to facilitate the exchange of information between the different HOs in the field in the aftermath of a disaster. One of the core functions of a cluster at country-level is to inform strategic decision-makers, and provide coordination of needs assessment, gap analysis and prioritization (UN OCHA, 2014).

However, some HOs feel that the Cluster Approach is contradictory to the humanitarian principles of independence, impartiality, and neutrality (Humphries, 2013). Other arguments against it are the lack of performance, most notably in overhead and lack of agility[1]. Delaunay, the MSF-USA Executive Director, declared in 2012, "*Coordination should not be an end. It should be a means and too often, especially what we have learned over the years in emergency situations, the coordination mechanism itself is an obstacle to intervene. It slows down the process.*" (Labbé, 2012).

There are other experiences of UN inter-organizational coordination approaches such as the one deployed during the West Africa Ebola Outbreak. WHO led the UN Mission for Ebola Emergency Response (UNMEER). It was set up as a temporary measure to meet immediate needs related to the unprecedented fight against Ebola. The mission deployed financial, logistical and human resources to Guinea, Liberia and Sierra Leone. However, as it was deployed "ad-hoc" in a complex situation, and

[1] Agility is defined as *(Detection + Adaptation) x Reactivity* by (Bénabén 2012)

some problems were encountered such as the lack of expertise of management leaders (Comes et al. 2015).

Out of all the sectors of the humanitarian response, this thesis focuses on the "logistics" activities, and in particular on certain HSC management challenges.

1.3. Humanitarian Supply Chain

To have the right resources in the right place and at the right time is crucial for a successful humanitarian intervention. In a disaster response, the main flows concerned were defined by (Tomasini and Van Wassenhove, 2009) as the 5b's: boxes (materials), bucks (finance), bodies (manpower), brains (knowledge and skills) and bytes (info).

HSC management is defined by (Thomas & Mizushima, 2005) as "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption." (Kovács and Spens, 2012) adds that HSC management also includes coordination and collaboration with supply chain third party service providers, and across HOs, but does not include the development aid aspect of humanitarian logistics.

Depending on the disaster, HSCs can take many forms and concern different actors. However, the material flow follows repetitive patterns. A typical HSC connects emergency item suppliers to the beneficiaries through a network of organizations, warehouses and transport flows (Figure 7) to satisfy the humanitarian needs.

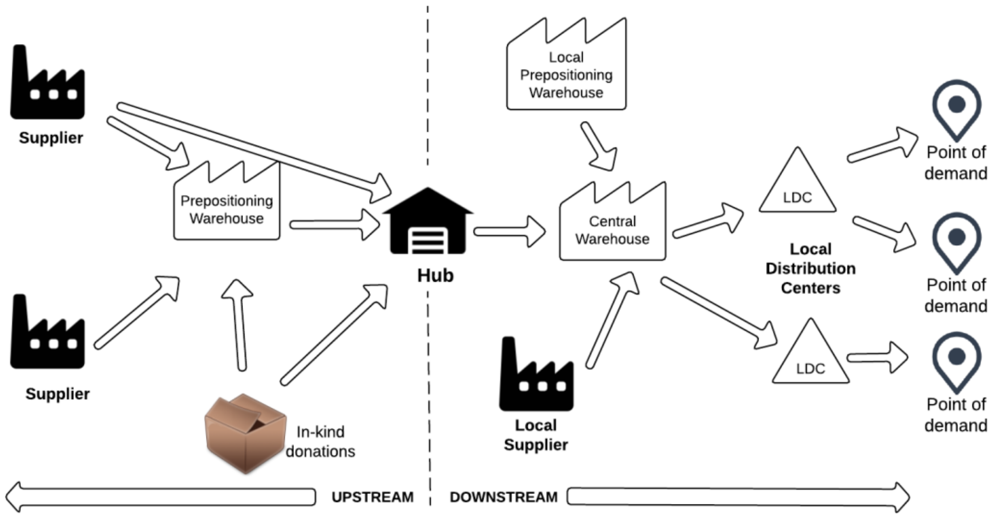


Figure 7 HSC network (inspired from (Baharmand et al. 2015))

In contrast to commercial supply chains (SC), and due to the nature of disasters, HSCs deal with extremely uncertain and unexpected needs, which result in the design and deployment of ad-hoc downstream networks to reach the beneficiaries (point of demand, see Figure 7). The upstream HSC deals with all upcoming and on-going humanitarian crises and resulting aggregated demands. Finally, the main humanitarian-specific attributes are (Widera et al. 2013):

- Prioritization of responsive (effective) instead of efficient (cost-effective) behaviors: due to the HSC purpose of "alleviating human suffering", the main concern at the response phase has historically been to satisfy humanitarian needs "no matter what the cost". This tendency is changing due to funding shortage.

- Uncertain and unpredictable demand: due to the nature of disaster, it is difficult to build long-term planning of humanitarian needs. Even though past trends allow "forecasting" of the potential needs, at least for recurrent disasters, decision-makers always face strong uncertainty.
- The role of donors as buyers and beneficiaries as end users: The definition of the customers of an HSC is difficult due to this duality. The value expected by beneficiaries and donors is not the same, but is strongly related. Thus, HSC decision-makers have to satisfy both beneficiaries' and donors' expectations.
- A highly volatile environment, and partly temporary and unknown HSC design: not only is demand uncertain, but also the environment and the HSC itself. Depending on the disaster context (which is unknown), the HSC network will adapt and deploy on the fly.
- Focus on procurement and distribution within the logistics value chain: With the exception of kitting, no transformation is made to the emergency products.

Some HOs have made HSCs part of their "core business", such as the IFRC, the UN Humanitarian Response Depot (UNHRD), managed by WFP, or MSF. These HOs have developed specialized skills in supply chain management (SCM).

2. Problem Statement

In this section, the past evolutions and upcoming challenges that the HSC managers face from a practical perspective will first be discussed, and second, the gaps will be identified from an academic perspective.

2.1. Towards a Humanitarian Sustainable Supply Chain

Even though HSC has always been part of disaster response, the awareness of its key role grew significantly during the last decade. Therefore, the management of HSC operations has evolved from a reactive behavior focused on disaster response towards the current effective/efficient behavior that includes the preparation phase. Nonetheless, performance has not been systematically evaluated in the HSC field, probably because measuring the "alleviation of human suffering" is intangible (Beamon and Balcik, 2008). This section explores past, present and future trends of HSC performance.

2.1.1. The effective and fire-fighting HSC management approach

In contrast with commercial supply chain performance approaches, effectiveness is, and has been, the main driver or value of HSC (Widera et al. 2013). Effectiveness is the ability to enhance the expected results (Lauras, 2004). It is commonly defined as achieving target outcomes.

Therefore, considering that the expected results of a relief operation are to alleviate human suffering by procuring emergency relief items, we can acknowledge that the effectiveness of an HSC is the ability to satisfy humanitarian needs in terms of emergency items (i.e. shelter, food, hygiene), on time.

However, fire-fighting behavior has also characterized disaster relief operations. Fire fighting happens when, due to time pressure, decision-makers rush from one humanitarian response to the next, and no time can be invested in solving problems.

Consequently, up until the end of the 20th century, decision-makers were mainly focused on response, and overlooked the preparedness phase. In addition, HSC management was a "back-office" support function.

At that time, the occurrence of major humanitarian disasters made evident the weaknesses of a responsive management approach. Due to the scale of the disasters, along with the unprecedented media coverage, the weakness of disaster response management became obvious, especially in terms of HSC. For instance, both Hurricane Mitch (1998) and the Indian Ocean Tsunami (2004) placed HSC under stress.

The response to Hurricane Mitch revealed the deficiencies of the IFRC HSCs in terms of effectiveness (weak responsiveness, lack of vertical coordination).

> **Hurricane Mitch (1998)**
> **What?** Between 22 October and 1 November 1998, a 180-mph Category 5 storm, the worst to hit the Gulf of Mexico in 200 years, swept through a number of Central American countries devastating the economies of Honduras, Nicaragua and Guatemala.
> **Disaster outcome:** 10,000 people were estimated dead while some two million were left homeless. About 400 bridges were destroyed in the region, while the course of rivers was changed and a three-foot layer of mud was deposited on flooded airport airfields.

Response weakness: IFRC's technical staff and relief delegates arrived late in the region. Emergency Response Units were deployed at the eleventh hours. It took weeks to mobilize and distribute basic supplies such as food, water and shelter to the population.
Source: INSEAD Case studies (2004)

Some years later, the disappointing response to the Indian Ocean Tsunami of 2004 weakened the perception of the HSC. The lack of preparedness and coordination in this response was criticized in the World Disaster Report 2004.

Indian Ocean Tsunami (2004)
What? In the early hours of the morning of Sunday 26 December 2004 a massive earthquake measuring 9.0 on the Richter scale struck the west of northern Sumatra. The quake triggered a powerful tsunami that swept the coasts of neighboring countries and caused serious damage and loss of life.
Disaster outcome: At least five million people were affected in Indonesia, Sri Lanka, Maldives, India, Thailand, Seychelles, and Myanmar. The death toll exceeded 280,000 people, and more than one million people were displaced as a result of the destruction.
Response weakness: The donors' response was unprecedented thanks to media coverage and familiarity with the affected areas (tourism). Moreover, there was also a huge mobilization of HOs. However, the low quality of operations and the excess of donated but unnecessary goods caused an HSC overload that added to operational problems inherent in the quantity and quality of local and international staff; inadequate methods, programs and tools, and little involvement in process management or coordination. Therefore, the consequences were obstructed airports, excess containers blocking ports and customs areas, saturated warehouses, expensive materials and equipment deteriorating in the sun and rain, inadequate supplies and insufficient staff to provide records of materials, poor logistics reports and, in addition to losses, the theft and sale of donations.
Source: (Costa et al. 2012)

Accordingly, HOs started considering HSC as a key factor for improving disaster response performance.

2.1.2. An effective and efficient disaster response

To face internal and external pressure, and maintain a competitive position, HOs encountered the urgent need to go beyond the effective and fire-fighting approach. Thus, they started to invest time and resources on the preparedness phase, with a special focus on how to improve HSC performance.

The effectiveness approach was also challenged by humanitarian needs and funding trends. Humanitarian needs are rising year after year. Both people targeted by HOs and the appeals requested by the HOs are increasing (Figure 8). Since 2006, needs have quadrupled. In addition, funding is also rising, even though the growth is less significant. Thus, there is a continuously increasing gap between humanitarian needs and available funding. Figure 9 shows how unmet requirements have been rising for the last 10 years.

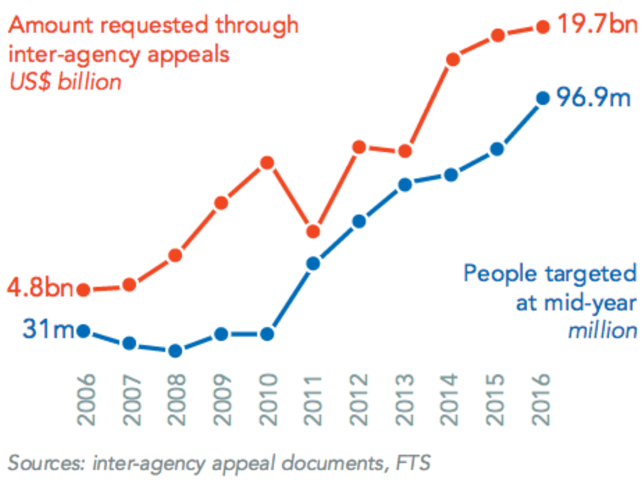


Figure 8 Inter-agency appeals: funding requested and people targeted (OCHA, 2017)

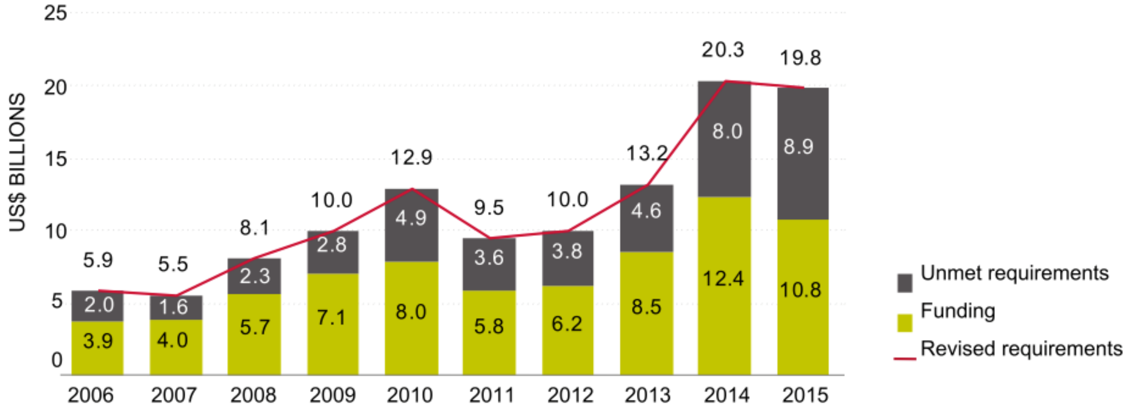


Figure 9 Requirements, funding and unmet requirements (source: Global Humanitarian Assistance report 2016)

Bearing in mind that HSC management was recognized as the most expensive part of relief operations (Van Wassenhove, 2006), HSC managers started considering cost-efficiency in addition to effectiveness, to obtain a competitive advantage. Donors are asking for greater accountability, and have become less tolerant of inefficiencies (Balcik et al. 2010). Thus, reducing the cost of operations, with an efficient performance perspective, allows HOs to compete in the "humanitarian donor market" and to retain and gain public and private donors who finance the operations.

Therefore, the change in performance paradigm plus the focus on the HSC resulted in a main strategic change. Major HSC organizations like IFRC or WFP shored up the design of their HSC. They deployed a network of strategically located prepositioned stocks.

This distribution strategy consists in pushing products from prepositioned contingency stocks into the country as soon as the humanitarian needs are assessed. If the response capacity of the contingency stock is exhausted, a pull model is then set up to source further goods from the suppliers. This hybrid model allows the first needs to be rapidly satisfied and gives decision-makers some buffer time to plan the upcoming procurement process.

This was a step forward in improving effectiveness (the reduction in response times) and efficiency (the reduction of acquisition costs) thanks to the management of centralized stocks and long-term relationships with suppliers (Jahre, 2008; Laguna Salvadó et al. 2016). Since then, the HSC has made significant progress in improving the efficiency of aid delivery. However, there are some limitations to this regionalization strategy.

"66% of the disaster response is related to small or middle scale emergencies, most of them recurrent"

Silent disasters campaign (Barrena, 2015)

The rise in humanitarian need is significant at all scales, including small- and medium-scale disasters. However, considering that only 10% of large disasters become news headlines (Barrena, 2015), and that 66% of disaster operations are for small and medium disasters, HOs struggle to get funds because of the lack of media coverage.

These so-called silent disasters are often recurrent, affecting the same region several times. In some areas, droughts occur regularly with shorter or longer breaks in between. Other recurring disasters are hurricanes (e.g. Haiti was affected by four of them in the course of 2008) or floods (e.g. Pakistan was affected in 2010, 2011 and 2012) (Ferris et al. 2013).

In the last few years, different models of shared and common service provision have emerged in the HSC context. The main objective of these approaches is to improve the cost efficiency of the regional structures. Examples are the IFRC or UNHRD logistic network, which offers specialized HSC services to the humanitarian community. These recent changes have contributed to rationalizing HSCs and meeting increasing needs, but are not sufficient (Laguna Salvadó et al. 2016). For instance, the economic sustainability to maintain these structures is still a challenge, and there is also room for improvement in terms of effectiveness.

2.1.3. HSC "in the age of sustainable development"[1]

"Billions of citizens continue to live in poverty and are denied a life of dignity. There are rising inequalities within and among countries. There are enormous disparities of opportunity, wealth and power. Gender inequality remains a key challenge. Unemployment, particularly youth unemployment, is a major concern. Global health threats, more frequent and intense natural disasters, spiraling conflict, violent extremism, terrorism and related humanitarian crises and forced displacement of people threaten to reverse much of the development progress made in recent decades. Natural resource depletion and adverse impacts of environmental degradation, including desertification, drought, land degradation, freshwater scarcity and loss of biodiversity, add to and exacerbate the list of challenges which humanity faces."

Transforming our world: the 2030 Agenda for Sustainable Development

UN Assembly Resolution (2016)

Even if world political leaders do not address the sustainable development challenges as they should, the commitment for sustainable development has captured public opinion, and people have become more sensitive to and concerned about the environmental and societal impact of their actions and choices. The 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals, emphasizes that developing a sustainable global economy is central to the debate.

The term sustainability has been widely used in a broad range of disciplines and contexts, but in the context of disaster response it has been given little attention. This is not surprising considering that "alleviating human suffering" is seen as a priority and comes first regardless of social, environmental

[1] Adapted from the UN report title, 'The United Nations in the Age of Sustainable Development'

and other costs (Oloruntoba, 2015). In the literature it is also argued that any HSC system is (somehow) a sustainable system since it contributes to saving lives and improving the living conditions of the population. Nonetheless, the same author rejects the argument by stressing the fact that SHSCs are conditioned by pursuing direct sustainability objectives while general HSCs may indirectly serve the purposes of sustainable development (Klumpp et al. 2015).

At the top management level, HOs have already been involved in the development of sustainable behavior, as the declaration below illustrates. However, today, it is still a high-level statement, and HSCs do not have the tools to manage a sustainable management approach.

> "*We happily endorse the 2030 Agenda, and our network stands ready to partner with governments, UN agencies, civil society, the corporate sector and communities themselves to turn this ambition into a reality.*"
>
> -IFRC Secretary General, Elhadj AS SY
>
> New York, 25 September 2015

The trends of increased globalization in the commercial SC have assisted logistics and SCM activities, but they have also been detrimental from a sustainability perspective (Grant et al. 2017). However, the commercial sector has understood the competitive advantage of considering sustainability, as illustrated by "green" marketing, or Corporate Social Responsibility programs: when seeking to improve the environment, and social and economic performance, companies act in their own interests, in the interests of their stakeholders and in the interests of society at large (Sisco et al. 2015). Sustainability has been identified as one of the biggest opportunities for doing business for decades (Hart, 1996). It has become an approach to both ensure long-term business viability and to obtain a "social license" to operate (integrity of a brand), and therefore, to enhance a competitive advantage (Kunz and Gold 2017).

The evolution of public opinion expectations (donors) suggests that sustainability will also have to be considered in the coming years for HOs seeking a competitive advantage. Sustainable Humanitarian Supply Chain (SHSC) implies innovative, socially responsible and proactive decision-making by all the stakeholders. According to (Oloruntoba, 2015) sustainable decision-making must:

- Minimize negative impacts;
- Enable long-term maintenance of community wellbeing; and
- Maintain a balance between life-saving, social, ethical, environmental and economic goals.

Les tendances à la mondialisation croissante dans le commerce SC ont aidé les activités de logistique et de gestion de la chaîne logistique, mais elles ont également été préjudiciables du point de vue de la durabilité (Grant et al. 2017). Cependant, le secteur commercial a compris l'avantage concurrentiel de la durabilité, comme en témoignent les programmes de marketing «vert» ou de responsabilité sociale des entreprises: lorsqu'ils cherchent à améliorer l'environnement et les performances sociales et économiques, les entreprises agissent dans leur propre intérêt. intérêts de leurs parties prenantes et de la société en général (Sisco et al. 2015). La durabilité a été identifiée comme l'une des plus grandes opportunités pour faire des affaires depuis des décennies (Hart, 1996). C'est devenu une approche à la fois pour assurer la viabilité à long terme de l'entreprise et pour obtenir un «permis social» (intégrité d'une marque), et donc pour renforcer un avantage concurrentiel (Kunz et Gold 2017).

L'évolution des attentes de l'opinion publique (donateurs) suggère que la durabilité devra également être prise en compte dans les années à venir pour les sociétés à la recherche d'un avantage concurrentiel. Sustainable Humanitarian Supply Chain (SHSC) implique une prise de décision innovante, socialement responsable et proactive par toutes les parties prenantes. Selon (Oloruntoba, 2015), une prise de décision durable doit:

• minimiser les impacts négatifs;

• permettre le maintien à long terme du bien-être de la communauté; et

• Maintenir un équilibre entre les objectifs vitaux, sociaux, éthiques, environnementaux et économiques.

2.1.4. Towards a SHSC

We demonstrated that HSC management has evolved over the past decades from a fire-fighting approach towards a performance-oriented perspective (efficiency and effectiveness). HOs have invested in HSCs in terms of strategy, and this evolution has been accompanied by professionalization, and an increase in skills (Jahre, 2008). To sum up, until now, the main objectives of the management of an HSC have consisted in improving competitiveness by effectively managing supply flows, while minimizing costs.

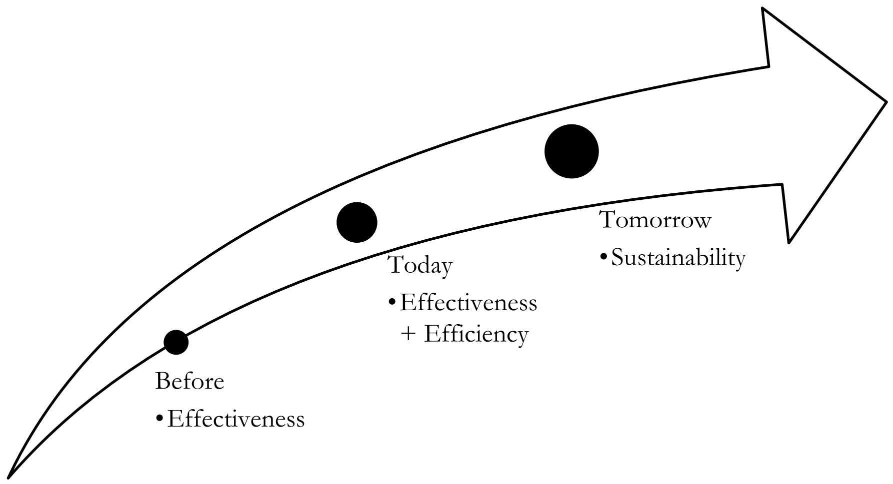


Figure 10 Evolution of HSC performance expectations

However, due to the awareness of donors and HOs to global sustainability challenges, the HSC needs to evolve and consider sustainability for near-future operations management. Thus, sustainability is a new paradigm for HSC managers that has been identified as a future requirement to maintain an “order winner[1]” position.

HOs are already concerned about the sustainability of disaster response, but difficulties remain for HSC decision-making to concretely introduce sustainability to their decision processes. Therefore, there is a call for more research that addresses issues of sustainability in HSC planning and decision-making (Haavisto and Kovács, 2014; Klumpp et al. 2015).

This research work focuses on how to support HSC decision-makers to establish and enhance a concrete SHSC system.

[1] The terms "order winners" and "order qualifiers" refer to the factors that may lead to competitive advantage and market success.

2.2. Research gaps

The literature states that sustainability is still overlooked in humanitarian settings, although it is essential for aligning operational objectives with longer-term objectives of humanitarian action. Although both practitioners and academics are concerned by HSC sustainability, the state of the art reveals several risks and challenges to enhancing sustainable HSC operations. Therefore, several authors have called for more research to integrate sustainability into humanitarian decision-making (Haavisto and Kovács 2014; Klumpp et al. 2015; Kunz and Gold 2017).

2.2.1. Gap 1: Difficulties in measuring sustainability

Sustainability approaches are a young topic in the field of SCM. The academic publications have appeared since the year 2000 but they mainly have a qualitative nature. State of the art works show that even though the concern for sustainable SC is widespread, there is a gap between intentions (discourse) and implementation (Ashby et al. 2012). They also warn of the gap between management research and management practice.

Following the Triple Bottom Line (TBL) model, it is widely accepted to present sustainability as the balance between environmental, societal and economic dimensions. TBL is a systemic approach developed in the mid-90s by John Elkington to "capture the essence of sustainability by measuring the impact of an organization's activities including its profitability and shareholder values and its social, human and environmental capital" (Savitz, 2012). It stresses the need to achieve a minimum in performance for the three dimensions. However, there is no consensus regarding the trade-offs and synergies across the economic, environmental and social objectives in a humanitarian context. Moreover, there is not a standard definition for each dimension.

The macro-economic definition of sustainability and the three dimensions can explain sustainable development on a conceptual level, but do not provide much guidance on how sustainability shall be addressed in the context of HSC operations.

2.2.2. Gap 2: Planning shortcoming

To improve sustainable operations, decision-makers need to evaluate the impact of their decisions on TBL dimensions. The role of anticipating the impact of decisions is the job of planning. "Planning supports decision-making by identifying alternatives of future activities and selecting some good ones or even the best one" (Stadtler, 2005).

However, the HSC context is characterized by a lack of structured planning processes (Haavisto and Kovács, 2014). Overlooking planning results in a lack of coordination and inefficiencies such as the bullwhip effect or distribution delays, and it is a barrier to aligning operations with sustainable objectives.

2.2.3. Gap 3: Lack of adequate Decision-support Systems

On the commercial SC management side, planning processes are supported by decision-support systems such as ERP (Enterprise Resource Planning), TMS (Transportation Management System), WMS (Warehouse Management System), and more recently, APS (Advanced Planning System). Therefore, developing adequate HSC planning decision-support systems may enable decision-makers to improve performance, and eventually consider sustainability challenges (Hella Abidi et al. 2014).

A decision-support system is generally defined as "an interactive computer-based information system that is designed to support solutions on decision problems" (Liu et al. 2010). In Operations

Management (OM), decision-support systems are often based on Operational Research (OR) approaches.

In disaster management, there is an increasing recognition of the need for study of OR applicability. Although much research has been conducted on developing OR models to support HSC decision-making, just a few have a real impact in the field (Laguna Salvadó et al. 2015). (Holguín-Veras et al. 2012) highlights the need for more research on specific OR models (routing, inventory allocation, planning) in humanitarian settings: "…as a result of the unique and complex features of Humanitarian Logistics – which are significantly different from the commercial setting – there is an urgent need for analytical tools that capture such complexity and enable disaster responders to determine the best course of action."

2.3. Research Statement

Addressing the sustainability of an HSC is a young subject of discussion, which deserves the attention of the academic community to solve the increasing scientific challenges. Today, very little research work has addressed the specific gaps that HSC -decision-makers have found in concretizing an SHSC.

Difficulties in measuring sustainability, planning shortcomings and a lack of adequate decision-support systems have been identified as the main practical gaps from an Operations Management perspective. Moreover, in the HSC research domain, there is still a gap between research proposals and field implementation. To contribute to bridging these gaps, it is fundamental to have a clear understanding of the HSC setting, and to build solutions with a strong, field-based hypothesis. Therefore, the objective of this research work is to address the following research questions:

RQ1: How to formally conceptualize what an HSC is?

The HSC can be described as a collaborative system, where many actors and stakeholders interact to achieve the ultimate goal of alleviating human suffering. To improve the overall performance of this system, it is essential to have sufficient knowledge of it. Previous research work has proposed models able to define such knowledge, but only partially and in a way that does not allow reusability. The difficulty remains in having a shared and sufficiently conveyed conceptualization of the HSC system for first, understanding, and second, improving system behavior. This research question is interesting for both academics and field practitioners, as it should contribute to knowledge sharing and communication among practitioners themselves, and between practitioners and academics. It also may contribute to academia by facilitating field research design and cross-case and longitudinal study analysis.

RQ2: What does sustainability mean in HSC operations and how can it be assessed?

Sustainability is a broad multidimensional concept. Given the increase in scientific publications considering sustainability in many disciplines, it can be considered a trendy topic. Nonetheless, the level of granularity of sustainability assessments is typically contrary to measurement transferability. It appears that sustainability assessments either remain at high-level definitions, aggregations and objectives that do not support tactical and operational decision levels, or are closely linked to the interests or needs of particular sectors and decision-makers. Thus, in low decision-making levels, each sector of activity has to find a reliable way to quantify sustainability. Even if HOs have already subscribed to the sustainability agenda, it is still difficult to concretize what a sustainable performance is at the different HSC decision levels. This research question is relevant for academics as it aims to contribute to bridging the gap between the general concepts of sustainability and the HSC research domain, and also for practitioners as it aims to enable the assessment of sustainability in HSC decision-making processes.

RQ3: How to support decision-makers consciously and systematically making sustainability trade-offs and exploring consequences?

To enhance sustainable operations, decision-makers may benefit from considering the sustainability assessment "a priori", in the planning process. To plan sustainable operations, -decision-makers need to make sustainability dimension trade-offs transparently, based on their knowledge of the situation (organizational objectives and interests, expertise, etc.), and being aware of the consequences. However, decision-support systems that address trade-offs are not aligned with practitioners' requirements in terms of skills and time. Users typically have to deal with abstract and complex weightings and dependencies, so it may represent a barrier for the acceptability of decision-support systems in the field. The challenge here is then to design and develop a decision-support system approach that contributes to bridging the gap between academic proposals and field usability. This research direction is interesting for academics as it aims to make accessible the use of OR methods for non-experts, and therefore it aims to improve systematically HSC planning processes.

3. The IFRC application case

This thesis has been conducted in close relation with the IFRC HSC, and especially, with the American and Caribbean Regional Logistics Unit (A&C RLU). This section presents the IFRC organization, and provides an overview of the A&C RLU.

3.1. The Red Cross and Red Crescent movement

The International Red Cross and Red Crescent Movement is a global humanitarian network of 80 million people that helps those facing disaster, conflict and health and social problems. It consists of the ICRC, the IFRC and the 190 Red Cross and Red Crescent National Societies (NS).

Humanity, impartiality, neutrality, independence, voluntary service, unity and universality are the key principles to the International Red Cross and Red Crescent Movement distinct identity. These seven Fundamental Principles provide an ethical, operational and institutional framework to the work of the Red Cross and Red Crescent Movement. They are at the core of its approach to helping people in need during armed conflict, natural disasters and other emergencies.

The ICRC, the Federation and the National Societies are independent bodies. Each has its own individual status and exercises no authority over the others.

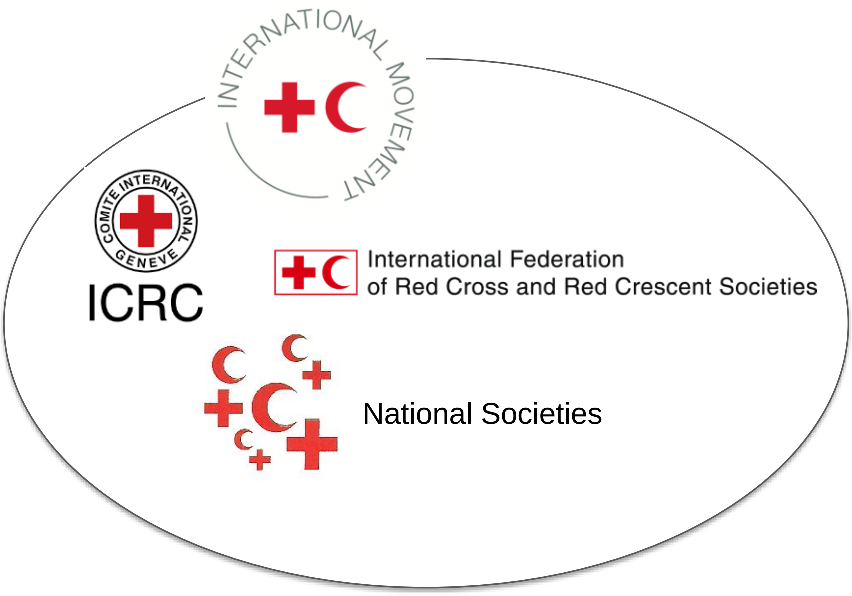


Figure 11 The Red Cross and Red Crescent International Movement

The ICRC is an impartial, neutral and independent organization whose mission is to protect the lives and dignity of victims of war and internal violence and to provide them with assistance.

The IFRC coordinates and directs international assistance following natural and man-made disasters in non-conflict situations.

The IFRC works with NSs in responding to catastrophes around the world. Their reliefs operations are combined with development work, including disaster preparedness programs, health and care activities, and the promotion of humanitarian values.

3.2. The IFRC Humanitarian Supply Chain network strategy

The Logistics, Procurement and Supply Chain Management (LPSCM) Department of the IFRC provides humanitarian logistics services[1]. Its key mission is to support the core work of the Red Cross Red Crescent network. It also offers these services on a non-profit basis to third parties in the humanitarian sector and to governments. The worldwide activities of the IFRC LPSCM focus on three strategic objectives:

1. Support the enhancement of National Society logistics capacities
2. Increase the IFRC's logistics capacity to deliver logistics services for preparedness and operational activities
3. Provide agreed logistics services to third parties in the humanitarian sector

The mission of the IFRC HSC upstream network is composed of five Regional Logistics Units (RLU) strategically located in Panama, Kuala Lumpur, Nairobi, Beirut and Budapest, to respond to humanitarian needs.

Moreover, sub-regional logistics units (LU) based at the country level with the support of the NS are connected to each RLU. This second layer, which responds to the need to get closer to beneficiaries, is still under deployment. LU stocks are located inside NS warehouses as part of the RLU contingency stock. The operational mode is linear: the regional hub manages all warehouse procurement, and each sub-regional warehouse distributes only to internal country needs.

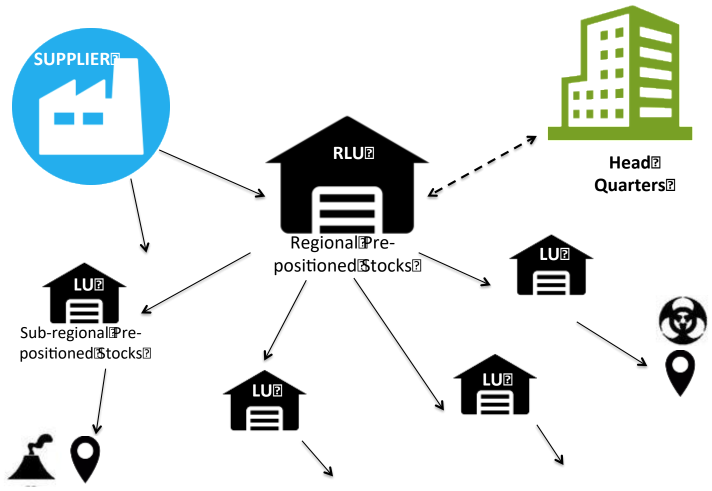


Figure 12 Linear sub-regional design

The sub-regional approach aims to add or reinforce a logistics capacity layer closer to the beneficiaries, while maintaining the RLU and its advantages. This enables the IFRC to:

- Improve response time, thanks to shorter geographical distance. Moreover, involving (or empowering) the country level on preparedness contributes to improving disaster response.
- Enhance local capability, which may also encourage local sourcing with a positive impact on the local economy.
- Re-design the HSC; this is an opportunity to improve the cost-efficiency of the system.

[1] It used to be called Global Logistic Services (GLS) up until 2016

However, the linear approach (stocks coming from the suppliers to the beneficiaries through regional and sub-regional hubs) continues to require high contingency stock. As long as the RLU strategy has not been reviewed, the regional contingency stock coverage increases if we take into account the hub and sub-regional stocks, which was already overestimated.

3.2.1. A&C RLU activity

The American continent is a good example of recurrent disasters. Looking at the Global Humanitarian Assistance Report 2015 (Swithern et al. 2015), none of the American countries is in the top 10 of affected countries nor in that of the international humanitarian assistance recipients (2004 to 2013). The crises affecting America are mostly natural disasters with recurrent patterns such as *El Niño* (Charvériat, 2000). These small- and medium-scale crises constitute a very high percentage of emergency interventions by HOs (Vargas Florez et al. 2015). Individually, each generates only a local impact, where there is no need to mobilize a massive amount of relief items.

In 2014, the A&C RLU launched 16 Disaster Response Emergency Funds (DREF) for small-magnitude disasters and three appeals (large-scale disaster funding procedures) (Figure 13). If we extrapolate the trend of the last 15 years, it seems that the number of small-to-medium response operations will tend to rise.

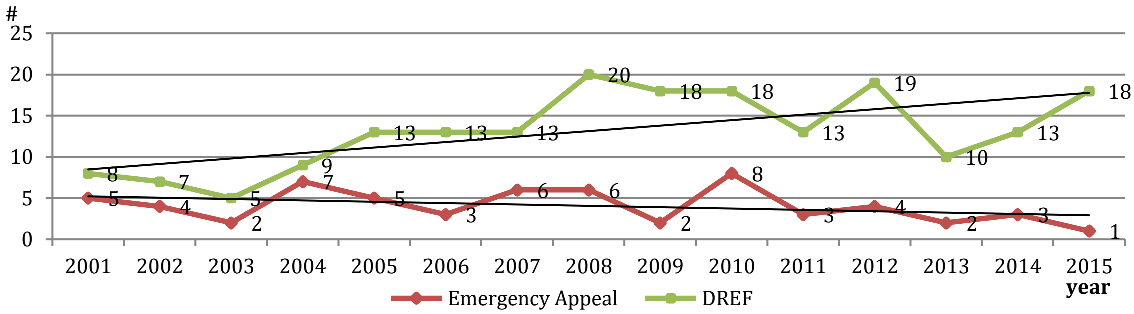


Figure 13 Emergency appeals and DREFs 2001-2015 (source: IFRC PADRU, 2015)

This pattern has a strong impact on the activity of the A&C RLU, which is sized for large-scale disaster responses. Each RLU has a contingency stock to assist 5,000 families, but the activity in a standard year can be considered low in America.

3.2.2. Cost recovery

The working costs of RLUs have been based since 2012 on full-cost recovery (assets and infrastructure). This mechanism charges the costs of (i) supplying goods and services and (ii) covering overheads related to the logistics services management. In a standard year, responses to crises do not generate enough rotation to cover the fixed cost of RLUs (IFRC, 2012).

The IFRC's strategy consists mainly in providing a panel of specialized services like procurement, warehousing and distribution to third parties. For the IFRC, the main customers of these services are the Partner NS and some international organizations such as Oxfam. Partner NSs are NSs from developed countries that invest part of their funds on prepositioning relief items in addition to the RLU contingency stock. But even though this provides some extra revenue, it is not sufficient to ensure the economic long-term sustainability of RLUs like those of the A&C.

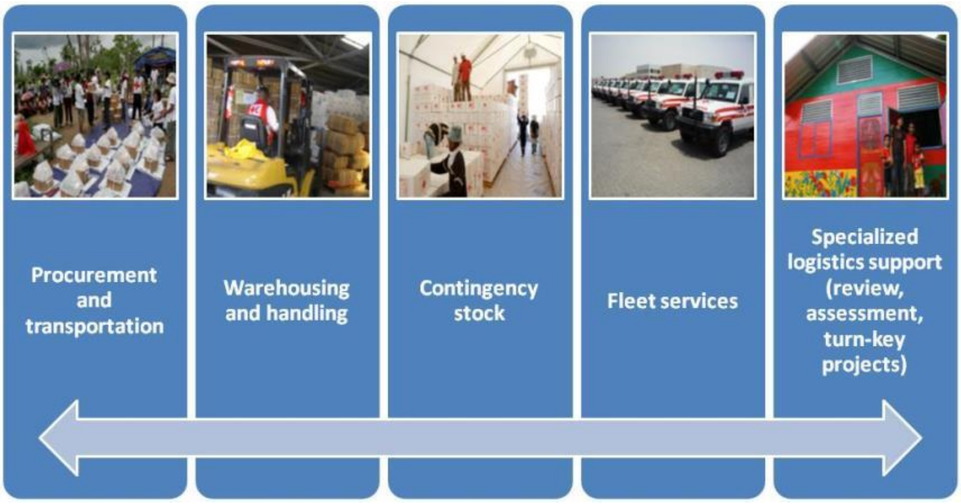


Figure 14 Logistics services provided by the IFRC (Grenade, 2015)

3.2.3. Operations

The IFRC has announced that it aims to reduce response time to 48 hours (Grenade 2015). Although with regionalization, emergency items are closer to the field than they used to be, this aim is still out of reach. By locating stocks closer to disaster-prone areas, transport time can be reduced.

Beyond risks to stock, the supply trigger procedures and coordination between actors can also cause delays. For the IFRC, an RLU cannot start any procurement activity without a formal request from the field assessment team. And this can take from several days to some weeks. An IFRC Procurement Officer (Panama, September 2015) explained a case where the request took three weeks to be validated. There was a crisis in the West Indies and the French Red Cross responded - instead of the IFRC - with their contingency stock placed at Guadeloupe island (not part of the IFRC contingency stock) because the RLU was waiting for the request validation. Practitioners consider that these recurrent delays are mainly due to cultural distances (no knowledge of the country), as Jahre has pointed out: "*even if RLUs are geographically closer to the regions often struck by disasters, they are still too far from the local communities with regards to culture, knowledge and geographical distance … they are stuck in the middle*".

3.2.4. Procurement strategy

Today, the procurement process of the IFRC is based on a competitive bidding process. In addition to the framework agreements with international suppliers that provide part of the standard contingency stock (e.g. blankets, jerry cans, kitchen sets, etc.). For regular replenishment (non-emergency), items are sourced internationally, mainly from Asia, due to the competitive cost even though there are long lead-times.

However, local sourcing stimulates local economies and reduces transportation costs. Moreover, local shipments require less documentation than international consignments that can stay blocked at customs for long periods. Despite these advantages, some items are difficult to be sourced at the country level as long as the procedures to purchase are strict to maintain standards. And at the regional level there is a lack of knowledge and visibility of the local sourcing capacity (quality and availability) because they are too far geographically and also culturally.

4. Research Methodology

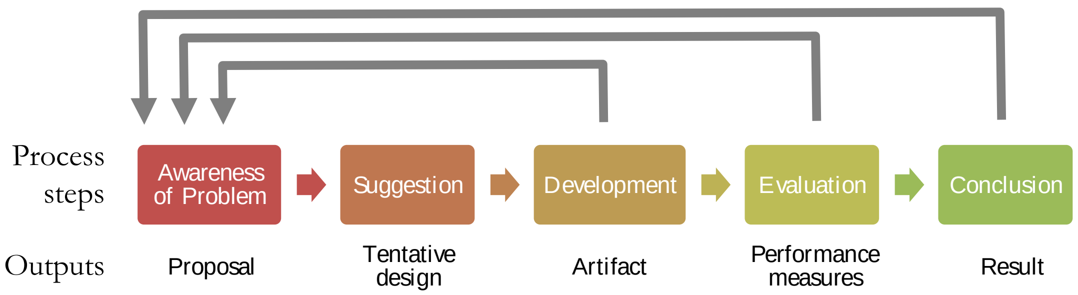
The objective of this research project is to develop concrete solutions to support sustainable decision-making in HSCs with a scientific, applied research[1] approach. Enhancing sustainable operations is an interdisciplinary matter as broad as the subject of 'sustainability': engineering sciences, economic sciences and social sciences are concerned to some extent. Here, we identify and address the problem with an engineering science point of view and methodologies.

The main difficulty is still to develop decision-support systems adequate for humanitarian needs and uses. One of the biggest criticisms in the HSC literature review is the barrier between scientific proposals and field acceptance (Holguín-Veras et al. 2012). Several authors conclude that field-grounded research should allow for building more adequate proposals. (Kunz et al. 2017) highlight the importance for both academics and practitioners to "jointly define research projects".

In this context, field-oriented research is a requirement for adequately developing applied research proposals to enhance an SHSC. However, it is not a trivial matter to classify a particular type of research into a single research methodology paradigm (Laurencelle, 2005). In the SCM literature, the most popular research methodologies are Model Building, Surveys, Case Study Research and Action Research (Seuring and Müller, 2005).

Our proposed research methodology fits in with the philosophy of Action Research, which has been identified as valid and relevant in the context of SCM (Müller, 2005). Briefly, "Action Research uses a scientific approach to study the resolution of important social or organizational issues together with those who experience these issues directly" (Coughlan and Coghlan, 2002). However, the Action Research paradigm has been criticized by some authors, mainly for the positivistic paradigm position. The principal difficulty in validating Action Research is the lack of impartiality on the part of the researcher and the view of Action Research as a "consulting process masquerading as research" (Coughlan and Coghlan, 2002). The research process has been carried out in close relation with the IFRC to identify the problem, which explicitly shared the interest in moving towards an SHSC, and has contributed by providing information and feedback on our proposals. However, they have not led the research process and we have been free to address the problems we found relevant from both practical and academic points of view.

Given the nature of the research questions, which aim to improve the performance of an organization, Design Sciences' research methodologies are also relevant (Figure 15).



[1] *Applied research* aims to find a solution for an immediate problem facing a society or an industrial/business organization

Figure 15 The general methodology of design research (Järvinen, 2007)

Design Sciences belongs to the Information Systems domain, which is at the confluence of people, organizations, and technology (Holmström et al. 2009). Design Sciences is a problem solving process through the building and evaluation of artifacts designed to meet the identified business need. The concordance between the characteristics of Action Research and Design Sciences has been highlighted by (Järvinen, 2007), who concludes that they should be considered similar research approaches. Both approaches have 5 similar steps, illustrated in Figure 15 with the design sciences approach.

In summary, to contribute to bridging the gap between practitioners and academics we followed an inductive research approach. Inductive, because the problem and the solutions are both grounded in field research, with the aim of creating a general hypothesis (Figure 16):

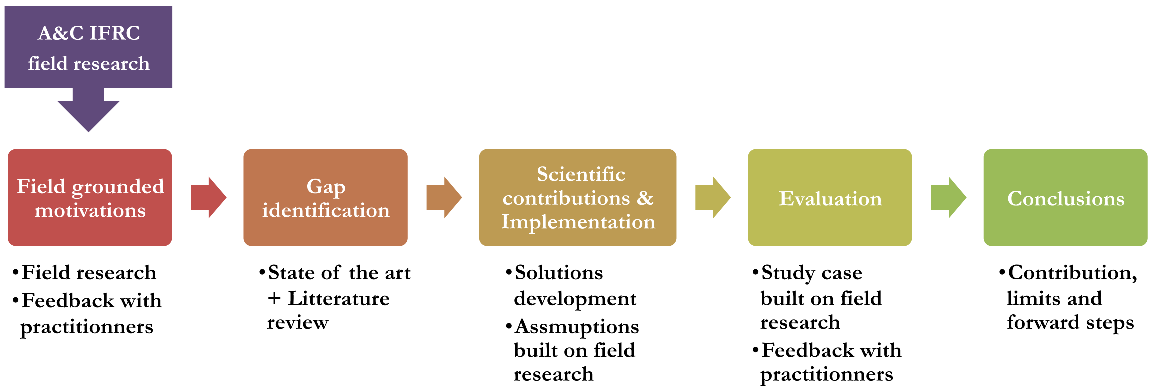


Figure 16 Research methodology overview

Field grounded motivations:

This is a critical step, as the relevance of the proposals rests on the capacity to identify a relevant problem for practitioners. The method used to identify a business challenge together with field practitioners is field data gathering, analysis and feedback with practitioners.

For data gathering, we used both secondary and primary data from HOs. Secondary data was mainly found on the Internet, and consists of annual reports and operations updates. For the primary data, we conducted a field research campaign and used semi-structured interviews, observations and access to HO documents.

A&C Field Research
Where? IFRC A&C RLU Office (Ciudad del Saber, Panama) & Warehouse (Panama Pacific Airport)
When? 10 days in September 2015
Who? One field researcher on site and two in the "back office"
What? The focus was on the upstream HSC business processes. The aim was to identify decision-makers' challenges.
Prior to the field research: Interviews with the Logistics Development Coordinator
On site: Observation of and semi-structured interviews with six IFRC A&C RLU team members**.**
Afterwards: The observations and data analysis helped to draw a picture of the business processes, and to identify the opportunities and challenges addressed in this thesis.

Gap identification:

Once the business stakes were defined, this step consisted in identifying the scientific challenges related to the business problem. To do so, it was necessary to know the state of the art, so we could build the contributions on existing evidence. The results of both the field research, mixed with the literature review, led to finding the three research questions presented previously.

The literature review was focused on past research work, and specific keywords to identify relevant contributions.

Building scientific contributions and implementation:

This step consisted in conducting in-depth work to build original methods or to adapt existing ones (for previously addressed scientific challenges) to answer the research questions and address the business stakes. Moreover, a prototype of each contribution is developed and validated with a proof of concept based on field research data.

Evaluation & conclusions

Each proposal has been implemented with a realistic case study based on the A&C RLU. Discussion with practitioners allowed us to identify a scope relevant for this purpose and to build the case based on data from the field.

5. Manuscript Structure

With the objective of supporting decision-makers to enhance an SHSC, the contributions are structured following a 3W story line: What? Why? How?

The first step (what?) is to describe the system that we want to have an influence on. Therefore, the research question addressed in Chapter 2 is:

RQ1: How to formally conceptualize what an HSC is?

Chapter 2 discusses the background on HSCs, SCs and disaster management collaborative systems knowledge structuring with reference models and metamodels, and proposes a specific metamodel for HSC to support field data gathering and knowledge structure. The concepts gathered during field research, added to the HSC core literature, have allowed an original and innovative HSC metamodel to be built. Model instances built from this metamodel provide potential input for developing adequate decision-support systems, as well as for supporting the design and analysis of field-oriented research. We illustrate the proposal with an example based on the A&C RLU.

The second step (why?) is to describe the decision-maker pursued objectives pursued by decision-makers. The research question addressed in Chapter 3 is thus:

RQ2: What does sustainability mean in HSC operations and how can it be assessed?

In Chapter 3 we give an overview of the significance of sustainability, and how it has been addressed in the literature and in practice. Previous research has shown that the challenge for HOs is to consider a sustainability perspective in their decision-making processes. We propose a performance measurement definition. Based on field research with the A&C RLU and a literature review on humanitarian performance measurement and sustainability, we define a set of criteria, objectives and key performance indicators that translates sustainability concepts to the context of HSC. Built on the TBL philosophy, the environmental and social dimensions are added to the economic one. The aim of Chapter 3 is to define the objectives of HOs to enhance SHSC operations. The framework use is illustrated with a maturity model of the SHSC.

The third step (how?) is to make sustainable decisions. Chapter 4 addresses the challenge of introducing sustainability objectives to the HSC decision-makers process:

RQ3: How to support decision-makers consciously and systematically making sustainability trade-offs and exploring consequences?

In Chapter 4, an OR approach is proposed to define sustainable planning "a priori": to anticipate outcomes with a decision-support system. To build the decision-support system, we model the SHSC Master Planning network flow problem, and propose an algorithm which ensures the decision-maker's central role. We illustrate the proposal with a use case based on the A&C RLU. This contribution has the originality of addressing both the challenges to improving the planning processes and to including sustainable objectives in the context of HSC.

Finally, in Chapter 5 we discuss the conclusions and the perspectives of this research project.

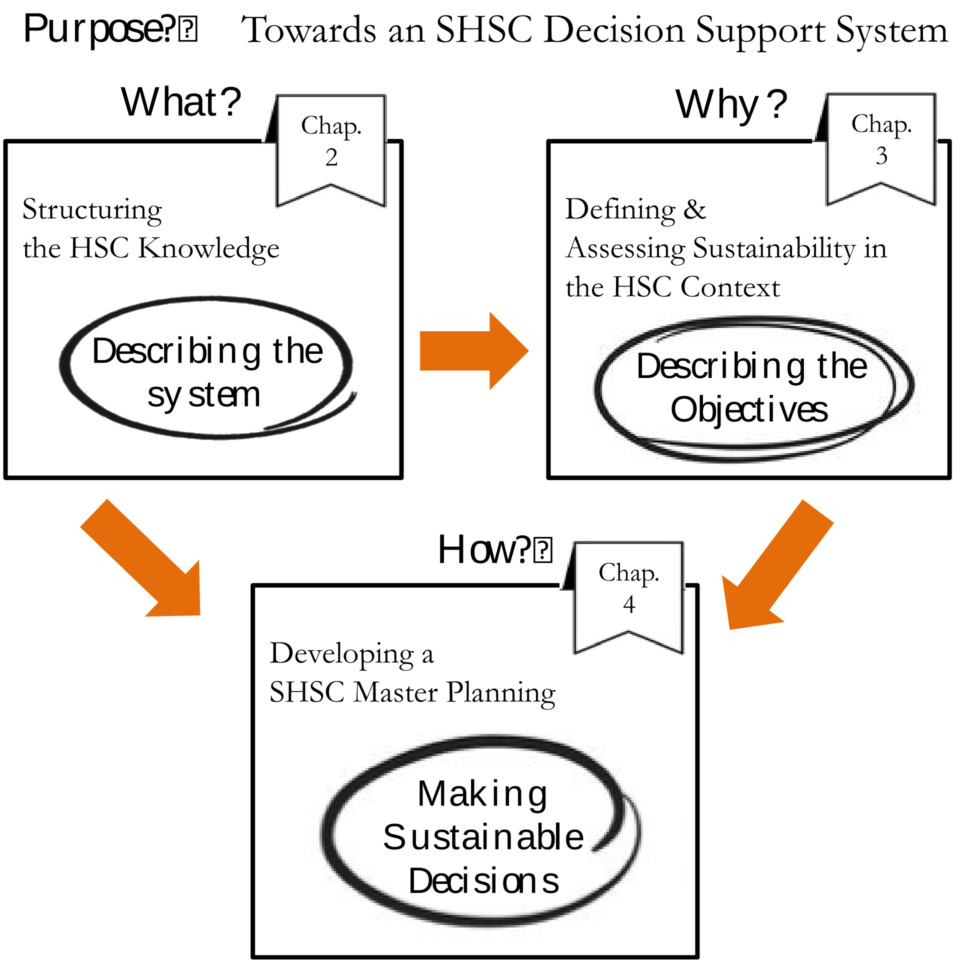


Figure 17 Manuscript Big Picture

Chapter II. HUMANITARIAN SUPPLY CHAIN METAMODELING

1. Towards an explicit conceptualization of the HSC

As discussed in the introduction, to improve the performance of the HSC, one of the challenges is to consider the complexity of the field. A shared, reusable and sufficiently conveyed view of the HSC domain may contribute to facilitating knowledge generation (field research data collection and analysis) and communication (between both practitioners and academics).

> "The more we know about a given domain and the more precise we are in representing it, the bigger the chance that we have of constructing computational systems and services that are consistent with the reality of that domain." (Guizzardy, 2005).

This part of our research aims to provide an explicit conceptualization of the HSC domain to build a bridge between "real world" data and the knowledge needed for decision-making, as illustrated in Figure 18. We consider here "data" as the raw data without contextualization, "information" as an understanding of the relationships among the domain data (HSC in this concrete case), and "knowledge" as the use of information to make decisions.

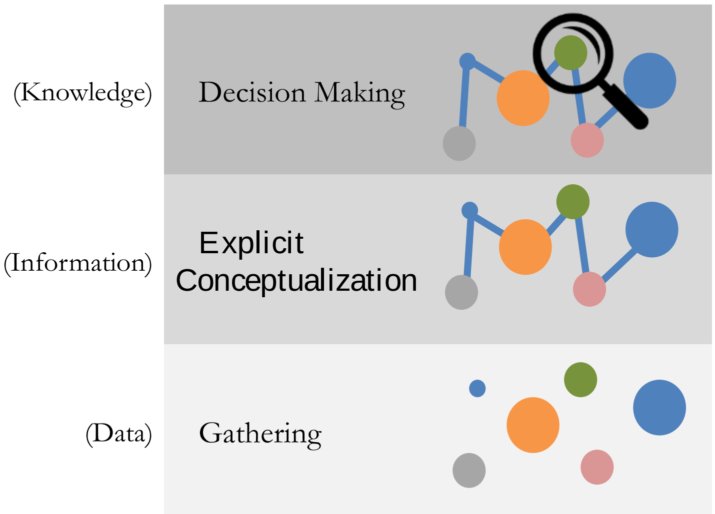


Figure 18 Chapter 2 research positioning

Therefore, this chapter addresses the research question: *How to formally conceptualize what an HSC is?*

1.1. From conceptualization to metamodeling

Concept /ˈkɒnsɛpt/

Noun. An abstract idea

Conceptualize /kənˈsep.tʃu.ə.laɪz/

Verb. To form a concept or idea of (something)

Conceptualization /kənˈsɛptjʊəlʌɪz/

Count noun. An abstract idea or concept of something

From a philosophical point of view, a concept is "an idea or mental image that corresponds to some distinct entity or class of entities, or to its essential features, or determines the application of a term (especially a predicate), and thus plays a part in the use of reason or language" (Oxford Dictionary). A conceptualization (as well as an abstraction) is described as "an immaterial entity that only exists in the mind of a user or a community of users of a language" (Guizzardi, 2005). Ullman's triangle (1972) represents the relationships between a thing in reality, its conceptualizations and a symbolic representation of this conceptualization (Figure 19).

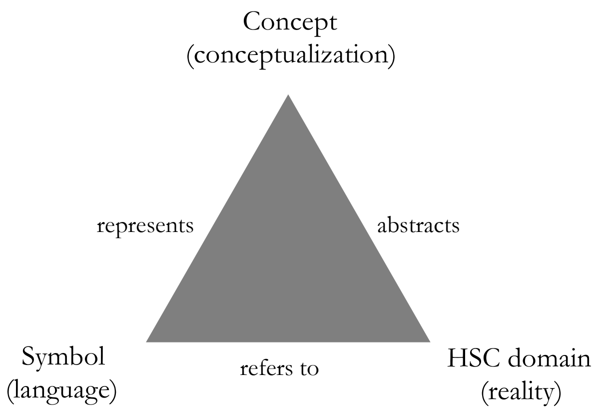


Figure 19 Adapted from Ullman's triangle

Thus, to build an explicit conceptualization of the HSC, we need to represent the concepts of the domain with symbols that refer to the things in the field.

Guizzardy (2005) stated that a model is the abstraction of a given portion of reality articulated according to a domain conceptualization. A model can be used either to document existing situations (descriptive mode) or to describe situations that have yet to eventuate (prescriptive mode) (Henderson-Sellers and Bulthuis, 2012). Within the Information Systems field, conceptual modeling is defined as a formal description of some aspects of the physical or social reality for understanding and communicating (Wand et al. 1995).

According to (Kung and Solverg, 1986), the main roles of conceptual models are (1) supporting communication between developers and users, (2) helping analysts understand a domain, (3) providing input for the design process, and (4) documenting the original requirements for future reference. In addition, the use of conceptual models allows static phenomena (things and their properties) and dynamic phenomena (events, processes) of a domain to be represented (Wand and Weber, 2002).

Formal (conceptual) models are built using more general models, also referred to as metamodels, or modeling language.

A metamodel then is the 'model of models': an explicit model of the constructs and rules needed to build specific models within a domain of interest (Gaševic et al. 2006). It (i) describes a domain that is representative of more than one instance in a less abstract domain, and (ii) is the core of a modeling language used to describe those instances (Bataille and Castellani, 2001; Henderson-Sellers, 2011). If we consider that no modeling is possible without some sort of metamodel (explicit or implicit), this also becomes true for metamodeling, as it also needs its own methods and tools, which, in turn, can be described one level higher in metamodels (and so on).

Moreover, metamodels are closely related to ontologies. In the Information System literature, an ontology is usually referred to as a formal, explicit specification of a shared conceptualization for a domain of interest (Gruber 1993) which may be used as a unifying framework (Uschold and Gruninger, 1996). It describes knowledge that can be used and reused to facilitate the comprehension of *concepts* and *relations* in a given domain as well as the communication between different domain actors.

When using the ontology concept for engineering purposes, two main categories are typically considered (Henderson, 2011):

- Domain ontologies, which are used to create common vocabulary for a specific application domain and are vital to ensuring that elements in the model have well-defined semantics;
- Meta-ontologies, which are equivalent to the metamodel of a modeling language and thus encapsulate the concepts needed for creating domain ontologies.

Over the past decades, there has been tremendous growth in metamodeling and ontology development (Henderson-Sellers and Bulthuis, 2012). In the literature both concepts often seem to be used indistinctly. Even if metamodels and meta-ontologies are not necessarily equivalent there is a fuzzy link between them. Metamodels can have ontological properties while treating them as a representation of the language underlying a worldview. Guizzardi conducted an in-depth study concerning the relationship between language, conceptualization metamodels and ontologies (Guizzardi, 2005). We conclude that to support the explicit conceptualization of a domain of interest, here the HSC, a formal metamodel should provide a high-level framework to define model concepts and its relationships.

1.2. Research direction

In order to address the research question, the center of this contribution is to specify an HSC metamodel (or meta-ontology), which is a set of terms naming concepts (classes) and relations. The metamodel should formally represent the abstract domain-conceptualization. The main objective is to use the metamodel to support analysts (academics and practitioners) in the creation of HSC conceptual models (or sets of organized data), or instances of the metamodel. Figure 20 shows the explicit conceptualization approach.

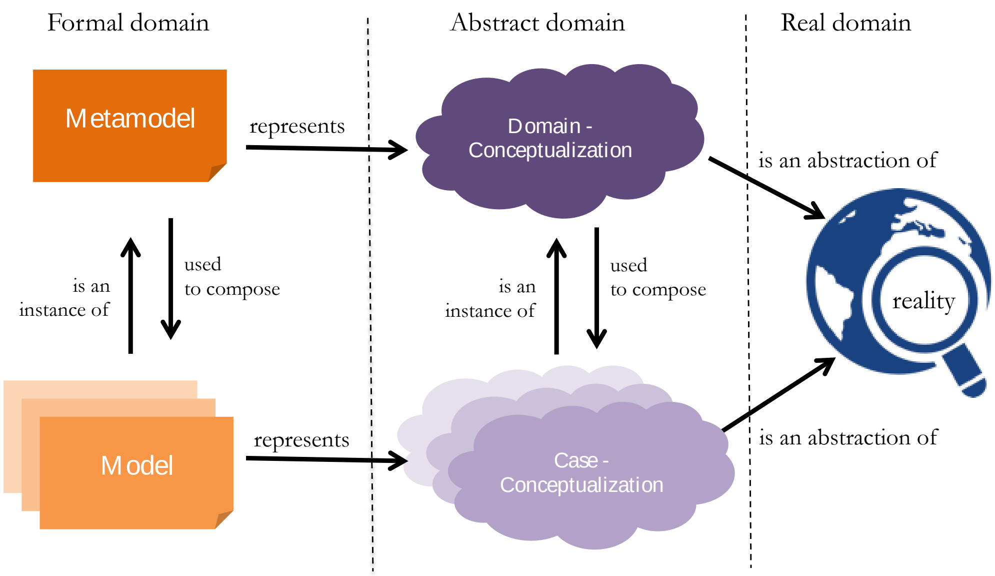


Figure 20 A metamodel as an explicit representation of a domain (inspired from Guizzardi, 2005)

In the sections below, an overview of the background and recent works is provided (section 2), related to the development of metamodels (including meta-ontologies) and referent models in Disaster Management, Supply Chains and HSC domains. Second, the main contribution of this chapter is presented: the HSC metamodel. Third, the use of a metamodel is illustrated in the IFRC case. This proof of concept has been built on the data gathered during the field research of IFRC A&C RLU. Finally, some discussions and further research directions are presented.

2. Background and related works

HSC has roots in both Disaster Management and SC. It integrates concepts and relationships coming from both domains (Figure 21). The HSC operates under the conditions of humanitarian disasters, therefore, (i) the objectives (life and death vs. profit and loss), (ii) the high levels of demand uncertainty, (iii) the SC formation (ad-hoc downstream design and implementation), and (iv) the changing operational conditions, make HSC part of Disaster Management, and a specific case within the SC. These specificities contribute to the fact that methods and best practices from SC are not necessarily appropriate for the HSC, and vice versa (Charles and Lauras, 2011).

In this section we provide an overview of metamodels and reference models in the three afore-mentioned areas, to identify the opportunities and limitations of current research. Reference models (or standards) are interesting for the purposes of building a shared and explicit metamodel of the HSC because they provide well-accepted and structured frameworks for concepts related to the domain. Even if the relationships are not explicit, they may provide validated concepts used in the domain.

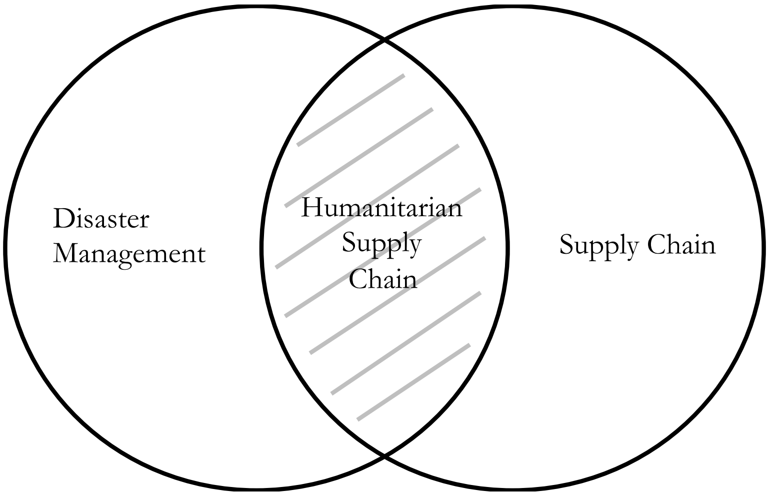


Figure 21 The Humanitarian Supply Chain domains

2.1. Humanitarian Supply Chain domain

In the specific HSC literature, we can identify different reference models that contribute to a better understanding of the HSC. (Kovács and Spens, 2007) proposed one of the first models related to humanitarian logistics. It provides a highly conceptual framework that distinguishes actors, phases and logistical processes of disaster relief logistics. (Blecken, 2010) proposed a specific reference framework for HSC, based on commercial SC reference models. It is organized in two dimensions. The hierarchical breakdown organizes SC tasks at strategic, tactical and operational levels. The structural breakdown organizes SC tasks related to assessment, procurement, warehousing and transport (Figure 22). These two dimensional frameworks help to classify the business tasks that are performed within an HSC.

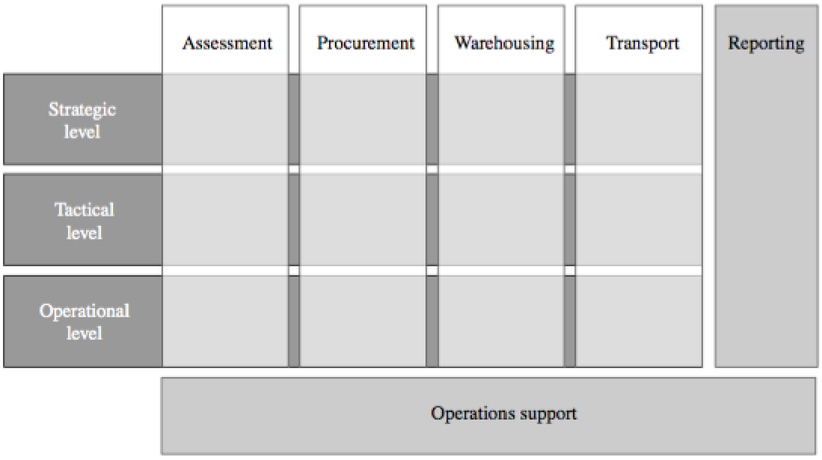


Figure 22 Blecken reference task framework model (Blecken, 2010)

Franke et al. (2011) combine Blecken's reference process model with a tool for coordinating the design, run-time and monitoring of inter-organizational humanitarian logistics processes. Both Blecken's and Franke's reference models are focused on the business process conceptualization of the logistics operations while the aim of our research work is to consider a wide view of the HSC system. Nonetheless, these contributions are relevant for our problem as they can support the identification and the definition of process concepts to be included in the HSC metamodel. However, they do not formalize a metamodel as such, which limits their reusability.

Overstreet et al. (2011) carried out a literature review on humanitarian logistics models. None of the models discussed addresses the challenge of data gathering and structuring through a metamodel.

Many mathematical models have been developed in the context of OR dedicated to HSC (Altay and Green, 2005; Van Wassenhove, 2006; Galindo and Batta, 2013). They are typically case-based, and do not provide any conceptual metamodels. However, these models are still interesting because they provide concepts and definitions of the HSC domain and relationships.

2.2. Supply Chain domain

In the commercial SC domain, many reference models have been developed; they mainly focus on the explicit conceptualization of business processes and activities in order to study their current practices and improve on them. They allow the processes to be conceptualized from several viewpoints and at various abstraction levels. There are many process modeling techniques and tools in the literature (Alotaibi, 2017; Min and Zhou, 2002).

The most famous SC reference model is probably the Supply Chain Operations Reference (SCOR) (Zhou et al. 2011). It structures the inter-organizational SC business processes around six top-level management processes: plan, source, make, deliver, return and enable. These levels are split into sub-levels.

Another reference model for representing an SC, the value stream in this case, is Value Stream Mapping (VSM). It is related to the Lean philosophy which begins by learning about the different kinds of waste that can affect the system (Womack and Jones, 1996). Waste is anything that adds cost or time without adding value (Tapping *et al.*, 2002). VSM is a visual representation of a workflow with quantitative data at each step of the process. Its principle consists in breaking down a process value stream along different operations (at a company scale) or along different installations (at a network scale) in order to analyze each activity that contributes to overall performance (Womack and Jones, 1996). Standardized pictograms are used to illustrate each activity.

Metamodeling approaches have also started to emerge. Given the strong competitiveness, the success of enterprises is strongly related to their ability to collaborate with other enterprises (Chan and Kumar, 2014; Daniele and Ferreira Pires, 2013). This emphasizes the need to have a common understanding of the systems, both within the boundaries of the organization and with other organizations. (Daniele and Ferreira Pires, 2013) identify 5 requirements to consider in SC metamodels, which are also relevant for the HSC context:

- Activity: represents the relevant actions to achieve logistics and provide value for customers.
- Actor: denotes individuals or companies that could be a provider or demander of activities and operates these activities on related resources.
- Physical Resource: denotes the objects that are used in the activities.
- Location: denotes the geographical area used to define the place relevant for the activities.
- Time: denotes the start/end time or the time interval associated with activities.

In addition, (Grubic and Fan, 2010) made a review and analysis of metamodels dedicated to SC. They identify a set of gaps that have to be considered in future developments. The most relevant ones concerning the HSC metamodels are summarized in Table 4.

Table 4 SC metamodel gaps, consequences and relevance for the HSC domain
(from Grubic and Fan, 2010)

Gap	Consequences	Relevance for the HSC
The granularity is only at the strategic level.	There is no work at tactical and operational levels, despite their importance.	To understand the overall HSC behavior, different decision levels must show up
Lack of metamodels grounded in empirical or field research	The methodological approaches adopted are too remote from real SC, thus, the proposals are oriented to an organizational view of reality rather than with reality itself	The objective of the HSC metamodel is to conceptualize the “real HSC world”, not to conceptualize how it should be.
Lack of knowledge of dyadic relationships or external SC (interoperability).	A very limited view of the scope of the SC.	To understand overall HSC behavior, relationships among stakeholders must show up
Very few metamodels have formally represented and acknowledged the importance of time.	A static view of the SC metamodel prevails.	The HSC evolves in a dynamic environment

More recently, and in the context of the European research project called C2NET[1], (Jiang et al. 2016) have developed a specific metamodel for the SC domain. Their proposal is built on Benaben's collaborative layered metamodel, with the aim of supporting Small and Medium Enterprise supply network data gathering and knowledge exploitation to optimize the logistics assets. The metamodel concepts and relationships are identified from collaborative business ontologies and reference models such as: Enterprise ontology, TOVE, SCOR, Transport ontology, etc.

Given the parallels between the HSC and the SC domain, concepts and relationships from the existing SC metamodels cited in this section can instigate an HSC domain metamodel.

2.3. Disaster Management domain

In the larger domain of crisis and disaster management, along with the open data movement and the semantic web, a lot of interest has been dedicated to developing crisis and disaster management metamodels (Aaltonen 2009; Asadi et al. 2011; Bénabén et al. 2008; Comes, Vybornova, et al. 2015; Imran et al. 2013). Only a few, however, attempt to represent crisis and disaster management information and knowledge structures in reusable form (metamodel). Most of the models in the literature facilitate access to crisis management expertise; however, they have several limitations (Benaben et al. 2016):

- Most of these metamodels are not formalized.
- Most of these metamodels do not provide detail of each crisis management phase.
- These metamodels focus on specific cases. The extraction of general concepts relating to specific types of crises, such as cyclones, is not generalizable.

We focus in the following section on proposals that address these challenges, and which are general enough to be interesting from an HSC domain perspective.

To overcome these limitations, (Benaben et al. 2016) presented a general crisis metamodel and associated ontology to facilitate knowledge sharing and develop advanced crisis management systems. They structure the metamodel with a perspective of "collaboration". To explicitly conceptualize the crisis response, they consider four knowledge areas: (i) the studied system, corresponding to the sub-part of the world impacted by the crisis; (ii) the crisis system, corresponding to the properties of a specific crisis; (iii) the treatment system, corresponding to a description of the abilities of actors who can be deployed in a crisis response; and (iv) the collaborative process, corresponding to a description of the crisis response. In particular, the metamodel's objective is to design the collaboration process. Thus, it identifies a particular partner, the mediator, whose role is to orchestrate the collaboration of other selected partners.

This approach can be generalized to other inter/intra-organizational collaboration situations than crisis responses. For example, it can be applied to virtual enterprise collaboration settings, where different partners share workflows. However, depending on the area of application, the concepts may not be the same. Thus, the proposed metamodel is structured with different layers as described in Figure 23:

[1] The C2NET project aims to create cloud-enabled tools which small and medium enterprises (SMEs) could afford, in order to help them to overcome the current economic crisis and to enhance their competitiveness in the global economy (C2NET Proposal, SEP 210155140 SignedEC)

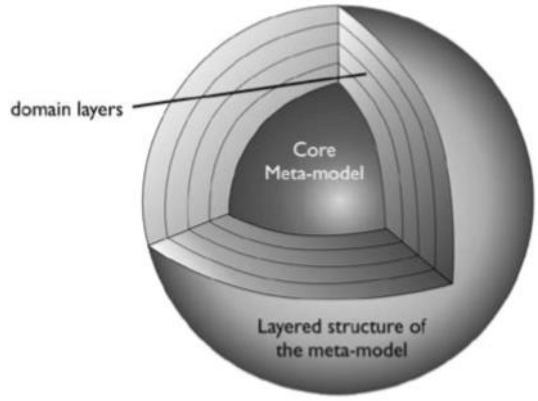


Figure 23 Structuration of a collaboration metamodel (from Lauras et al. 2014)

- A core metamodel relates to the general concepts of collaboration in social systems. This "kernel" is common to all collaborative situations regardless of the application domain;
- A set of layers that helps to define the concepts associated with a particular domain of application with a specific granularity level.

Their approach has been tested and validated, especially through several specific instantiations regarding crisis management applications (civil crises, but not humanitarian disasters), virtual enterprise applications and healthcare applications. Based on this principle, and considering the HSC as part of a crisis response, it is possible to define a specific layer for HSC that would be linked with the existing layer dedicated to the parent crisis management domain.

(Othman and Beydoun, 2010) developed a disaster management metamodel to help access Disaster Management knowledge, which is typically distributed across time, space and people. In contrast to (Benaben et al. 2016), they used existing disaster response models, and ten earlier crisis metamodels (Benaben et al. 2008) to identify the concepts and potential relationships. Moreover, their proposal is structured following the phases of the crisis management cycle: mitigation, preparedness, response and recovery. This approach is interesting because it adds the cyclical dimension of the disaster response; however, there is no relationship established between the different phases of metamodels, and the concepts are too specific for rescue operations.

Another original contribution to Disaster Response knowledge management is the Humanitarian eXchange Language (HXL) Situation and Response Standard (Clark et al. 2015). HXL is a project led by UNOCHA that aims to define data exchange for disaster responses. This is a joint project between academics and practitioners with a knowledge management approach, developed with the specific humanitarian field constraints that may be considered. Data is structured in 4 main topics:

- Geolocalization Information
- Victim Profiles
- Response Actions
- Situation and Evolution

All the reference models and metamodels discussed in this section are complementary and interesting. Concepts and relationships can be considered to be within the HSC domain. However, for building a specific metamodel for the HSC system, some of the concepts are either not relevant (outside the

HSC system scope), or not specific enough. The main conclusion here is that the Collaborative System metamodel with the Crisis Management layer can be used as a metamodel for building the specific HSC metamodel.

3. Humanitarian Supply Chain Metamodel Proposal

As discussed in the introduction, the purpose of the HSC metamodel is to deal with the problem of structuring and sharing the implicit and explicit HSC conceptualization. In the background section it has been highlighted that previous research on Disaster Management and SC domains provide valuable metamodeling and reference model approaches, concepts and relationships that can be integrated into the HSC metamodel.

According to Benaben et al. (2016), collaborative systems can be built on a layered metamodel structure. The core is a metamodel that defines the general concepts of collaboration systems. It is common to all collaborative situations regardless of the application domain. Around the core, a set of layers allows the concepts associated with a particular domain of application to be defined.

Considering that the HSC domain is a child of Disaster Response, the proposal is structured on two complementary layers. The first one relates to generic concepts and relationships in crisis management. The second one relates to the HSC domain, and is based on the knowledge contained in the previous section.

Therefore, considering that the HSC system is a collaborative system, the HSC system metamodel is built as an external layer of a collaborative system core, in the continuity of a Crisis Management layer, which structures the concepts and relationships in Crisis Management (Lauras et al. 2015) and (Bénaben et al. 2016). The Crisis Management layer here becomes a "meta-metamodel", and the core, the "meta-meta-metamodel" of the HSC.

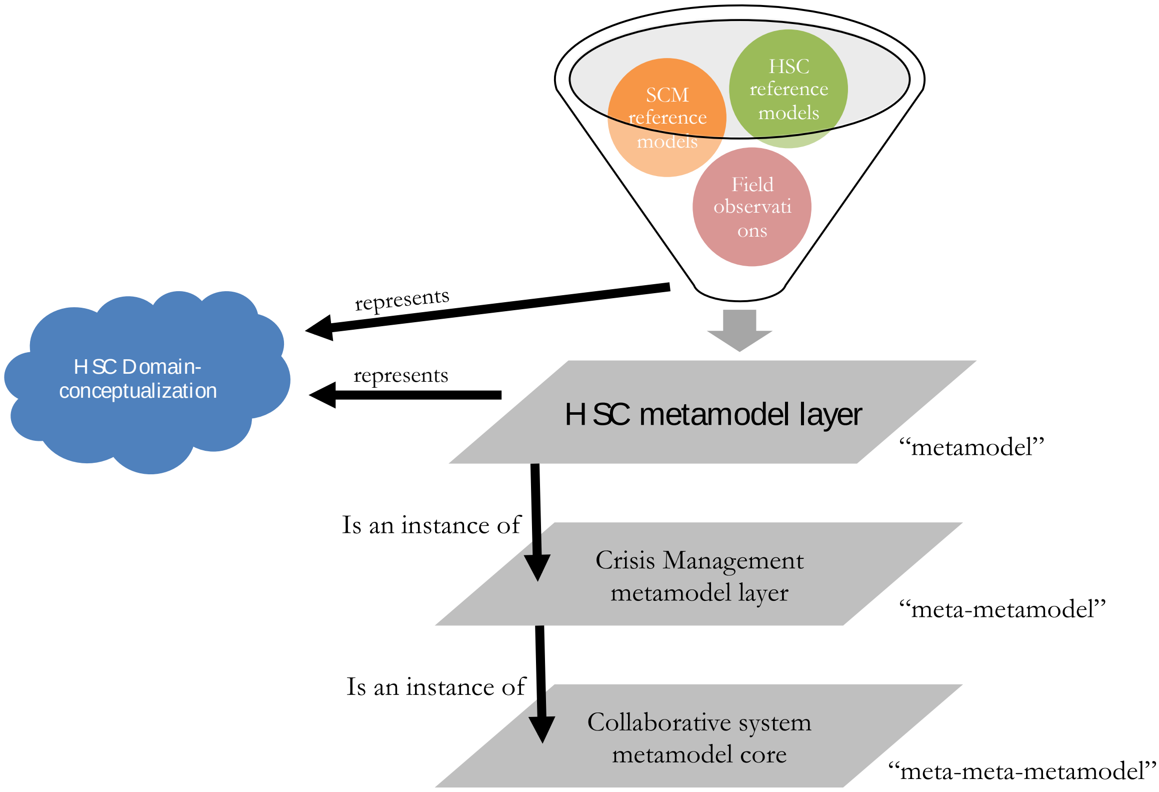


Figure 24 The HSC metamodel layer positioning

The HSC layer integrates SC and specific HSC domain reference models and previous field research (Figure 24).

This section presents the HSC layer, which is connected to the Crisis Management layer proposed by (Benaben et al. 2016). First, the system description is given. Next, the metamodel formalization is presented, using UML graphical language, accompanied by precise descriptions, relationships and links to the Crisis Management metamodel.

3.1. HSC system description

This section provides an overview of the concepts and relationships to be considered in the HSC system. Most of these concepts have been already discussed in the introduction; however, here we get a structured overview of the HSC system under the four areas of the collaborative systems metamodel: context, objectives, partners and behavior.

As described in (Benaben et al. 2016) a collaborative system can be described with four sub-domains (Context, Partners, Objectives and Behavior) that contain concepts dedicated to the collaboration situation:

- Objective: objectives addressed by the partners.
- Context: components and characteristics of the considered environment, along with related opportunities, threats and risks.
- Partners: resources and the know-how of partners, including capabilities, patterns, instructions, and resources (people, material, information, etc.) and flows (links among capabilities).
- Behavior: characteristics of the collaboration. This package includes the business activities and processes, and associated events.

3.1.1. Objectives

According to (Sarkis et al. 2012), the HSC system encompasses the planning and management of all activities related to material, information and financial flows in disaster relief. Importantly, it also includes coordination and collaboration with supply chain partners, third party service providers (3PL), and across HOs in a complex and dynamic environment. To be successful, the HSC has to be able to respond to multiple interventions, often on a global scale, as quickly as possible and within a short time frame (Van Wassenhove, 2006). The main objective of the HSC is then to satisfy the material humanitarian needs identified in the aftermath of a crisis.

The HSC operates without the market forces of demand and supply regulated through price. "Donors have become particularly influential in prompting HOs to think in terms of greater donor accountability and transparency of the whole HSC" (Van Wassenhove, 2006). Moreover, and as discussed in the introduction, the financial gap gives donors the role of "customers". Therefore, despite the traditional focus on the responsiveness of HSC operations, now, HOs are motivated to measure performance and invest in improving it.

Thus, HOs consider the performance of the operations as an objective. This performance is not universal, and depends on the HO's strategy.

3.1.2. Context

In the HSC literature it is clearly stated that the HSC evolves in a complex environment characterized by:

- The large number of stakeholders interacting in the field.
- A politically volatile climate in which the HSC must operate, which implies issues of safety.
- A high level of uncertainty in terms of demand, supply and environment.
- The possibility of unforeseeable conditions and very short time frames.

This environment adds an element of risk to the enhancement of HO objectives. SC risks refer to the possibility and effects of a mismatch between supply and demand (beneficiary's needs in an HSC context). "Risk sources are the environmental, organizational or supply chain-related variables that cannot be predicted with certainty and that impact on the SC outcome variables. Risk consequences are the focused supply chain outcome variables like costs or quality" (Jüttner et al. 2003). The potential mismatch of sources in the HSC is grouped here in three categories of danger:

- **Organizational failure:** During a crisis response, HOs can be overwhelmed and it can be difficult to apply best practices in terms of collaboration, planning or scheduling. There is evidence of a frequent lack of planning in relief supply chains, resulting in inefficiencies. For example, the overuse of expensive and unsafe air charters, failure to pre-plan stocks, congestion at ports caused by unplanned deliveries, delivery of useless or unwanted items to disaster victims and a lack of inter-organizational collaboration (Oloruntoba and Gray, 2009).
- **Assessment uncertainty:** Demand is often unpredictable, and may evolve during HSC operations. The difficulties in assessing the exact needs can generate misalignment (in both shortages and overstocks).
- **Supply shortage:** Even if HSC organizations are agile enough to manage organizational failures and needs misalignments, the peaks in demand of specific emergency items within short time periods can produce shortages at the local and international level. A clear and recent example is the shortage of homologated Personal Protection Equipment during the West Africa Ebola Outbreak in 2014-2015.

These dangers are related to disaster environment elements such as the beneficiaries (who are the origin of the demand), the administrative procedures (access) and the logistics infrastructures, all of them related to the affected geographical area.

- The socio-cultural context impacts the beneficiary's requirements. Even though beneficiaries do not express their needs as a customer can do on the commercial SC (HOs assess the needs), beneficiaries are part of a certain community, which may have cultural specificities. For example, in terms of dietary restrictions or kitchen tool standards.
- Administrative procedures such as customs clearance can produce extra delays in relief item distribution, and have to be considered while planning the operations.
- The logistics infrastructures are required for carrying out logistics activities. They are often at the origin of HSC disruption or extra delays due to congestion or collapse.

Moreover, there is the media, which plays an interesting role in the funding of HO operations. HOs need to highlight the consequences of disasters and their interventions to attract donors. It has been demonstrated that the lack of media coverage has a negative impact on funding, as illustrated by the so-called silent disasters. Only 10% of world disasters became a news headline (IFRC, 2015).

Moreover, because the media places such intense pressure on agencies to compete for visibility, organizations also have to consider communication with the international community, which mainly happens through the media (even if they are not always able to manage it effectively). For instance, Van Wassenhove (2006) explains that ineffective use of the media by HOs can lead to waves of unsolicited donations (with resulting bottlenecks) instead of the much-needed resources.

3.1.3. Partners

The HSC is comprised of different partners with different motivations. By partners, we refer here to the actors who have an active role in the HSC network. We do not consider here the beneficiaries, insofar as the demand is assessed by HOs. In the literature, donors, HOs, governments, the military and private Third Party Logistics Providers (3PLs) are considered to be the main HSC partners (Kovács and Spens, 2007). HOs can be considered the primary actors of an HSC supply network as long as they have the role of managing public and private donations. HOs include aid agencies such as all the UN agencies (i.e. WFP, UNICEF), the IFRC/ICRC, and local and international non-governmental organizations (NGOs) such as Oxfam or MSF.

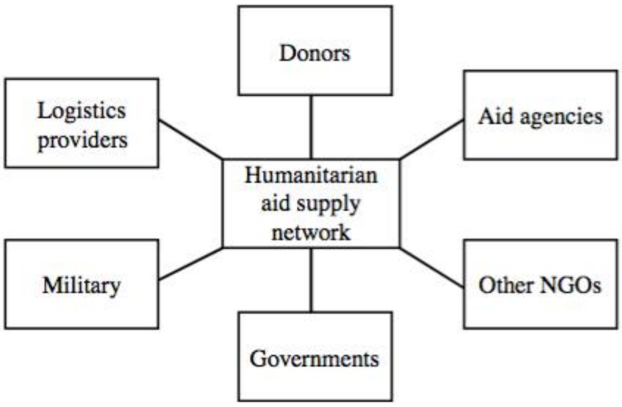


Figure 25 Actors in the supply network of humanitarian aid (Kovács and Spens, 2007)

HO relationships occur within the HO itself and with the other partners. HO internal relationships (collaborations) occur vertically between headquarters and field staff, and between various national or regional divisions, or horizontally across functional units (Day et al. 2012). The definition of the internal structures cannot be generalized. However, HO internal links can be represented with hierarchical "parent-child" relationships. When non-command and control management exists, there is a need to define a coordination entity that gathers the different decision-makers, such as PADRU (Pan American Disaster Response Unit) for the IFRC.

Partner-based relationships are mainly with other HOs, with 3PLs, or with military units and governments. These relationships can be defined as "customer-logistics service provider" relationships. When an HO offers a service to a government, it can be considered that the HO is the Logistics Service Provider and the government the customer, whereas when an HO orders a service from a 3PL, the HO has the customer role.

Therefore, all these partners can take the role of a Logistics Service Provider, as they contribute to the HSC network with material resources, skills, facilities or services. They can also be customers, as long as they receive services from other organizations.

As highlighted by (Charles et al. 2009) all these partners have different incentives and means of action. Depending on their presence or not in the field, the response varies drastically. It is also true that some of them, like local governments or the military, often add complexity to the situation.

3.1.4. Behavior

The behavior of the HSC concerns all the activities within the HSC. The HSC network supports the three main SC flows: material, informational and financial (Luk N. Van Wassenhove, 2006).

- **Material flows** which represent physical product flow (food, relief items, etc.).
- **Informational flows** (order transmission, tracking and coordination of physical flows) are poorly structured and managed.
- **Financial flows**. HSCs are funded by donors (individuals, international organizations (i.e. ECHO), governments, and the private sector). The funding process is a channel for donations from individual people or donor organizations to the beneficiaries through the HSC. Thus, contrary to commercial SCs, the financial flows are not "parallel" with the material flows.

To formalize the concepts and relationships within these flows, and make HSC behavior explicit, two modeling languages have been identified in the literature which formalize the processes: Business Process Modeling (BPM) and Value Stream Mapping (VSM).

Business Process Modeling

To improve HSC flow management, several authors have used BPM approaches, such as the HSC process reference model discussed in the background section (Blecken, 2010). BPM formalizes the partner's activities and relationships along the flows through process flow modeling. It also identifies the key performance indicators of each activity which contributes to the overall performance objectives. Figure 26 is an example from (Blecken, 2010) of a field ordering process illustration using the standard BPMN (Business Process Model Notation). In this process, three partners of an HO (logistics center, regional center and headquarters) interact to purchase ordered goods.

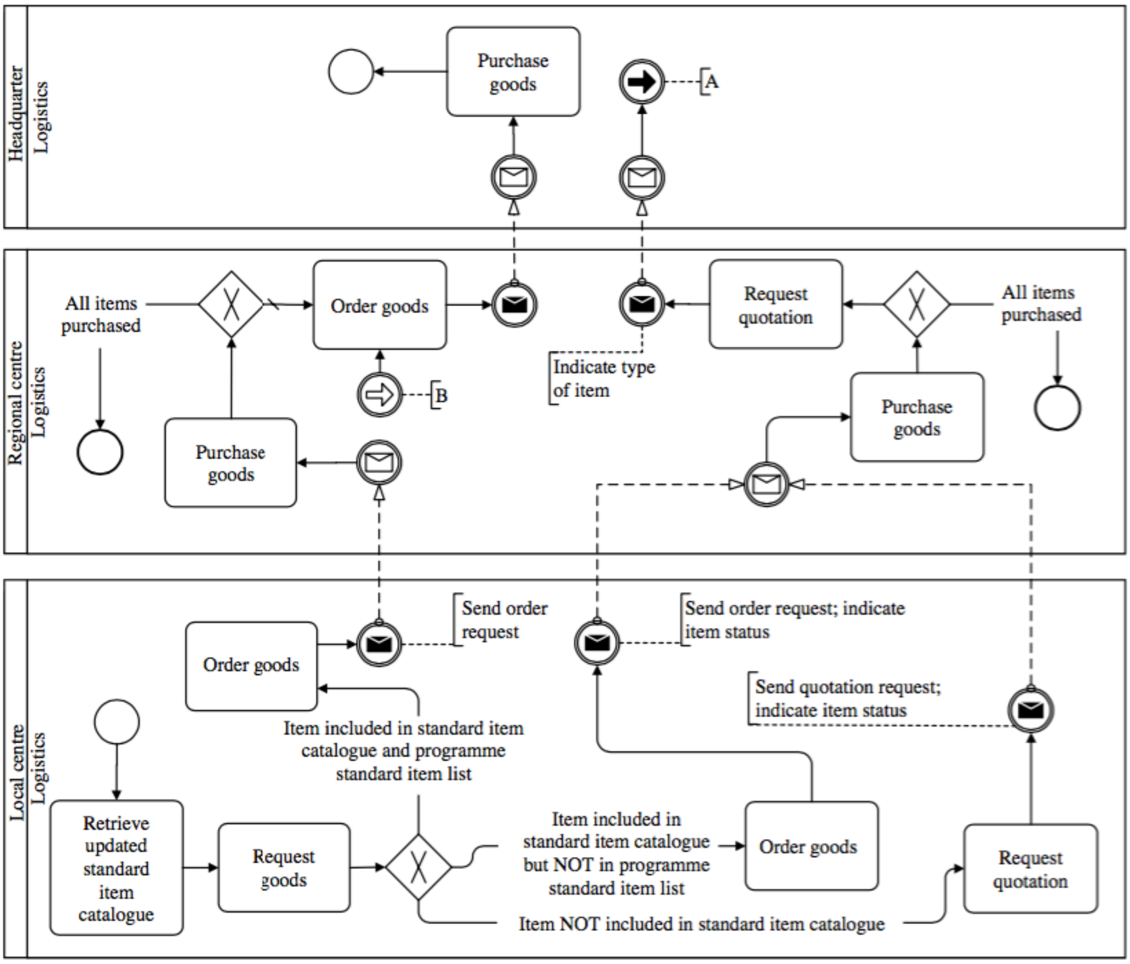


Figure 26 A 'field ordering' process model example (Blecken, 2010)

Value Stream Mapping

The HSC network information and material flows can be also represented from a value stream perspective. A VSM represents the physical flow from origin to destination for a given product (or product family) and the related information flows. It makes explicit the waste, such as unnecessary transportation, inventory or any activities, therefore improving the overall HSC network flows. Figure 27 shows an example of a Personal Protection Equipment value stream during the Ebola Outbreak built with data from the field (Laguna Salvadó, Laura et al. 2015).

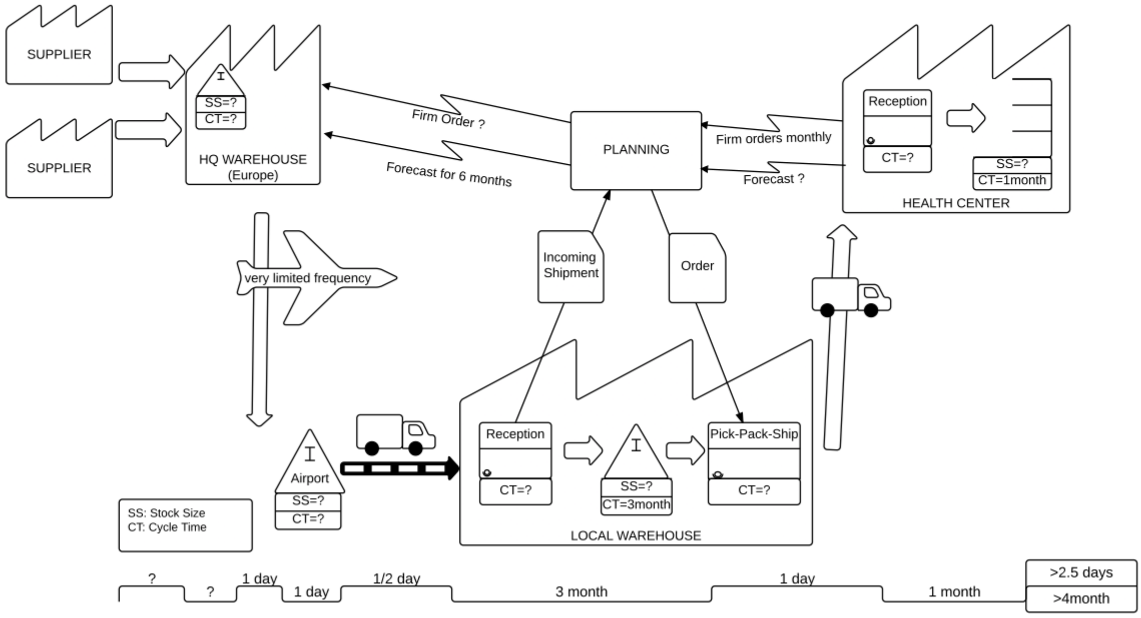


Figure 27 VSM example: "VSM for the Personal Protection Equipment value chain" (Laguna Salvadó, Laura et al. 2015)

3.2. HSC metamodel

The full HSC metamodel is structured as presented in Figure 28. At the center, the Collaboration Systems core metamodel, surrounded by the Crisis Management layer and the HSC layer.

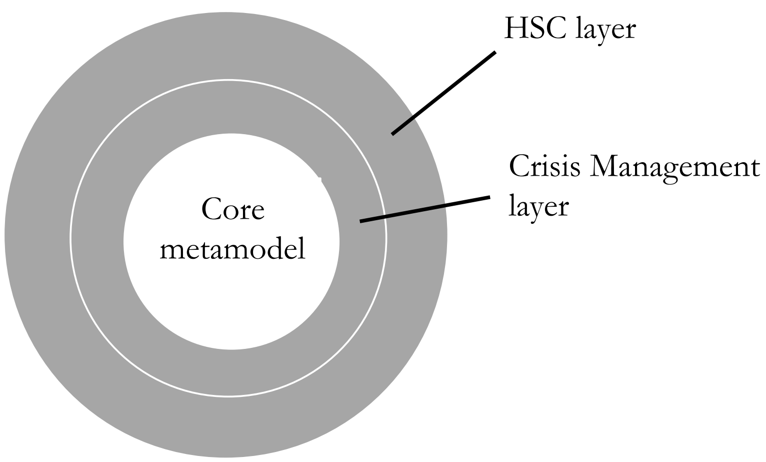
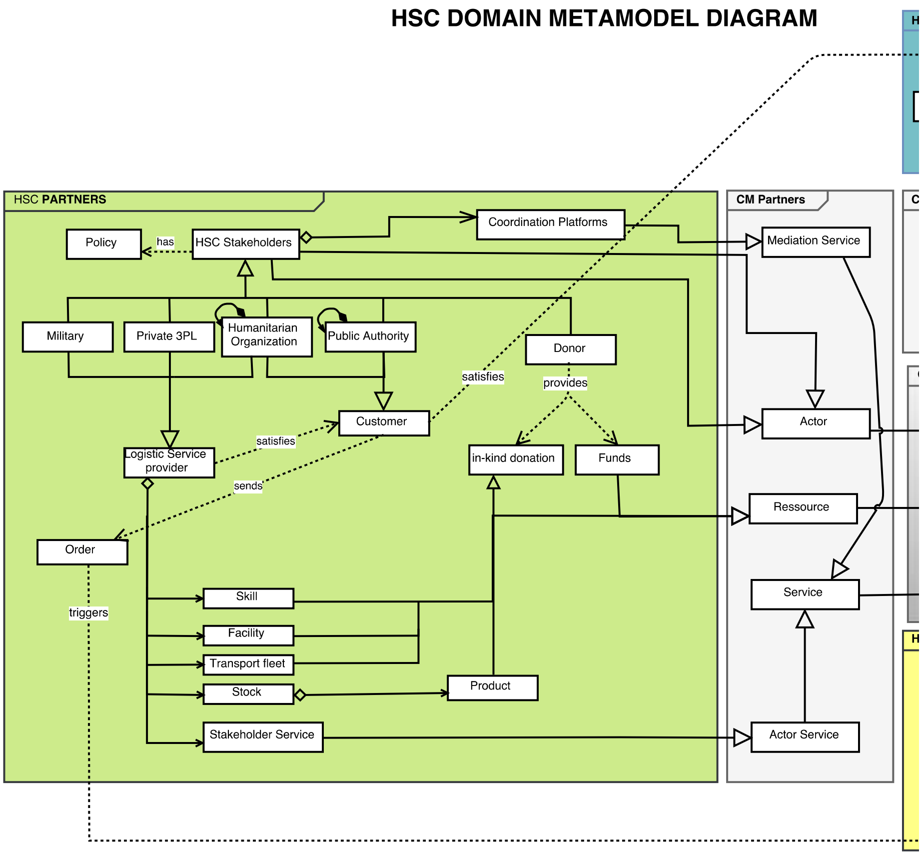
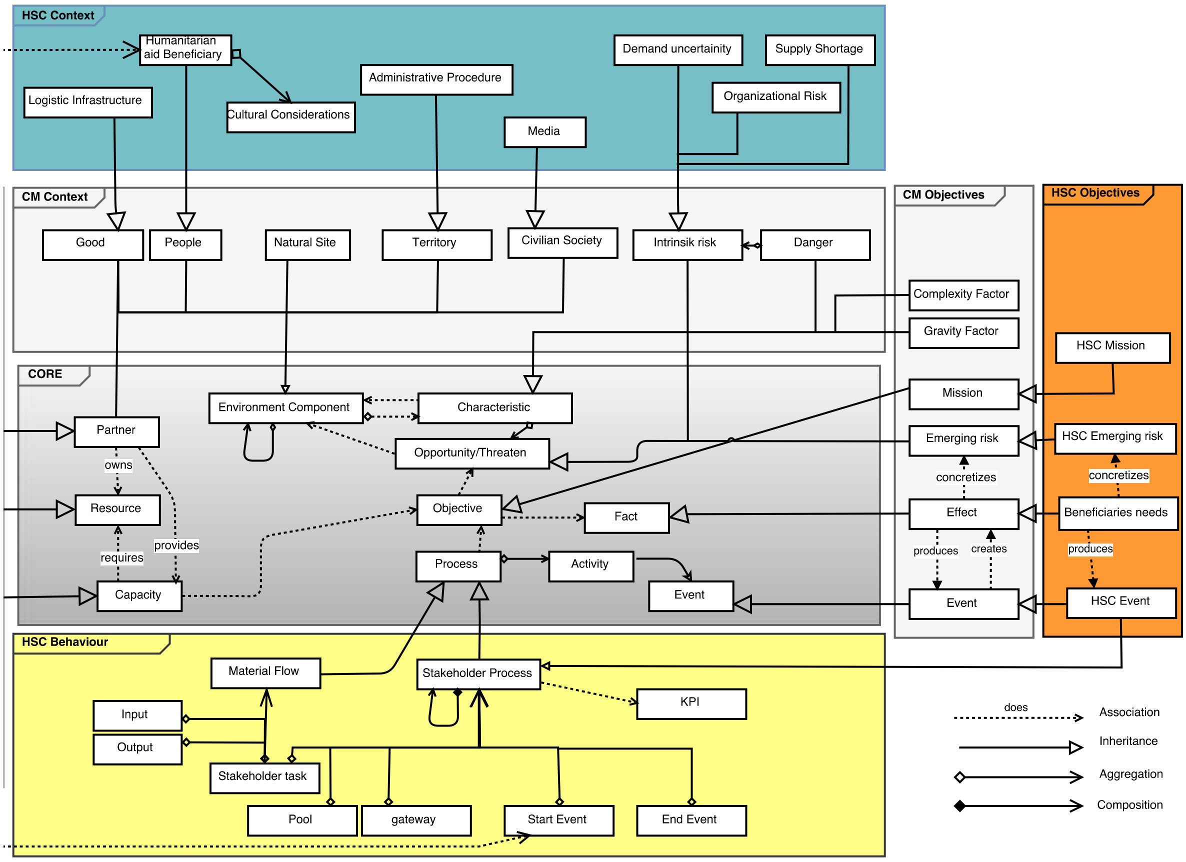


Figure 28 HSC layered metamodel structure inspired from (Lauras et al. 2014)

The HSC metamodel is formalized using the graphical UML (Unified Modeling Language), which links classes (the concepts) using different kinds of relationships: association, inheritance, aggregation and composition (Figure 29).


HSC DOMAIN METAMODEL DIAGRAM
HSC PARTNERS
Policy
has
HSC Stakeholders
Coordination Platforms
Military
Private 3PL
Humanitarian Organization
Public Authority
Donor
satisfies
provides
Customer
Logistic Service provider
satisfies
in-kind donation
Funds
sends
Order
triggers
Skill
Facility
Transport fleet
Stock
Product
Stakeholder Service
CM Partners
Mediation Service
Actor
Ressource
Service
Actor Service



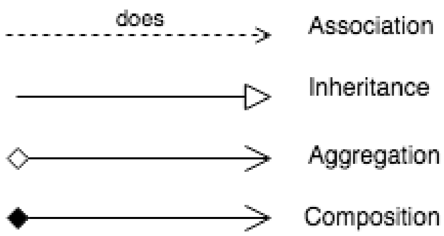


Figure 29 UML relationships between classes used on the HSC metamodel

- An association is a linkage between two classes.
- Inheritance refers to the ability of one class (child class) to inherit the identical functionality of another class (parent class), and then add new functionality of its own.
- Aggregation is a special type of association used to model a "whole to its parts" relationship.
- The composition relationship is just another form of the aggregation relationship, but the child class's instance existence is dependent on the parent class's instance existence.

To build the HSC layer, the concepts and relationship specifics from the HSC domain have been defined as classes and linked to the Crisis Management generic layer. Only the HSC Behavior package has been connected directly to the Core (see Chapter I.3.1.4 for more details). The HSC packages are then: (i) HSC Context, (ii) HSC Partners, (iii) HSC Objectives and (iv) HSC Behavior.

3.2.1. HSC Context Package

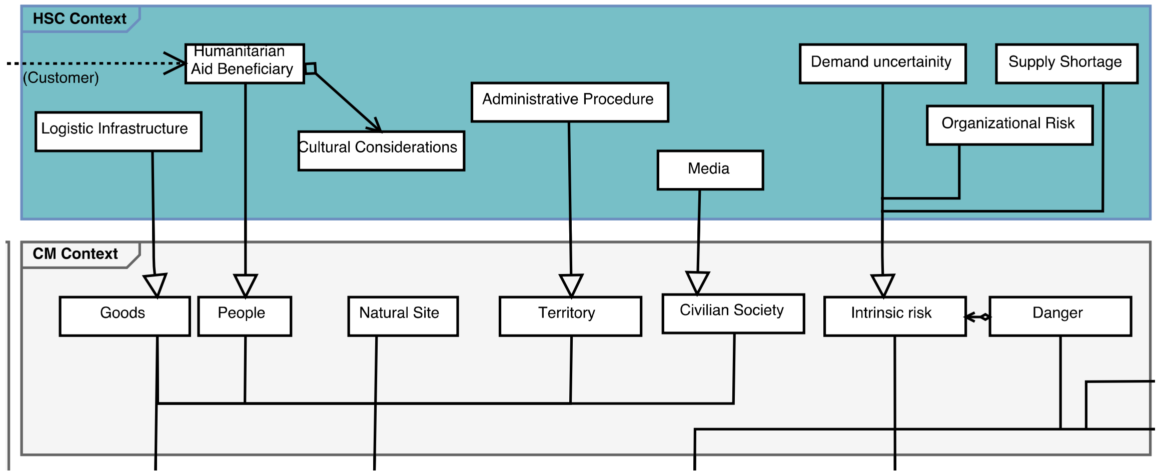


Figure 30 HSC Context Package

The HSC Context package (Figure 30) defines the circumstances that form the setting where the HSC system has to evolve. Based on the HSC domain characteristics captured in the previous section, what is relevant for the concretizing of the HSC has been identified from each Crisis Management general concept. We have defined the concepts listed below to characterize the environment specificities.

The Crisis Management "Goods" concept inherits "Logistics Infrastructure":

- *Logistics Infrastructure*: any man-made element related to logistics activities (*e.g.* airport, bridges, etc.).

The Crisis Management "People" concept inherits "Humanitarian Aid Beneficiaries", which aggregates "Cultural Considerations".

- *Humanitarian Aid Beneficiaries:* Any group of people affected by the crisis situation and seeking humanitarian aid.
- *Cultural Considerations*: the cultural specificities of any group of humans that can affect HSC (*e.g.* food exceptions, hygiene standards).

The Crisis Management "Civilian Society" concept inherits "Media".

- *Media*: any characteristic related to media that can influence the HSC, for example the donors, or any stakeholder decisions.

The Crisis Management "Territory" concept inherits "Administrative Procedure".

- *Administrative Procedure*: any procedure related to an administrative area (customs, pharmaceutical authorizations, etc.). This will have an impact on the Stakeholders process.

Moreover, the HSC system has intrinsic risks related to context; we have identified three main risks sources:

- *Demand uncertainty:* as a consequence of crisis uncertainty.
- *Organizational failures:* any risk source related to the HSC partner processes. There can be undesired behavior as a consequence of the context (i.e. the bullwhip effect caused by logistics infrastructure disruption, as observed in the Haiti crisis, 2010; or the Nepal Earthquake, 2015).
- *Supply shortage:* Private Suppliers may be not able to supply some item references, as observed during the Ebola Outbreak for Personal Protection Equipment.

3.2.2. HSC Objectives Package

As discussed previously, the goal of the HSC is to manage the flows (physical, informational, and financial) to provide material assistance to the populations affected by a humanitarian crisis, and therefore, to alleviate human suffering. The HSC objectives are to satisfy humanitarian needs, and to maintain or enhance performance that can be expressed in different dimensions depending on each partner's strategy. Therefore, two classes inherit from the Crisis Management "Mission" class:

- *Beneficiaries' needs forecast*: humanitarian needs generated by the crisis situation that have to be satisfied.
- *Performance dimension:* Partner's objectives in terms of performance.

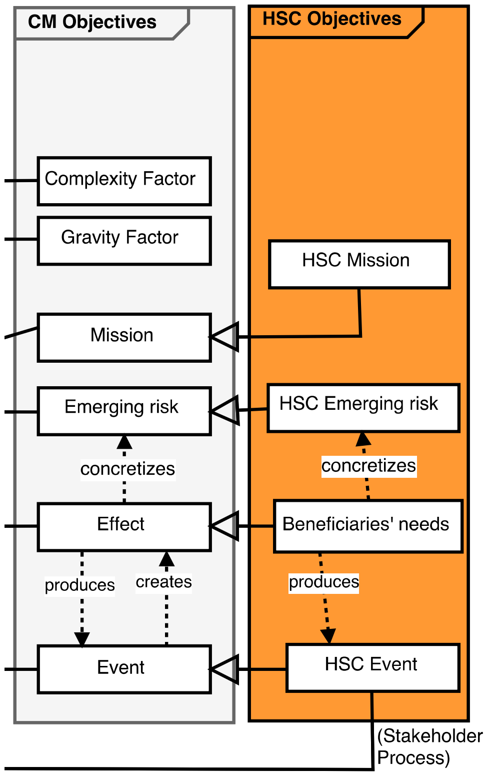


Figure 31 Objectives Package

3.2.3. HSC Partner Package

The HSC partner package (Figure 32) includes all the concepts and relationships that help to describe the HSC system (actors, resources and skills) and the links between them.

- *HSC Stakeholders:* inherits from Actor and is the parent class for any organization that has a role in the HSC.
- *Donor:* can be a private or a public actor. They provide *Funds*, or *in-kind donations* of any kind of resources, and also unsolicited goods (products, services, facilities, transportation). Donations are either for a concrete crisis response or for general humanitarian responses.
- *Humanitarian Organization:* the parent concept of *an NGO* or International NGOs and Humanitarian Agencies. HOs can inherit from other HOs, to represent internal relationships.
- *Military*: national or international forces collaborating on HSC operations.
- *Private 3PL*: Providers or Third Party Logistics are any private companies specialized in logistic services and product supply.
- *Public Authority:* local, regional or national authority that can play a role in the HSC decisions related to location or access authorizations.
- *Coordination platform:* the concept relates to all stakeholder coordination initiatives (e.g. UN Logistics Cluster).

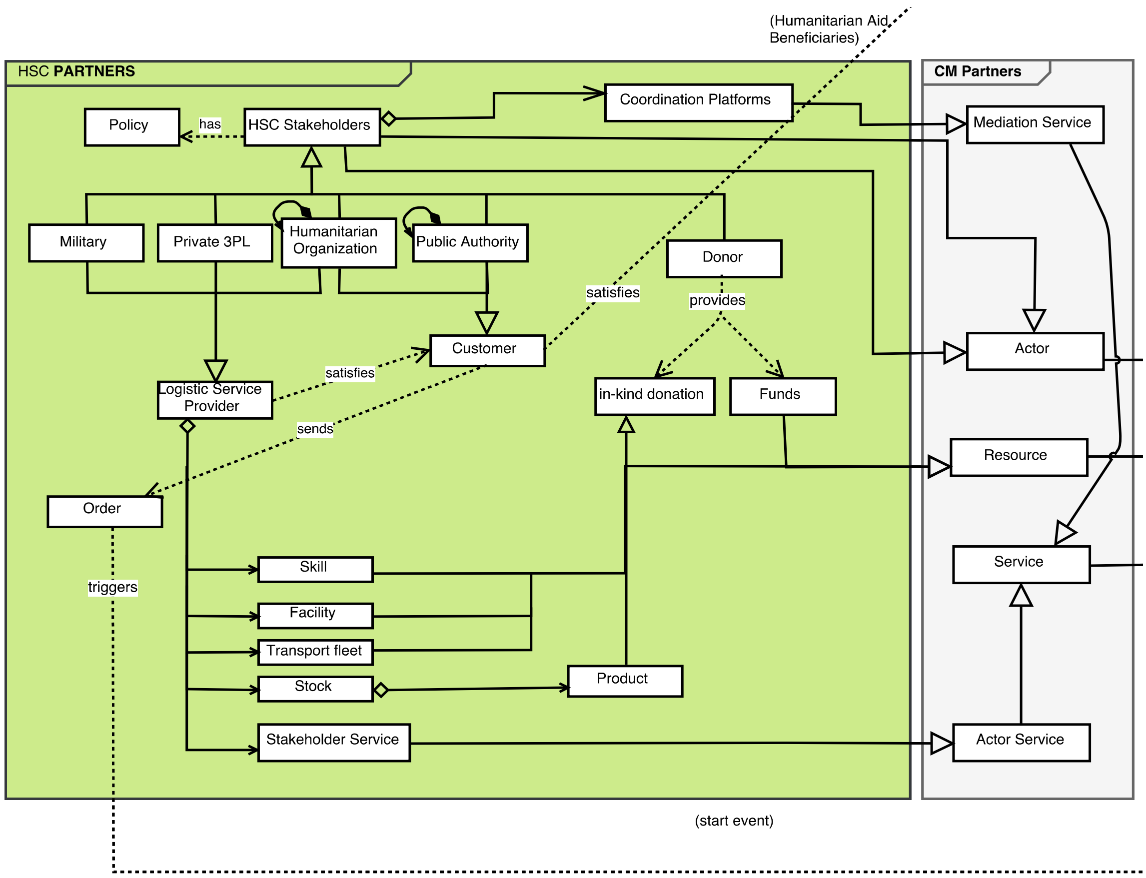


Figure 32 HSC Partner package

HSC stakeholders can be both *Customers* and *Logistics Service Providers*. For example, HOs can provide HSC services for other HOs, and outsource services from private companies as the IFRC does (Laguna Salvadó et al. 2016).

- *Customer:* Any organization that orders services and/or products to another organization.
- *Logistics Service Provider:* Any organization that provides services and/or products and has facilities/skills/transport fleets and/or stocks.
- *Skills:* all the human capabilities (management and operational).
- *Transport fleets:* the transportation vehicle fleets owned by HOs or other actors (cars, planes, trucks, etc.).
- *Facilities*: all the buildings (e.g. warehouses) and materials necessary for the logistic operation.
- *Products*: the emergency items that can be medical, food or non-food items (shelters, hygiene kits, etc.).
- *Stock*: Collections of products.
- *Stakeholder service*: Any service provided to a third stakeholder, e.g. stock management, supply.

3.2.4. HSC Behavior Package

The HSC Behavior Package conceptualizes the process of an HSC, related to the material, information and finance flows as they are. In contrast, the Crisis Management Behavior package was developed to define and orchestrate the Crisis Management partner process. It includes concepts such as a "mediation component" and a "mediator pool" which corresponds to a mediation information system that should define all the partners' processes.

Therefore, the HSC Behavior Package concepts are connected directly to the Collaborative Model metamodel (core). The advantage of a layered approach is that in the future, the HSC could evolve in a direction where a strong collaboration can occur (a central mediator who decides for a group of partners), and then it would be possible to link to the Crisis Management Behavior layer to use its concepts.

The HSC Behavior package (Figure 33) formalizes the operational processes that the HSC partners use to achieve the objectives in a given context. This package includes concepts related to both modeling approaches discussed in the previous section: a process oriented view (BPM), and a value stream oriented view (VSM).

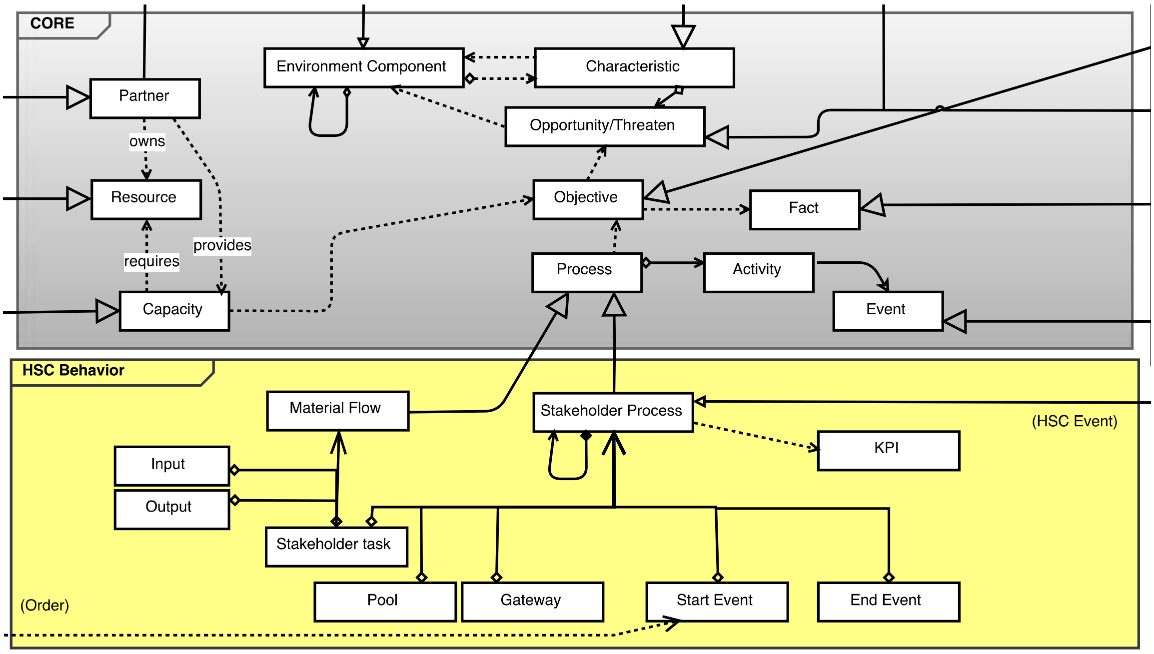


Figure 33 HSC Behavior Package

The main concepts of both approaches are conceptualized in the HSC metamodel, and linked directly to the core concept "*Process*".

- *Business Process*: business oriented flow of activities
- *Value Stream Process:* value stream oriented flow of activities

Both modeling approaches are made up of a sequence of activities that produces an outcome:

- *Activity:* any task performed by a partner of the HSC.
- *Flow*: defines the link between activities.
- *KPI:* Key Performance Indicator, to measure the outcome of a process

Then, to define a business process it also contains:

- *Gateway*: defines the flow/activity sequence.

- *Event*: anything that takes place, for example a start or end event of a business process (i.e. order reception)
- *Swimlane*: defines the events and activities related partners.

And the additional value stream process concepts are:

- *Inventory:* the staging areas between each activity in the process.
- *Timeline:* the time consumed by activity/inventory

3.3. Potential uses and engineering methods

The conceptualization of HSC knowledge is required for both academics and practitioners to make the relationships among the stakeholders explicit. The HSC metamodel aims to provide a shared and common understanding of the HSC concepts and relationships, which can support data gathering, information contextualization and knowledge exploitation (Figure 34). It defines a framework for keeping, comparing and reusing information.

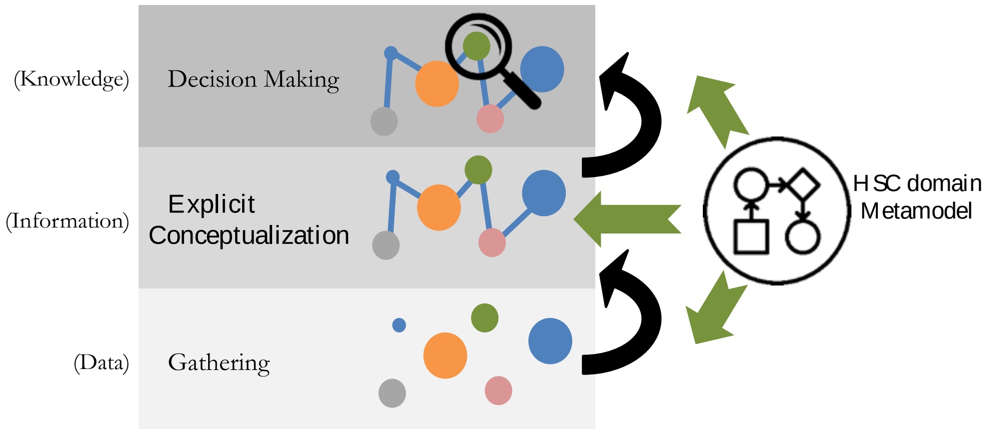


Figure 34 HSC metamodel contribution

The following section describes the potential uses of such a contribution, and engineering methods for implementing it are suggested.

3.3.1. HSC academic field research

It is clear that a real gap exists between research proposals on HSC and their application in the field. Among the authors aware of this issue, (Galindo and Batta, 2013; Pedraza-Martinez *et al.*, 2013) have indicated that research work should be closer to practice, taking into consideration real problems and real data. The problem is that such an approach is time-consuming, as researchers find it difficult to get accurate, and above all, reliable data to support their work (Galindo and Batta, 2013). Another issue is the capacity of researchers to structure this knowledge in order to support the development of original research and operational innovation for humanitarians.

Tomasini and Van Wassenhove (2009) argued that one of the main humanitarian challenges consists in learning from previous disasters by capturing, codifying and transferring knowledge of logistics operations. Researchers are no doubt aware that the main criterion of the success of scientific approaches consists in producing a complete and representative model of the studied system that helps practitioners to address problems in practice. Considered an art by many and weird science by some, modeling is not as simple as it seems. This is particularly true in the humanitarian context, as in all new research areas, where researchers have difficulty identifying appropriate decision variables and parameters to be able to develop accurate and relevant models (Charles and Lauras, 2011).

Field research, in the context of HSC operations management, seeks to understand the AS-IS state of the current system's business process, and to identify limits, weaknesses and potential improvements and enablers. To do so, a macroscopic picture of the existing system can be seen as a priority. Typically, diagnosis of an SC (and any other corporate system), are made by conducting an investigation with various actors of the SC, to acquire knowledge of the organization, its culture and its modes of operation (Lauras, 2004). This approach can be supported by the use of interview questionnaires, and other graphical supports (i.e. maps, flow diagrams, organizational charts). Afterwards, the collected elements have to be analyzed.

To enhance the integrity and repeatability of the analysis (within different systems, or the system over time), it is interesting to build the investigation with reusable field research supports. SC investigation supports are kept confidential by consulting groups, who develop their own references. Moreover, both in the literature and the practice there is no consensus on SC field data gathering support structuration: (Uschold and Gruninger, 1996) highlighted the need for common frameworks for field research. A classic methodology for designing field investigation can be structured with four steps, inspired from (Berthier, 1998):

- **Field research planning:** objective, hypothesis, implementation plan, scope;
- **Prepare field research supports:** define a research protocol, questionnaires, graphic supports, an observation strategy;
- **Implementation:** introduction, data gathering, feedback;
- **Analysis & research questions:** AS-IS evaluation, preliminary research questions;
- **Results communication:** share the diagnoses.

Therefore, using the HSC metamodel to build the questionnaires and supports may facilitate the evaluation of the observed systems by building consistent and repeatable analyses.

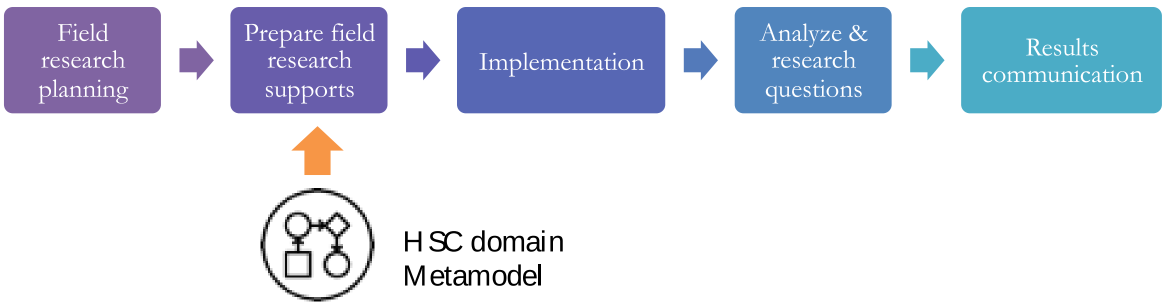


Figure 35 HSC metamodel use within the diagnosis method

3.3.2. HSC continuous improvement

Beyond the scientific approaches, practitioners can also take advantage of using the HSC metamodel as a support in improving HSC processes. On the commercial SC, continuous improvement approaches have increased in order to align the SC process with market needs (Van Wassenhove, 2006). Continuous improvement is generally defined as "a culture of sustained improvement targeting the elimination of waste in all systems and processes of an organization" (Bhuiyan and Baghel, 2005).

Therefore, it can have a positive impact on cost, customer service, capacity utilization and sustainability (Kovács et al. 2016). Continuous improvement was popularized by Lean Manufacturing practices, which involves everyone working together to make improvements without necessarily making huge capital investments. In the context of HSC, it is not a well-developed approach: however, (Fulzele et al. 2016; Pettit and Beresford, 2009) identified it as a success factor in measuring and improving performance, and (Cozzolino et al. 2012; Taylor and Pettit, 2009) also encourage the adaptation of commercial lean practices in the context of HSC.

Continuous improvement occurs through evolutionary improvement (improvements are incremental), or through radical changes (innovative ideas or new technology). The approach is cyclical, with methods such as the data-driven improvement cycle DMAIC (Define Measure Analyze Improve Control):

- **Define:** The purpose of this step is to identify the business problem, goal, potential resources, project scope and high-level project timeline.
- **Measure:** This is a data collection step, the purpose of which is to establish process performance baselines.
- **Analyze:** The purpose of this step is to identify, validate and select root causes for elimination.
- **Improve:** The purpose of this step is to identify, test and implement a solution for the problem in part or in whole.
- **Control:** The purpose of this step is to sustain the gains. Monitor the improvements to ensure continued and sustainable success.

In this context, the use of the HSC metamodel should facilitate the identification of the business problem and the continuous improvement project scope, as well as the measurement and analysis steps.

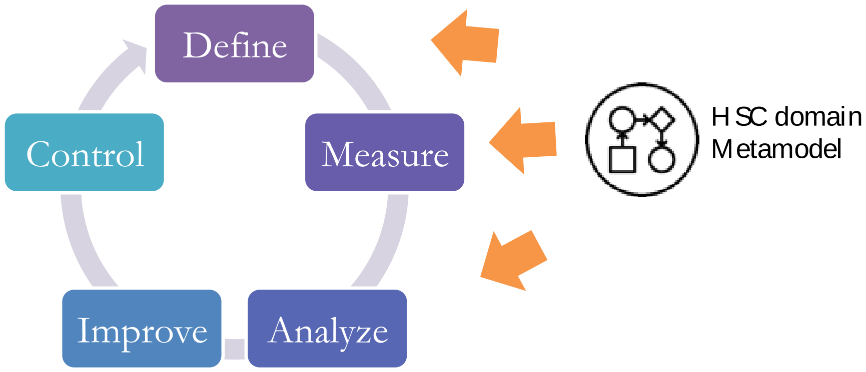


Figure 36 HSC metamodel use within the DMAIC method

3.3.3. HSC Information Systems design

People, organizations, and Information Systems software must communicate between and among themselves. However, as discussed by (Uschold and Gruninger, 1996), due to different needs and background contexts, there can be widely varying viewpoints and assumptions regarding what is essentially the same subject matter.

One of the difficulties in transferring technology from the commercial SC to the HSC is the lack of consideration of HSC context specificities. A shared understanding of the HSC system can assist in the specification of adequate Information Systems (Rodrigues da Silva, 2015). The HSC metamodel may facilitate the process of identifying the requirements of the system and understanding the relationships among the components of the future Information System. In most descriptions of the system development lifecycle, there are eight distinct phases (Cervone, 2007), as illustrated in Figure 37. Therefore, the HSC metamodel can support the problem analysis and requirement definition.

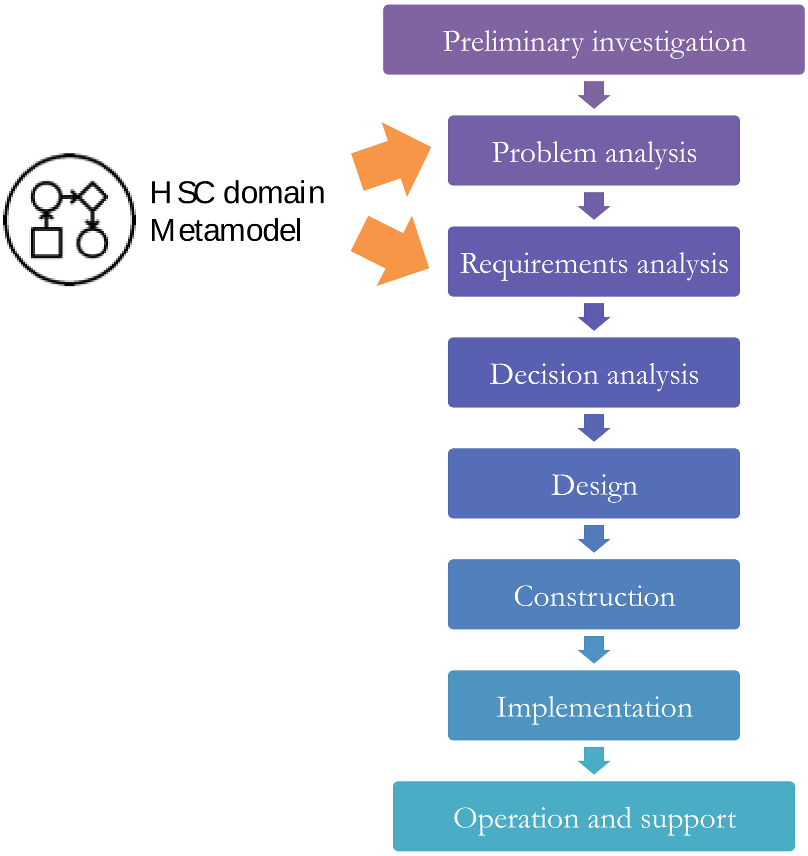


Figure 37 HSC metamodel use within Information Systems design

3.3.4. HSC coordination

We indicated that coordination between HOs is a difficult exercise, and sharing information is a recurrent problem. The metamodel can play the role of a shared database (instance model) to facilitate such coordination. With a common model of the HSC situation, each actor can share his abilities, capacities (in terms of resources) and any relevant information in a way that is understandable to everyone, and all actors of the crisis response can share the same picture of the situation.

Moreover, it is possible to use this structured knowledge to develop and use advanced management tools, such as Mediation Information Systems that support the orchestration of business processes between stockholders (Lauras et al. 2015). Furthermore, this offers the potential to improve the agility and collaboration of HSC stakeholders by proposing detection and adaptation systems based on real-time knowledge updates.

The HSC metamodel can be used as a “template” to characterize the HSC situation. Therefore, following a Mediation Information System approach, the methodology for coordinating HSC stakeholders can follow these four steps (Macé-Ramete et al. 2012):

- **HSC characterization:** definition of the context, the partners and the objectives of the collaboration.
- **Collaboration deduction:** analyzing the knowledge gathered from the previous step, in order to deduce collaborative behaviors.
- **Orchestration:** introduction, data gathering, feedback.
- **Monitoring:** research protocols, questionnaires, graphic supports, observation strategy.

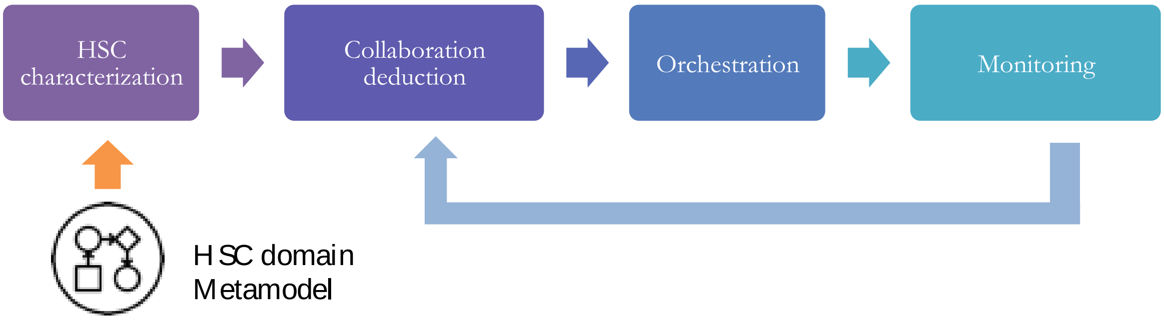


Figure 38 HSC metamodel use within the coordination method

4. Illustration: A&C RLU academic field research

Because practitioners and academics ideally would like to have a perfect understanding of the HSC operating modes, they have to collect and organize data. However, due to the complexity of disaster response, direct observation, and manual data collection and processing without a clear and transparent methodology is fastidious and inefficient.

This section presents a potential use of the HSC metamodel, based on the A&C RLU use case. Intentionally simplified, this proof of concept aims to give readers an example of field research design supported by the HSC metamodel, and how can it support structured data gathering.

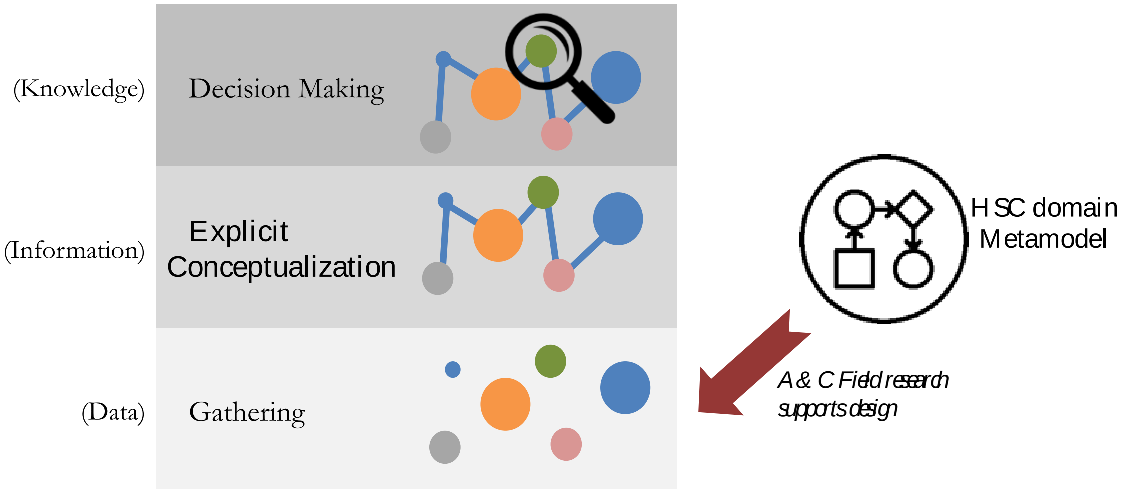


Figure 39 Metamodel used for A&C RLU diagnosis

4.1. Field research planning

The IFRC sub-regionalization strategy was still vague when the collaboration with the IFRC began in 2015. The initial goal was to support the A&C RLU to become more cost-effective by developing innovative HSC approaches. In compliance with (Eisenhardt, 1989), we decided to create research propositions based on empirical evidence.

Therefore, the scope of the field research was the A&C RLU, and the objective was to identify weaknesses of the current activity model in terms of business processes, decision-making and information systems.

The strategy for collecting the A&C RLU AS-IS business process data was to do field research at the Panama hub, based on interviews with practitioners, observations and data collection:

(1) Before the field campaign: Conducting preliminary informal interviews with the Regional Logistics Development Coordinator; primary and secondary data collection.

(2) During the field campaign: Conducting on-site semi-structured interviews with all the A&C RLU practitioners; observations and primary data collection.

(3) After the field campaign: Complete the data and analysis with remote informal interviews.

4.2. Field research supports

From the HSC metamodel and the aim of making a diagnosis of a current state, the following interview protocol was devised to guide the visit of a field team to the A&C RLU. It was inspired from previous field research work conducted by the Disaster Resilience Lab (Comes et al. 2015; Van de Walle and Comes, 2014).

Four generic categories of information are aligned with the HSC metamodel packages: the context, the objectives, the partners and the behavior (Figure 40). However, given the interactions between the concepts, there is an overlap between the questions and the related "packages".

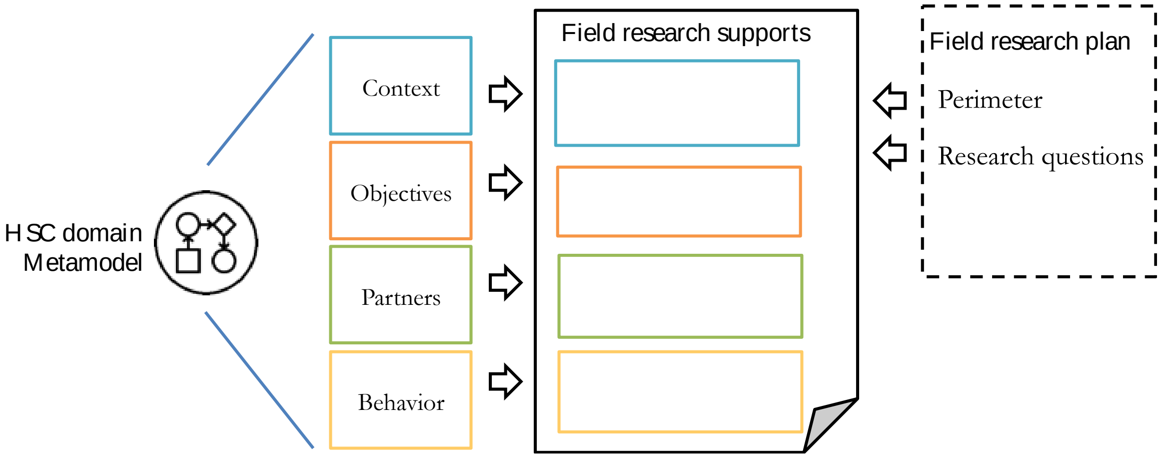


Figure 40 From the metamodel concepts & field research plan, to the field research supports

Context: Identify the characteristics of the A&C region in terms of logistics infrastructure, cultural & climatological specificities.

Objective: Identify the regional humanitarian needs profile and the A&C RLU performance approaches.

Partners: Identify the A&C RLU resources and relationships with other humanitarian actors (i.e. donors, suppliers, 3PL).

Behavior: Identify the physical, informational and financial flows, the information systems and decision-making processes.

4.2.1. Interview protocol

The interview protocol provides key elements that should be discussed and addressed in the opportunities we have to talk to various people in the A&C RLU. However, it is important to take advantage of the opportunity to have an open conversation and to capture as much data as possible. The elements in this document (1) help us map the content of the interviews and (2) ensure that we all collect the same information at the same level of detail.

Ideally, this document is set up in such a way that the same method can be applied by others as well: for example, in a second field visit as well as during online interviews outside of the field.

<u>Introduction</u>

Please share with us who you are, a bit of your background and what role you are currently playing in the A&C RLU activities.

<u>PART 1: Context</u>

The first part aims to describe both the A&C regional context and the A&C RLU objectives. The key here is to understand the regional profile; including logistics infrastructures and cultural specificities.

Can you explain to us what the specificities of the A&C region are? I would like to understand how the regional context is affecting your work."

- Disasters typically affecting the region.
- Seasonality?
- Logistics infrastructure? Logistics hubs, transportation, etc. (use of geographical maps)
- Cultural specificities?

<u>PART 2: Objectives</u>

The second part aims to understand the humanitarian needs, the objectives the organization has, and the objectives per department. Moreover, the challenge is to find out how these objectives are evaluated.

Needs

- Type of humanitarian needs in the region?

Organization/Department:

- Type and size of the A&C RLU organization, the supply network
- Size of operations
- What are the A&C RLU objectives, your department's objectives?

Outcome:

- How are the objectives evaluated?
- Any KPIs or indicators that you are reporting? How often? To whom?
- What is the impact of your monitoring / reporting?
- Potentially off the record: would you suggest any strategic changes / lessons learned?
- Time frame: during what stages are decisions being made?
- Is the decision reversible? Can it be adapted or changed?

PART 3: Partners

The objective here is to provide a mapping of the links between partners, and to identify the assets and skills of each.

Cartography

- What are the skills and assets that the A&C RLU has?
- Which organizations do you interact with? (Governments, donors, etc.)
- Can I have a list of your providers?
- Any partners? (Network / Cluster, formal and informal links to other organizations)

Coordination

- Who do you coordinate with? How do you coordinate with others internally? (with respect to other departments, logs, transportation companies, suppliers, etc.)
- How do you coordinate between the A&C RLU and the field ("your customers")?

PART 3: Behavior

Quantitative data

- Do you have any data on the volumes of items that have been managed (supply and delivery) during the last few years (throughput? flow per time unit? flow per item or group of items?). Could you give us any information about where we can find such data?
- What is the cycle-time of item X (reception time, waiting time, transportation time, shipment time, frequency of shipments, etc.)?

Network and Flow cartography

- Could you explain the different material flows? (*use of geographical maps*)
- Which are the most representative emergency kits?
- Could you map the physical flow main steps from the source to the beneficiaries or destruction? Could you draw them in a diagram? If possible, provide any information about the suppliers and the beneficiaries.
- What are the main difficulties in managing these flows?

Activity and Business Process cartography

- Which are the main activities that you or your colleagues have to manage (procurement, stock, dispatch, shipment, kitting, transportation, coordination, etc.)?
- Could you explain the relationship that exists between all these activities? If sufficient time: How would that look in such a diagram? *Hand Out Simple Diagram*
- For the most important (of each of these activities), what are the main Inputs and Outputs (materials, information, documents, people, etc.), the main Resources (human, skills, equipment, machinery, vehicles, ITC, etc.) and the main Controls (objectives, constraints, order, etc.)?

- Could you explain the sequencing / scheduling of these activities? When should the activity start, finish? Is there any gateway between activities (things that have to be done in parallel, things that have to be synchronized, etc.).
- How can we define the performance of your business processes (activities)? Do you report any indicators (time, lack of quality, costs, etc.) of the work you are doing?

Information sharing

- How do you manage information (sharing) inside A&C RLU?
- How do you share with other organizations?
- How do you place / receive orders? [push vs. pull]
- How are you involved in the planning / inventory mgt. / etc.

Information Systems use

(Descriptions of how the work is achieved and the purpose of that work)

These questions could be covered with a conversational approach where the different aspects are articulated in a nice flowing talk.

- Describe your work day
  - What are the primary activities during a day?
  - When do you start and stop, and where do you conduct your work?
- Who do you typically interact with?
  - People that give you assignments, or people you give assignments to
  - People that report to you, people you report to
- Describe the technology you use: mobile phone / land-line, laptop (and which programs and what for), dedicated software (maps, reporting systems, news sources)
- Describe the information products produced: emails (type of emails), checklists or activity schedules, reports, status updates for meetings, meeting notes, white board illustrations
- Describe your work environment: office, meeting rooms, ad-hoc meeting settings, field environments, and vehicle-based work settings.

4.2.2. Data collection supports

To be more efficient and to facilitate uptake, a flowchart grid has been designed in coherence with HSC metamodel behavior concepts and relationships. This is the main support for the quantitative data collection. As shown in Figure 41, the flowchart sheet is a template that chronologically describes the activities of an HSC. These activities are classified in 4 main categories: operation, transfer, stock/wait and control. For each activity the main inputs, outputs and resources can be traced, in addition to other relevant information like cycle time or available capacity.

The rationale for using such a template is to describe the value stream map and business processes. It is important to notice that through this approach small parts of the HSC concepts are collected from each practitioner's point of view. All these elements should then be connected with the HSC metamodel relationships.

To complement the data collection step, information can be gathered (qualitative and quantitative) on physical flows that involve all processes throughout the A&C HSC. These elements can be visualized in geographical maps.

IFRC FIELD RESEARCH: SUPPLY CHAIN ORIENTED INTERVIEW GUIDELINE

Operation ○	**Considered Flow :**	Filed by:	General Comments:
Transfer ⇨	Organization:		
Stock/Wait ▽	Location:	Date:	
Outstanding D	Respondent:		
Control □	Position:		

Description of the Value Stream										Description of the Business Processes					
○	⇨	▽	D	□	AS IS description	Main Evolutions	km	Qt	Time	Inputs	Outputs	Resources	Controls	Events	Comments
■					Order preparation		0	3000	0.5						
				■	Customs		0	3000	0.5						
		■			Waiting for shipment to the airport		0	3000	1						
	■				Transfer to the airport (truck)		3	3000	0.3						
		■			Waiting for cargo shipment		0	3000	0.3						

Figure 41 Example of the workflow grid to support the field interview protocol

4.3. Implementation

The fieldwork was conducted during a 10-day mission in October 2015 at the IFRC A&C RLU Panama site (office and warehouse).

The on-site research started with a meeting where the field research campaign was introduced to the team. Then, for a week all members of the RLU structure were interviewed individually at the IFRC office: Head, Service Officer, Procurement Officers, Logistics Officers and Warehouse Manager and Officers as well as the PADRU Coordinator. The warehouse facilities (which are located on a different site) were also visited for one day.

During the 10 days, there was continuous feedback with the A&C Logistics capacity development officer, to discuss missing information or misunderstandings, and to gather as much complete data as possible.

4.4. Analysis & research directions: IFRC sub-regionalization

The interviews and observations highlighted that the strategy is currently evolving. We identified the sub-regionalization challenges and the practitioners' needs.

4.4.1. The set-up

The sub-regional logistics network design consists of a regional hub extended by a network of capacities (inventory and infrastructures) and capabilities (logistics skills) at the country level (Figure 42). The sub-regional contingency stocks are owned by the IFRC, but hosted by the Red Cross National Societies (independent entities, but members of the IFRC), who are in charge of logistics management (warehousing, customs, transportation). In the function of capability enhancement, they could also be in charge of sourcing and procurement.

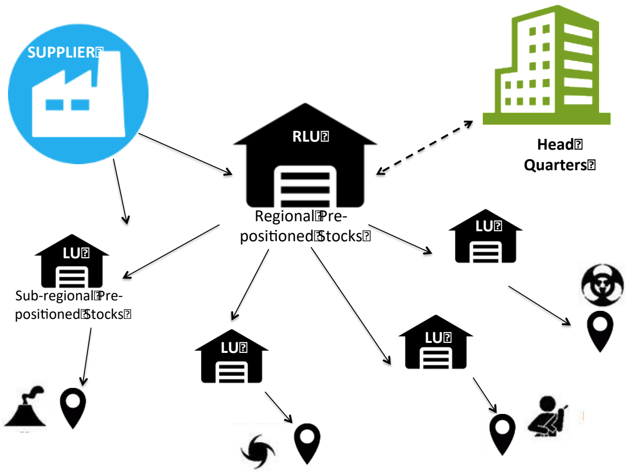


Figure 42 Linear sub-regional design

When starting our analysis in 2015, the network had four sub-regional prep-stocks that were already deployed and a dozen more were planned. Although the network is growing, the operation mode is centralized. The RLU, based in Panama, manages all warehouse procurement, and the Sub-Regional Logistics Units (LU) distribute only for internal country needs. As almost all the stocks are mobilized from (or through) the regional hub, and transportation options are limited, decision-making at the regional level is based on reliable monitored information and the experience of the practitioners. With the current information management system, it will be difficult to enhance responsiveness and sustainability due to the increase in the overall stock level (decentralization) and to the rigidity of operations. Figure 43 summarizes the main outcomes from the field research, according to the sub-regionalization strategy.

Strengths

- Local sourcing: Developing a local (country level) logistic capacity is an enabler to develop local procurement.
- Response time: Pre-positioning contingency stock closer to the potential beneficiaries permits a reduction of response time.

Weaknesses

- Cost: The multiplication of contingency stocks and facilities increases the fixed and immobilization costs of the HSC network.
- Vulnerability of the contingency stock: Getting closer to the potential affected areas by natural phenomenon may increase the exposure of the contingency stocks.

Opportunities

- Operations coordination: Given that the sub-regional network increases the potential material flows in the HSC network, there is the opportunity to improve HSC coordination within the A&C RLU and NS.
- Sustainable decision-making: Moreover, the operations coordination can be managed with a sustainability perspective.

Threads

- Current Information Systems: The coordination of the supply operations is limited by current Information Systems, which do not permit a real-time exchange of information within the sub-regional network.
- Decision-making based on experience: To coordinate (i.e. plan) operations may be a challenge with experienced base approaches given the increasing complexity of the network.

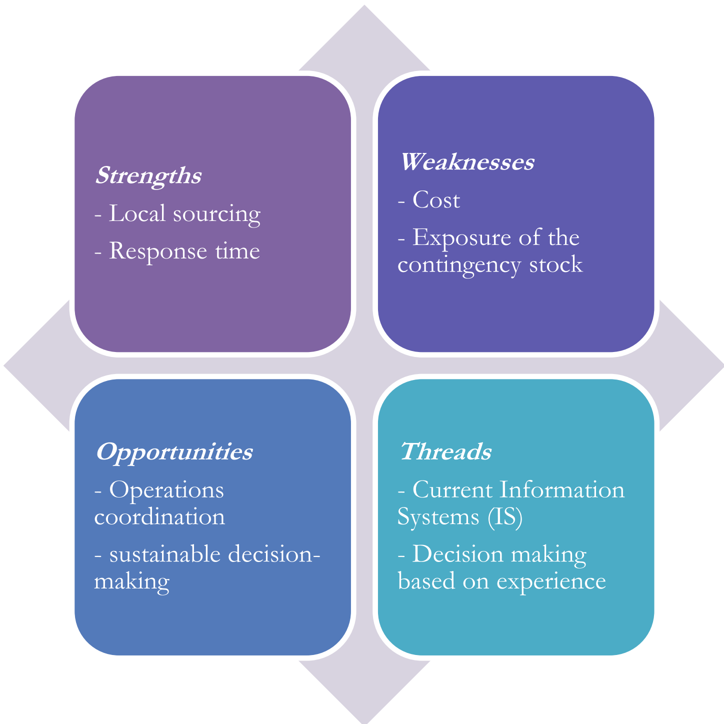


Figure 43 IFRC sub-regionalization SWOT analysis

4.4.2. Improvement road map

From the field research analysis, three main improvement steps have been identified.

4.4.2.1. Short term: Implementing capacities and capabilities

The first step in enhancing a sustainable sub-regional system is to implement capacities and capabilities at a country level.

The first challenge is to define an RLU strategy with respect to capacity, and to determine optimal stock levels for the sub-regional network. To improve in-country logistics capability, there is a need for functioning infrastructures (warehouses, materials, vehicles, etc.) as well as people with dedicated logistics skills. Warehouse deployment is based on an agreement with the A&C RLU, the concerned

NS, and funding organizations (IFRC or a Partner NS). A&C RLU wants to involve NSs as "subcontractors", and this is a huge obstacle.

NSs have very different maturity levels concerning logistics. To cope with this situation, A&C RLU is in charge of developing logistics capacities through the National Societies Logistics Capacity Enhancement (NSLCE).

One main issue with this is the high turnover of local volunteers and as a consequence, the volatility of NS priorities. Moreover, NSLCE is financed by Partner NSs (such as Norway or Canada), and it is difficult to sustain enhancement in the long term, when funding runs out.

4.4.2.2. Mid term: Monitoring the capacities and capabilities

Once the capacities and capabilities are deployed, the next challenge is how to manage and ensure the real-time state of the network. This is a prerequisite for any decision or action on the network.

However, as observed during our research visit to A&C RLU in 2015, the current HSC Management Support Systems have several limitations to properly supporting this approach. Practitioners will struggle to manage the inventories and replenishments properly (no visibility, no warnings, no decision-support) and will consequently increase the fixed costs.

The support used for following inventory levels is the HumLog software application for warehouse management. The Panama warehouse manager sends a report (an Excel Spreadsheet) each month to the Logistics Officer who integrates the inventory level with another Excel Spreadsheet. Then, the Logistics Officer has to manually verify the inventory levels in accordance with defined thresholds. In the future, there will be at least eight more stock capacities (warehouses) to be followed in "real-time" and there will also be the corresponding increase in capabilities to manage. In all evidence, the management system is not ready to do that.

4.4.2.3. Long term: Planning sustainable relief operations

To make sustainable use of the sub-regional network, practitioners should be able to coordinate network resources during the same operation (Figure 44). For instance, when there is a need in the region, which warehouse will have to send what and when? Who will manage the replenishments? Today, decision-making is based only on the Procurement Officer's experience and is fully centralized.

However, when the network is deployed the possible options will be multiplied by the combination of cost (items, transport), lead-time, and event expiration date. Thus, experience will not be enough to establish the best response for executing.

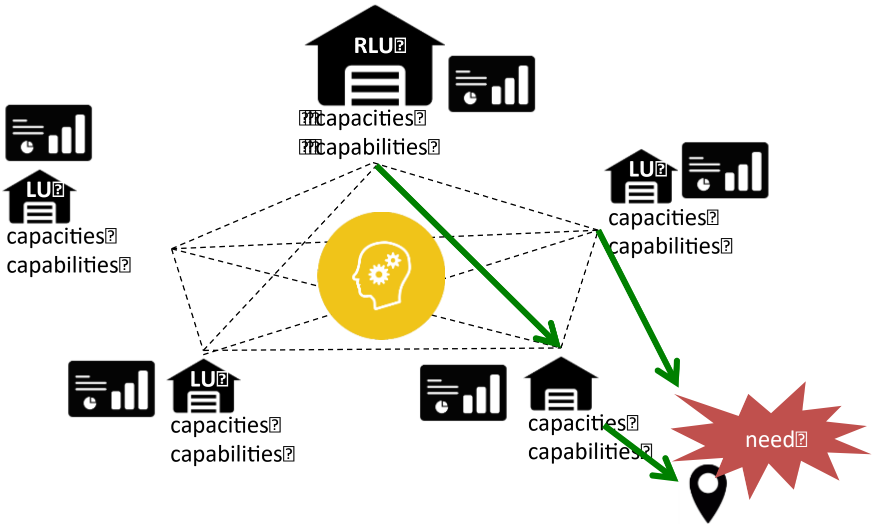


Figure 44 Sub-regional coordinated response

4.5. Results communication

The results of the field research were shared and discussed with the IFRC with the aim of highlighting the priorities and identifying the research directions to be followed.

Part of the field research results were also communicated with scientific publications at the 2016 ISCRAM conference (Laguna Salvadó et al. 2016).

Finally, this thesis mansucript summarizes the overall impact of the field research.

5. Discussion

Both academics and practitioners may benefit from a clear understanding of the HSC system in order to improve performance. This chapter aims to move the conceptualization of HSC knowledge a step forward by developing a metamodeling approach. Metamodels facilitate integration among stakeholders, information systems, intelligent processing and shared reuse of knowledge among systems (Pinto and Martins, 2004). It is particularly promising in a humanitarian context that requires making the knowledge of the relationships among relief stakeholders explicit (Humphries, 2013).

The HSC metamodel has been developed to provide a framework for classifying gathered data by connecting it to HSC concepts. It has a clear, collaborative perspective, and builds on the Crisis Management metamodel proposed by (Benaben et al. 2016). The HSC metamodel is a layer that includes four packages defining the HSC collaborative system (context, partners, objectives and behavior).

The potential uses are numerous, including the design and fulfillment of academic field research, the implementation of continuous improvement approaches, the design of adequate information systems and even the development of collaborative decision-support systems. The results of current and future research work should be helpful, considering that each organization —each actor— possesses its own knowledge, with its own semantics, usually limited to its core activity. However, even though all the actors possess all the knowledge of the domain collectively, none of them will master all the knowledge or its boundaries individually.

The illustration of the IFRC field research design using the HSC metamodel as a framework for building field research supports is simple proof of the usability of the proposal. The proposed HSC metamodel is a first attempt to describe all the concepts related to the HSC as a layered metamodel, developed by a limited group of experts. It aims to bring a shared and common understanding of the HSC.

However, a significant limitation of this study is that validity and reliability in qualitative research is controversial. To go further, a reference metamodel should be validated with a large spectrum of humanitarian actors, including academics and practitioners. The different perspectives of the actors may produce some misunderstandings with the concepts included in the model, or with the identification of missing concepts unknown by the author. More work has to be done to obtain a generic HSC metamodel that can be accepted by the humanitarian community as a standard.

Moreover, the metamodel gives a static view of the HSC. By implementing it, we can obtain a “picture” of the HSC as observed in a given moment. Due to the dynamic nature of the HSC, the need for introducing a time dimension concept to the metamodel is considered.

Chapter III. SUSTAINABLE HUMANITARIAN SUPPLY CHAIN PERFORMANCE

> "Definitional diversity is to be expected during the emergent phase of any potentially big idea of general usefulness."
>
> Gladwin et al. (1995)

1. Introduction

Typically, HSCs refers to criteria such as efficiency and effectiveness to measure the performance of their operations. This approach allows HSCs to maintain their order-qualifier position in the humanitarian response "marketplace".

To secure an order-winning position, and in line with the global trend to address sustainability challenges, there is increasing interest in sustainable approaches in HSC management. In the HSC literature, several papers call for innovations on the sustainability of humanitarian response (Haavisto and Kovács 2014; Kunz and Gold 2017). (Haavisto and Kovács 2014) highlighted the need to find a link between the short-term aims on operational performance and the long-term impact.

Moreover, sustainability is an abstract concept, and depending on the perspectives of people, disciplines and organizations, the concept of sustainability is addressed or understood in different manners and for different purposes. From the academic side, while sustainability is used in a wide range of scientific disciplines, it does not 'belong' to any body of knowledge (Oloruntoba 2015), and there are no clear standards and definitions. Already on 1995, academics expected that sustainability would "remain fuzzy, elusive, contestable, and/or ideologically controversial for some time to come" (Gladwin et al. 1995).

Although performance measurement and metrics are essential to effectively manage SC operations (Gunasekaran and Kobu 2007), the development of performance measurement systems for HSC operations is still in its infancy.

Therefore, even if sustainability can be considered a future lever to maintain an "order winner" position for HOs, it remains an abstract objective that is difficult to quantify in HSC operations. The challenge for HSC practitioners is first to develop an understanding of what a SHSC is, so then they can adopt suitable performance measures and metrics to make the right decisions that contribute to creating the value expected by donors: sustainability.

This can be achieved by a sustainable performance approach that goes beyond the effectiveness/efficiency paradigm. Moreover, using a sustainability maturity model can also contribute to improving sustainable performance (Kurnia et al. 2014). Unfortunately, in the literature there is no unanimously accepted performance measurement framework, nor any maturity model, for defining and measuring HSC operations sustainable performance.

To begin closing this research gap, this chapter addresses the following research question: *What does sustainability mean in HSC operations and how can it be assessed?*

To address the above question, we suggest a framework and assessment model to define and quantify sustainable performance in HSC operations.

In this way, this chapter contributes to turning sustainability from a set of high-level principles and blurry definitions into a concrete and measurable criterion for the HSC decision-making process.

Starting from a literature review on sustainability, sustainable SC performance and SHSC to obtain an overview of the state of the art, including methods and models, the maturity of sustainability will be assessed. The literature review was a qualitative selection of papers based on citation rate. We also considered HO reports to identify "best practices" in the sustainability field.

The remainder of the chapter is structured as follows: in Section 2, a literature review of sustainable SC, maturity models and SHSC performance approaches is presented, which outlines the origins and characteristics of the sustainability concept, and shows how this global challenge is affecting organizations with a focus on SC. Section 3 develops the first contribution of this chapter: a SHSC operations framework. In section 4, a maturity assessment model and method based on the SHSC operations framework are presented and illustrated with the IFRC application case. Finally, in Section 5 the implications of the proposal are discussed.

2. Background

> **Sustainability** /səsteɪnəˈbɪlɪti/
>
> Noun. The ability to be maintained at a certain rate or level.

This section provides an exploratory overview of sustainability as it has been addressed in practice and literature to clarify the notion of SHSC and examine how to build a consistent SHSC framework.

2.1. Sustainability: a historical perspective

Sustainable development is strongly related to the concept of progress and growth. This concept dates back as far as the Greco-Roman period, which was the starting point for formulating ideas of progress. Christian theology later consolidated this understanding by introducing "a linear conception of time as a directed succession of events, that transformed the way of thinking about history and progress" (Du Pisani 2006). The idea evolved over the centuries, and during the Industrial Revolution (18th Century), human progress became strongly linked to economic growth and material prosperity.

Industrialization, however, also brought about a growing gap between rich and poor and environmental degradation caused by the exploitation of raw materials on an unprecedented scale. Therefore, in the 20th century, the ideas about growth and development where challenged. In the late 1960's and 1970's, people became aware of the threats that industrial and commercial expansion posed to the environment and their own survival as human beings (pollution and resource depletion). Western societies became conscious that scientific and technological progress could not address the problems related to the massive consumption of resources. This period saw the beginning of environmental protection movements, with NGOs such as Greenpeace. The notion of sustainable development emerged, taking the word 'sustainability' from the ecology discourse[1].

The modern idea of sustainable development was defined on 1987 during The World Commission on Environment and Development (so called Brundtland Commission):

> "Development that meets the needs of the present without compromising the ability of the future generations to meet their own needs"
>
> (Brundtland, 1983).

It was the first time sustainability was presented as the balance between the dimensions environment, society and the economy (Du Pisani 2006). Nonetheless, sustainable development, as addressed by the Brundtland Commission, has been subject to considerable criticism, as it is accused of:

(i) being vague, "*it sounds so good everyone can agree with it whatever their own interpretation*" (Pearce et al., 1989),
(ii) promoting 'fake greenery' (Robinson 2004).
(iii) being an oxymoron. '*Is it possible to increase world industrial output in a way that is environmentally sustainable?*' (Robinson 2004).

Although sustainability is still a fuzzy and, at times, contested concept, the definition of the Brundtland commission is still the most widely used (Klumpp et al. 2015).

[1] In ecology, sustainability refers to the state or condition that can be maintained over an indefinite period of time.

Today, there is a consensus that sustainability is *the* scientific and political challenge of the 21st century. Environmental sustainability is the most "mainstream" concern, due to the urgent need to address climate change. In November 2017, for the second time after the 1992 "World scientist's warning to humanity", 15,000 scientists signed a strong message of alarm on environmental trends, making a special call for a "… more environmentally sustainable alternative to business as usual" (Ripple et al. 2017).

The social consequences of the environmental crisis are also of great concern. Global commitments like the Millennium Development Goals (MDGs), updated by the 2030 Agenda for Sustainable Development (ASD), both promoted by the United Nations, are an attempt to define sustainable development goals with a focus on the societal aspects. The UN SDGs includes 17 goals (Figure 45) with 169 targets that relate to the three dimensions of sustainability: economic, social and environmental.

Figure 45 UN Sustainable development goals

During the 2016 World Humanitarian Summit HOs committed to contributing to the empowerment of local communities as a way to improve resilience. Sustainability challenges are already being addressed by HOs as part of their development programs, primarily during reconstruction and mitigation phases, by working on sustainable solutions that allow the impact of disasters to be reduced.

2.2. The Triple Bottom Line

Sustainability has gained recognition since the early 2000s in business. Corporate social responsibility (, good governance, and many other terms have been used to define the policies, practices, and programs to incentivize the positive impacts of companies on societal aspects (Jamali et al. 2008; Pojasek 2012; Virakul 2015).

In the literature, it is a widely accepted notion to present organizational sustainability as a consideration of the balance between environment, society and economy, also known as the TBL (Carter and Easton 2011; Carter and Rogers 2008; Elkington 1998; Virakul 2015). These three pillars are also referred to as "People, Planet and Profit". The TBL model is a systemic approach developed on the mid 90's by John Elkington to "capture the essence of sustainability by measuring the impact of an organization's activities including its profitability and shareholder values and its social, human and environmental capital" (Savitz 2012). It stresses the need to engage on the performance achievement of these three sustainability dimensions.

This idea comes from the recognition of the environmental, economic and social systems intersection, where sustainability is achieved (Mebratu 1998). The TBL dimensions are defined here as:

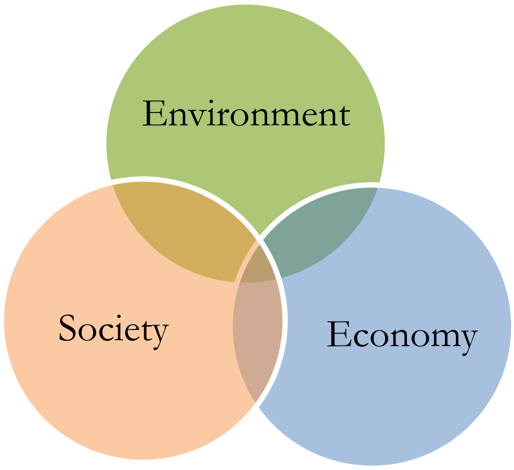


Figure 46 TBL dimensions

- Economic sustainability or "Profit": relates to cost and productivity considerations. An organization has to use its resources so that it can consistently produce an operational profit, and sustain its activities.
- Social sustainability or "People": relates to proper and favorable business impact for employees, population, and the area in which the organization conducts its activities.
- Environment sustainability or "Planet": relates to environmental impact. It attempts to benefit the natural setting as much as possible or at least do no damage and decrease the environmental effect.

According to (Pojasek 2012), all activities, products and services have a footprint. This footprint creates impacts on each of the TBL dimensions. Each impact creates risks for the organization's sustainability. The organization can mitigate these risks through a sustainable management of operations that avoid creating negative impacts, as far as is possible.

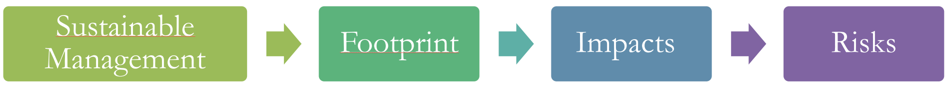


Figure 47 Sustainability with an organizational perspective (Pojasek 2012)

TBL is widely used as a synonym of sustainability in the business literature. However, some authors argue that the TBL elements are conflicting and that their common achievement is therefore impossible (Milne and Gray 2013). Accordingly, the TBL approach, as it is currently used, reinforces a position where financial viability is prioritized and environmental and social considerations remain an afterthought. It is considered by some as a pathway for corporations to easily ignore or bypass key sustainability issues (Sridhar and Jones 2013).

Here, the problem may not be the TBL philosophy itself, but to recognise and accept the limited function of measuring sustainability, which is useful for (Burritt and Schaltegger 2010):

- Providing information about an organization's impact;
- Understanding situations;
- Answering specific questions;
- And enabling comparisons.

2.3. Sustainability of the Supply Chain

80% of global trade passes through SCs. The SC is considered one of the most important levers for business to create positive (or negative) impacts in the world (Carter and Easton 2011). Therefore, SC sustainability is a growing global concern. According to the UN Global Compact Initiative a sustainable SC should follow ten Principles related to the environmental and social dimensions.

The UN Global Compact Principles for SSCM

Human Rights

- Principle 1: Businesses should support and respect the protection of internationally proclaimed human rights; and
- Principle 2: make sure that they are not complicit in human rights abuses.

Labour

- Principle 3: Businesses should uphold the freedom of association and the effective recognition of the right to collective bargaining;
- Principle 4: the elimination of all forms of forced and compulsory labour;
- Principle 5: the effective abolition of child labour; and
- Principle 6: the elimination of discrimination in respect of employment and occupation.

Environment

- Principle 7: Businesses should support a precautionary approach to environmental challenges;
- Principle 8: undertake initiatives to promote greater environmental responsibility; and
- Principle 9: encourage the development and diffusion of environmentally friendly technologies.

Anti-Corruption

- Principle 10: Businesses should work against corruption in all its forms, including extortion and bribery.

Derived from: the Universal Declaration of Human Rights, the International Labour Organization's Declaration on Fundamental Principles and Rights at Work, the Rio Declaration on Environment and Development, and the United Nations Convention Against Corruption (Sisco et al. 2015).

The objective of Sustainable Supply Chain Management (SSCM) is to contribute to reducing the negative footprint (Kleindorfer et al. 2005). The most cited definition of SSCM is from (Seuring and Müller 2008):

> "The management of materials, information and capital flows as well as cooperation among companies along the SC while integrating goals from all three dimensions of sustainable development, i.e. economic, environmental and social, which are derived from customer and stakeholder requirement"

More recently, (Ahi and Searcy 2013) proposed an extended definition that integrates the previous one, but covers 7 business sustainability characteristics (economic, environmental, social, stakeholder, volunteer, resilience, and long-term focuses) and 7 SCM characteristics (flow, coordination, stakeholder, relationship, value, efficiency, and performance focuses):

> "The creation of coordinated SCs through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short and long-term."

Sustainable SCM (SSCM) is therefore a challenging task that basically needs to integrate economic, environmental, and social dimensions in the decision-making processes.

2.3.1. Sustainable SC Performance measurement

> **Performance /**pəˈfɔː.məns/
> Noun. How well a person, machine, etc. does a piece of work or an activity

Performance Measurement is a way to quantify and control the outcomes obtained in any organization's process. It can be used to compare goals, standards, past results or organizations, and to anticipate the impact of decisions on planning processes. Given the far-reaching consequences of their activities, SC decision-makers are in a position to impact the economic, social and environmental dimensions of sustainability (Carter and Easton 2011).

The traditional objective of SC performance is to maximize financial profit, paying little or no attention to environmental and social impacts.

SC performance measurement has been addressed widely in the literature. The main focus of the academic studies has been (Ahi and Searcy 2015):

- Evaluating and monitoring progress,
- Reporting of performance,
- Identifying achievements,
- Promoting improved process understanding,
- Identifying critical issues,
- Providing guidance for future actions, among other topics.

There is evidence of growing interest in research that focuses specifically on measuring performance in sustainable SCs. Although SSCM is still a young discipline, there has been a dramatic rise in the number of publications since the beginning of the 2000's. A search of the Web of Science database shows an exponential increase in publications with the topic "sustainable SC performance".

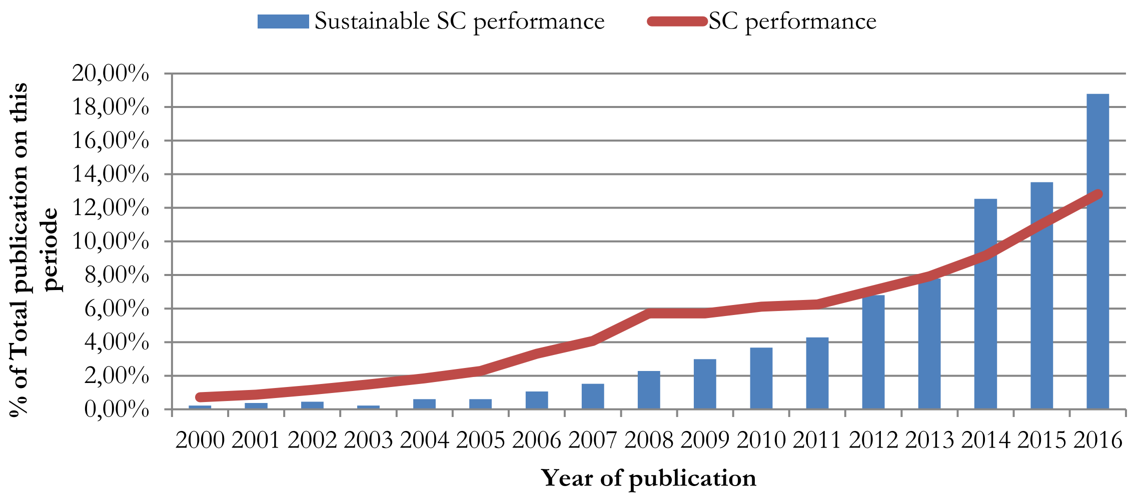


Figure 48 Sustainable SC performance WoS publications growth

While analyzing sustainability SC disclosure initiatives, (Okongwu et al. 2013) identified TBL performance as one of the main drivers. Also (Baumann 2011; Beske and Seuring 2014; Carter and Liane Easton 2011; Seuring and Müller 2008; Taticchi et al. 2015) refer to the TBL when addressing SC sustainability. Therefore, TBL performance measurements for SC operations are abundant in the literature. (Chardine-Baumann and Botta-Genoulaz 2014) define the sustainable performance of a practice as the combination of its economic, social and environmental performances. A recent study identified a total of 2555 unique metrics in the SSCM literature published by the end of 2012 (Ahi and Searcy 2015). The results highlight the great variety of approaches for measuring SC sustainability.

Academic proposals typically deal with the strategic decisional level (network design) (Eskandarpour et al. 2015), or with a focus on one of the SC SCOR reference operational processes (Huan et al. 2004): make, source, deliver or return. Moreover, the TBL dimensions are often addressed alone, or two by two (economic-environmental, economic-social or environmental-social).

2.3.2. Economic performance

The SC economic performance dimension measures the financial benefit. The economic performance is therefore strongly related to the satisfaction of customer expectations. For different industries, customers look at different measures, such as delivery service, where time is no doubt their major concern; whereas for parts manufacturing, the accuracy of the specification may be the most important consideration (Chan 2003). The economic performance is a balance between effectiveness in delivering customer value and the cost-efficiency of the SC process. SC models have typically focused on performance measures such as a combination of cost (inventory costs and operating costs) and customer responsiveness (i.e. lead time, stock-out probability, fill rate) (Beamon 1999).

2.3.3. Environmental performance

The environmental impact of increasingly globalized SCs has been widely investigated since the 1990's. It is the most highly-developed concept of the TBL. "Green business", or corporate commitment to environmental protection has been demonstrated to lead to competitive advantage (Esty and Winston 2009), as it is seen as an opportunity for growth and profit. Reducing resource consumption can lead to an improvement in economic performance.

Environmental performance focuses on environmental protection principles that cover all phases of a product's life cycle, from the extraction of raw materials through the design, production, and distribution phases, to the use of the product by consumers and its disposal at the end of the product's life cycle (Ahi and Searcy 2015). The World Economic Forum estimates that logistics activity accounts for 6% of the total 50,000 mega-tons of CO_2 annually produced by human activity (Grant et al. 2017). Therefore, it is not surprising that the most popular metric for measuring environmental impact is the carbon footprint emitted by a company or an SC. Some other key indicators, even if defined using different words, are related to energy use, hazardous wastes generated, and material recovery (Okongwu et al. 2013).

2.3.4. Social performance

Social sustainability has been less fully explored than the environmental dimension in SCs. Furthermore, the definition of social sustainability itself is still not clear. Social sustainability in SCs typically refers to issues of social justice and human rights, with studies focusing on practices such as supplier human rights actions, labor conditions, gender equality or supplier compliance with child labor laws, and the delivery of social justice through sourcing from “ethical” suppliers. Including social aspects in network design decisions allows a better evaluation of the impact of an SC on its stakeholders: employees, customers and local communities.

2.3.5. Standard Sustainable SC performance frameworks

The debate remains open in the Operations Management literature regarding the possibility of having standard sustainable SC performance measures. Given the lack of standardization, some authors argue that indicators need to be established on a case-by-case basis (Bouchery et al. 2010). Also (Pojasek 2012) suggests that each organization should create its own definition of the term. Others argue that it is possible to have a standard set of indicators to measure the sustainable performance of a given process (i.e. source, make, deliver) (Veleva and Ellenbecker 2001).

SSCM performance measurement has been mostly addressed - both in practice and in the literature - with a focus on accountability reporting (Carter and Rogers 2008). Therefore, methods such as Life Cycle Sustainability Assessment (LCSA), ISO 26000 (international standard), or the Global Reporting Initiative (GRI) suggest frameworks to report the impact of the SC on sustainability. The GRI is one of the most used references in terms of sustainability reporting. It provides guidelines on how a report should be built. The GRI defines a list of over 90 indicators in the three TBL categories. The social category is further divided into four sub-categories, which are Labor Practices and Decent Work, Human Rights, Society and Product Responsibility (Global Reporting Inititative 2015). Although the GRI is widely-used by many organizations, it has been criticized for its complexity. It adds a lot of criteria, and gathering and analyzing the data is time- and cost-consuming.

Other references, such as the ISO 14000 international standard family, or GreenSCOR are focused only on one of the environmental dimensions. For example, ISO 14031 is designed for environmental performance evaluation with indicators in three key areas: (1) environmental condition indicators, (2) operational performance indicators and (3) management performance indicators.

2.3.6. Sustainability maturity methods and models

> **Maturity** /məˈtʃʊə.rə.ti/
> Noun. A very advanced or developed form or state

A maturity model is defined by (Battista 2013) as:

> "A framework conceived to evaluate the maturity of an organization through the definition of a set of structured levels that describe how well behavior, practices and processes can reliably and sustainably produce required outcomes".

The origin of maturity models comes from the "Capability Maturity Model" (Paulk et al. 1993), which is used to assess an organization on a scale of five process maturity levels. Each level ranks the organization according to its standardization of processes in areas as diverse as software engineering, systems engineering, project management, risk management, system acquisition, information technology (IT) services and personnel management (Correia et al. 2017).

The use of maturity models to analysis and optimize processes has seen exponential growth in recent years, with encouraging results. Therefore, many authors have focused on the development of SC sustainability specific domain models (Baumann 2011; Golinska and Kuebler 2014; Kurnia et al. 2014; Okongwu et al. 2013; Reefke et al. 2014; Srai et al. 2013). (Correia et al. 2017) recently published a literature review on the topic, and identified the potential uses of Maturity Models as:

- A descriptive tool for the evaluation of strengths and weaknesses
- A prescriptive instrument to help develop a guide (roadmap) for performance improvement
- Comparative tool to evaluate the processes/organization and compare them with standards and best practices from other organizations
- Enablers for internal and external benchmarking

Typically, a method to assess a maturity level consists of measures and questionnaires, which allow the organization to perform self-assessment and benchmarking of their sustainability level. However, there is no standard definition of maturity levels. As an example, (Baumann 2011) proposes an analytical evaluation model to characterize the global performance of an SC based on performance measurement aggregation, which is built on the TBL dimensions. The maturity of sustainable practices is defined on 4 levels proportional to the degree of implementation.

2.4. Sustainability in the HSC

Today, there is no clear global consensus on how the humanitarian system should address HSC sustainability. Previous research focuses on: (i) the theoretical conceptualization of sustainability and (ii) the analytical modeling of the HSC at different levels (i.e. network design, operations, or procurement policy).

2.4.1. HSC sustainability concept

Recently, (Klumpp et al. 2015) proposed a definition for sustainable humanitarian operations built on a combination of HOs' objectives, logistics definition (from the CSCMP[1]) and the Brundtland sustainable development definition:

> "Sustainable humanitarian logistics has the objective to assure every human being—especially in situations of disasters and emergencies—a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services by planning, implementing, and controlling the efficient, effective forward and reverse flow and storage of goods, services and related information throughout the whole SC in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs"

This definition includes a large (but fuzzy) view of stakeholders' expectations on sustainability. With an analysis of Annual Reports from several HOs – given the lack of sustainability reports –, (Haavisto and Kovács 2014) concluded that HOs mainly view sustainability in terms of the expectations of society and the beneficiaries.

Moreover, according to (Hausladen and Haas 2013), development aid and ad-hoc disaster relief have to be considered simultaneously to achieve sustainability. They proposed a theoretical framework to integrate a TBL-oriented sustainability perspective within HSC operations planning. It is a holistic approach that combines disaster relief assistance and long-term planned continuous development for strategic, tactical and operational planning.

Also with a theoretical point of view, Kunz and Gold (2015) have developed a framework of SHSC at the rehabilitation phase. The sustainable performance is conceptualized as flowing from a strategic reconciliation between relief organizations' enablers (resources, capabilities and commitment) and beneficiaries' requirements, via an optimal SC design.

2.4.2. Analytical approaches

Apart from the theoretical discussions on sustainability, few proposals use analytical methods to assess SHSC performance.

HSC Network design

(Dubey and Gunasekaran 2016) identify three important characteristics of SHSC networks that contribute to HSC performance: agility, adaptability and alignment, and explore possible linkages using extant literature and interpretive structural modeling with sustainability.

Accordingly, dynamic sensing, responsiveness and flexibility are important dimensions of HSC agility. In order to improve the adaptability of the HSC network, focus should be placed on culture, developing mutual respect and trust among SC partners and responding to environmental needs. HSC alignment can be improved by effective communication design, through proper training and development, collaboration and by maintaining transparency.

[1] The Council of SC Management Professionals (http://cscmp.org)

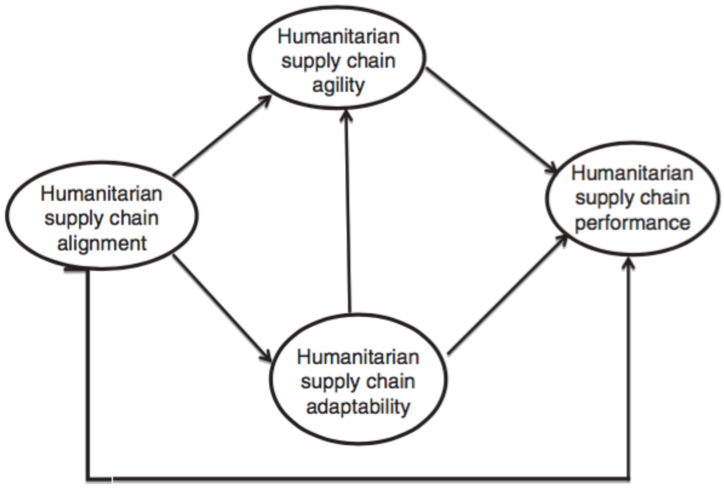


Table 5 Humanitarian SC performance enablers (Dubey and Gunasekaran 2016)

HSC Operations

Within the SC processes, transport has been the focus of sustainable SC research and practice due to the high energy consumption, emission of gases, noise pollution and other impacts on the environmental dimension. Therefore, in the context of HSC, (Wei et al. 2015) presented an optimization model to demonstrate the interest of measuring the impact of HSC transport on TBL performance. The model ensures sustainable economic operations with an effective use of the financial resources of donors (minimization of the economic dimension). For the environmental dimension it computes the resulting CO_2 emissions of transportation, and for the social dimension, it constrains a timely distribution and measures the response 'credibility'. The objective of the mathematical model is to minimize the total cost of procurement plus transportation.

HSC Procurement policies

Using Value Chain Analysis (VCA), (Taylor and Pettit 2009) demonstrate that the use of local manufacturing and prepositioning stocks reduces the Carbon Footprint. Considering that the HSC has similar processes to a commercial SC, (Van Kempen et al. 2017) used a LCSA to discuss international versus local procurement strategies and their impact on the TBL. The study focuses on the distribution of kitchen sets to refugee camps, and although difficulties were encountered in collecting data, they conclude that based on the LCSA, local sourcing is preferable over international sourcing in social and environmental TBL dimensions.

2.5. Conclusion

The TBL is the most widely accepted approach to address sustainability. Even if it comes from the for-profit sector, in the literature many authors have already made the assumption that it is a substantial part of a sustainable humanitarian system (Klumpp et al. 2015; Kunz and Gold 2017).

Unfortunately, there is no universal definition of the three TBL dimensions; neither is there an accepted standard to measure it. Even if this lack of standardization can be seen as a weakness, several authors highlight the fact that it provides the possibility to adjust this general framework to any organization.

Moreover, there is significant literature on SC and HSC that deals with one or several of the TBL dimensions. Indicators are abundant in the literature referring to each dimension. The difficulty remains in identifying the objectives that decision-makers need to consider in SHSC operations.

Thus, the macro-economic definition of sustainability, and the three categorical dimensions can explain sustainability on a conceptual level (Santiteerakul et al. 2015), but do not provide much guidance on how sustainability should be measured in the context of HSC operations. Nonetheless, according to (Haavisto and Kovács 2014), the sustainable performance expectations from the organization's perspective seem to have been overlooked.

Therefore, given our focus on HSC operations decision-making, we aim to address sustainable performance in the light of SC and program sustainability expectations. Nonetheless, we want to consider also the context expectations (beneficiary and societal expectations), to be coherent with the broad conceptualization of sustainability.

The ultimate objective then, is to define a performance framework that links the short-term performance expectations and the long-term impact of aid in the social and environmental dimensions, and to define a maturity model to monitor SHSC performance.

3. Definition of Sustainable HSC performance

This section presents the SHSC operational performance framework to assess the impact of operations. It is based on the TBL dimensions, and decomposed into a set of sub-dimensions, with the related definitions and examples of criteria to measure it. The criteria are related to the main HSC processes: procurement, warehousing and transport.

3.1. Economic dimension

Traditional SC performance is directed towards financial and operational indicators (Kunz and Gold 2017). In HSC, the added value of operations is defined by accomplishing general humanitarian ambitions like “saving lives”. To do so, the main criteria to evaluate HSC performance are generally effectiveness, efficiency, and equity (Gralla et al. 2014).

Effectiveness is the capability of achieving the organization’s target. In a “value driven” organization, the target will be to satisfy the customer’s needs. In HSC, donors ask for specific aims and target levels such as numbers of households that are provided with humanitarian relief items, shelter, or education. In HSC literature, the effectiveness objective usually corresponds to the demand satisfied. To measure it, different KPI are proposed, like population coverage, order fulfillment, stock-out minimization, etc. By looking at the specifics of the three HSC processes, the effectiveness key performance indicator for “source” will be defined as a measurement of effective replenishment, for “make”, as the strategic contingency stock level maintenance, and for “deliver”, as the needs coverage (real demand) on time. Others have used the deprivation cost approach (Holguín-Veras et al. 2013) or the amount of suffering of the victims.

Equity is considered as an important objective by HOs, however, considering it as a performance indicator is still the exception rather than the rule in the humanitarian setting. Here it is understood as a complement of effectiveness because it is an integral part of humanitarian principles. It also could be considered in the social dimension, as it has a direct link with societal wellbeing. In fact, equity has been defined as the intersection between people and profits (Carter and Easton 2011). Tzur measured the equity of HSCs using the Gini Index (Tzur 2016), a non-linear measurement of inequality. Others have used disparity in demand satisfaction. Non-discriminatory distribution is an objective for the “making” and “distribution” processes (contingency stock maintenance, needs coverage). For the sourcing process, field-observations at the IFRC also show that the objective is the respect of fair commercial competition.

Efficiency can be defined as the ability to avoid wasting resources to reach a target. In HSC, this dimension corresponds to the minimization of operation costs. Although making a profit is not their objective, non-profit organizations also care about financial wellbeing, since financial stability is crucial to their missions and survival. Cost key performance indicators have already been used as an objective function in many humanitarian distribution models (Beamon and Balcik 2008). Regarding the upstream HSC, Beamon and Balcik identified three dominating costs: the cost of supplies, distribution costs, and inventory holding costs. Other costs that can be considered are handling costs, kitting or consolidation costs (cost of building emergency item kits).

Thus, we propose the performance criteria, objectives and key performance indicators, as presented in

Table 6, to define and quantify the economic TBL performance dimension of the HSC operations.

Table 6 Economy sub-dimensions, definitions and criteria

Sub-dimension	Definition	Procurement	Warehousing	Transport	Criteria example
Effectiveness	The ability to satisfy demand on time	x	x	x	Needs coverage on time, deprivation cost
Equity	The ability to satisfy the demand in a proportional manner (downstream)			x	Inequality measures (i.e. Gini index)
Efficiency	The ability to reduce the financial spending	x	x x	x x	HSC costs (Acquisition cost + Holding cost + Kitting cost + Distribution cost)

3.2. Environmental dimension

The HSC is not a closed system. Therefore, the achievement of its objective of emergency items distribution it will inevitably imply consumption of resources (materials, energy) and discharge into the environment (wastes, pollution, noise).

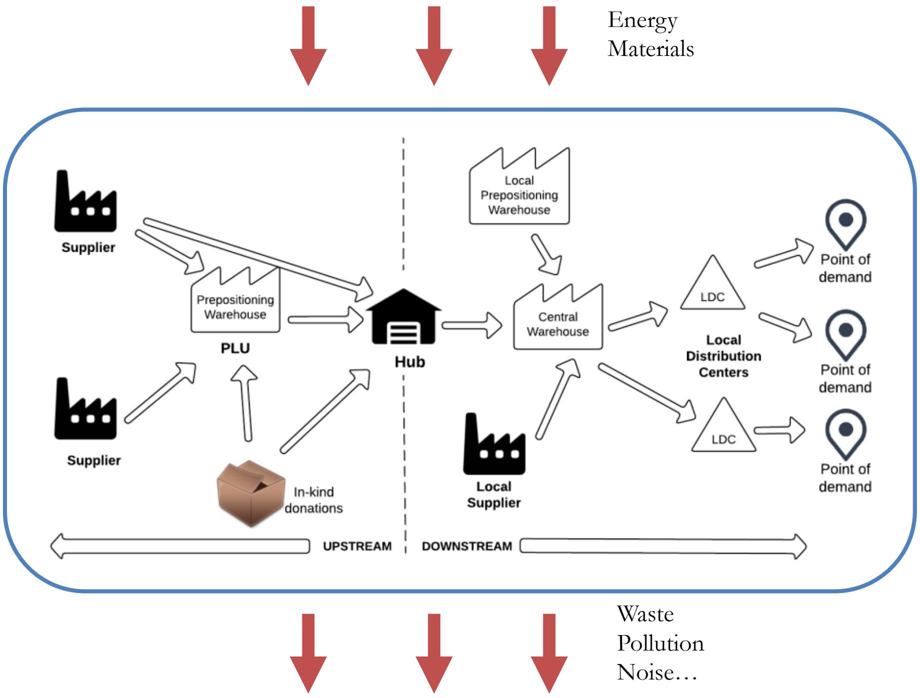


Table 7 Environmental footprint of the HSC schema, inspired from (Hervani et al. 2005)

SC literature contends that logistics operations can particularly influence pollution (i.e. air, noise), and the conservation of resources (i.e. energy, water) (Murphy and Poist 2003). Thus, we assume that performance in these two areas constitutes the HSC environmental dimension.

The objectives of measuring environmental pollution are mostly to reduce green house gas emissions, and to manage hazardous materials. Hazardous materials are rare in Humanitarian relief distribution, but they may be present as part of the wastes for medical relief organizations (e.g., medical disposals were an important consideration in the Ebola response). However, we consider that its management it is outside the procurement, warehousing and transport processes, and thus outside the scope of this study. Regarding greenhouse gases, the most widely used key performance indicator is direct and indirect CO2 emissions, or the carbon footprint, coming from life cycle assessment approaches (LCA) (Baumann 2011). Carbon emissions can be differentiated between two categories: stationary sources (emissions from material processing, manufacturing, and warehousing) and non-stationary sources (emissions from inbound and outbound logistics) (Sundarakani et al. 2010). In the GreenSCOR reference model, best practice and performance metrics are suggested by each of the SCOR processes regarding pollution reduction and resource conservation. However, there is no agreed framework for measuring the environmental footprint of the SC.

The resource conservation objective is to reduce wastes like energy, water, packaging, etc. Resources are consumed all along the SC processes. Inventory immobilization (contingency stock) generates significant energy consumption, especially in warm countries (air conditioning). Choices with regard to the mode of packaging or transportation may influence the quantity of packaging consumed

We summarize the criteria on the environmental dimension in Table 8.

Table 8 Environment sub-dimensions, definitions and criteria

Sub-dimensions	Definition	Procurement	Warehousing	Transport	Criteria example
Pollution reduction	Ability to reduce the HSC footprint	x	x	x	Carbon Footprint
Resources conservation	Ability to reduce resources consumption (energy, water, packaging…)	x	x	x	Resources management capability

3.3. Social dimension

The social dimension was the last to be developed in the TBL framework; it has been typically neglected in quantitative models (Brandenburg et al. 2014). In holistic social definitions, there are many criteria that can be found: education, equity and access to social resources, health and well-being, quality of life, and social capital.

Internal and external factors need to be differentiated here. In HSC operations, internal factors are related to labor conditions and external factors to community empowerment. Both criteria build the social sustainability performance as Table 9 shows.

Labor conditions are strongly highlighted by the 2030 Agenda for Sustainable Development, which aims at enhancing prosperity by reducing poverty and economic disparity (wages), gender equality or decent work. The labor conditions objective for the HSC seeks to preserve the health and security of employees, and ensure good conditions of work (Baumann 2011).

Table 9 Social sub-dimensions, definitions and criteria

Sub-dimension	Definition	Procurement	Warehousing	Transport	Criteria example
Local communities empowerment	The ability to develop local wealth	x	x	x	Local procurement
Labour conditions	Ensure good conditions of work and preserve health and security of employees	x	x	x	Employee management (internal)
		x		x	Suppliers assessment (external)

One pillar of a humanitarian organization's strategy (HWS 2015) is to empower local communities with the aim, (among others), of improving disaster resilience (Comes 2016). Community empowerment can be seen as an external influence including contribution to employment and the creation of wealth. Many authors also refer to the positive impact of local sourcing as an action in favor of community empowerment (Kovács and Spens 2011; Kunz and Gold 2017) with a positive impact on regional economic development. Therefore, the current trend is favoring local sourcing wherever possible (Haavisto and Kovács 2014).

3.4. Conclusion: The house of SHSC operations

Despite the published studies, including those noted above, no comprehensive inventory of metrics applied to SSCM is yet available.

The proposal set up concrete criteria, objectives and KPI sets for assessing the operations impact in the TBL approach. Figure 49 illustrates the proposed approach with the "House of SHSC Operations".

The House of SHSC Operations is based on the HSC operational processes: Procurement, Warehousing and Transportation. Each pillar is built on one of the TBL performance criteria. To enhance an overall sustainable performance, the three pillars have to be balanced, so the roof is in equilibrium. This image reflects the importance of considering all the TBL performance objectives to enhance an overall sustainable performance. Carter and Rogers (2008) emphasize that organizations that seek to maximize the performance of all three pillars simultaneously will outperform organizations that only maximize the economic performance, or the ones that attempt to achieve high levels of social and environmental performance without explicit considerations of economic performance.

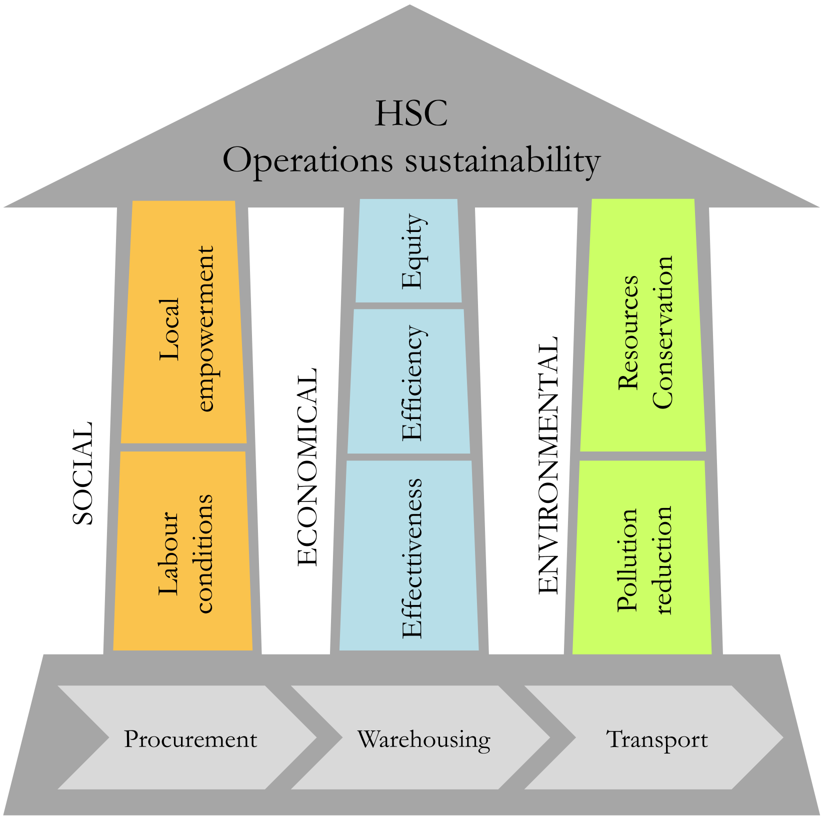


Figure 49 The House of HSC Sustainable Operations

Therefore, bypassing one of the dimensions, or focusing on just one of them does not contribute to the overall sustainability performance. Figure 50 illustrates some disequilibrium scenarios where HSC dimensions are not balanced.

The first scenario (a) illustrates the current HSC approach, where economic dimension objectives drive operations. There is some awareness of the social and environmental dimensions, but they are not really considered in decision-making. The roof of the House is not stable, so not sustainable in the long term.

The second scenario (b) is the opposite case, where the focus is only on environmental and social dimensions, but forgetting the economic sustainability of the organization. The sustainability cannot be enhanced without ensuring the economical prosperity of the organization.

The third scenario (c) is a "green HSC" approach, where all efforts are put into reducing the environmental impact. As with the previous scenarios, the sustainability of the HSC is not ensured.

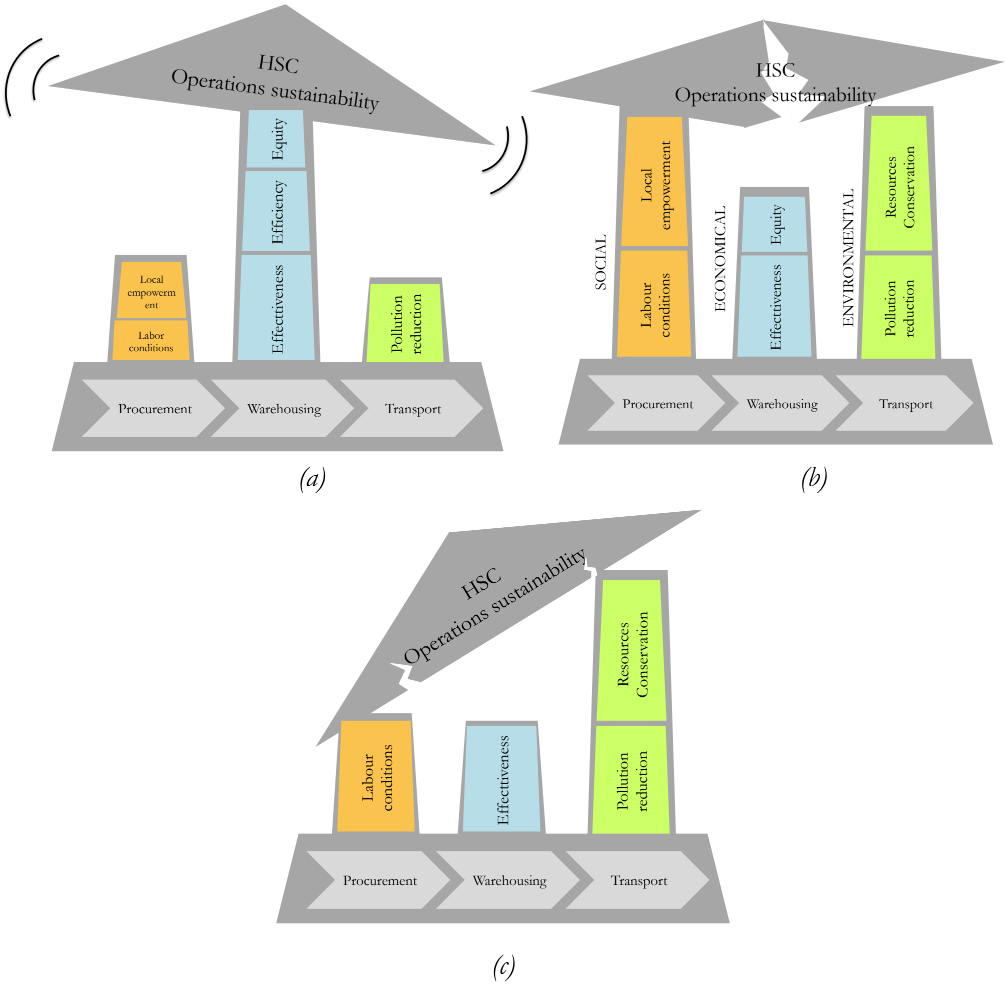


Figure 50 Illustration of HSC operations sustainability conceptual "disequilibrium"

Finally, Figure 51 illustrates the case where all the dimensions are considered, without reaching the maximum performance expectations in any of them. The sustainability is then reached, without excelling in any of the dimensions.

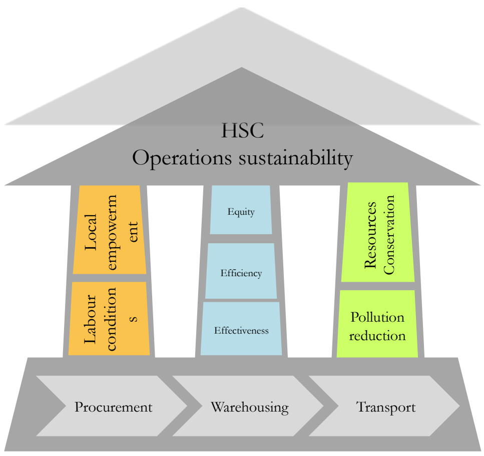


Figure 51 A balanced SHSC performance

4. SHSC maturity assessment

Previously, we have defined the elements that impact the ability of an HSC to be sustainable. Once sustainable performance dimensions and sub-dimensions have been defined with the "House of HSC sustainable operations", the challenge remains to measure them. This section suggests a maturity assessment model that enables quantification of SHSC performance.

The interest of the assessment model is that it involves both benchmarking and monitoring SHSCs. Benchmarking allows internally or externally different systems or sub-systems to be compared, for example disaster responses, or for the case of the IFRC, different RLUs. Monitoring enables the evolution of a system over time to be assessed, and therefore drive the performance.

4.1. HSC sustainability assessment method

4.1.1. Assessment model

A performance maturity level assessment, based on the TBL dimensions and sub-dimensions, is a way to measure the sustainability of the HSC. For this specific purpose, we suggest using a quantitative and symbolic modeling approach (Figure 52). The SHSC maturity is built on the maturity of each of the TBL dimensions, defined here by five levels:

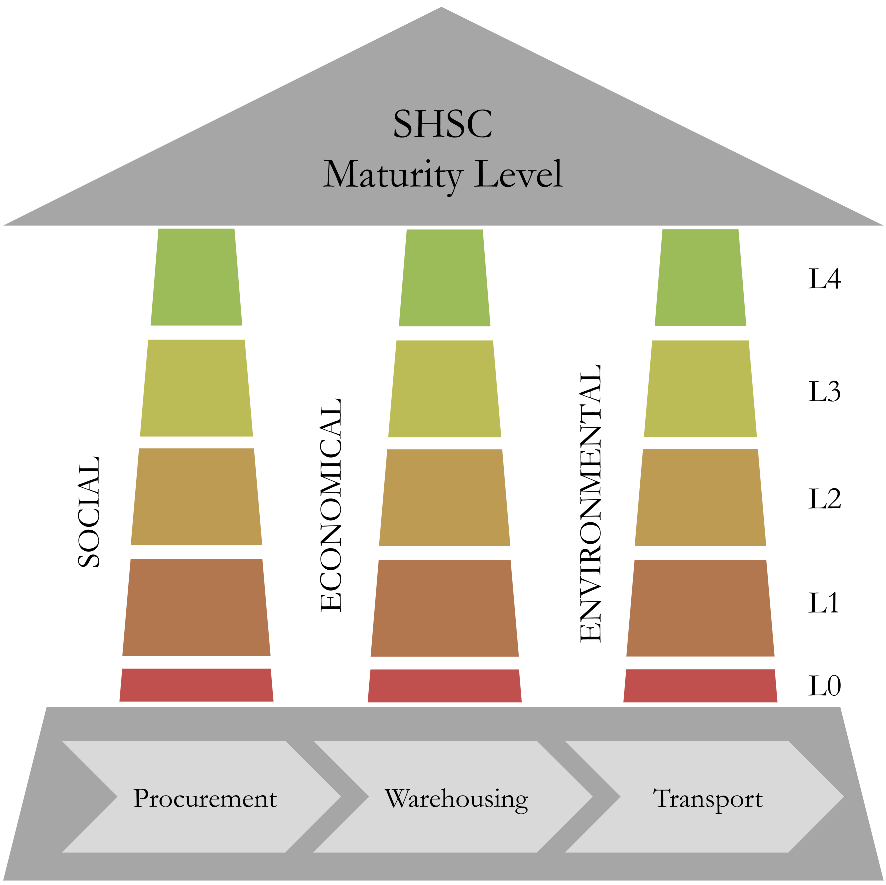


Figure 52 HSC sustainable performance maturity levels

- L0 – Unaware: The sustainable performance dimension is not considered at all by decision-makers. There is no information.

- L1 – Beginner: Decision-makers are aware, but quantitative/qualitative results are not satisfactory.
- L2 – Medium: The performance dimension results are mitigated or insufficient.
- L3 – Good: The performance dimension is well considered and results are satisfactory.
- L4 – Expert: Decision-Makers are able to make decisions in alignment with the objectives of this dimension and considering the whole HSC (upstream and downstream). The quantitative results are excellent.

4.1.2. Assessment method

To define the maturity level of the SHSC, first of all, each of the maturity sub-dimensions has to be assessed. The suggestion is to use either qualitative or quantitative metrics, with an assessment grid that makes it possible to define one maturity level per sub-dimension.

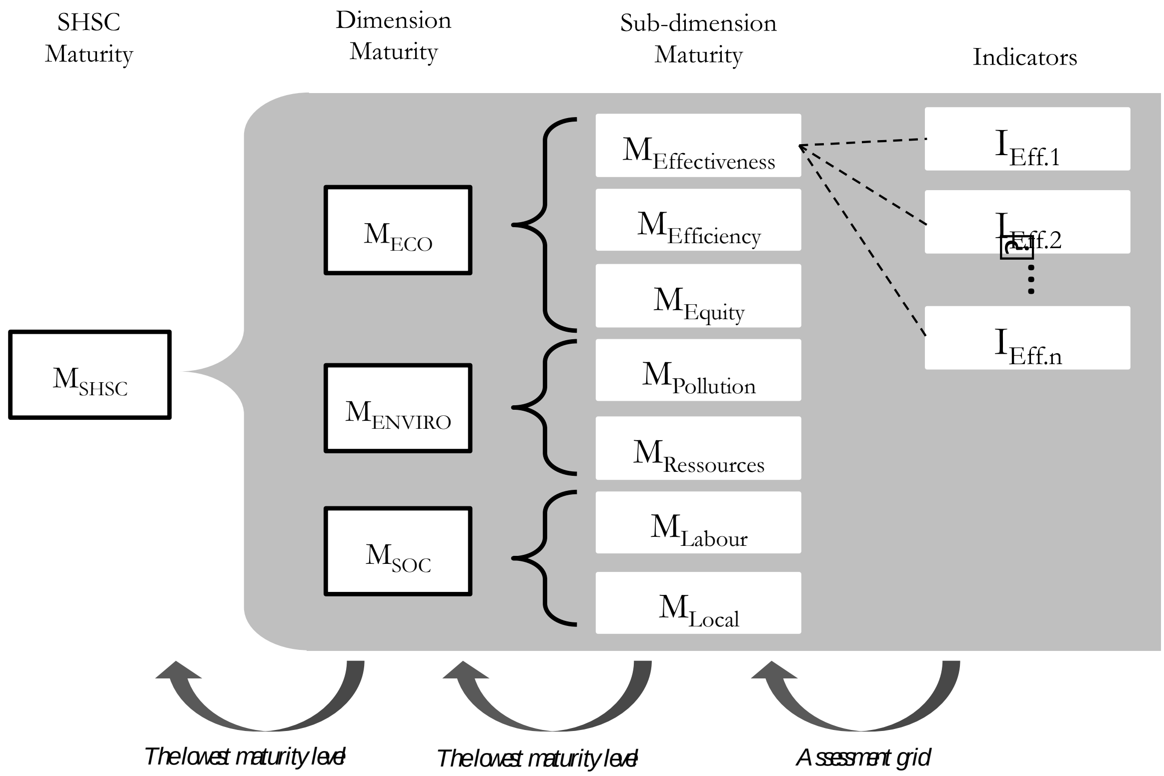


Figure 53 SHSC Maturity assessment method

Secondly, once the sub-dimensions are assessed, the maturity level of each dimension of sustainability is deduced by taking the lowest sub-dimension maturity level. All the sub-dimensions are considered of equal importance because the objective is to enhance equilibrium.

Finally, a global HSC sustainability maturity level can be deduced. Based on the House of SHSC principle, which encourages equilibrium within the TBL dimensions, the method to deduce the global level is also to take the lowest dimension level. Therefore, as long as one of the dimensions is mostly ignored, the symbolic global level will remain at L0. The objective is to highlight which are the dimensions that should be improved as a priority in order to improve sustainability with a balanced approach.

4.2. A proof of concept: Assessing the sustainability of IFRC HSC

To illustrate how to use the SHSC maturity assessment model, we built a use case based on the IFRC A&C RLU operations. First, a set of the metrics and the assessment grid are defined, and secondly, the results are given and interpreted.

4.2.1. Assessment metrics & grid

The metrics to assess the sustainability performance can be either quantitative or qualitative. As long as the objective is to define a performance level for each of the sub-dimensions, we consider a quantitative measure if possible (a ratio can be defined). Otherwise, we have defined a qualitative assessment of the criteria, which is based on the practitioner's appreciation of the dimension (i.e. for the labor conditions). The metrics are inspired by previous discussion, and are illustrative. Depending on the HO, the criteria to define each of the sub-dimensions, as well as the measures, may be different.

Table 10 presents an example of the metrics and Table 11 shows an assessment grid that can be used for each criterion in the IFRC upstream context.

Table 10 Sustainability performance metrics per dimension

TBL	Sub-dimension	Criteria	Typology	Measurement
Economic	**Effectiveness**	Demand satisfaction	quantitative	$\frac{\text{Needs coverage on time}}{\text{total demand}}$
	Efficiency	HSC Cost ROI	quantitative	$\frac{\text{(Net incomes-HSC Cost)}}{\text{Net incomes}}$
	Equity	Non-discriminatory distribution	quantitative	Gini Index (beneficiary inequality)
Environmental	**Pollution reduction**	Carbon footprint	qualitative	Appreciation
	Resource conservation	Reduction resource consumption	qualitative	Appreciation
Social	**Local community development**	Local procurement	quantitative	$\frac{\text{CHF expended locally}}{\text{CHF total expenses}}$
	Labor conditions	Employee management	qualitative	Appreciation

All the economical dimensions are quantifiable. For effectiveness, the ratio between the total needs over a time period, and the needs covered on time are considered. For efficiency, we consider a HSC Costs ROI (Return of Investment). A negative ROI result implies that the HSC system loses money, and a positive gives the margin that is generated. The equilibrium is around 0, considering that the objective is not to make a profit but to maintain the activity. For equity we propose using the Gini Index, as suggested by (Tzur 2016). It allows the inequalities within the distribution to be determined, where 0 indicates that there is no inequality.

The environmental sub-dimensions are both qualitative. The overall objective is to reduce both the carbon footprint and the consumption of resources. Given that it is not possible to normalize these absolute values, we define different maturity levels in Table 11. The Carbon Footprint levels are based on the LCA assessment approach, which seeks to include the whole product lifecycle (from raw materials to end of life). For resource conservation (reducing consumption) the levels are similar, considering consumption of resources such as water, energy, packaging, etc. Therefore, expertise is reached when the Carbon Footprint and LCA sub-dimensions are managed upstream and downstream. The high level is also reached by using LCA and resource consumption assessments while planning operations.

Last but not least, for the social sub-dimension, we consider one quantitative and one qualitative factor. Local community empowerment (local procurement) is measured as the ratio of local investment over total investment. At the IFRC, it is not expected that 100% of local investments will be reached in the short term, due to the difficulties in finding some emergency items locally owing to strict requirements, and also because of the framework agreements the organization has with global suppliers. Labor conditions (employee management) are assessed through internal and provider audits. The high level is reached when the labor conditions are considered in the planning phase.

		UNAWARE	BEGINNER	MEDIUM	GOOD	EXCELENT
TBL	Sub-dimension	L0	L1	L2	L3	L4
Economic	Effectiveness	<10%	10% □ Indicator <50%	50%□Indicator <75%	75% □ Indicator <90%	□ 90%
	Efficiency	<-10%	-10% □ Indicator < -5%	-5% □ Indicator < 0%	0% □ Indicator < 5%	□ 5%
	Equity	>50%	50% □ Indicator >30%	30% □ Indicator <10%	10% □ Indicator <0%	0%
Environmental	Pollution reduction	no info	The Carbon footprint is assessed occasionally	The Carbon emissions are assessed systematically	LCA: The Carbon emissions are assessed internally + externally (upstream and downstream)	SC flows are planned based on LCA impact
	Resources conservation	no info	Resources use is assessed occasionally	A management system for pollution and energy use is in place systematically	A global management system is in place (upstream and downstream)	SC flows are planned to reduce resources consumption
Social	Local community development	0%	0% □Indicator <30%	30% □Indicator <50%	50% □Indicator <70%	□ 70%
	Labor conditions	no info	Occasional Internal assessment	Systematic Internal assessment	Suppliers assessment	SC flows are planned based on labor conditions

Table 11 SHSC performance assessment grid

4.2.2. Illustrative results

Based on the IFRC A&C field observations and discussion with practitioners, the following illustrative data set was built, with its related sub-dimensions maturity levels.

Effectiveness

Table 12 Data set to assess effectiveness

Order #	Lead time	Grand Total (CHF)	Value delivered on time (<1 week)
1	10.00	650	
2	8.00	9107	
3	7.00	554	554.00
4	28.00	17831	
5	22.00	15000	
6	36.00	5000	
7	5.00	50000	50000.00
8	18.00	50000	
9	9.00	58000	
10	5.00	5000	5000.00
11	1.00	16000	16000.00
12	11.00	28000	
13	15.00	17000	
14	5.00	35000	35000.00
15	5.00	136000	136000.00
16	5.00	32000	32000.00
	TOTAL	**475142**	**274554**
	RATE	**58%**	

The effectiveness is computed as the proportion of orders delivered on time. The data from 2015 A&C IFRC operations do not consider an expected delivery time. For the illustration, the hypothesis is made that an acceptable delivery lead-time is one week (7 days) since orders placed will usually be urgent (Table 1).

Efficiency

In a standard year, it is obvious that response to crises does not generate enough rotation to cover the fixed cost of RLUs. Based on the data of the A&C RLU activity between January and September 2015, an amount of nearly 760,000 CHF was charged to customers for a total number of 41 orders. From this total amount, 56,000 CHF corresponds to a service fee (around 7%), and the rest to the procurement costs (704,000 CHF). The income value, extrapolated over a year, results in a total income of around 1,000,000 CHF, and the procurement costs 940,000 CHF (Table 13).

The holding inventory costs correspond to the expenses generated due to the inventory's existence (i.e. waste, infrastructure, handling). This value is evaluated at between 20 and 30% of the mean inventory level value for the industry, depending on the deterioration and obsolescence risks. Considering that the A&C IFRC infrastructure is of basic standard, and that emergency items are robust, and only hygiene kits are perishable in the long term, we diminish this value to 10% to make the estimation. Appendix A contains the A&C RLU contingency stock value on September 2015. Considering the hypothesis that this value is close to the mean over the year, the Holding Costs of the region are around 90,000 CHF over the year (Table 13).

Table 13 Data set to assess efficiency

	HSC Costs (year)	**HSC Incomes (year)**
Procurement costs	940,000 CHF	
Holding costs (including handling, waste and infrastructure)	90,000 CHF	
Service Provision Income		1,000,000 CHF
TOTAL	1,030,000 CHF	1,000,000 CHF
RATE	-3%	

If we compute the effectiveness indicator with this data set, considering that the HSC annual Costs are around 90,000, and that the net income (without the procurement costs) is around 75,000:

$$HSC\ Cost\ ROI = {}^{(1{,}000{,}000 - (1{,}030{,}000 +)}/_{1{,}000{,}000} = -3\%$$

Without a full data set, it is difficult to establish an exact value for the effectiveness indicator. However, the A&C RLU has clearly stated the difficulties it has in covering the costs (IFRC 2013, 2014)

Equity

In the assessment grid it is suggested that the equity should be assessed based on the Gini Index. The value of this index is between 0 and 1, and represents the level of inequality within a studied population. In this case it is the satisfaction of the customer orders of the HSC. The red line in Figure 54 represents the Lorenz curve (Gastwirth 1972), which plots the proportion of the variable observed of the population (y axis) that is cumulated by the bottom x%. The Gini index is equal to the A area divided by the sum of the A and B areas, that is to say: Gini = A / (A + B). The bigger A is, the higher is the level of inequality.

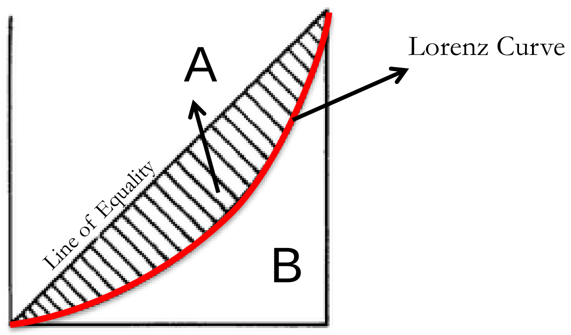


Figure 54 Gini Index

The IFRC A&C decision-makers ensure that if there is a situation where they have to share the upstream resources within different demand points, this will be done equitably (although this situation is not common upstream). Therefore, the Lorenz curve of such a situation is at 45°, and the Gini Index equal to 0, with a perfect equality.

Pollution reduction

There is no data available to compute the CO2 emissions

Resources conservation

There is no data available to assess the resources consumption

Local community development

The indicator for this sub-dimension is the proportion of procurement value from local suppliers. Let us consider the following dataset:

Table 14 Local procurement data set

Order #	Origin	Grand Total (CHF)	Value from local suppliers
1	International	5000	
2	International	2000	
3	International	36000	
4	International	2500	
5	Local	300	300
6	International	2100	
7	International	3000	
8	International	1000	
9	Local	580	580
10	International	600	
11	Local	3000	3000
12	Local	2500	2500
13	International	6000	
14	International	260	
15	Local	1000	1000
	TOTAL	**65840**	**7380**
	RATE	11%	

Labor conditions

There is a general standard for the staff rules at the IFRC, approved by the general assembly in 1976. Therefore, it is assumed that there is a systematic internal assessment of the Labor conditions. As part of the supplier selection process, it has to be guaranteed that suppliers:

- Adhere to the Fundamental Principles of the International Red Cross and Red Crescent Movement
- Maintain ethical business practices always
- Are not involved in any form of corruption or any fraudulent activities
- Do not engage in any collusive or coercive practices

The sub-dimensions maturity levels can be deduced using the assessment grid (Table 11) as follows:

Table 15 Illustrative assessment of the A&C RLU

TBL	Sub-dimension	L0	L1	L2	L3	L4	Dimension Maturity level
Economic	**Effectiveness**			x			**L2**
	Efficiency			x			
	Equity					x	
Environmental	**Pollution reduction**	x					**L0**
	Resource conservation	x					
Social	**Local community development**		x				**L1**
	Labour conditions				x		

For the economic dimension, both effectiveness and efficiency performance are well developed, but still far from optimal. The high immobilization of stocks, and the low turnover of inventory cause the level of efficiency to be negative. Regarding effectiveness, the response time is still long, in most cases. Equity is considered as achieved, given that it is considered as a constraint by IFRC decision-makers.

For the environmental dimension, nothing is done to assess and reduce the carbon footprint and resource consumption.

For the social dimension, local procurement is being developed, but it is still difficult to find suppliers that satisfy the requirements in most countries. This indicator could be improved with the development of sub-regional LUs. Regarding the Labor conditions, the IFRC standards are satisfactory, but no information was found on the assessment of their supplier's labor conditions.

To increase the readability of the assessment grid, these results can be presented in the form of a radar graph (Figure 55). Each TBL dimension is then assessed as the lowest one within its sub-dimensions levels (Table 15). The global maturity level of the A&C RLU is also defined by the lowest dimension level (L0), as showed in Figure 56.

A simple analysis of the results from the SHSC maturity assessment allows us to identify the sub-dimensions that have to be prioritized in order to achieve a more balanced sustainability performance.

This result shows that the environmental dimension is completely overlooked by decision-makers at the A&C RLU. Based on this model approach to improving the overall SHSC performance, the priority should be to work on both environmental sub-dimensions. The social dimension also remains in a lower maturity level than the economic dimension, as is predictable, given that the SHSC is still in its infancy.

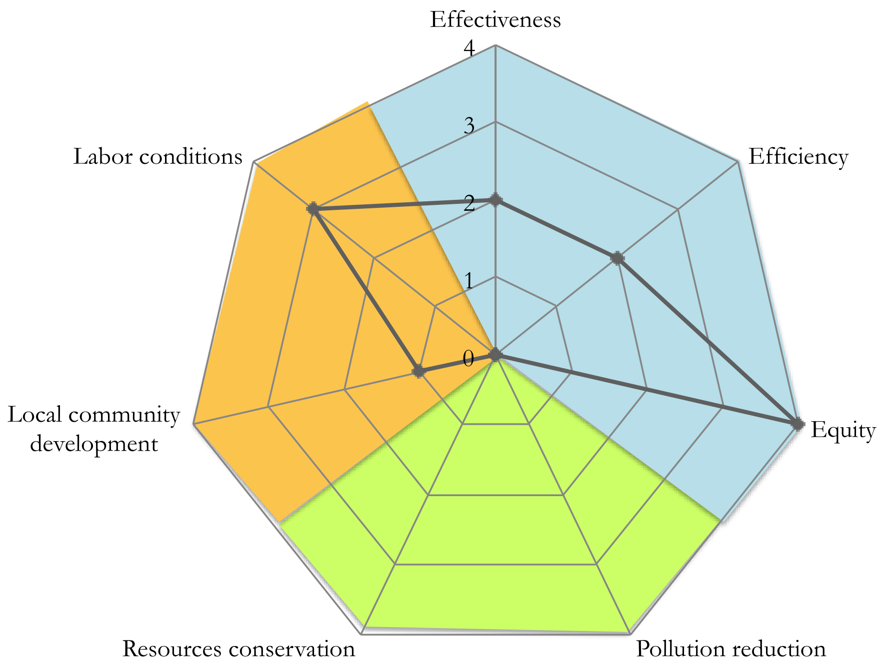


Figure 55 A&C RLU SHSC sub-dimensions performance maturity level (radar graph)

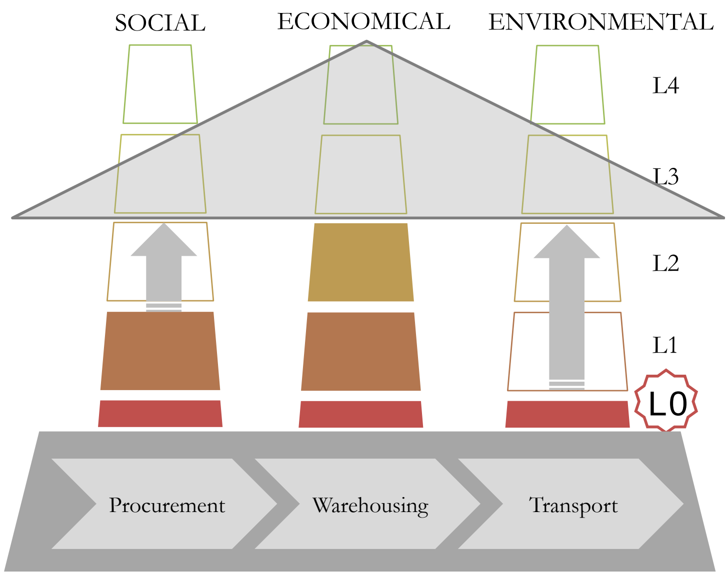


Figure 56 A&C RLU SHSC performance maturity level

5. Discussion

The overall aim of this thesis is to set the basis for a Humanitarian Decision-support System in sustainable operations planning. The literature review and previous research show the challenge for HOs to consider sustainability in their decision-making processes. The objectives of this chapter are twofold: (1) clarifying the concept of SHSC, (2) building a framework for assessing the performance of SHSC operations.

First, a performance measurement framework that translates sustainability concepts into concrete HSC operations (procurement, warehousing, transport) is defined. Based on the TBL approach, environmental and social dimensions are added to the economic dimension. The *House of SHSC operations* is a general framework that stresses the need to consider the three TBL dimensions to enhance sustainable operations. The criteria have been defined considering the literature review on sustainable SC and the impact that HSC processes (procurement, warehousing and transport) have on the different sub-dimensions. Secondly, a model and method to assess SHSC performance maturity is suggested. To illustrate the use of the maturity assessment model, a proof of concept has been built based on the IFRC HSC use case.

This chapter contributes significantly to the fledgling discussion of HSC sustainability. It bridges the gap between high-level sustainability theoretical discussions and the concrete assessment of HSC operations sustainability, which still seems to be difficult in many disciplines.

The contributions have been developed thanks to inputs from IFRC field research. The practical application to various humanitarian relief operations is yet to be achieved.

The SHSC performance framework presented in this chapter forms the basis for developing a Decision-support System that makes it possible to optimize the planning of HSC operations with regard to TBL impacts. However, as sustainability is a multi-dimensional concept, with conflicting objectives, the challenge now is to address these trade-offs and synergies across the economic, environmental and social dimensions. Therefore, the next chapter discusses this set of problem, and develops a Decision-support System, which integrates the HSC sustainable operations framework.

Chapter IV. PLANNING SUSTAINABLE HSC OPERATIONS

This chapter has been published as:

Laguna-Salvadó, L., Lauras, M., Okongwu, U., & Comes, T. (2018). A multicriteria Master Planning DSS for a sustainable humanitarian supply chain. Annals of Operations Research, 1-41.

1. Introduction

Enhancing sustainable operations is a challenge in terms of decision-making. As discussed in the previous chapter, many conflicting dimensions have to be considered with a holistic view of the HSC system. Therefore, the decision process should take into account the complexity of sustainability objectives and trade-offs.

Along an HSC many different individual decisions are made and coordinated. In an HSC network such as the IFRC, but also the WHO or even MSF, decisions are centralized (e.g.. relief items standardization), or decentralized (e.g. regionally adapted operations design). Moreover, decisions are of different importance, from the rather simple question of scheduling shipments, to the challenging decision of whether to open or close a warehouse. To enhance a sustainable HSC, the impact of any decision has to be assessed in terms of sustainable performance.

Given that HOs have a project management approach where the response to each disaster constitutes a project, humanitarian efforts have for a long time been focused more on the execution steps (with very reactive behavior) and much less on the planning steps. As a result, the lack of preparedness and planning – developing strategies and coordinating HSC operations – has led to inefficiencies and misallocation of resources (Jahre 2008). Today, anticipating the performance outcomes of HSCs has become very necessary and important, for three major reasons.

There is a need for decision-makers to evaluate the impact of their decisions with respect to sustainable performance objectives. In the humanitarian sector, this practice would enhance not only the improvement of HSC processes both a priori and a posteriori, but also the anticipation of the impact of future actions on performance. We note that in this sector the inclusion of the concept of sustainability in the management process is quite recent, and decision-makers do not have concrete indicators and tools for measuring sustainability performance. Moreover, the lack of structured planning processes in HSCs (Haavisto and Kovács 2014), which are typically supported by decision-support systems, hinders the management a priori of the impact of both strategic and operational decisions. Thus, developing a decision-support systems adapted to the HSC not only may help to improve the performance of planning processes (Abidi et al. 2014), but also will enable decision-makers to take into consideration sustainability performance objectives. Structured planning processes are necessary to align decisions with the expected performance objectives.

Decision-support systems for planning are not commonly used for managing HSCs. Previous researchers have highlighted that misalignment with field specificities and lack of trust are the main reasons for the difficulties of transferring information technology from the commercial sector to humanitarian settings (Abidi et al. 2014). Using a functional model specifically created for HSCs may facilitate the development of appropriate IT systems (Blecken 2010).

The trends are clear: scholars and practitioners are asking for more solutions that support decision-making, but also emphasize the importance of including humanitarian context constraints. The challenge remains to find a planning method that considers the problem of sustainable performance multi-criteria decision-making.

Therefore, this chapter aims to address the following research question: *How to support Decision-Makers in consciously and systematically making sustainability trade-offs and exploring their consequences?*

2. Humanitarian Supply Chain Planning

Improving the planning process of HSC operations is necessary to align decisions with the expected sustainable performance throughout the process. In commercial SCs, decision-support systems have been developed to supports the different planning decisions and time horizons (Figure 57).

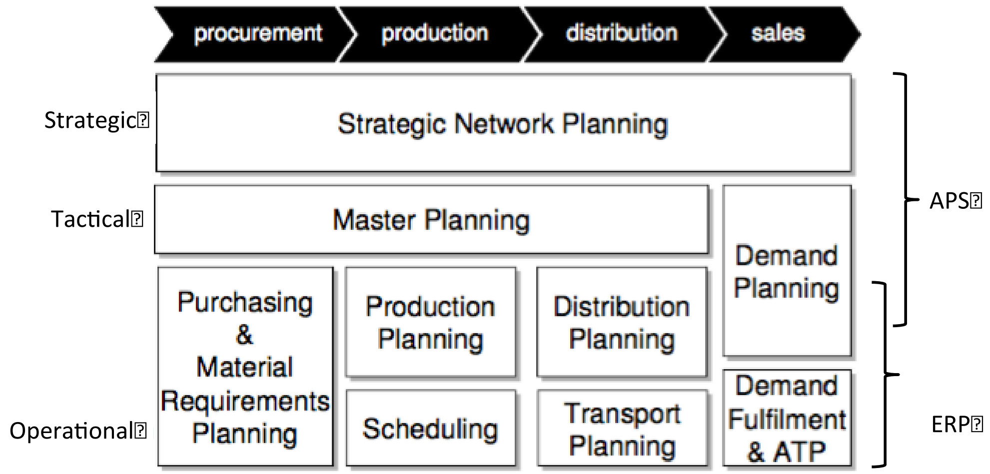


Figure 57 Commercial SC planning matrix (Adapted from Stadtler, 2005)

Advanced Planning Systems (APS), for example, have shown an impressive potential for integrating organizational units and planning efforts along an SC (Forme et al. 2009). Unlike traditional Enterprise Resource Planning (ERP), APS systems try to find feasible, (near) optimal plans across the SC (Stadtler 2005). APSs are modular, and cover the different tasks and decision levels from the SC planning matrix.

2.1. Humanitarian Supply Chain Planning Matrix

Although planning decision-support systems are widely used in commercial SC, they are not common in the HSC. The decomposition of the HSC on tasks and time horizons has been discussed in the literature, and (Blecken 2010) suggested an HSC standard referent model including processes and decision levels, which has already been discussed and used in previous chapters (Figure 58). The standard referent decision levels suggested for HSC are the same as those in commercial SCs: strategic, tactical and operational, also referred to as long, mid and short-term horizon levels (Stadtler 2005).

However, in practice, HSC tactical and operational planning is mainly based on the experience of decision-makers. Nonetheless, as in the commercial SC, HSC decision-makers may also benefit from the decision-support systems in the low decision levels, notably because of information granularity and the decision perimeter.

2.1.1. HSC Strategic planning

Decisions at this level should create the prerequisites for the development of the HSC in the future. They typically concern the design and structure of an SC and, at the HSC upstream have long-term effects, noticeable over several years. The HSC downstream design, however, is typically planned ad-hoc, when a crisis occurs (Baharmand and Comes 2015).

Decision-support systems at the strategic level have been explored both for the upstream HSC design and for the downstream (Balcik and Beamon 2008; Charles 2010; Vargas Florez et al. 2015).

This decision level is a lever to enhance economic sustainability, as it involves the design of the HSC network, and therefore allows the improvement of the network performance in terms of efficiency, effectiveness or agility (Charles 2010; Dubey and Gunasekaran 2016; Jahre 2008; Laguna Salvadó et al. 2016).

2.1.2. HSC Tactical planning

Within the scope of the strategic decisions, tactical planning, or mid-term planning, aims to define the forecast demand and to find the most suitable way of fulfilling it through an effective management of the assessment, procurement, warehousing and transport processes across an organization's supply network and over a medium-term planning horizon. This planning horizon allows for the consideration of seasonal developments, e.g. of demand.

This decision level has been overlooked both in practice and in the literature in the HSC domain (both Master Planning and Demand Planning), probably because of the segmented nature of the management of disaster responses within HOs. HSCs already have a limited ability to anticipate demand, due to the uncertainty of the occurrence of a humanitarian crisis. Moreover, HSC managers conceive each disaster response as a single SC solution instead of building a tactical planning system that aggregates the HO's network, in parallel with other on-going operations.

Master Planning allows a link to be made between the strategic decisions and the operational process, and to coordinate the different processes of procurement, warehousing and transport to ensure the fulfillment of needs (Demand Planning). Therefore, this decision level is a lever to improve SHSC performance, as it globally defines the operations that will take place according to the assessed demand. It enables the optimization of HSC flows, and therefore, of operational performance.

2.1.3. HSC Operational planning

The lowest planning level has to specify all activities as detailed instructions for immediate execution and control. Therefore, short-term planning models require the highest degree of detail and accuracy to define procurement, warehousing and transport tasks. Short-term planning is restricted by the decisions on structure and quantitative scope from the upper levels.

Field research at the A&C RLU shows that in the upstream HSC, the operational capacity exceeds the workload; so there is no urgency to optimize resource allocation for the operational level tasks.

In the HSC literature, operational level research works focus on transport planning, especially the downstream HSC with the last mile distribution problems (Balcik et al. 2008; Van Wassenhove and Pedraza Martinez 2012).

2.1.4. Conclusion

Field research at the A&C RLU (upstream) highlights the "case by case" management of the humanitarian crisis, which was identified as a main weakness to improve the overall performance of the regional operations. There is a need to improve coordination within the different warehouses, the procurement process and the distribution flows. Therefore, considering the SHSC Master Planning problem seems relevant for both practitioners and academics.

Figure 58 illustrates the positioning of this Chapter contribution within Blecken's HSC reference Model (Blecken 2010).

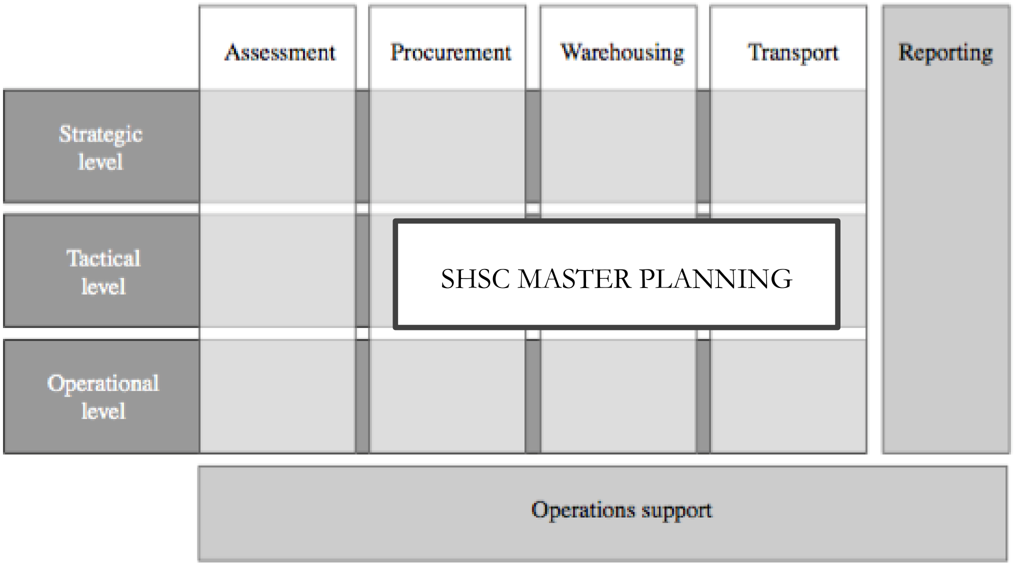


Figure 58 SHSC Master Planning Module in the Blecken (2010) reference task framework model

2.2. SHSC Master Planning problem

The SHSC Master Planning decision-support system has to define the material flows from suppliers to the demand points. Master Planning not only balances demand forecasts with available capacities, but also assigns demands (procurement and distribution amounts) in order to avoid bottlenecks (Rudberg and Thulin 2009).

Therefore, the problem boils down to answering the following questions for a mid-term horizon:

- What (product reference) to deliver?
- How much (quantity) of each item to deliver?
- When (schedule) to deliver?
- Which supplier / warehouse should provide the products?
- Where (warehouse /demand point) to deliver the items?
- How (transportation mode) to move the items?

In other words, the question is how to choose between all potential material flow combinations (within a given network and in each time horizon) those that fulfill the demand with the best acceptable performance in the three dimensions of sustainability (economic, social and environmental).

SHSC Master Planning should result in an HSC tactical plan regarding distribution, inventory, and procurement.

2.3. Master Planning Approaches

In the commercial SC, before OR tools like optimization and simulation entered the "enterprise-planning arena", Master Planning was often done by MRP II systems[1], or by simple calculations using spreadsheets without considering capacity limitations (Rudberg & Thulin, 2009).

OR-related decision-support systems that conduct Master Planning use mathematical programming to maximize performance objectives while taking constraints (e.g. capacity) into consideration as an integrated part of the planning process.

To be able to optimize the Master Planning problem, procurement, inventory and distribution must be monitored. Inputs are forecast demand data and network constraints in terms of a model that defines capacity and dependencies between different processes.

The three major difficulties in using optimization methods and approaches to define a plan are, according to Fleischmann et al. (Stadtler and Kilger 2005):

- There are often several criteria, which imply conflicting objectives and ambiguous preferences between alternatives. This is the main concern when introducing the sustainable performance that typically considers at least the three TBL conflicting dimensions.
- A huge number of alternatives are a predominant feature in SC planning. In the case of continuous decision variables, e.g. order sizes, the set of alternatives is actually infinite.
- Uncertainty. The forecast demand may be fuzzy. Moreover, nearly always, reality deviates from the plan, especially in the context of HSC. The uncertainty in the data is addressed using fuzzy logic approaches, which model the vagueness and imprecision by adding a probabilistic dimension to the values. Exact methods can also be used. The deviation has to be controlled and the plan needs to be revised if the discrepancy is too large. Planning on a rolling horizon basis is an implementation of this plan-control-revision interaction. The planning horizon (e.g. three months) is divided into periods (e.g. weeks). This procedure is a common way of coping with uncertainty in operational planning, both in classical planning systems and in OR approaches.

OR Master Planning approaches are an attempt to "computerize" planning. Therefore, decision-makers have to be aware that modeling is a relaxation of reality, and remains only a decision- support system. Human knowledge will still be essential to bridge the gap between model and reality. Otherwise, OR solutions will hardly ever be adopted, especially in the context of humanitarian operations.

Nonetheless, OR methods have a "tremendous potential" in the disaster response domain, according to (Altay and Green 2005; Galindo and Batta 2013). Since 2005, there has been a noticeable increase in the publications that address HSC decision-support system problems with OR methods (Charles and Lauras 2011). OR is a well-established discipline regarding allocation of scarce resources, because it offers the tools to support HSC operational decision-making (Van Wassenhove and Pedraza Martinez 2012). By adapting OR best practices that have proven their value in commercial SCs, relevant

[1] MRP II is a successive planning concept that begins with a not necessarily feasible schedule derived from end product demand. The bill of material is used together with inventory records, lot-sizing rules, and expected lead times to calculate the time-phased material requirements. Capacity limits are not explicitly taken into account, therefore, the planned process may be infeasibleunfeasible (Drexl and Kimms 2013).

solutions can be proposed to the complex problems faced by HOs (Charles and Lauras 2011).

2.4. A Multi-Objective Decision Problem

Due to the multi-objective nature of sustainability performance measurement, decision-makers must deal with the conflicting objectives between the economic, social and environmental dimensions of sustainability. Many OR modeling approaches can be found in the literature to solve multi-objective decision problems (Branke 2008; Deb et al. 2016).

As multiple Pareto optimal solutions usually exist, the most preferred results (or acceptable solution) can be found by using different philosophies. In no-preference methods, no decision-maker is expected to be available, but a neutral compromise solution is identified without preference information. The other classes are so-called a priori, a posteriori and interactive methods and they all involve preference information from the decision-maker in different ways. In an a posteriori method, multiple solutions are generated for decision-makers to choose from. A priori methods require that sufficient preference information is expressed before the solution process.

In the specific case of Master Planning problem, the objective is to support the decision-maker in the planning, by giving a single acceptable solution, so the a-posteriori methods are not considered. Regarding the a-priori methods, it appears difficult to put a weight on the sustainable performance objectives. However, discussion with experts allows the hypothesis that the decision-maker can order the sustainable performance dimensions by relative importance. Well-known examples of a priori methods include the utility function method, the lexicographic method, and goal programming.

In the utility function method, the decision-maker assigns weights to prioritize objective functions. As Gralla discusses, these weights are based on assumptions about the relative importance of each objective (Gralla et al. 2014). We note that in theory, and based on previous chapter conclusions, all three dimensions need to be equally considered, but in practice they have different relative importance in any given real-life planning situation.

Goal programming can be thought of as an extension or generalization of linear programming to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in an achievement function.

In the Lexicographic Optimization Method (LOM), the decision-maker ranks the objective functions according to some subjective degree of priority, and then a multi-stage optimization algorithm enables a solution to be found (Branke 2008; Rentmeesters et al. 1996; Sherali 1982). Considering that the decision-maker has an active role, and can prioritize the objectives "a priori", the balance between SHSC performance objectives can be addressed following an interactive variant of the LOM. As long as the decision-maker has only to classify the objectives by priority, this approach avoids the need to specifying an abstract weight between objectives that are not homogeneous (cost vs. CO_2 emissions vs. social costs…).

However, with the LO described previously, it is very likely that the process stops before less important objective functions are taken into consideration. Combining different methods could help to improve the preferred plan. In the literature, there is an extension of the LOM (Rastegar and Khorram 2014; Wray et al. 2015), which introduces a slack component. With the slack or constraint relaxation, the Interactive LOM (ILOM) increases the range of possible feasible solutions at each stage. The decision-maker can interact with the algorithm by defining a small deviation from the optimal value of a primary variable so as to improve the secondary value functions. Interactive methods are interesting because they allow the readjustment of the a priori inputs or the introduction of additional information depending on the behavior of the model. Thus, the decision-maker can orient the solution process toward preferred solutions.

2.5. Conclusion

Until now, the main objectives of HSC managers have been to improve competitiveness by simply having an effective management of the supply flows while minimizing costs. With the continuous development of the sustainability paradigm, social and environmental performance indicators need to be added to the performance measurement dashboard of HSCs. But, the lack of structured planning processes, concrete sustainability measurement tools, and decision-support systems jeopardizes the enhancement of sustainable operations. Tactical planning has been overlooked, but it has a huge potential because it is at the crossroads between decision levels and HSC process.

In Chapter 3, we developed a conceptual performance framework to assess the maturity of SHSC operations based on the TBL model. This framework is, however, generic and does not consider the various decision levels (strategic, tactical and operational). Consequently, it does not by itself allow a concrete quantification for the Master Planning processes.

Although tactical decision-making shows a potential to improve SHSC performance, the literature has overlooked Master Planning problems in the HSC. This chapter aims to contribute to filling this gap by setting the basis for a Master Planning decision-support system, following an OR approach.

The remainder of the chapter is organized as follows. Sections 2, 3 and 4 present the SHSC Master Planning contributions: selection of Master Planning sustainable performance criteria; an ILOM proposal, and the adaptation of the network flow model for SHSC Master Planning. Section 5 presents a proof of concept, with a numerical application based on the A&C IFRC upstream use case, to demonstrate the relevance of the proposed decision-support system. Finally, conclusions and perspectives are presented in section 6.

3. SHSC Master Planning Objectives

To solve the sustainable Master Planning problem, the impact of material flows on sustainable performance needs to be measured. Therefore, based on the sub-dimensions identified in Chapter 3, we suggest considering only the sustainable performance criteria that can be quantified. To select the indicators, three main parameters have been assessed:

(i) The decisions taken in the Master planning process (flow selection) have an impact on the sub-dimension criteria
(ii) The sub-dimension criteria have to be quantifiable, so it is important to have access to the related data
(iii) There is at least one indicator per TBL dimension.

Based on these constraints, each of the sub-dimensions is evaluated (Table 16). The sub-dimensions selected are effectiveness, efficiency, local empowerment and pollution reduction.

Table 16 SHSC Sub-dimension selection

TBL	**Sub-dimension**	**Criteria**	**(i) Master planning impact**	**(ii) Data accessibility**
Economic	**Effectiveness**	Demand satisfaction	Yes	Yes (Outcome of the Master Plan)
	Efficiency	HSC Cost	Yes, on variable costs	Yes
	Equity	Non-discriminatory distribution	Yes	Yes (Outcome of the Master Plan)
Environmental	**Pollution reduction**	Carbon footprint	Yes*	Yes, based on transport flows
	Resource conservation	Reduction in resource consumption	N/A	Difficult to quantify, need for an LCA per flow
Social	**Local community development**	Local procurement	Yes	Yes (Outcome of the Master Plan)
	Labour conditions	Employee management	Yes	Difficult to quantify, need or an audit per flow

Considering the equity sub-dimension, when asked, the IFRC upstream managers state that in the face of a dilemma resulting from the shortage of resources (even though this is not typically happening at the upstream level), the distribution of items may be shared equally between the demand points that need them most urgently. Therefore, in the Master Planning problem, equity is considered as a constraint, and not as an objective function.

3.1. The set of SHSC Master Planning objectives

Four sustainable performance objectives have been retained to define the SHSC: effectiveness, efficiency, local empowerment and pollution reduction. Although all four of them have to be considered, effectiveness is an essential criterion to maintain HSC activities and the value chain. Humanitarian guidelines, principles, and measures of success emphasize meeting the needs of beneficiaries as the first priority (Gralla et al. 2014).

Hence, effectiveness it is an order qualifier objective, and has a larger relative importance than the other three objectives, so it is translated in the ILOM approach as the 1st lexicographic objective (presented in the next section). The other three objectives have a conditional lexicographic order depending on situational state variables (that is, the strategic priorities, the funding/needs gap, etc.).

With the aim of simplifying the understanding of the SHSC Master Planning ILOM algorithm and the mathematical model, effectiveness is defined separately from the conditional lexicographic TBL dimensions. Therefore, in this Chapter, it is considered hereafter as a prerequisite in the SHSC.

Table 1 summarizes the set of objectives retained to measure the sustainable performance of SHSC Master Planning.

Table 17 Sustainability performance measures and indicators

		Sub-dimensions	**Criteria**
	Order qualifier	Effectiveness	Demand satisfaction
TBL dimensions (order winner)	Economy	Efficiency	Variable operations cost
	Social	Local empowerment	Local sourcing rate
	Environmental	Pollution reduction	Carbon Footprint

4. Interactive Lexicographic Optimization Method Algorithm

To plan the HSC processes from a sustainability perspective, the four indicators that were retained in previous section have to be considered in a multi-objective optimization model. As discussed previously, it is unlikely that a single solution will be found that simultaneously satisfies each optimal objective.

To choose the method, the decision-makers needs and capabilities have been considered. It is important to integrate decision-makers into the definition of an objective trade-off. However, given the difficulties in comparing the values of the objectives (i.e. carbon footprint vs. cost of operations) we made the hypothesis that decision-makers can give a priority order to the objectives.

If the decision-maker has an active role and can prioritize the objectives "a priori", the problem can be solved using the interactive variant of the ILOM. Effectiveness is an essential objective (order qualifier). The other three objectives (efficiency, local empowerment and pollution reduction) may be prioritized depending on v contextual variables: the decision level, HSC network perimeters (single or inter-organizational; upstream or downstream) or situation (disaster response, replenishment).

The proposed algorithm is illustrated by a flow chart in Figure 59. The pool on the left represents the decision-maker's tasks, while the pool on the right represents the decision-support system activities. The algorithm solves the SHSC Master Planning problem considering the four sustainable performance indicators. The execution starts when the decision-maker wants to define a Master Plan for HSC operations. But before then, (s)he has to define the HSC network model to identify potential suppliers, warehouses, forecast needs, potential transportation flows.

The algorithm is as follows (Figure 59):

(a) The first task of the decision-maker is to rank the sustainability performance objectives (economic, social and environmental) according to their relative importance or LO. This input gives the optimization order to the decision-support system (LO^1, LO^2, LO^3). LO^0 is the effectiveness, which is not prioritized but is rather considered as a prerequisite.

(b) For the decision-support system, the first activity is to solve the optimization problem with the effectiveness objective function (OF). The output of this activity (solving Sub-Model 0) is the effectiveness optimal value (O^0) that the model can attain with the network and forecast demand.

- Sub-model 0

Optimize: Effectiveness OF

Subject to: HSC network model

(c) The loop (n from 1 to 3) starts with one iteration per criterion. Following the LO approach, the Sub-model 'n' is constrained by the previous (n-1) optimal value found, but with a tolerance defined by the decision-maker. To define this tolerance, the decision-support system computes O^n with a variation on the O^{n-1} tolerance value. For the first iteration, LO^{n-1} is the effectiveness, so the decision-support system optimizes the LO^1 Objective Function (either economic, social or environmental) with a variation on the effectiveness constraint tolerance.

- Sub-model 1

From t = 0 to t=T;

Optimize: LO^1 Objective Function

Subject to: HSC network model + Effectiveness Constraint(t)

(d) The result is displayed to the decision-maker, who decides which is the most "acceptable" trade-off: deteriorating the Effectiveness optimal value or improving the O^1 optimal value. The decision-maker fixes the pair: O^1 optimal value and tolerance level t^0.

(e) These values serve as input for the decision-support system.

The second loop (n=2) will repeat the process with LO^1 and LO^2, in order to define O^2 optimal value and tolerance level t^1, while the third loop (n=3) repeats the process with LO^2 and LO^3 in order to define O^3 optimal value and tolerance level t^2,

- Sub-model 2

From t = 0 to t=T;

Optimize: LO^2 Objective Function

Subject to: HSC network model + Effectiveness Constraint (t^0) + LO^1 Constraint (t)

- Sub-model 3

From t = 0 to t=T;

Optimize: LO^3 Objective Function

Subject to: HSC network model + Effectiveness Constraint (t^0) + LO^1 Constraint (t^1)

+ LO^2 Constraint (t)

(f) At the end of the third loop, the output is the most acceptable Master plan, based on the LO optimization and the decision-maker's expertise.

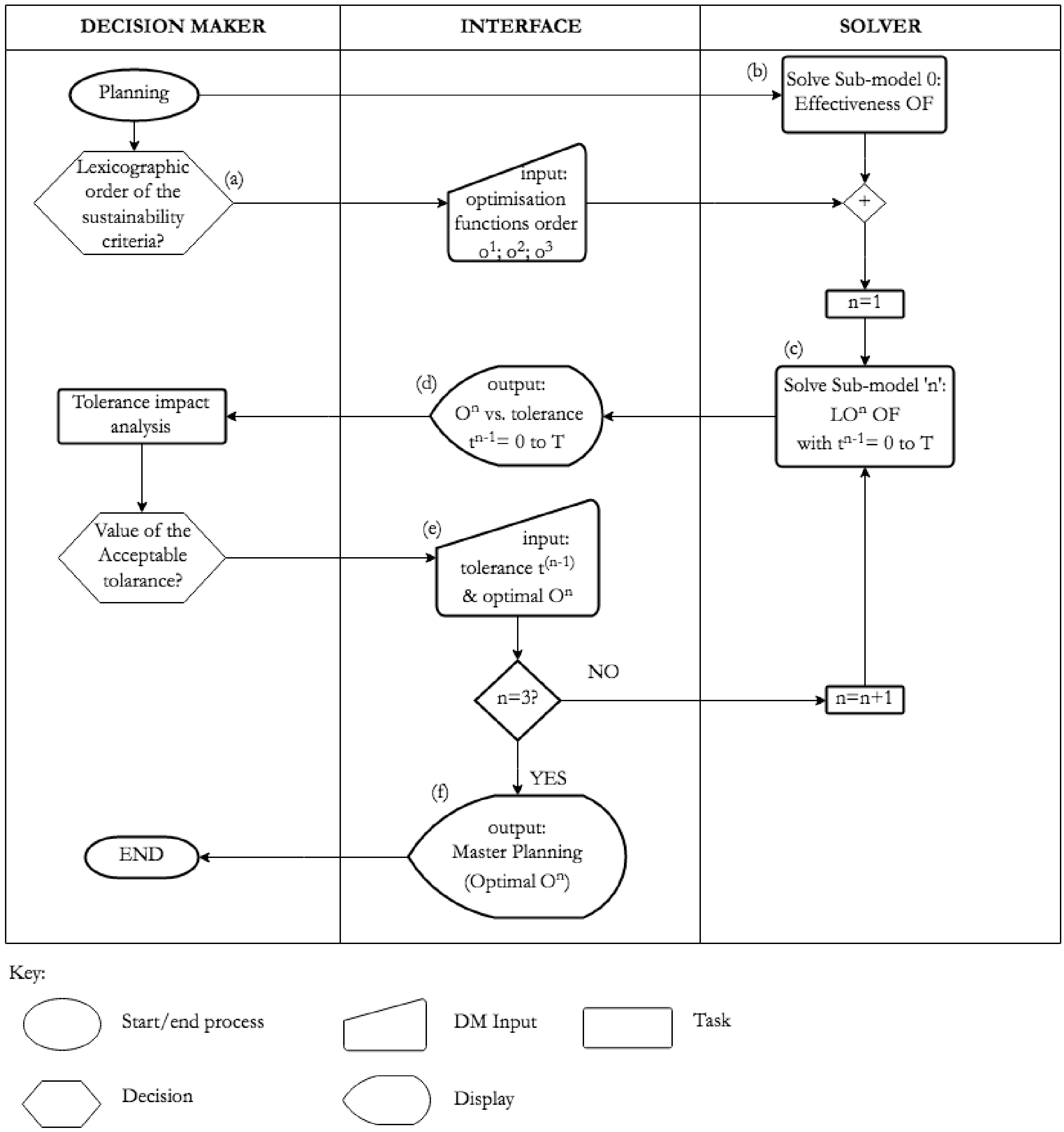


Figure 59 ILOM algorithm for SHSC Master Planning

5. SHSC Master Planning Model

The SHSC Master Planning model is a variant of the network-flow problem (Bradley et al. 1977). The common problem in the industrial sector relates to the distribution of a product from plants (origins) to consumers (destinations), with the objective being to minimize costs. In the case of an SHSC, the main differences that we address are due to the following reasons:

- The network provides more than one product,
- The optimization objectives are multiple, since sustainability is multidimensional
- The problem is solved considering several time periods (time horizon).

5.1. The supply network and assumptions

The supply network is composed of three elements: supplier, warehouse and customer. The model is sufficiently abstract to represent a large variety of HSC designs and perimeters. Supplier refers to the source of relief products. Depending on the perimeter, suppliers can be private sector providers or other HOs that are specialized in the distribution of relief products. Warehouse refers to the intermediate locations where relief products are stored, but can also represent permanent locations with contingency stocks or warehouses deployed when a disaster occurs. Customer refers to the demand points of relief products, but can also be a field entry point (hub or warehouse), a distribution point or a third-party organization warehouse. The sources, destinations, and intermediate points are the nodes of the network, while the transportation links connecting the nodes (or flows) are the arcs (see Fig. 5). As in the standard problem, the suppliers' capacity, as well as the total number of products required by the customers, are assumed to be known. The products can be sent directly from source to destination, or may be routed or sourced through intermediate points (warehouses).

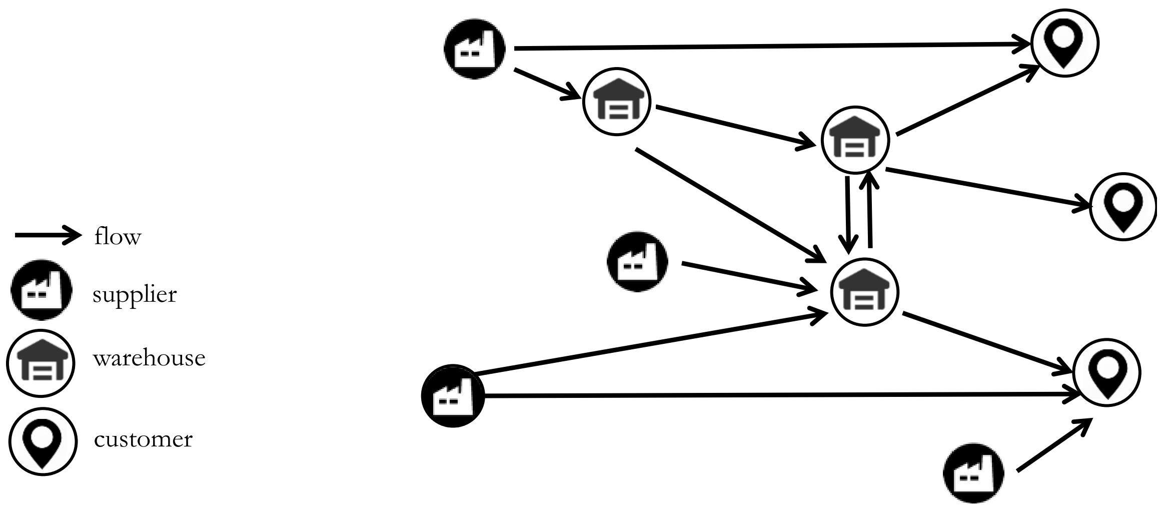


Figure 60 SHSC Master Planning problem network elements

The Master Planning is calculated for a number of periods on a pre-defined time horizon. Whereas in the industrial sector the tactical level typically considers 6 to 12 months, in the HSC this period may be shorter due to uncertainties, and depending on the HSC perimeters considered. The last-mile distribution activity may be characterized by a shorter time horizon and granularity than the upstream HSC (permanent network of prepositioned stocks).

The following assumptions are developed based on both the field research presented in the methodology section and information gathered from the literature. All the network elements are supposed to be known a priori by the decision-maker.

5.2. Mathematical Model sets and parameters

This section describes all components of the flow network model: the indices and the objects built of parameters and variables.

5.2.1. Model indices

Symbol	Description
	Indices
t	t € [1.. nbT] time periods
f	Flow record index
s	Product-supplier record index defined by (sid, sprod)
w	Product-warehouse record index defined by (wid, wprod)
c	Product-customer (demand point) record index defined by (cid, cprod)

5.2.2. HSC Network model objects

5.2.2.1. Distribution Flow object

The distribution flow object gathers the data related to the physical connections between the network nodes. Each record is a physical connection between nodes, unique for each product.

Symbol	Description
	Input parameters
Fori(f)	Origin
fdes(f)	Destination
fpro(f)	Product reference
ftlt(f)	Lead time (or flow Δt)
fitc(f)	Product acquisition cost
fcost(f)	Cost (acquisition and transport) per unit
fenv(f)	CO2 emission par unit

fsoc(f)	Defines nearness: 1 if local, 0 any other
fope(t,f)	The flow is operational (1) or not (0) at time t
fexp(t,f)	Expected products reception, defined before t0
	Variables
Fin(t,f)	Quantity of products received at fdes at period t
Fout(t,f)	Quantity of products shipped from fori at period t

5.2.2.2. Customer-product (demand point) object

Each record relates to one product and demand point throughout the time horizon.

Symbol	Description
	Input parameters
cid(c)	Customer identification
cpro(c)	Product reference
cunc(c)	Product standard cost
cqua(t,c)	Units of products needed at time t
ctqua(c)	Estimated value of the total amount of products needed by customer during the time horizon
cpri(t,c)	Priority of the needs/penalty par unit
	Variables
Cin(t,c)	Units of products received by the client at time t
Csto(t,c)	Units of stock-out products at period t
Cove(t,c)	Units of over-stock products at period t
Ctpen(c)	Total stock-out penalty value over the time horizon

5.2.2.3. Supplier-product object

Each record relates to one product and sourcing point throughout the time horizon.

Symbol	Description
	Input parameters
Sid(s)	Supplier identification
Spro(s)	Product reference
ssca(t,s)	Supplier shipment capacity for product p at period t
	Variables
Sout(t,s)	Products shipped at period t

5.2.2.4. Warehouse-product object

Each record relates to one product inventory and location throughout the time horizon.

Symbol	Description
	Input parameters
wid(w)	Warehouse identification
wpro(w)	Product reference
wini (w)	Inventory level at period t0
wreq(w)	Expected Contingency stock level (constant in the time horizon)
wtreq(w)	Expected Contingency stock value
wunc(c)	Product standard cost
	Variables
Winv(t,w)	Warehouse inventory level at period t
Wsto(t,w)	Warehouse contingency stock-out
Wove(t,w)	Warehouse contingency over-stock
Wtavg(w)	Warehouse average inventory level
Wtpen(w)	Warehouse total penalty over the time horizon

5.2.3. Other Parameters

Each record relates to one constraint regarding the TBL objectives.

Symbol	Description
	Input parameters
effopt	Optimal effectiveness constraint
eff_tol	Effectiveness constraint tolerance
envopt	Optimal Pollution reduction constraint
env_tol	Pollution reduction constraint tolerance
socopt	Optimal local empowerment constraint
soc_tol	Local empowerment constraint tolerance
ecoopt	Optimal efficiency constraint
eco_tol	Efficiency constraint tolerance

5.2.4. Objective functions

In this section, we will first present four sub-models before presenting the general model and the constraints of the algorithm. Each sub-model (objective function) represents one of the performance objectives. The order of the general constraints depends on the optimization sequencing.

5.2.4.1. Objective function for effectiveness

The objective function for effectiveness aims to find a feasible distribution planning that maximizes the satisfaction of demand on time. It is computed as the maximum value that can be achieved if everything is on time, minus the penalty for delays. The maximum value refers to the value of the total demand for a given period multiplied by its priority factor plus the contingency stock value of one period. The customer's penalty is proportional to the total stock-out quantity par period, the priority of demand, and the product's standard value divided by the number of periods. The warehouse's penalty is proportional to the total warehouse stock-out quantity in the time horizon divided by the number of periods.

$$Max\ \sum_c ctqua(c) - \sum_c Ctpen(c)/nbT + \sum_w wtreq(w) - \sum_w Wtpen(w)/nbT \tag{1a}$$

where:

$$ctqua(c) = \sum_t cqua(c,t) \times cpri(c) \times cunc(c) \tag{1b}$$

$$Ctpen(c) = \sum_t Csto(c,t) \times cpri(c) \times cunc(c) \tag{1c}$$

$$wtreq(w) = wreq(w) \times wunc(w) \tag{1d}$$

$$Wtpen(w) = \sum_t Wsto(w,t) \times wunc(w) \quad (1e)$$

5.2.4.2. Objective Function for efficiency (economic dimension)

The objective function for efficiency aims to minimize the costs of purchasing and distribution while satisfying the needs. In our model, the fixed cost of purchasing is not taken into consideration since the cost function is proportional to the product flow (quantity delivered).

$$\text{Min } \sum_f \sum_t Fin(f,t) \times fcost\,(f) \quad (2)$$

5.2.4.3. Objective Function for pollution reduction (environmental dimension)

The objective function for pollution reduction aims to minimize carbon emissions in the procurement and distribution activities. To compute the unitary emission of a shipped product, the Greenhouse Gas protocol is the most common model (Absi et al. 2013). The total amount is calculated with a linear function that depends on both the distance travelled and the carbon emission of the vehicle used (gCO/kilometer). Based on this model, the carbon emission indicator is proportional to the number of units of products allocated to each flow in the network, depending on the transportation flow.

$$\text{Min } \sum_f \sum_t Fin(f,t) \times fenv\,(f) \quad (3)$$

5.2.4.4. Objective function for local empowerment (social dimension)

The objective function for local empowerment aims to maximize local investments in the procurement distribution activities. In other words, this objective function maximizes purchases from local suppliers. Local suppliers are defined by the decision-maker and include those located not only in the same region, but also in neighboring countries.

$$\text{Max } \sum_{f|fsoc=local} \sum_t Fin(f,t) \times fitc\,(f) \quad (4)$$

5.2.5. General constraints

These objective functions are subject to two categories of constraints: general and sustainability performance constraints.

5.2.5.1. Flow-balance

The flow-balance constraints apply the conservation-of-flow law which states that for all inflow records (Fin), when the time is equal to or less than the flow lead time, the inflow can only be the delivery quantities scheduled before t_0 (fexp).

$$Fin(f,t) = fexp(f,t), \quad \forall f\ \forall t\ /\ t \leq ftlt(f) \quad (5a)$$

Another way of expressing them is that the inflow record (Fin) is equivalent to the outflow (Fout) from a node before the flow Δt.

$$Fin(f,t) = Fout\big(f, t - ftlt(f)\big), \quad \forall f \; \forall t \;/\; t > ftlt(f) \tag{5b}$$

5.2.5.2. Supplier-balance

The supplier-balance constraint stipulates that for each supplier-product record, the quantity of products dispatched at period t must be equal to the sum of all the inbound flows at time t for which the point of origin and product are the same as for the supplier-product couple.

$$Sout(s,t) = \sum_{f|Fori(f)=sid(s)\,\&\,fpro(f)=spro(s)} Fout(f,t), \quad \forall s \; \forall t \tag{6}$$

5.2.5.3. Maximum capacity of suppliers

The quantity of products dispatched must not exceed the maximum capacity of the suppliers per period.

$$Sout(s,t) \leq ssca(s,t), \quad \forall s \; \forall t \tag{7}$$

5.2.5.4. Warehouse inventory-balance

For each warehouse-product couple, the sum of the inventory in the warehouse (Winv) at time t-1 and the products received at time t is equal to the sum of the inventory at time t and the products dispatched at time t. At time t_1, the warehouse inventory level at time t-1 is represented by the parameter wini.

$$wini(w) + \sum_{f|fdes(f)=wid(w)\,\&\,fpro(f)=wpro(w)} Fin(f,1) = Winv(w,1) + \sum_{f|fori(f)=wid(w)\,\&\,fpro(f)=wpro(w)} Fout(f,1) \quad \forall w,\; t=1 \tag{8a}$$

$$winv(w,t-1) + \sum_{f|fdes(f)=wid(w)\,\&\,fpro(f)=wpro(w)} Fin(f,t) = Winv(w,t) + \sum_{f|fori(f)=wid(w)\,\&\,fpro(f)=wpro(w)} Fout(f,t) \quad \forall w,\; t>1 \tag{8b}$$

5.2.5.5. Satisfaction of the warehouse contingency stock level

The stock-out quantity (Wsto) refers to the difference between the desired contingency stock and the actual inventory level. It becomes an over-stock (Wove) if the requested quantity is less than the inventory level.

$$Winv(w,t) - wreq(w) = Wove(w,t) - Wsto(w,t), \quad \forall w, \forall t \tag{9a}$$

We note that at the end of the planning horizon, the forecast demand may tend to be underestimated (the demand estimation veracity and the forecast quantities decrease with the time horizon) due to the unexpected consequences and behavior of humanitarian crises. Hence, the model forces the network to finish the planned period with the required contingency stock level. This prevents the economic objective function from depleting the contingency stocks.

$$\mathrm{Winv}(\mathrm{w}, \mathrm{nbT}) = \mathrm{wreq}(\mathrm{w}), \quad \forall w \tag{9b}$$

5.2.5.6. Customer (or Demand Point) balance

For each Demand Point-product couple, the quantity of products received per period is equal to the sum of all the inbound flows (Fin).

$$Cin(c,t) = \sum_{f|fdes(f)=cid(c)\ \&\ fpro(f)=cpro(c)} Fin(f,t) \quad \forall c, \forall t \tag{10}$$

5.2.5.7. Satisfaction of the demand

The quantity of products that a demand point receives at period t, must be equal to the demand (cqua). It may be lower in case of stock-out or higher due to over-stock.

$$Cin(c,1) + Csto(c,1) = cqua(c,1) + Cove(c,1), \forall c,\ t=1 \tag{11a}$$

$$Cin(c,t) + Csto(c,t) = cqua(c,t) + Cove(c,t) + Csto(c,t-1) - Cove(c,t-1), \forall c,\ t>1 \tag{11b}$$

However, given that the objective is to respond to all the demands and that the network can achieve this a priori, the model forces the satisfaction of all the demand.

$$\sum_t \mathrm{creq}(\mathrm{c},\mathrm{t}) = \sum_t \mathrm{Cin}(\mathrm{c},\mathrm{t}), \quad \forall c, \forall t \tag{11c}$$

5.2.5.8. Equity constraint

The equity constraint forces the distribution of products to be proportional to demand, with the same ratio for all the priority customers (level 1) and a tolerance of 10%.

$$\left. \sum_t Csto(c,t) \middle/ \sum_t Cqua(c,t) \right. < \left(\left. \sum_c \sum_t Csto(c,t) \middle/ \sum_c \sum_t Cqua(c,t) \right. \right) \times 1.1, \quad \forall c/\mathrm{cpen}(c)=\mathrm{Level}\ 1 \tag{12}$$

5.2.6. Sustainability performance constraints

5.2.6.1. Effectiveness constraint

The effectiveness constraint is the maximum value obtained by the objective function for effectiveness (Effopt) minus a given tolerance (%).

$$Effopt[1 - (1 - Efftol)] \leq \sum_c ctqua(c) - \sum_c Ctpen(c)/nbT + \sum_w wtreq(w) - \sum_w Wtreq(w)/nbT \tag{13}$$

5.2.6.2. Economy (Efficiency) constraint

The economy constraint is the minimum value obtained by the objective function for Economy (Ecoopt) plus a given tolerance (%).

$$Ecoopt \times (1 + eco_{tol}) \geq \sum Fin(f) \times fcost\,(f) \tag{14}$$

5.2.6.3. Environment (Pollution reduction) constraint

The environment constraint is the minimum value obtained by the objective function for Environment (Envopt) plus a given tolerance (%).

$$Envopt \times (1 + env_{tol}) \geq \sum Fin(f) \times fenv\,(f) \tag{15}$$

5.2.6.4. Social (Local empowerment) constraint

The social constraint is the maximum value obtained by the objective function for social (Socopt) minus a given tolerance (%).

$$Socopt - (socopt \times sustol) \leq \sum_{f|fsoc=local} \sum_t Fin(f,t) \times fitc\,(f) \tag{16}$$

6. Master Planning for the IFRC A&C RLU use case

This section illustrates the SHSC Master Planning decision-support system in use, following the A&C RLU use case.

We developed the Master Planning dataset based on the field study data gathered at the A&C RLU, as well as on interviews with the Regional Logistic Development Officer. We also built it by imagining what the future IFRC upstream HSC would look like.

6.1. Sustainability at the IFRC

To enhance sustainable operations with the future (or under construction) sub-regional network, decision-makers should be able to coordinate the different stakeholders during an operation. For instance, if there is a need in the region, which warehouse will have to send what and when? Who will manage the replenishments? Today, decision-making is only based on the Procurement Officer's experience and is fully centralized.

When the network will be deployed the possible options will be a combination of variables that need to be considered, e.g., cost (items, transport), sourcing, or lead-time. Thus, experience will not be enough to establish the best response to execute and decision-support systems will be needed.

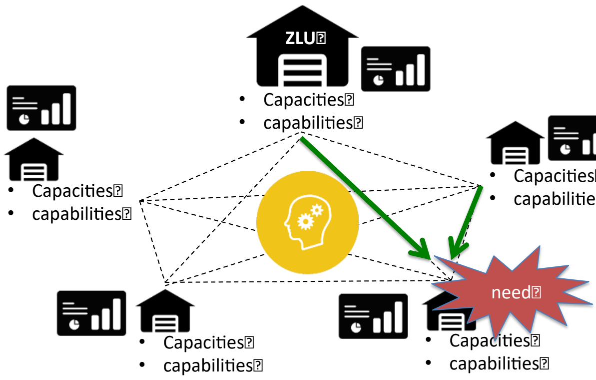


Figure 61 Sub-regional coordinated response

6.1.1. American & Caribbean IFRC sub-regional upstream network

The A&C RLU network is composed of 7 LUs and the Panama RLU. All warehouses are located close to the respective capitals and in proximity to Logistic infrastructures such as seaports and/or airports. The contingency stock level of each LU is defined by the IFRC strategy. The Panama RLU has a contingency stock level that corresponds to the needs of 5,000 families. LUs have smaller quantities, which can support between 2,000 and 5,000 families depending on the country. Figure 62 shows the geographical locations of warehouses (house), demand points (star) and regional and local suppliers (pointer).

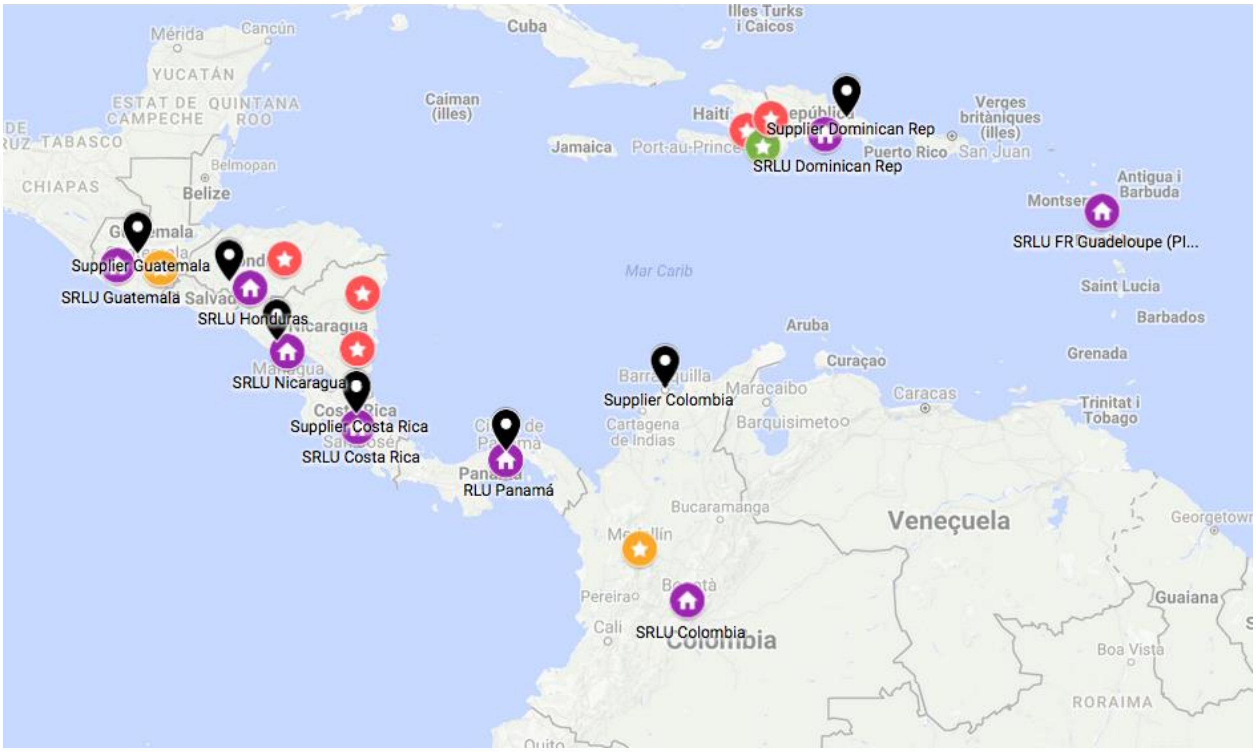


Figure 62 Geographical locations of local suppliers, SRLU/RLU and customers

6.1.2. Catalogue

Though the IFRC catalogue has many thousands of references, only a few products that correspond to basic needs (for hygiene, shelter and kitchen use, for example) are kept in the contingency stock at the LUs and RLUs depending on the specificities (climate and culture, for example) of the affected region. For the illustrative purpose of our model, we have selected only two products, one that can be sourced locally (blankets) and one that is difficult to find (tents) even at the national level in most of the countries of the A&C region.

6.1.3. Suppliers

Despite long lead times, most of the suppliers are based in Asian countries due to their competitive prices. At the country level, there are few local suppliers that are competitively responsive and impact positively on local empowerment. The sub-regionalization strategy helps to promote and enhance local capacity, with the aim to develop local sourcing. For our case study, we shortlisted 12 potential suppliers for blankets and 6 for tents. Only blankets are potentially sourced locally, due to the strict IFRC standard products requirements. Family tents are not commonly provided in the A&C region.

6.1.4. Planning horizon

The scope of the Master Planning decisions is to define, with a mid-term horizon, the emergency product flows from suppliers to the field entry points. The assessment of the demand is part of the Demand Planning, out of the scope of this Chapter. Inspired from available data, we consider that demand forecast can be done for a time horizon of 3 months and a time bucket of one week.

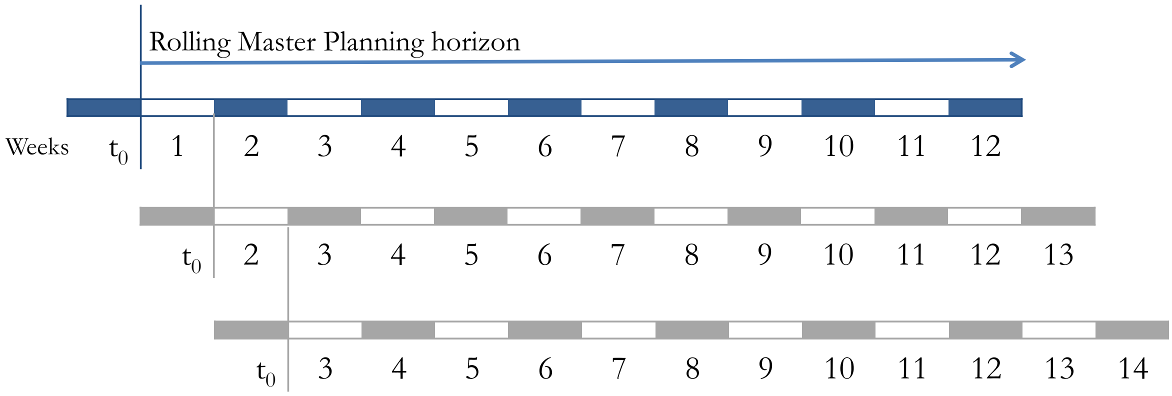


Figure 63 Master Planning Rolling horizon

6.1.5. Demand Points and Scenario

As discussed in the Introduction, the main service offered by the IFRC upstream is the management of procurement, warehousing and distribution processes of emergency products to feed entry points (warehouses, airports, seaports, etc.). It does not cover last-mile delivery. The demand can be then classified into different categories depending on the origin or the priority level.

For the illustration, we consider three priority levels: no priority/priority/urgent. The latter level adds a proportional penalty to the effectiveness when not delivered on time. Moreover, only urgent needs are considered by the equity constraint.

The demand of the illustration dataset is based on the socio-economic situation and the political instability of most of the countries in the area, as well as on natural phenomena (such as El Niño) that make the population especially vulnerable.

The illustration scenario is situated at the beginning of the rainy season, and therefore several countries are expecting flooding in the coming weeks/months. The consequence may be displaced people in Dominican Republic, Nicaragua, Honduras, Guatemala and Haiti and therefore, the need of tents and blankets (among other emergency items not considered here). Moreover, Colombia is facing a long-term political crisis, and the number of displaced people is increasing slightly.

Figure 64 shows the total demand of each product per week, versus the capacity. It is evident that the total supply capacity is oversized. The situation is not a grave crisis, so the choices between suppliers can be made depending on the different performance dimensions (economic, environmental, social). In an extreme crisis situation, where the total demand is close to, or exceeds the total capacity, there is no interest on using such an approach, because the effectiveness prioritization would constrain almost any other option.

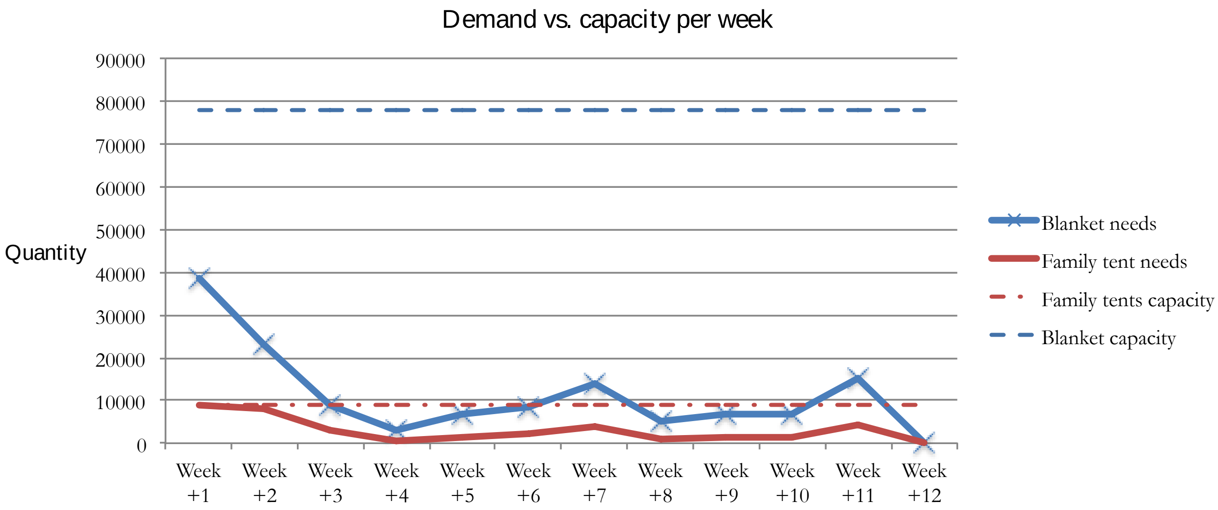


Figure 64 Demand versus capacity per week

6.1.6. Sustainable performance objectives

The LO of the performance objectives has to be established by the decision-maker. Funding is always a problem in the A&C RLU due to the recurrent disasters affecting this area, which do not receive the attention of the media. The strategy of the IFRC is to give more priority to the development of local markets than to environmental considerations. Therefore, it is assumed in this paper that the decision-maker prioritizes the three sustainability dimensions in the following order: (1) economic, (2) social and (3) environmental.

6.1.7. Numerical application

Based on this hypothesis, we built a database for the A&C RLU network flow. This database is composed of four sub-databases that can be seen in Appendix B. They are:

1) Suppliers' weekly capacity information
2) Warehouse inventory input data of LUs and the RLU,
3) Demand input data, and
4) Input data to define the potential flows.

The initial inventory corresponds to the target contingency stock level. The demand input data correspond to the estimated needs per product and per demand point for the first 7 weeks of the planning horizon. The "cpen" value represents de priority of the order (the higher this parameter, the higher the priority).

The flow database is constituted of 150 flows from suppliers to LUs and the RLU. To limit the quantity of flows, it is assumed that suppliers do not deliver directly to the field. The parameters used to define each flow are: origin, destination, mode, distance, lead-time, product environmental impact, product economy impact, product social impact, and the outstanding orders (expected receipts). Table 18 shows the parameters used to compute the cost and environmental impact. They are proportional to the transported weight and distance. For the multimodal flows, the different parameters are applied proportionally to the distance. They are inspired from (Meiginien 2014), and although they do not allow the exact real impact to be measured, they give a magnitude for comparison between the different options. It has to be noted that the environmental indicator results are expressed on CHF to homogenize the results, and that the equivalence has been computed as 100 CHF par ton of CO2. This pricing is inspired from the 2016 World Bank report (Zechtar et al. 2016).

Table 18 Model parameters

Transport type	Transport Cost CHF/(T Km)	Transport emissions gCO_2/(T Km)
Ship long (from Asia)	0,001	16,05
Ship short (within the region)	0,005	16,05
Air	0,2	1320
Road	0,1	81,48

6.1.8. Results and discussion

First an illustration of the decision-making process with one LO will be presented. Then, an Experimental Plan will be outlined, showing the behavior of the model when all the potential LOs are considered. Finally, the interest of using the interactive tolerance variation will be discussed.

6.1.8.1. Sustainable Master Planning decision process

We simulated the decision-making process based on the ILOM (see Figure 59). The objectives of the ILOM are:

- LO^0: Effectiveness
- LO^1: Economic
- LO^2: Social
- LO^3: Environmental

The first optimization step aims to maximize the Master Planning effectiveness of the SHSC. Then, following the algorithm, the optimal LO^1 (Economic) is calculated with the Effectiveness tolerance as a constraint. The interface shows the results of varying the Effectiveness constraint tolerance. In the example, the computation was done using variations that go from 0 to 20% with an incremental step of 1% (see Figure 65).

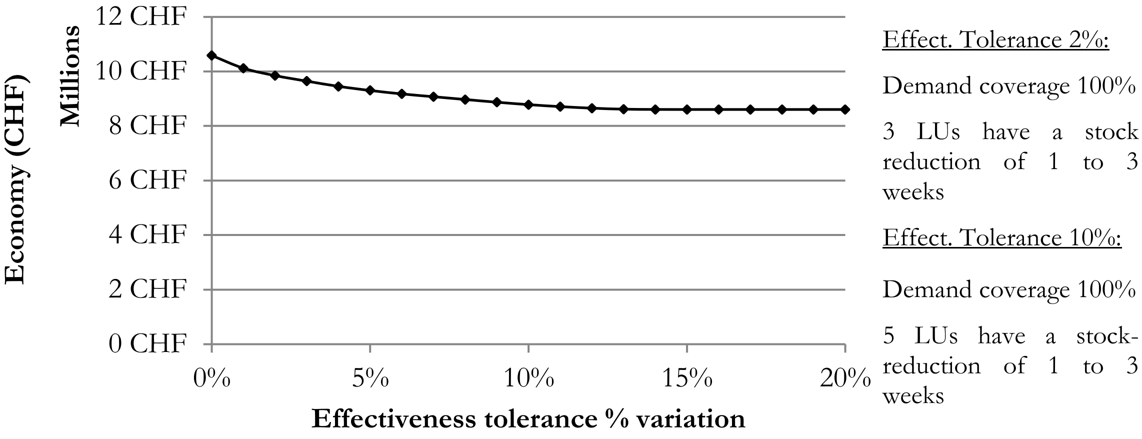


Figure 65 First iteration output: Economy indicator vs. Effectiveness Tolerance variation

We observe that demand fulfillment, which is the main performance driver, is not impacted by small tolerance variations. Small tolerances induce delays only on the warehouses inventory level. To illustrate the decision-making algorithm, we assume that the decision-maker chose to sacrifice 2%.

With 2% tolerance, the Effectiveness constraint is then fixed at 27 Million CHF and the minimal Economy Optimum at 10 million CHF.

Then, the second iteration loop computes the Social optimum (LO^2) with the fixed effectiveness constraint plus the variation of the Economy optimum (LO^1) as a constraint. The result is shown in Figure 66.

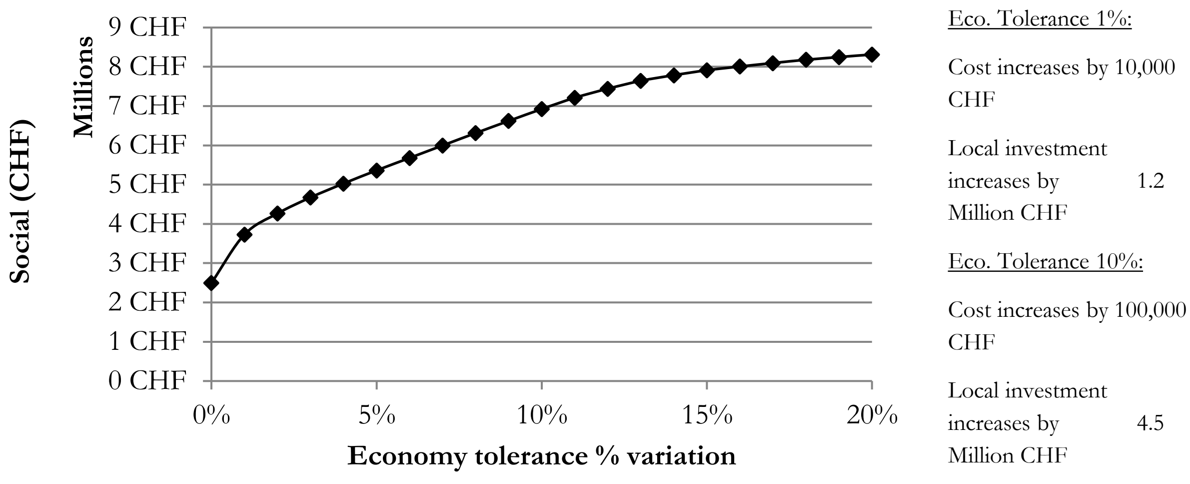


Figure 66 Second iteration output: Social indicator vs. Economy Tolerance variation

Considering that a degradation of 2% of the Economy Indicator (about 10,000 CHF) allows the Social Indicator to increase by 1.2 Million CHF (about 1,205,500 CHF), we assume that the decision-maker accepts a 1% tolerance for the Economy Indicator. The Economy constraint is then fixed at 9.9 Million CHF and the Social optimum (O2) at 3.7 Million CHF.

The last optimization loop computes the LO³ optimum (Environmental) with the O2 optimum (Social) tolerance variation as a constraint. It varies from 0 to 20%, with incremental steps of 1%. The interface with the decision-maker shows the resulting graph (see Figure 67).

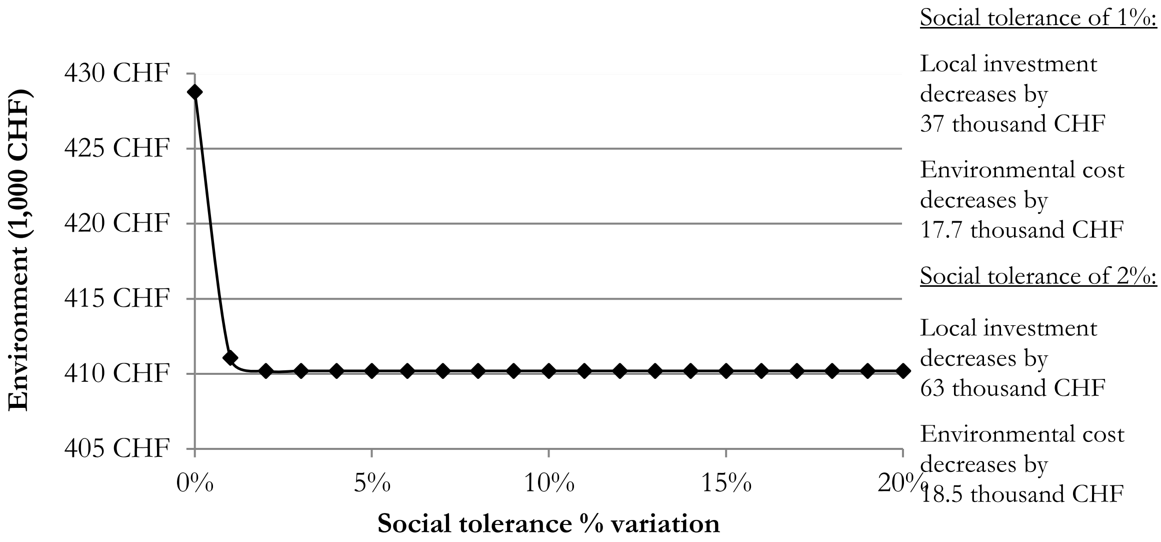


Figure 67 Third iteration output: Environment indicator vs. Social Tolerance variation

The output graph resulting from the third iteration leaves a low choice margin for the decision-maker. Reducing the Social Indicator by 1% (37 thousand CHF) allows an improvement of 17.7 thousand CHF on the Carbon Footprint, whereas a reduction of 2% (63 thousand CHF) leads to an improvement of 18.5 thousand CHF. The assumption is therefore to accept a tolerance of 1%. The Social constraint is then fixed at 37 thousand CHF and the minimum Environment optimum (LO³) at 17.7 thousand CHF. The resulting Master Planning indicators are summarized in Table 19.

Table 19 Results of the Master Planning Indicators

Indicator	Effectiveness	Economic	Social	Environmental
Accepted Tolerance	2%	1%	1%	/
Value	27 CHF Million	9.9 CHF Million	37 CHF thousand	17.7 CHF thousand

In addition to the indicators, the model outputs are the weekly procurement and distribution flows. Table 20 shows a sample of the Master Planning flows allocation for the SHSC.

Table 20 SHSC Master Planning case flows allocation sample

#	#Origin	#Destination	Mode	Product	1	2	3	4	5	6	7
	fori	fdes								Fout	
1	1001	2001	Sea	Blanket	12000	7574	0	0	0	0	0
2	2001	2002	Air	Blanket	0	0	0	0	0	0	0
3	2001	2003	Air	Blanket	0	0	0	0	0	0	0
4	2001	2004	Air	Blanket	0	0	0	0	0	0	0
5	2001	2005	Air	Blanket	0	0	0	0	0	0	0
6	2001	2006	Air	Blanket	0	0	0	0	0	0	0
7	2001	2007	Air	Blanket	0	0	0	0	0	0	0
8	2001	2008	Air	Blanket	0	0	0	0	0	0	0
9	2001	2002	Multi	Blanket	0	0	0	0	0	0	0
10	2001	2005	Sea	Blanket	0	0	0	0	0	2000	0
11	2001	2007	Sea	Blanket	0	0	0	0	0	2000	0
12	2001	2003	Road	Blanket	0	0	0	426	4100	0	200
13	2001	2004	Road	Blanket	0	0	0	0	0	0	0
14	2001	2006	Road	Blanket	0	0	0	0	9000	0	0
15	2001	2008	Road	Blanket	0	0	0	0	0	0	0
16	2003	2001	Air	Blanket	0	0	0	0	0	0	0

The decision-maker also has access to the planning of receipts, the eventual stock-outs (or over-stocks) and the expected inventory levels.

6.1.8.2. Experimental Plan of LO

For a better understanding of the proposed SHSC Master Planning decision-support system, as well as the behavior of the algorithm, we built an Experimental Plan with all the possible Lexicographic Orders. Given that effectiveness is considered as a fixed LO objective and that only the three other objectives (economic, social and environmental) have to be ordered, there are six possible LO combinations of the performance indicators. Table 21 summarizes the six combinations

Table 21 Experimental Plan Lexicographic Orders

Order	LO^0	LO^1	LO^2	LO^3
A (example)	Effectiveness	Economic	Social	Environmental
B	Effectiveness	Economic	Environmental	Social
C	Effectiveness	Social	Economic	Environmental
D	Effectiveness	Social	Environmental	Economic
E	Effectiveness	Environmental	Economic	Social
F	Effectiveness	Environmental	Social	Economic

Figure 68 shows how the optimal values of the three TBL objectives evolve with the tolerance variation of effectiveness. All the LO^1 objectives benefit from the relaxation of the LO^0 (effectiveness). The improvements in the objectives amount to a decrease of 95% for the environmental impact and an increase of 20% for the social impact.

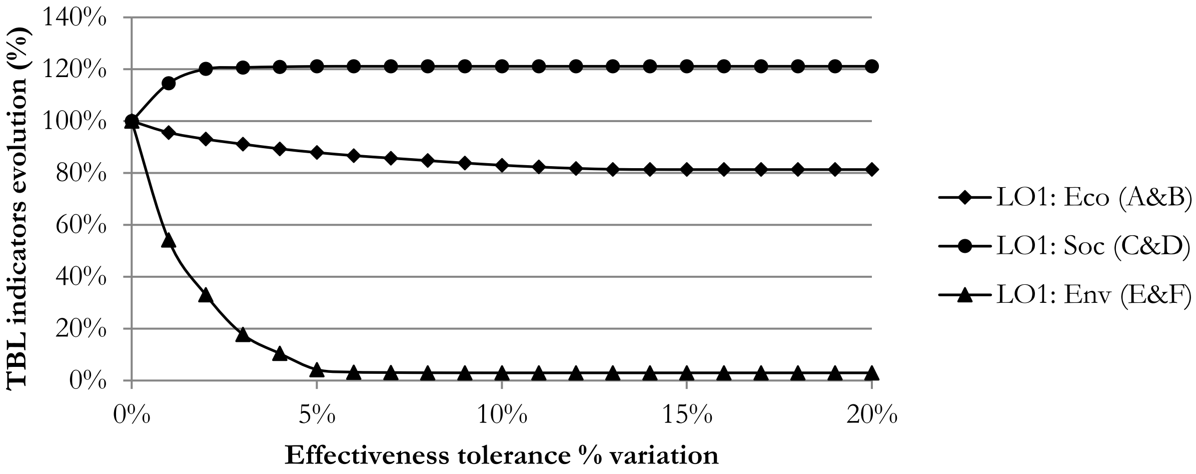


Figure 68 Variation of the TBL indicators (LO^1) while varying effectiveness tolerance

The results of LO^1, LO^2 and LO^3 depend on the tolerance defined for LO^0. Fixing the tolerance at 2% for LO^0 (effectiveness), we observed that LO^1 and LO^2 tolerances also have an impact on the next optimization sequences.

Table 22 shows the results of the Experimental Plan of the LO, with the case data first of all set at a tolerance of 2% for LO^0; 0% for LO^1 and 0% for LO^2 (Table 4a) and then at 2% for LO^0; 1% for LO^1 and 1% for LO^2 (Table 22b) The indicators are normalized based on the optimal result that can be achieved with the LO^0 tolerance fixed at 2%. The results show that both the LO and the tolerance variation have a relevant impact on the indicators. It can be observed that with a 0% tolerance (Table 22a) the order of LO^2 and LO^3 has no impact on the indicators, while with a 1% tolerance (Table 4b) there is a significant impact of the order on the indicators. It is therefore important to fix the tolerance using an interactive method, since it may lead to an important degradation of the indicators, which may not be acceptable by the decision-maker.

Table 22 Experimental Plan (for a: tolerance = 0, and for b: tolerance = 1%)

Effectiveness
Economy
Social
Environmental

(a)

	LO0	LO1	LO2	LO3
A	98%	100%	30%	160%
B	98%	100%	160%	30%
C	98%	100%	125%	324%
D	98%	100%	324%	125%
E	98%	100%	110%	81%
F	98%	100%	81%	110%
Tolerance	*2%*	*0%*	*0%*	*0%*

(b)

	LO0	LO1	LO2	LO3
A	98%	101%	44%	112%
B	98%	101%	113%	44%
C	98%	99%	121%	238%
D	98%	99%	241%	121%
E	98%	101%	108%	73%
F	98%	101%	82%	110%
Tolerance	*2%*	*1%*	*1%*	*1%*

6.2. Limitations

The illustrations presented above show that our proposal allows sustainable alternatives to be found for supporting humanitarian logistics. However, this illustration also indicates that decision-makers have a lot of intermediate choices to make all through the process in order to reach a good solution (ordering the TBL criteria and fixing the tolerance ratios). All these intermediate decisions can be difficult to make in an emergency context. Moreover, such a Master Planning system (as in the case of any planning system) needs a lot of data to run correctly. But in an HSC, this kind of dataset is not easy to put together and could constitute a considerable limitation to our proposal. Nevertheless, practitioners already collect such kind of data (on demand, suppliers, etc.) but may not do so in such an exhaustive manner.

7. Discussion

Given the growing interest in sustainable approaches for the management of humanitarian supply chains (HSCs), both academics and humanitarian organizations (HOs) are in search of effective methods for the implementation of the three sustainability dimensions (economic, social and environmental). In this chapter, we have proposed an approach that can be used for the tactical planning of sustainable operations in the HSC. Based on information gathered from the literature on sustainable HSC and performance measurement, as well as our field research, we presented three complementary contributions aimed at the development of a Master Planning decision-support system for an SHSC.

We started by defining a set of performance indicators used to quantify the Master Planning performance of the SHSC. A brief discussion enabled us to retain four parameters (Effectiveness, Efficiency, Local empowerment and Carbon emission) as the key performance indicators for the tactical Master Planning. To solve the multi-objective problem, we presented an ILOM approach. This sequential and interactive optimization algorithm makes it possible to take into consideration the expertise of the decision-maker by prioritizing the performance objectives. This allows a sequence of single-objective problems to be solved while progressively adding the optimums of previous solutions as constraints. Finally, we proposed a network flow model to execute the Master Planning of the SHSC while optimizing the performance objectives.

For the numerical illustration of our model, we built a case study inspired from the A&C IFRC Regional upstream network. The outcome of the case shows how the ILOM approach enables the decision-maker's expertise and knowledge of the prioritization of planning performance objectives to be integrated. In this experimental section, we emphasized the interest of using an interactive approach to define tolerances. We note that an interactive approach is mandatory since there is no trivial method for identifying a priori the impact of tolerance on performance objectives.

Several perspectives arise from this research work. The first one would consist in testing our proposal in a real context by applying it to real-life operations. Such a project is currently going on with the A&C RLU of IFRC. The objective here is firstly to go deeper into the assessment of the benefits and limits of our proposal, and secondly to ensure its usability by practitioners.

The second perspective would consist in assessing the accuracy of our ILOM outputs with respect to current practices. Our proposal is mathematically and theoretically valid but the relevance of the outputs remains to be studied and confirmed.

The third perspective would consist in extending the experimental plan to dataset combinations in order to better support decision-makers in using the SHSC Master Planning system that correspond to their own business objectives. Although we were able to develop a business case to concretely test our proposal, the parameterization remains complex for users who have to make a lot of intermediate choices in the process. Therefore, it might be valuable to help them by performing a sensitivity analysis of our model and by suggesting sets of parameters depending on the target objective (especially regarding the tolerance ratios).

The fourth perspective would consist in considering much more variability and uncertainty in our Master Planning system. Currently, our proposal is purely deterministic and the hazards are only managed through the rolling horizon of the plan. For further research, it may be interesting to use a stochastic or fuzzy approach. The last perspective is about considering an extension of the SHSC Master Planning to a global HSC management model, just as the for-profit business sectors are doing with Advanced Planning Systems.

Chapter V. CONCLUSION AND PERSPECTIVES

"Utopia lies at the horizon.
When I draw nearer by two steps,
it retreats two steps.
If I proceed ten steps forward, it
swiftly slips ten steps ahead.
No matter how far I go, I can never reach it.
What, then, is the purpose of utopia?
It is to cause us to advance."

- Eduardo Galeano

1. Academic and practical contributions

The "raison d'être" of HSCs is to diminish human suffering. However, HSCs are not isolated systems. The increasing financial gap between needs and funding that HOs are suffering from, the global pressure to embrace sustainable development, and donor's expectations on accountability, all lead us to the conclusion that HSCs should consider a sustainable performance approach as an "order winner" enabler.

Enhancing sustainability in the HSC is a utopia. Sustainability can only be attained by a transformation of our entire society, culture, and economic system. However, this is not an overnight transformation, and thus, the short term challenge is to support organizations on their way towards sustainability. In this context, enhancing sustainability in the HSC can be seen as a "continuous improvement" process that constantly questions the impact of decisions in the short and in the long term.

There are many aspects of the HSC where this evolution can take place, from the mitigation of the impact of disasters, which may contribute to reducing humanitarian needs, to the conscious design of relief items or the strength of collaboration and synergies between actors.

These problems have been addressed here from an Operations Management perspective. From field observations and a literature review, three main gaps were identified: (1) the difficulties in measuring the impact of humanitarian operations on « sustainability », (2) a lack of planning in the context of HSC and (3) the difficulties in developing adequate decision-support systems (academic and in-practice gap).

These issues have been addressed through an inductive research approach, based on IFRC field research outcomes, and with three main focuses: What? Why? How?

What? The HSC system

RQ1: How to formally conceptualize what an HSC is?

Why? Sustainability in the HSC

RQ2: What does sustainability mean in HSC operations and how can it be assessed?

How? Planning Sustainable HSC operations

RQ3: How to support Decision-makers in consciously and systematically making sustainability trade-offs and exploring consequences?

1st contribution: An HSC metamodel (what?)

To facilitate the formalization and understanding of HSC systems, Chapter 2 presents an HSC dedicated metamodel. This approach lies in the idea that the HSC is a collaborative system, where different actors have to interact. The HSC system is formalized with four packages: the context, the partners, the objectives and the behavior. This proposal is original given that today, there is no standard formal conceptualization of an HSC system. Potential uses are multiple: it may facilitate field research design, as well as the development of HSC dedicated Information Systems, or support concrete continuous improvement steps for logistics aspects. We have made an HSC metamodel proof of concept, by building field research supports in alignment with the metamodel.

Limits: a proof of concept of the HSC metamodel has been done only to develop field research supports. The practical application (and therefore validation) for the other suggested uses is yet to be implemented (to define information system requirements and to facilitate coordination).

2nd contribution: the house of SHSC operations (why?)

The second contribution seeks to define the objectives that an SHSC should consider. Following the TBL approach, we propose a set of dimensions that defines SHSC operational performance. This second contribution merges the literature on the concept of sustainability, and sustainable performance with the field of HSC operations. The framework is used to build an SHSC maturity assessment method, implemented with an A&C RLU proof of concept, which enables the measurement of sustainability.

Limits: the framework has been developed thanks to inputs from IFRC field research, as well as the maturity assessment grids. A wider validation of the sustainable criteria and maturity assessment process should be conducted with experts from different HOs, in order to consolidate a benchmark to compare organizations.

3rd contribution: A Master Planning decision-making system (how?)

Finally, the last contribution pursues the objective of concretely incorporating a sustainable performance approach while planning SHSC operations. From field research and the literature, the tactical Master Planning process is identified as a potential enabler to introduce sustainability in the decision-making process. Therefore, the SHSC Master Planning problem has been addressed. Based on the IFRC A&C network, a set of sustainable performance criteria has been selected. Then, the multi-objective decision problem is solved with an Interactive Lexicographic Ordering Algorithm that allows decision-makers' expertise to be taken into account, linked to a deterministic HSC network flow model. The relevance of the proposal is illustrated through the A&C RLU use case.

Limits: the A&C RLU use-case covers the upstream and internal decision-making process, which is only a limited perimeter of the entire IFRC HSC (from suppliers to end-users). The practical application to a larger perimeter and various HOs is yet to be accomplished. Nonetheless, a lot of data is already needed to run the model, so the capability of gathering this data has to further investigated, as well as the sensitivity of the outputs.

2. Perspectives

This research has contributed to the literature on the challenge of enhancing SHSC operations. Based on the Technology Readiness Level (TRL) scale[1], the contributions are on level 3-4 maturity levels: "research to prove feasibility". We present here a research agenda to both consolidate the proposals and to propose further research directions.

- The **short-term** perspectives aim at consolidating a TRL 5 (technology validated in relevant environment). Therefore, we consider the need to validate the contributions with (i) a real scenario from the IFRC HSC network, (ii) a wider set of HO use cases, (iii) and a deeper study of the model sensitivity.
- The **mid-term** perspectives aim at consolidating a TRL 7 (system prototype demonstration in operational environment). Therefore, it appears relevant to reinforce the prototype implementation with the development of (iv) adequate interfaces in alignment with practitioners' expectations (usability), and (v) methods for a successful technology transfer to the end-users (acceptability).
- The **long-term** perspectives aim at going beyond the scientific proposals. Within the many potential evolutions, we find it relevant to consider three main research directions. First, (vi) a deeper study of sustainability assessment all along the HSC lifecycle. Secondly, (vii) the extension over two dimensions of the SHSC planning decision-support system: the decision planning levels and tasks, and the end-to-end supply chain (from suppliers to beneficiaries). Last, but not least, (viii) the integration of an agile decision-making dimension into the decision-making process.

Short-term perspectives (validation)

x. *Wider Validation with real scenario:* to demonstrate the validity of the proposals, all the contributions have been validated through the IFRC A&C RLU use case. Nonetheless, each of the contributions was built with a limited data set extended by assumptions. Although the assumptions were discussed with practitioners or built on field observations, and/or the literature review, it would be relevant to frame a complete dataset with real data.

To build a real scenario, it would be appropriate to engage with the IFRC on a field research campaign dedicated to gathering the data, and to building the real scenario. Furthermore, practitioners could perform a validation step, by contrasting the performance outcomes with and without using the SHSC Master Planning system.

xi. *Contrast model assumptions with other HOs:* the assumptions were built on the specifics of the IFRC upstream HSC. This is clearly a limitation, and thus, one perspective would be to extend the validation with a wider range of HOs, such as the WFP or even MSF, who manage similar HSC networks. The scope of other HSCs may differ in terms of disaster typology (i.e. conflicting situations) and therefore, the HSC network flow model hypothesis and constraints may differ.

[1] Technology Readiness Levels (TRLs) are indicators of the maturity level of particular technologies. This measurement system provides a common understanding of technology status and addresses the entire innovation chain. There are nine technology readiness levels; TRL 1 being the lowest and TRL 9 the highest (European Comission 2017).

xii. *A deeper sensitivity evaluation:* the sensitivity of the model needs to be investigated more deeply with a real dataset. The objective is to support the users in interpreting and anticipating the implications of their choices during the decision process.

Mid-term perspectives (implementation)

xiii. *Human-computer interaction:* in the third contribution, we have focused on the algorithm and model to assess sustainability, and solve the sustainable Master Planning decision-making problem. Although we have considered the user dimension and user expertise on the prioritization of the performance objectives, the usability of the system remains complex for the non-initiated. To reinforce the applied research approach, further work has to be done to design and develop ergonomic human-computer interactions. Developing usable (efficient, effective and satisfying) interfaces is an interdisciplinary matter that concerns at least and computer engineering, and which would also benefit from a social sciences perspective (interaction design) (Dix 2009).

xiv. *Technology transfer to the field:* once a prototype has been implemented, it is important to consider the dissemination of the decision-support system among the potential users (access to knowledge). An important related issue to be considered is integration with existing information systems (i.e. ERP). This may notably reveal interoperability challenges.

Long-term perspectives (evolutions)

xv. *Life Cycle Assessments:* a standard approach to assessing the impacts of a product on the different dimensions of sustainability is to make a Life Cycle Assessment (LCA). This assessment has typically been conducted for the environmental dimension, but some authors also consider carrying out a social LCA. This is a challenging but interesting perspective to follow because it may make it possible to identify, in a continuous improvement perspective, the stages of the HSC that have the most negative impact.

xvi. *Towards and Humanitarian Advanced Planning System:* the ultimate goal of SHSC is to generate synergic decision-making behavior with all the HSC stakeholders upstream and downstream. This research work has addressed a first step, with the development of a Master Planning module, for the upstream HSC. However, the question remains of how decisions taken upstream impact on global HSC sustainability. How can decision-makers gain a holistic perspective?
Therefore, to enhance SHSC operations, two interesting perspectives arise: (1) the integration of the different planning levels (Figure 69) and (2) the integration of the upstream and downstream stakeholders (Figure 70).

In the commercial SC context, APSs are seen as the solution to integrate all the decision processes using a hierarchical approach. However, the context of humanitarian operations brings additional difficulties: downstream networks are deployed ad-hoc, the collaborations between stakeholders may be sporadic, and decision-making can be decentralized. Is it then possible to develop a flexible Humanitarian APS? How can the dynamics and uncertainty in the system be addressed?

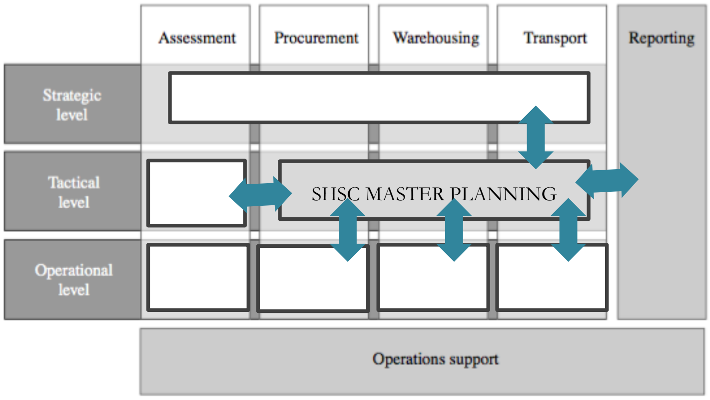


Figure 69 Perspective: Planning decision levels and tasks integration

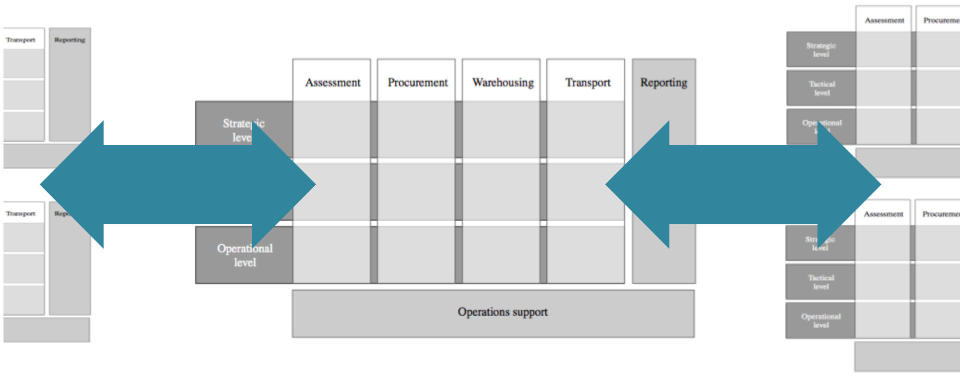


Figure 70 Perspective: Upstream and downstream integration

Nonetheless, many research studies have already been conducted that address strategic level decision-making with, for example, network design (Aurélie Charles 2010; Vargas Florez et al. 2015), or operational levels with last mile distribution decision-making problems (Burcu Balcik et al. 2008). The remaining issues still involve the questions of how to introduce the sustainable perspective in the different decision levels and how to ensure the interoperability of the different systems.

The use of the HSC metamodel may be an enabler to facilitate the development of Humanitarian Sustainable APS (interoperability), if used as a common reference conceptualization of the network.

xvii. *Agility (detection, adaptation):* finally, HSC operations have to cope with a high degree of uncertainty. Therefore, the HSC decision-making process requires methods that adapt to the dynamics of the environment. Our contribution is limited to the design of a process (the Master Planning), and to deal with the uncertainty, we have proposed a rolling horizon planning approach. An agile decision-making process can be implemented by adding the two dimensions: detection and adaptation. An agile system can **detect** the deviations between plan and reality, and **adapt** to the new situation.

BIBLIOGRAPHY

Aaltonen, M. (2009). Multi-ontology, sense-making and the emergence of the future. *Futures*, *41*(5), 279–283.

Abidi, H., Leeuw, S. de, & Klumpp, M. (2014). Humanitarian supply chain performance management: a systematic literature review. *Supply Chain Management: An International Journal*, *19*(5/6), 592–608.

Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of Cleaner Production*, *52*, 329–341.

Ahi, P., & Searcy, C. (2015). An analysis of metrics used to measure performance in green and sustainable supply chains. *Journal of Cleaner Production*, *86*, 360–377.

Alessandra Cozzolino, Silvia Rossi, & Alessio Conforti. (2012). Agile and lean principles in the humanitarian supply chain. *Journal of Humanitarian Logistics and Supply Chain Management*, *2*(1), 16–33.

Alotaibi, Y. (2017). Graphical business process modelling standards, techniques and languages: a literature review. *International Journal of Business Information Systems*, *25*(1), 18–54.

Altay, N., & Green, W. G. (2005). OR/MS research in disaster operations management. *European Journal of Operational Research*, *175*(1), 475–493.

Asadi, S., Badica, C., Comes, T., Conrado, C., Evers, V., Groen, F., et al. (2011). ICT solutions supporting collaborative information acquisition, situation assessment and decision making in contemporary environmental management problems: the DIADEM approach. In *Conference on Innovations in Sharing Environmental Observation and Information (EnviroInfo 2011), October 5-7, 2011, Ispra, Italy* (pp. 920–931).

Ashby, Leat, & Hudson-Smith. (2012). Making connections: a review of supply chain management and sustainability literature. *Supply Chain Management: An International Journal*, *17*(5), 497–512.

Baharmand, H., & Comes, T. (2015). A Framework for Shelter Location Decisions by Ant Colony Optimization. In *ISCRAM*.

Baharmand, H., Laguna Salvadó, Laura, Comes, T., & Lauras, M. (2015). On the Literature Divergences of the Humanitarian Supply Chain. Presented at the ISCRAM-med, Tunis.

Balcik, B., & Beamon, B. M. (2008). Facility location in humanitarian relief. *International Journal of Logistics Research and Applications*, *11*(2), 101–121.

Balcik, B., Beamon, B. M., Krejci, C. C., Muramatsu, K. M., & Ramirez, M. (2010). Coordination in humanitarian relief chains: Practices, challenges and opportunities. *International Journal of Production Economics*, *126*(1), 22–34.

Balcik, B., Beamon, B. M., & Smilowitz, K. (2008). Last Mile Distribution in Humanitarian Relief. *Journal of Intelligent Transportation Systems*, *12*(2), 51–63.

Barrena, I. (2015, October). *Mesa redonda con embajadores en Panamá, IFRC*.

Bataille, V., & Castellani, X. (2001). Métamodélisation et ingénierie des systèmes d'information. *Ingénierie des systğmes dἰnformation*, 149–174.

Battista, C., & M., M. (2013). The Logistic Maturity Model: Application to a Fashion Company. *International Journal of Engineering Business Management*, 1.

Baumann, E. (2011). *Modèles d'évaluation des performances économique, environnementale et sociale dans les chaînes logistiques* (Phd thesis). INSA de Lyon.

Beamon, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management*, *19*(3), 275–292.

Beamon, B. M., & Balcik, B. (2008). Performance measurement in humanitarian relief chains. *International Journal of Public Sector Management*, *21*(1), 4–25.

Bénabén, F. (2012). *Conception de système d'Infromation de Médiation pour la prise en charge de l'Intéroperabilité dans les Collaborations d'Organizations* (HDR). INP Toulouse.

Bénabén, F., Hanachi, C., Lauras, M., Couget, P., & Chapurlat, V. (2008). A metamodel and its ontology to guide crisis characterization and its collaborative management. In *Proceedings of the 5th International Conference on Information Systems for Crisis Response and Management (ISCRAM), Washington, DC, USA, May* (pp. 4–7).

Bénabén, F., Lauras, M., Truptil, S., & Salatgé, N. (2016). A Metamodel for Knowledge Management in Crisis Management. In *2016 49th Hawaii International Conference on System Sciences (HICSS)* (pp. 126–135). Presented at the 2016 49th Hawaii International Conference on System Sciences (HICSS).

Beske, P., & Seuring, S. (2014). Putting sustainability into supply chain management. *Supply Chain Management: An International Journal*, *19*(3), 322–331.

Bhuiyan, N., & Baghel, A. (2005). An overview of continuous improvement: from the past to the present. *Management Decision*, *43*(5), 761–771.

Blecken, A. (2010). Supply chain process modelling for humanitarian organizations. *International Journal of Physical Distribution & Logistics Management*, *40*(8/9), 675–692.

Bouchery, Y., Ghaffari, A., & Jemai, Z. (2010). *Key Performance Indicators for Sustainable Distribution Supply Chains: Set Building Methodology and Application*.

Branke, J. (Ed.). (2008). *Multiobjective optimization: interactive and evolutionary approaches*. Berlin ; New York: Springer.

Burritt, R. L., & Schaltegger, S. (2010). Sustainability accounting and reporting: fad or trend? *Accounting, Auditing & Accountability Journal*, *23*(7), 829–846.

Carter, C. R., & Liane Easton, P. (2011). Sustainable supply chain management: evolution and future directions. *International Journal of Physical Distribution & Logistics Management*, *41*(1), 46–62.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, *38*(5), 360–387.

Cervone, H. F. (2007). The system development life cycle and digital library development. *OCLC Systems & Services: International digital library perspectives*, *23*(4), 348–352.

Chan. (2003). Performance Measurement in a Supply Chain. *The International Journal of Advanced Manufacturing Technology*, *21*(7), 534–548.

Chan, H. K., & Kumar, V. (2014). Special Issue – Applications of reference models for supply-chain integration. *Production Planning & Control*, *25*(13–14), 1059–1064.

Chardine-Baumann, E., & Botta-Genoulaz, V. (2014). A framework for sustainable performance assessment of supply chain management practices. *Computers & Industrial Engineering*, *76*(Supplement C), 138–147. doi:10.1016/j.cie.2014.07.029

Charles, A. (2010). *Improving the design and management of agile supply chains: feedback and application in the context of humanitarian aid*. Unicersité de Toulouse, Albi.

Charles, A., & Lauras, M. (2011). An enterprise modelling approach for better optimisation modelling: application to the humanitarian relief chain coordination problem. *OR Spectrum*, *33*(3), 815–841.

Charles, A., Lauras, M., & Tomasini, R. (2009). Learning from previous humanitarian operations, a Business Process Reengineering approach. In *Proceedings of the 6th International ISCRAM Conference* (p. 40). Accessed 6 June 2015

Charles, A., Lauras, M., & Tomasini, R. (2010). Collaboration Networks Involving Humanitarian Organisations – Particular Problems for a Particular Sector. In L. M. Camarinha-Matos, X. Boucher, & H. Afsarmanesh (Eds.), *Collaborative Networks for a Sustainable World* (pp. 157–165). Springer Berlin Heidelberg.

Charvériat, C. (2000). *Natural Disasters in Latin America and the Caribbean: An Overview of Risk* (SSRN Scholarly Paper No. ID 1817233). Rochester, NY: Social Science Research Network.

Clark, T., Keßler, C., & Purohit, H. (2015). Feasibility of Information Interoperability in the Humanitarian Domain. In *2015 AAAI Spring Symposium Series*.

Comes, T. (2016). Designing for Networked Community Resilience. *Procedia Engineering*, *159*, 6–11.

Comes, T., Van de Walle, B., Laguna Salvadó, L., & Lauras, M. (2015). Understanding the Health Disaster: Research Design for the Response to the 2014 West African Ebola Outbreak, *107*, 81–89.

Comes, T., Vybornova, O., & Van de Walle, B. (2015). Bringing Structure to the Disaster Data Typhoon : An Analysis of Decision-Makers ' Information Needs in the Response to Haiyan. In *2015 AAAI Spring Symposium* (pp. 7–11).

Correia, E., Carvalho, H., Azevedo, S., & Govindan, K. (2017). Maturity Models in Supply Chain Sustainability: A Systematic Literature Review. *Sustainability*, *9*(1), 64.

Costa, S. R. A. da, Campos, V. B. G., & Bandeira, R. A. de M. (2012). Supply Chains in Humanitarian Operations: Cases and Analysis. *Procedia - Social and Behavioral Sciences*, *54*, 598–607.

Coughlan, P., & Coghlan, D. (2002). Action research for operations management. *International Journal of Operations & Production Management*, *22*(2), 220–240.

Daniele, L., & Ferreira Pires, L. (2013). An ontological approach to logistics. In M. Zelm, M. J. Sinderen, & G. Doumeingts (Eds.), (pp. 199–213). Presented at the Enterprise Interoperability, Research and Applications in the Service-oriented Ecosystem, IWEI 2013, Surrey, UK: ISTE Ltd, John Wiley & Sons, Inc.

Day, J. M., Melnyk, S. A., Larson, P. D., Davis, E. W., & Whybark, D. C. (2012). Humanitarian and disaster relief supply chains: a matter of life and death. *Journal of Supply Chain Management*, *48*(2), 21–36.

Deb, K., Sindhya, K., & Hakanen, J. (2016). Multi-objective optimization. In *Decision Sciences: Theory and Practice* (pp. 145–184). CRC Press.

Dix, A. (2009). Human-Computer Interaction. In *Encyclopedia of Database Systems* (pp. 1327–1331). Springer, Boston, MA.

Drexl, A., & Kimms, A. (2013). *Beyond Manufacturing Resource Planning (MRP II): Advanced Models and Methods for Production Planning*. Springer Science & Business Media.

Du Pisani, J. A. (2006). Sustainable development – historical roots of the concept. *Environmental Sciences*, *3*(2), 83–96.

Dubey, R., & Gunasekaran, A. (2016). The sustainable humanitarian supply chain design: agility, adaptability and alignment. *International Journal of Logistics Research and Applications*, *19*(1), 62–82.

Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Review*, *14*(4), 532–550.

Elkington, J. (1998). Accounting for the Tripple Bottom Line. *Measuring Business Excellence*, *2*(3), 18–22.

Eskandarpour, M., Dejax, P., Miemczyk, J., & Péton, O. (2015). Sustainable supply chain network design: An optimization-oriented review. *Omega*, *54*(Supplement C), 11–32.

Esty, D., & Winston, A. (2009). *Green to Gold: How Smart Companies Use Environmental Strategy to Innovate, Create Value, and Build Competitive Advantage*. John Wiley & Sons.

European Comission. (2017). Horizon 2020 work programme 2016-17 - 20. General Annexes. European Comission.

Ferris, E., Petz, D., & Stark, C. (2013). *The year of recurring disasters: A review of Natural Disasters in 2012*. The Brookings Institution.

Forme, F. A. G. L., Genoulaz, V. B., & Campagne, J. P. (2009). The role of APS systems in Supply Chain Management: a theoretical and industrial analysis. *International Journal of Logistics*

Systems and Management, *5*(3/4), 356. doi:10.1504/IJLSM.2009.022502

Franke, J., Widera, A., Charoy, F., Hellingrath, B., & Ulmer, C. (2011). Reference process models and systems for inter-organizational ad-hoc coordination-supply chain management in humanitarian operations. In *8th International Conference on Information Systems for Crisis Response and Management (ISCRAM'2011)*.

Fulzele, V., Gupta, R., & Shankar, R. (2016). Identification and Modelling of Critical Success Factors of a Humanitarian Supply Chain. In *Managing Humanitarian Logistics* (pp. 33–50). Springer, New Delhi.

Galindo, G., & Batta, R. (2013). Review of recent developments in OR/MS research in disaster operations management. *European Journal of Operational Research*, *230*(2), 201–211.

Gaševic, D., Djuric, D., & Devedžic, V. (2006). *Model Driven Architecture and Ontology Development*. Springer Science & Business Media.

Gastwirth, J. L. (1972). The Estimation of the Lorenz Curve and Gini Index. *The Review of Economics and Statistics*, *54*(3), 306–316.

Gladwin, T. N., Kennelly, J. J., & Krause, T.-S. (1995). Shifting paradigms for sustainable development: Implications for management theory and research. *Academy of management Review*, *20*(4), 874–907.

Global Logistic Services IFRC. (2012). *2011 GLS Annual Report*.

Global Repporting Inititative. (2015). GRIG4 - Reporting Principles and Standard Disclosures. GRI.

Golinska, P., & Kuebler, F. (2014). The Method for Assessment of the Sustainability Maturity in Remanufacturing Companies. *Procedia CIRP*, *15*, 201–206.

Gralla, E., Goentzel, J., & Fine, C. (2014). Assessing Trade-offs among Multiple Objectives for Humanitarian Aid Delivery Using Expert Preferences. *Production and Operations Management*, *23*(6), 978–989.

Gralla, E., Goentzel, J., & Van de Walle, B. (2013). *Field-based decision makers' information needs in sudden onset disasters*. Accessed 26 September 2017

Grant, D. B., Wong, C. Y., & Trautrims, A. (2017). *Sustainable Logistics and Supply Chain Management: Principles and Practices for Sustainable Operations and Management*. Kogan Page Publishers.

Grenade, M. (2015, September). *IFRC Global Logistics Service - Colombia*. Panamá.

Gruber, T. R. (1993). A translation approach to portable ontology specifications. *Knowledge acquisition*, *5*(2), 199–220.

Grubic, T., & Fan, I.-S. (2010). Supply chain ontology: Review, analysis and synthesis. *Computers in Industry*, *61*(8), 776–786.

Guizzardi, G. (2005). *Ontological Foundations for Structural Conceptual Models*. Universiteit Twente, Enschede. Retrieved from http://doc.utwente.nl/50826/1/thesis_Guizzardi.pdf

Gunasekaran, A., & Kobu, B. (2007). Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. *International Journal of Production Research*, *45*(12), 2819–2840.

Haavisto, I., & Kovács, G. (2014). Perspectives on sustainability in humanitarian supply chains. *Disaster Prevention and Management: An International Journal*, *23*(5), 610–631.

Hart, S. L. (1996). Beyond greening- Strategies for a Sustainable World. *Harvart Business Review*, 66–78.

Hausladen, I., & Haas, A. (2013). Considering Sustainability in the Context of Hu-manitarian Logistics. In *Managing Humanitarian Supply Chains* (pp. 314–329). DVV Media Group GbbH. Accessed 14 April 2016

Hella Abidi, Sander de Leeuw, & Matthias Klumpp. (2014). Humanitarian supply chain performance management: a systematic literature review. *Supply Chain Management: An International Journal*, *19*(5/6), 592–608.

Henderson-Sellers, B. (2011). Bridging metamodels and ontologies in software engineering. *Journal of Systems and Software*, *84*(2), 301–313.

Henderson-Sellers, B., & Bulthuis, A. (2012). *Object-Oriented Metamethods*. Springer Science & Business Media.

Hervani, A. A., Helms, M. M., & Sarkis, J. (2005). Performance measurement for green supply chain management. *Benchmarking: An International Journal*, *12*(4), 330–353.

Holguín-Veras, J., Jaller, M., Van Wassenhove, L. N., Pérez, N., & Wachtendorf, T. (2012). On the unique features of post-disaster humanitarian logistics. *Journal of Operations Management*, *30*(7–8), 494–506.

Holguín-Veras, J., Pérez, N., Jaller, M., Van Wassenhove, L. N., & Aros-Vera, F. (2013). On the appropriate objective function for post-disaster humanitarian logistics models. *Journal of Operations Management*, *31*(5), 262–280.

Holmström, J., Ketokivi, M., & Hameri, A.-P. (2009). Bridging Practice and Theory: A Design Science Approach. *Decision Sciences*, *40*(1), 65–87.

Huan, S. H., Sheoran, S. K., & Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply Chain Management: An International Journal*, *9*(1), 23–29.

Humanitarian Coalition. (2015, May 6). Humanitarian Needs. Text.

Humphries, V. (2013). Improving Humanitarian Coordination: Common Challenges and Lessons Learned from the Cluster Approach | The Journal of Humanitarian Assistance. *The Journal of Humanitarian Assistance*. Accessed 8 October 2014

IFRC. (2013). *Global Logistic Services Annual Report*. IFRC.

IFRC. (2014). *Global Logistic Services Annual Report*. IFRC.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., & Meier, P. (2013). Extracting information nuggets from disaster-related messages in social media. In *ISCRAM* (pp. 791–800). Baden-Baden.

Jahre, M. (2008). *The organisational change of logistics in International Federation of the Red Cross and Red Crescent Societies* (Case Study). HUMLOG-NET Project. Accessed 11 June 2015

Jamali, D., Safieddine, A. M., & Rabbath, M. (2008). Corporate Governance and Corporate Social Responsibility Synergies and Interrelationships. *Corporate Governance: An International Review*, *16*(5), 443–459.

Järvinen, P. (2007). Action Research is Similar to Design Science. *Quality & Quantity*, *41*(1), 37–54.

Jiang, Z., Lamothe, J., & Bénaben, F. (2016). Meta-Modeling of Collaborative Supply Chain. In *Enterprise Interoperability VII* (pp. 307–320). Springer, Cham. Accessed 17 December 2017

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics Research and Applications*, *6*(4), 197–210.

Kleindorfer, P. R., Singhal, K., & Van Wassenhove, L. N. (2005). Sustainable Operations Management. *Production and Operations Management*, *14*(4), 482–492.

Klumpp, M., De Leeuw, S., Regattieri, A., & de Souza, R. (2015). *Humanitarian Logistics and Sustainability*. Springer. Accessed 13 November 2015

Kovács, G., Spens, K., & Haavisto, I. (2016). *Supply Chain Management for Humanitarians: Tools for Practice*. Kogan Page Publishers.

Kovács, G., & Spens, K. M. (2007). Humanitarian logistics in disaster relief operations. *International Journal of Physical Distribution & Logistics Management*, *37*(2), 99–114.

Kovács, G., & Spens, K. M. (2011). Trends and developments in humanitarian logistics – a gap analysis. *International Journal of Physical Distribution & Logistics Management*, *41*(1), 32–45.

Kovács, G., & Spens, K. M. (Eds.). (2012). *Relief Supply Chain Management for Disasters: Humanitarian, Aid and Emergency Logistics*. IGI Global. http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-60960-824-8. Accessed 17 December 2017

Kunz, N., & Gold, S. (2017). Sustainable humanitarian supply chain management – exploring new theory. *International Journal of Logistics Research and Applications*, 1–20.

Kunz, N., Wassenhove, L. N. V., Besiou, M., Hambye, C., & Kovács, G. (2017). Relevance of humanitarian logistics research: best practices and way forward. *International Journal of Operations & Production Management*, *37*(11), 1585–1599.

Kurnia, S., Rahim, M. M., Samson, D., & Prakash, S. (2014). Sustainable Supply Chain management capability maturity: framework development and initial evaluation. *ECIS 2014 Proceedings*.

Laguna Salvadó, L., Lauras, M., Comes, T., & Grenade, M. (2016). A study on the sub-regionalization of Humanitarian Supply Chain: the IFRC case. In *Proceedings of the International Conference on Information Systems for Crisis Response and Management*. Presented at the ISCRAM 2016, Rio de Janeiro.

Laguna Salvadó, L., Lauras, M., Comes, T., & Van de Walle, B. (2015). Towards More Relevant Research on Humanitarian Disaster Management Coordination. Presented at the ISCRAM 2015 Conference, Kristiansand.

Laguna Salvadó, Laura, Lauras, M., & Comes, T. (2015). Humanitarian Value Stream Mapping: Application to the EBOLA Outbreak. Presented at the 12th International Conference on Information Systems for Crisis Response and Management, Kristiansand (Norwey).

Lauras, M. (2004). *Méthodes de diagnostic et d'évaluation de performance pour la gestion de chaînes logistiques: application à la coopération maison-mère–filiales internationales dans un groupe pharmaceutique et cosmétique*. Institut National Polytechnique de Toulouse.

Lauras, M., Bénaben, F., Truptil, S., Lamothe, J., Macé-Ramète, G., & Montarnal, A. (2014). A meta-ontology for knowledge acquisition and exploitation of collaborative social systems. In *Behavior, Economic and Social Computing (BESC), 2014 International Conference on* (pp. 1–7). IEEE.

Lauras, M., Truptil, S., & Bénaben, F. (2015). Towards a better management of complex emergencies through crisis management meta-modelling. *Disasters*, *39*(4), 687–714.

Laurencelle, L. (2005). *Abrégé sur les méthodes de recherche et la recherche expérimentale* (PUQ.).

Liu, S., Duffy, A. H. B., Whitfield, R. I., & Boyle, I. M. (2010). Integration of decision support systems to improve decision support performance. *Knowledge and Information Systems*, *22*(3), 261–286.

Macé-Ramete, G., Lauras, M., Benaben, F., & Lamothe, J. (2012). A collaborative information system supporting decision and coordination in transport crisis context. In *9th International Conference on Modeling, Optimization & SIMulation*.

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. *Environmental impact assessment review*, *18*(6), 493–520.

Meiginien, B. (2014). *Guide méthodologique Transport de marchandises - Caractéristiques de l'offre et capacité des modes de transport* (2nd ed.). Paris: Cerema.

Milne, M. J., & Gray, R. (2013). W(h)ither Ecology? The Triple Bottom Line, the Global Reporting Initiative, and Corporate Sustainability Reporting. *Journal of Business Ethics*, *118*(1), 13–29.

Min, H., & Zhou, G. (2002). Supply chain modeling: past, present and future. *Computers & Industrial Engineering*, *43*(1–2), 231–249. doi:10.1016/S0360-8352(02)00066-9

Müller, M. (2005). Action research in supply chain management–an introduction. *Research methodologies in supply chain management*, 349–364.

Murphy, P. R., & Poist, R. F. (2003). Green perspectives and practices: a "comparative logistics" study. *Supply Chain Management: An International Journal*, *8*(2), 122–131.

Okongwu, U., Morimoto, R., & Lauras, M. (2013). The maturity of supply chain sustainability disclosure from a continuous improvement perspective. *International Journal of Productivity and Performance Management*, *62*(8), 827–855.

Oloruntoba, R. (2015). Chapter 3: A Planning and Decision-Making Framework for Sustainable Humanitarian Logistics in Disaster Response. In *Humanitarian Logistics and Sustainability*. Springer.

Oloruntoba, R., & Gray, R. (2009). Humanitarian aid: an agile supply chain? *International Journal of Physical Distribution & Logistics Management*, *39*(6), 486–505.

Othman, S. H., & Beydoun, G. (2010). A Disaster Management Metamodel (DMM) Validated. In B.-H. Kang & D. Richards (Eds.), *Knowledge Management and Acquisition for Smart Systems and Services* (pp. 111–125). Springer Berlin Heidelberg.

Paulk, M. C., Curtis, B., Chrissis, M. B., & Weber, C. V. (1993). Capability maturity model, version 1.1. *IEEE Software*, *10*(4), 18–27.

Pearce, L. D. R. (2000). *An integrated approach for community hazard, impact, risk and vulnerability analysis: HIRV*. The University of British Columbia.

Pettit, S., & Beresford, A. (2009). Critical success factors in the context of humanitarian aid supply chains. *International Journal of Physical Distribution & Logistics Management*, *39*(6), 450–468.

Pojasek, R. B. (2012). Understanding sustainability: An organizational perspective. *Environmental Quality Management*, *21*(3), 93–100.

Rastegar, N., & Khorram, E. (2014). Relaxation of constraints in lexicographic multiobjective programming problems. *Optimization: A Journal of Mathematical Programming and Operations Research*, *64*(10), 2111–2129.

Reefke, Ahmed, & Sundaram. (2014). Sustainable Supply Chain Management—Decision Making and Support: The SSCM Maturity Model and System. *Global Business Review*, *15*(4_suppl), 1S–12S.

Rentmeesters, M. J., Tsai, W. K., & Lin, K.-J. (1996). A theory of lexicographic multi-criteria optimization. In *Engineering of Complex Computer Systems, 1996. Proceedings., Second IEEE International Conference on* (pp. 76–79). IEEE.

Ripple, W. J., Wolf, C., Newsome, T. M., Galetti, M., Alamgir, M., Crist, E., et al. (2017). World Scientists' Warning to Humanity: A Second Notice. *BioScience*.

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*(4), 369–384.

Rodrigues da Silva, A. (2015). Model-driven engineering: A survey supported by the unified conceptual model. *Computer Languages, Systems & Structures*, *43*, 139–155.

Rudberg, M., & Thulin, J. (2009). Centralised supply chain master planning employing advanced planning systems. *Production Planning & Control*, *20*(2), 158–167.

Santiteerakul, S., Sekhari, A., Bouras, A., & Sopadang, A. (2015). Sustainability Performance Measurement Framework for Supply Chain Management. *ResearchGate*. Accessed 13 December 2016

Sarkis, J., Spens, K. M., & Kovács, G. (2012). Chapter 11: A Study of Barriers to Greening the Relief Supply Chain. In *Relief supply chain management for disasters: humanitarian aid and emergency logistics*. Hershey, PA: Information Science Reference.

Savitz, A. (2012). *The Triple Bottom Line: How Today's Best-Run Companies Are Achieving Economic, Social and Environmental Success -- and How You Can Too*. John Wiley & Sons.

Seuring, S., & Müller, M. (2005). Is there a right research design for your supply chain study? In *Research Methodologies in Supply Chain Management* (pp. 1–12). Springer.

Seuring, S., & Müller, M. (2008). Core issues in sustainable supply chain management - a Delphi study. *Business Strategy and the Environment*, *17*(8), 455–466. doi:10.1002/bse.607

Sherali, H. D. (1982). Equivalent weights for lexicographic multi-objective programs: Characterizations and computations. *European Journal of Operational Research*, *11*(4), 367–379.

Sisco, C., Chorn, B., & Pruzan-Jorgensen, P. M. (2015). *Supply Chain Sustainability, a practical guide for continuous improvement*. UN Global Compact. Accessed 16 November 2017

Srai, Alinaghian, & Kirkwood. (2013). Understanding sustainable supply network capabilities of multinationals: A capability maturity model approach. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *227*(4), 595–615.

Sridhar, K., & Jones, G. (2013). The three fundamental criticisms of the Triple Bottom Line approach: An empirical study to link sustainability reports in companies based in the Asia-Pacific region and TBL shortcomings. *Asian Journal of Business Ethics*, *2*(1), 91–111.

Stadtler, H. (2005). Supply chain management and advanced planning—basics, overview and challenges. *European Journal of Operational Research*, *163*(3), 575–588.

Stadtler, H., & Kilger, C. (Eds.). (2005). *Supply chain management and advanced planning: concepts, models, software and case studies* (3rd ed.). Berlin ; New York: Springer.

Sundarakani, B., de Souza, R., Goh, M., Wagner, S. M., & Manikandan, S. (2010). Modeling carbon footprints across the supply chain. *International Journal of Production Economics*, *128*(1), 43–50.

Swithern, S., Sardiwal, D., & GHA, team. (2015). *Global Humanitarian Assitance report 2015*. Global Humanitarian Assitance.

Taticchi, P., Garengo, P., Nudurupati, S. S., Tonelli, F., & Pasqualino, R. (2015). A review of decision-support tools and performance measurement and sustainable supply chain management. *International Journal of Production Research*, *53*(21), 6473–6494.

Taylor, D., & Pettit, S. (2009). A consideration of the relevance of lean supply chain concepts for humanitarian aid provision. *International Journal of Services Technology and Management*, *12*(4), 430–444.

Tomasini, R. M., & Van Wassenhove, L. N. (2009). From preparedness to partnerships: case study research on humanitarian logistics. *International Transactions in Operational Research*, *16*(5), 549–559.

Tzur, M. (2016, March 5). *The humanitarian pickup and distribution problem*. Presented at the EuroHope mini-conference, Hamburg.

UCSUSA. (2016). Hurricanes and Climate Change. *Union of Concerned Scientists*. Accessed 26 September 2017

UNISDR. (2009). Terminology on Disaster Risk Reduction. Accessed 24 September 2017

United Nations. (2011). *OCHA and Slow Onset Emergencies*. UN OCHA.

United Nations. (2015). *Sendai Framework for Disaster Risk Reduction 2015 - 2030*.

Uschold, M., & Gruninger, M. (1996). Ontologies: Principles, methods and applications. *The knowledge engineering review*, *11*(2), 93–136.

Van de Walle, B., & Comes, T. (2014). Risk Accelerators in Disasters; Insights from the Typhoon Haiyan Response on Humanitarian Information Management and Decision Support. *Disaster Resiliance Lab*.

Van Kempen, E. A., Spiliotopoulou, E., Stojanovski, G., & de Leeuw, S. (2017). Using life cycle sustainability assessment to trade off sourcing strategies for humanitarian relief items. *The International Journal of Life Cycle Assessment*, *22*(11), 1718–1730.

Van Wassenhove, L. N. (2006). Humanitarian aid logistics: supply chain management in high gear†. *Journal of the Operational Research Society*, *57*(5), 475–489.

Van Wassenhove, L. N., & Pedraza Martinez, A. J. (2012). Using OR to adapt supply chain management best practices to humanitarian logistics. *International Transactions in Operational Research*, *19*(1–2), 307–322.

Vargas Florez, J., Lauras, M., Okongwu, U., & Dupont, L. (2015). A decision support system for robust humanitarian facility location. *Engineering Applications of Artificial Intelligence*, *46*, 326–335.

Veleva, V., & Ellenbecker, M. (2001). Indicators of sustainable production: framework and methodology. *Journal of Cleaner Production*, *9*(6), 519–549.

Virakul, B. (2015). Global challenges, sustainable development, and their implications for organizational performance. *European Business Review*, *27*(4), 430–446.

Wei, X., Al-Refaie, A., Robles, M., & Noche, B. (2015). Chapter 11: A Sustainable Humanitarian Relief Network Study for the Wenchuan Earthquake. In *Humanitarian Logistics and Sustainability* (pp. 195–215). Springer.

Widera, A., Dietrich, H.-A., Hellingrath, B., & Becker, J. (2013). Understanding Humanitarian Supply Chains–Developing an Integrated Process Analysis Toolkit. In *10th International ISCRAM Conference*. Presented at the Information Systems for Crisis Response and Management, Baden-Baden.

Wray, K. H., Zilberstein, S., & Mouaddib, A.-I. (2015). Multi-Objective MDPs with Conditional Lexicographic Reward Preferences. In *Twenty-Ninth AAAI Conference on Artificial Intelligence* (pp. 3418–3424). Presented at the AAAI, Austin, Texas, USA: AAAI Press.

Zechtar, R., Kerr, T., Kossoy, A., Oppermann, K., Peszko, G., Ramstein, C., & Pritz, N. (2016). *State and Trends of Carbon Pricing 2016*. Washington: World Bank, Ecofys and Vivid Economics.

Zhou, H., Benton, W. C., Schilling, D. A., & Milligan, G. W. (2011). Supply Chain Integration and the SCOR Model. *Journal of Business Logistics*, *32*(4), 332–344.

LIST OF FIGURES

LIST OF TABLES

List of Abbreviations

APS	Advance Planning System
A&C RLU	American & Caribbean Regional Logistic Unit (IFRC)
BPM	Business Process Modeling
BPMN	Business Process Modeling Notation
ERP	Enterprise Resource Planning
GRI	Global Reporting Initiative
LCA	Life Cycle Assessment
LCSA	Life Cycle Social Assessment
LOM	Lexicographic Optimization Method
LU	Logistic Unit
HO	Humanitarian Organization
HSC	Humanitarian Supply Chain
SHSC	Sustainable Humanitarian Supply Chain
IASC	Inter-Agency Standing Committee
ICRC	International Committee of the Red Cross and the Red Crescent
ILOM	Interactive Lexicographic Optimization Method
IFRC	International Federation of the Red Cross and the Red Crescent
LO	Lexicographic Order
MSF	Médecins Sans Frontières / Doctors Without Borders
NGO	Non Governmental Organization
NS	Red Cross and Red Crescent National Society
OF	Optimization Function
OR	Operational Research
PADRU	Pan American Disaster Response Unit
RLU	Regional Logistic Unit
SC	Supply Chain
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SSCM	Sustainable Supply Chain Management
TBL	Triple Bottom Line

UNDP	United Nations Humanitarian Development Programme
UNHRD	United Nations Humanitarian Response Depots
UNOCHA	United Nations Coordination of Humanitarian Affairs
UNISDR	United Nations International Strategy for Disaster Reduction
UN	United Nations
VSM	Value Stream Mapping
WFP	World Food Programme
3PL	Third Party Logistics

APPENDIX A. INVENTORY AT THE A&C RLU

(September 2015)

	RLU- Panama		Guatemala		Nicaragua		Honduras		Ecuador		Total	
Standard items	Qty.	Value	Qty.2	Value3	Qty.3	Value4	Qty.4	Value5	Qty.5	Value6	Qty.	Value
Blanket light thermal	21003	87582.51	2025	10003.5	5000	23950	2500	11861.75	5000		35528	133397.76
Blanket medium thermal	4443	17389.72					2500	12950			6943	30339.72
Bucket plastic	5281	15853.12	500	1757.5				0			5781	17610.62
Family tent	316	112173.74					50	15061.5			366	127235.24
Hygiene kit	2451	43241.04	275	6437.75	850	19771	1000	23240	1000		5576	92689.79
Jerrycan	0	0	0	0	1700	4726	2000	5539.68	2000		5700	10265.68
Kitchen set	6436	140695.28	275	5898.75	850	19541.5	1000	22970	1000		9561	189105.53
Mosquito net	2200	5544	1000	3550	2000	5760	2000	5720	2000		9200	20574
Shelter tool kit	4732	124956.96	500	11435			250	7041.09	500		5982	143433.05
Tarpaulin	8395	105329.22	0	0	1550	16910.5	2000	21780	1000		12945	144019.72
Total of per country (CHF)		652765.59		39082.5		90659		126164.02				908671.11
											Holding costs (10%)	90867.111

APPENDIX B. USE CASE INPUT DATA SAMPLES

a) **Suppliers Data**

#	Supplier Typology	Supplier	Item	Factory price par unit (CHF)	Supply capacity par week
1001	International	Relief Supplier A	Blanket light thermal	6	12000
1002	International	Relief Supplier B	Blanket light thermal	5	13750
1003	International	Relief Supplier C	Blanket light thermal	7	9900
1006	International	Relief Supplier D	Family tent	150	2000
1009	International	Relief Supplier E	Family tent	160	2000
1009	International	Relief Supplier E	Blanket light thermal	6	1200
1010	International	Relief Supplier F	Family tent	170	3000
1011	International	Relief Supplier G	Blanket light thermal	6	5000
1012	Regional	Panama Supplier	Blanket light thermal	8	6000
1012	Regional	Panama Supplier	Family tent	300	1000
1013	Local	Nicaragua Supplier	Family tent	250	500
1014	Local	Colombia Supplier	Family tent	250	500
1014	Local	Colombia Supplier	Blanket light thermal	7	5000
1015	Local	Honduras Supplier	Blanket light thermal	7	5000
1016	Local	Guatemala Supplier	Blanket light thermal	7	5000
1017	Local	Dominican Rep Supplier	Blanket light thermal	7	5000
1018	Local	Costa Rica Supplier	Blanket light thermal	7	5000
1013	Local	Nicaragua Supplier	Blanket light thermal	7	5000

b) **Inventory input data of LUs and the RLU**

	#	National Society	Blanket Contingency Stock	Family tent Contingency Stock
1	2001	RLU Panama	40000	10000
2	2002	LU Colombia	20000	5000
3	2003	LU Nicaragua	8000	2000
4	2004	LU Honduras	20000	5000
5	2005	LU FR Guadelpoue	20000	5000
6	2006	LU Guatemala	8000	2000
7	2007	LU Dominican Rep	8000	2000
8	2008	LU Costa Rica	8000	2000

c) Demand input data

	Demanding point	Item	⚠	Week +1	Week +2	Week +3	Week +4	Week +5	Week +6	Week +7
cid			cpen	cqua						
3001	R Dominicana DP	blanket	1.5	2000	0	0	0	2000	0	0
3001	R Dominicana DP	Family tent	1.5	500	0	0	0	500	0	0
3002	Nicaragua North DP	blanket	1.5	0	5000	0	3000	0	1000	0
3002	Nicaragua North DP	Family tent	1.5	0	1000	0	700	0	500	0
3003	Nicaragua South DP	blanket	1.5	9000	0	0	0	0	5000	0
3003	Nicaragua South DP	Family tent	1.5	2000	0	0	0	0	1000	0
3004	Honduras DP	blanket	1.5	0	6000	0	0	0	0	5000
3004	Honduras DP	Family tent	1.5	0	1500	0	0	0	0	1000
3005	Colombia DP	blanket	1.25	7500	0	0	0	5000	0	0
3005	Colombia DP	Family tent	1.25	1500	0	0	0	1000	0	0
3006	Guatemala DP	blanket	1.25	0	0	9000	0	0	0	9000
3006	Guatemala DP	Family tent	1.25	0	0	3000	0	0	0	3000
3007	Haiti DP	blanket	1.5	20000	10000	0	0	0	0	0
3007	Haiti DP	Family tent	1.5	5000	5000	0	0	0	0	0
3008	Haiti NGO DP	blanket	1.1	0	2000	0	0	0	2500	0
3008	Haiti NGO DP	Family tent	1.1	0	500	0	0	0	600	0

	Demanding point	Item	⚠	Week +8	Week +9	Week +10	Week +11	Week +12
cid			cpen					
3001	R Dominicana DP	blanket	1.5	0	2000	0	0	0
3001	R Dominicana DP	Family tent	1.5	0	500	0	0	0
3002	Nicaragua North DP	blanket	1.5	0	0	0	1000	0
3002	Nicaragua North DP	Family tent	1.5	0	0	0	500	0
3003	Nicaragua South DP	blanket	1.5	0	0	5000	0	0
3003	Nicaragua South DP	Family tent	1.5	0	0	1000	0	0
3004	Honduras DP	blanket	1.5	0	0	0	5000	0
3004	Honduras DP	Family tent	1.5	0	0	0	1000	0
3005	Colombia DP	blanket	1.25	0	5000	0	0	0
3005	Colombia DP	Family tent	1.25	0	1000	0	0	0
3006	Guatemala DP	blanket	1.25	0	0	0	9000	0
3006	Guatemala DP	Family tent	1.25	0	0	0	3000	0
3007	Haiti DP	blanket	1.5	5000	0	0	0	0
3007	Haiti DP	Family tent	1.5	1000	0	0	0	0
3008	Haiti NGO DP	blanket	1.1	0	0	2000	0	0
3008	Haiti NGO DP	Family tent	1.1	0	0	500	0	0

1d) Flows input data from suppliers to RLU and LUs

								Times	
#Origin	#Destination	Mode	Lead-time (week)	Product	Environmental cost (CHF) /unit	Economic cost (CHF)/unit	Local origin? (1=Yes)	1	2
fori	fdes		ftlt		fenv	fcost	fsoc	fexp	
1001	2001	Sea	3	Blanket	0.0182	5.011	0	0	0
1012	2001	Road	0	Blanket	0.0004	8.005	1	0	0
1002	2001	Sea	5	Blanket	0.0155	5.010	0	0	0
1012	2001	Road	0	Family tent	0.0359	320.440	1	0	0
1006	2001	Sea	3	Family tent	1.6066	221.001	0	0	0
1009	2001	Sea	3	Family tent	1.4618	240.911	0	0	0
1009	2001	Sea	3	Blanket	0.0165	5.010	0	0	0
1010	2001	Air	0	Family tent	105.2700	369.500	0	0	0
1003	2001	Sea	4	Blanket	0.0091	5.006	0	0	0
1011	2001	Air	0	Blanket	1.1867	6.798	0	0	0
1013	2003	Road	0	Blanket	0.0003	7.503	1	0	0
1014	2002	Road	0	Family tent	0.0224	300.275	1	0	0
1013	2003	Road	0	Family tent	0.0224	300.275	1	0	0
1014	2002	Road	0	Blanket	0.0003	7.503	1	0	0
1015	2004	Road	0	Blanket	0.0003	7.503	1	0	0
1016	2006	Road	0	Blanket	0.0003	7.503	1	0	0
1017	2007	Road	0	Blanket	0.0003	7.503	1	0	0
1018	2008	Road	0	Blanket	0.0003	7.503	1	0	0

Flows input data between the RLU and LUs

								Times	
#Origin	#Destination	Mode	Lead-time (week)	Product	Environmental cost (CHF) /unit	Economic cost (CHF)/unit	Local origin? (1=Yes)	1	2
fori	fdes		ftlt		fenv	fcost	fsoc	fexp	
2001	2002	Air	1	Blanket	0.0622	0.094	0	0	0
2001	2003	Air	1	Blanket	0.0697	0.106	0	0	0
2001	2004	Air	1	Blanket	0.0871	0.132	0	0	0
2001	2005	Air	1	Blanket	0.1763	0.267	0	0	0
2001	2006	Air	1	Blanket	0.1146	0.174	0	0	0
2001	2007	Air	1	Blanket	0.1250	0.189	0	0	0
2001	2008	Air	1	Blanket	0.0414	0.063	0	0	0
2001	2002	Multi	2	Blanket	0.0058	0.067	0	0	0
2001	2005	Sea	2	Blanket	0.0007	0.005	0	0	0
2001	2007	Sea	2	Blanket	0.0007	0.005	0	0	0
2001	2003	Road	1	Blanket	0.0058	0.071	0	0	0
2001	2004	Road	1	Blanket	0.0086	0.105	0	0	0
2001	2006	Road	1	Blanket	0.0111	0.136	0	0	0
2001	2008	Road	1	Blanket	0.0045	0.056	0	0	0
2003	2001	Air	1	Blanket	0.0697	0.106	0	0	0
2004	2001	Air	1	Blanket	0.0871	0.132	0	0	0
2005	2001	Air	1	Blanket	0.1763	0.267	0	0	0
2006	2001	Air	1	Blanket	0.1146	0.174	0	0	0
2007	2001	Air	1	Blanket	0.1250	0.189	0	0	0
2008	2001	Air	1	Blanket	0.0414	0.063	0	0	0
2005	2001	Sea	2	Blanket	0.0023	0.015	0	0	0
2007	2001	Sea	2	Blanket	0.0016	0.010	0	0	0
2003	2001	Road	1	Blanket	0.0058	0.071	0	0	0
2004	2001	Road	1	Blanket	0.0086	0.105	0	0	0
2006	2001	Road	1	Blanket	0.0111	0.136	0	0	0
2008	2001	Road	1	Blanket	0.0045	0.056	0	0	0
2003	2004	Road	1	Blanket	0.0020	0.025	0	0	0
2004	2003	Road	1	Blanket	0.0020	0.025	0	0	0
2006	2004	Road	1	Blanket	0.0033	0.040	0	0	0
2004	2006	Road	1	Blanket	0.0033	0.040	0	0	0
2003	2008	Road	1	Blanket	0.0021	0.026	0	0	0
2008	2003	Road	1	Blanket	0.0021	0.026	0	0	0
2005	2007	Sea	2	Blanket	0.0009	0.006	0	0	0
2007	2005	Sea	2	Blanket	0.0009	0.006	0	0	0
2001	2002	Air	1	Family tent	5.5176	8.360	0	0	0
2001	2003	Air	1	Family tent	6.1855	9.372	0	0	0
2001	2004	Air	1	Family tent	7.7246	11.704	0	0	0
2001	2005	Air	1	Family tent	15.6380	23.694	0	0	0
2001	2006	Air	1	Family tent	10.1640	15.400	0	0	0
2001	2007	Air	1	Family tent	11.0860	16.797	0	0	0
2001	2008	Air	1	Family tent	3.6736	5.566	0	0	0
2001	2002	Multi	2	Family tent	0.5141	5.911	0	0	0
2001	2005	Sea	2	Family tent	0.2076	1.294	0	0	0
2001	2007	Sea	2	Family tent	0.1430	0.891	0	0	0
2001	2003	Road	1	Family tent	0.5154	6.325	0	0	0
2001	2004	Road	1	Family tent	0.7618	9.350	0	0	0
2001	2006	Road	1	Family tent	0.9859	12.100	0	0	0
2001	2008	Road	1	Family tent	0.4033	4.950	0	0	0
2002	2001	Air	1	Family tent	5.5176	8.360	0	0	0
2003	2001	Air	1	Family tent	6.1855	9.372	0	0	0
2004	2001	Air	1	Family tent	7.7246	11.704	0	0	0
2005	2001	Air	1	Family tent	15.6380	23.694	0	0	0
2006	2001	Air	1	Family tent	10.1640	15.400	0	0	0
2007	2001	Air	1	Family tent	11.0860	16.797	0	0	0
2008	2001	Air	1	Family tent	3.6736	5.566	0	0	0
2002	2001	Multi	2	Family tent	0.5141	5.911	0	0	0
2005	2001	Sea	2	Family tent	0.2076	1.294	0	0	0
2007	2001	Sea	2	Family tent	0.1430	0.891	0	0	0
2003	2001	Road	1	Family tent	0.5154	6.325	0	0	0
2004	2001	Road	1	Family tent	0.7618	9.350	0	0	0
2006	2001	Road	1	Family tent	0.9859	12.100	0	0	0
2008	2001	Road	1	Family tent	0.4033	4.950	0	0	0
2003	2004	Road	1	Family tent	0.1793	2.200	0	0	0
2004	2003	Road	1	Family tent	0.1793	2.200	0	0	0
2006	2004	Road	1	Family tent	0.2913	3.575	0	0	0
2004	2006	Road	1	Family tent	0.2913	3.575	0	0	0
2003	2008	Road	1	Family tent	0.1882	2.310	0	0	0
2008	2003	Road	1	Family tent	0.1882	2.310	0	0	0
2005	2007	Sea	2	Family tent	0.0826	0.515	0	0	0
2007	2005	Sea	2	Family tent	0.0826	0.515	0	0	0

Flows input data from RLU and LUs to Demanding Points

								Times	
#Origin	#Destination	Mode	Lead-time (week)	Product	Environmental cost (CHF) /unit	Economic cost (CHF)/unit	Local origin? (1=Yes)	1	2
fori	fdes		ftlt		fenv	fcost	fsoc	f exp	
2001	3005	Sea	2	Blanket	0.0010	0.006	0	0	0
2002	3005	Road	1	Blanket	0.0045	0.056	1	5000	0
2001	3008	Sea	2	Blanket	0.0016	0.010	0	0	2000
2001	3008	Air	1	Blanket	0.1115	0.169	0	0	0
2001	3008	Sea	2	Family tent	0.1430	0.891	0	0	500
2001	3008	Air	1	Family tent	9.8954	14.993	0	0	0
2001	3007	Sea	2	Blanket	0.0016	0.010	0	0	0
2001	3007	Air	1	Blanket	0.1115	0.169	0	0	0
2001	3005	Sea	2	Family tent	0.0860	0.536	0	0	0
2001	3005	Air	1	Blanket	0.0597	0.091	0	0	0
2001	3005	Air	1	Family tent	5.2998	8.030	0	0	0
2002	3005	Road	1	Family tent	0.4033	4.950	1	1000	0
2001	3007	Sea	2	Family tent	0.1430	0.891	0	0	0
2001	3007	Air	1	Family tent	9.8954	14.993	0	0	0
2007	3007	Road	1	Blanket	0.0015	0.019	1	0	0
2005	3007	Sea	2	Blanket	0.0016	0.010	0	0	0
2007	3007	Road	1	Family tent	0.1344	1.650	1	0	0
2005	3007	Sea	2	Family tent	0.1391	0.867	0	0	0
2001	3002	Air	1	Family tent	5.0820	7.700	0	0	0
2001	3003	Air	1	Family tent	5.0820	7.700	0	0	0
2001	3002	Air	1	Blanket	0.0573	0.087	0	0	0
2001	3003	Air	1	Blanket	0.0573	0.087	0	0	0
2004	3002	Road	1	Family tent	0.3137	3.850	1	0	0
2004	3003	Road	1	Family tent	0.3137	3.850	1	0	0
2004	3002	Road	1	Blanket	0.0035	0.043	1	0	0
2004	3003	Road	1	Blanket	0.0035	0.043	1	0	0
2003	3002	Road	1	Family tent	0.2317	2.844	1	0	0
2003	3003	Road	1	Family tent	0.1631	2.002	1	1000	0
2003	3004	Road	1	Blanket	0.0020	0.025	1	0	0
2006	3004	Road	1	Blanket	0.0033	0.040	0	0	0
2003	3004	Road	1	Family tent	0.1793	2.200	1	0	0
2006	3004	Road	1	Family tent	0.2913	3.575	0	0	0
2001	3004	Air	1	Blanket	0.0871	0.132	0	0	0
2001	3004	Air	1	Family tent	7.7246	11.704	0	0	0
2004	3004	Road	1	Blanket	0.0020	0.025	1	0	0
2005	3001	Sea	2	Blanket	0.0009	0.006	0	0	0
2005	3001	Sea	2	Blanket	0.0009	0.006	0	0	0
2001	3001	Sea	1	Blanket	0.0016	0.010	0	0	0
2001	3001	Sea	1	Family tent	0.1430	0.891	0	0	0
2001	3001	Air	1	Blanket	0.1250	0.189	0	0	0
2001	3001	Air	1	Family tent	11.2312	17.017	0	0	0
2007	3001	Road	1	Blanket	0.0011	0.014	1	2000	0
2007	3008	Road	2	Blanket	0.0015	0.019	1	0	0
2005	3008	Sea	2	Blanket	0.0016	0.010	0	0	0
2003	3002	Road	1	Blanket	0.0026	0.032	1	0	0
2003	3003	Road	1	Blanket	0.0018	0.023	1	5000	0
2004	3006	Road	1	Family tent	0.3137	3.850	1	0	0
2004	3006	Road	1	Blanket	0.0035	0.043	1	0	0
2006	3006	Road	1	Family tent	0.0448	0.550	0	0	0
2006	3006	Road	1	Blanket	0.0005	0.006	0	0	0
2001	3006	Air	1	Family tent	9.4380	14.300	0	0	0
2001	3006	Air	1	Blanket	0.1064	0.161	0	0	0
2007	3008	Road	2	Family tent	0.1344	1.650	1	0	0
2005	3008	Sea	2	Family tent	0.1391	0.867	0	0	0
2004	3004	Road	1	Family tent	0.1793	2.200	1	0	0
2007	3001	Road	1	Family tent	0.0986	1.210	1	500	0
2001	3004	Road	1	Blanket	0.0086	0.105	0	0	0
2001	3004	Road	1	Family tent	0.7618	9.350	0	0	0

APPENDIX C. USE CASE OUTPUT DATA SAMPLES

Flows result (OUT) sample from suppliers to RLU and LUs

				Time											
#Origin	#Destination	Mode	Product	1	2	3	4	5	6	7	8	9	10	11	12
fori	fdes			Fout											
1001	2001	Sea	Blanket	12000	7574	0	0	0	0	0	0	0	0	0	0
1012	2001	Road	Blanket	6000	3726	0	0	0	0	0	0	0	0	0	0
1002	2001	Sea	Blanket	0	0	0	0	0	0	0	0	0	0	0	0
1012	2001	Road	Family tent	1000	1000	1000	1000	1000	92	0	0	0	0	0	0
1006	2001	Sea	Family tent	2000	2000	2000	2000	2000	2000	2000	0	0	0	0	0
1009	2001	Sea	Family tent	2000	2000	2000	1101	500	0	0	0	0	0	0	0
1009	2001	Sea	Blanket	1200	1200	0	0	0	0	0	0	0	0	0	0
1010	2001	Air	Family tent	1607	0	0	0	0	0	0	0	0	0	0	0
1003	2001	Sea	Blanket	9900	9900	5200	9900	9900	0	0	0	0	0	0	0
1011	2001	Air	Blanket	5000	0	0	0	0	0	0	0	0	0	0	0
1013	2003	Road	Blanket	5000	0	0	0	0	0	0	0	0	0	0	0
1014	2002	Road	Family tent	500	500	500	500	500	0	0	0	0	0	0	0
1013	2003	Road	Family tent	500	500	500	500	500	500	0	0	0	0	0	0
1014	2002	Road	Blanket	2500	0	0	0	0	0	0	0	0	0	0	0
1015	2004	Road	Blanket	5000	4000	0	0	0	0	0	0	0	0	0	0
1016	2006	Road	Blanket	5000	5000	0	0	0	0	0	0	0	0	0	0
1017	2007	Road	Blanket	5000	5000	0	0	0	0	0	0	0	0	0	0
1018	2008	Road	Blanket	5000	0	0	0	0	0	0	0	0	0	0	0

Flows result sample (IN) from suppliers to RLU and LUs

				Time											
#Origin	#Destination	Mode	Product	1	2	3	4	5	6	7	8	9	10	11	12
fori	fdes			Fin											
1001	2001	Sea	Blanket	0	0	0	12000	7574	0	0	0	0	0	0	0
1012	2001	Road	Blanket	6000	3726	0	0	0	0	0	0	0	0	0	0
1002	2001	Sea	Blanket	0	0	0	0	0	0	0	0	0	0	0	0
1012	2001	Road	Family tent	1000	1000	1000	1000	1000	92	0	0	0	0	0	0
1006	2001	Sea	Family tent	0	0	0	2000	2000	2000	2000	2000	2000	2000	0	0
1009	2001	Sea	Family tent	0	0	0	2000	2000	2000	1101	500	0	0	0	0
1009	2001	Sea	Blanket	0	0	0	1200	1200	0	0	0	0	0	0	0
1010	2001	Air	Family tent	1607	0	0	0	0	0	0	0	0	0	0	0
1003	2001	Sea	Blanket	0	0	0	0	9900	9900	5200	9900	9900	0	0	0
1011	2001	Air	Blanket	5000	0	0	0	0	0	0	0	0	0	0	0
1013	2003	Road	Blanket	5000	0	0	0	0	0	0	0	0	0	0	0
1014	2002	Road	Family tent	500	500	500	500	500	0	0	0	0	0	0	0
1013	2003	Road	Family tent	500	500	500	500	500	500	0	0	0	0	0	0
1014	2002	Road	Blanket	2500	0	0	0	0	0	0	0	0	0	0	0
1015	2004	Road	Blanket	5000	4000	0	0	0	0	0	0	0	0	0	0
1016	2006	Road	Blanket	5000	5000	0	0	0	0	0	0	0	0	0	0
1017	2007	Road	Blanket	5000	5000	0	0	0	0	0	0	0	0	0	0
1018	2008	Road	Blanket	5000	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D. MODEL

```
Lingo Main Model:

! SETS DECLARATION;

Sets:
   Times:;
   Flow                                                                    :
fori,fdes,fpro,ftlt,fope,fcost,fitc,fsoc,fenv,Ftcost,Ftimp,Ftloc;
   MatFT(Flow, Times): fexp,Fout,Fin;
   Supplier:sid,spro;
   MatST(Supplier,Times): ssca,Sout;
   Warehouse:wid,wpro,wini,wunc,wreq,Wtpen,Wavg,Wtavg;
   MatWT(Warehouse,Times): Winv,Wsto,Wove;
   Customer:cid,cpro,cunc,Ctpen,cpen,Ctrec,Ctqua,Ctsto;
   MatCT(Customer,Times): cqua,Cin,Csto,Cove;
   Lexicographic:;
   Test:eff_tol,soc_tol,env_tol,eco_tol;
    MatLT(Test,Lexicographic):eff_cons,soc_cons,env_cons,eco_cons,eff_ind
    ic,soc_indic,env_indic,eco_indic,eff_init,soc_init,env_init,eco_init;

   Cell/1..1/: ;

EndSets

!.........................................................
.                    SUB MODELS                          .
!.........................................................;

! Sub models list
1. GENERAL CONSTRAINTS SUB MODELS
1. INDICATORS
2. EFFICACY OPTIMIZATION
3. SOCIAL IMPACT OPTIMIZATION
4. ECONOMY IMPACT OPTIMIZATION
5. ENVIRONMENT IMPACT OPTIMIZATION
6. EFFICACY CONSTRAINT
```

```
7. SOCIAL COSNTRAINT
8. ECONOMY CONSTRAINT
9. ENVIRONMENT CONSTRAINT

!******* 1. GENERAL CONSTRAINTS SUB MODELS **************;

SubModel Constraints:

! Numbero of time periods;
      NT=@SIZE(Times);

! FlOWS CONSERVATION
      @for(MatFT(f,t)|t#LE#ftlt(f):Fin(f,t)=fexp(f,t));
      @for(MatFT(f,t)|t#GT#ftlt(f):Fin(f,t)=fout(f,t-
ftlt(f))+fexp(f,t));
      @for(MatFT(f,t)|t#GT#(NT-ftlt(f)):fout(f,t)=0);

! SUPPLIERS
! supplier balance, or flow conservation;
      @for(MatST(s,t):
            Sout(s,t)=@sum(MatFt(f,t)|(fori(f)#EQ#sid(s))          #AND#
            (fpro(f)#EQ#spro(s)): Fout(f,t)));
! supply capacity constraint;
      @for(MatST(s,t):Sout(s,t)<=ssca(s,t));

! WAREHOUSE;

! warehouse balance, or flow conservation;

      @for(MatWT(w,t)|t#EQ#1:
            wini(w)+                  @sum(Flow(f)|fdes(f)#EQ#wid(w)#AND#
      fpro(f)#EQ#wpro(w): Fin(f,1))=
            Winv(w,1)+@sum(Flow(f)|(fori(f)#EQ#wid(w))             #AND#
            (fpro(f)#EQ#wpro(w)):Fout(f,1)));



      @for(MatWT(w,t)|t#GT#1:
            Winv(w,t-1)+@sum(Flow(f)|(fdes(f)#EQ#wid(w))           #AND#
      (fpro(f)#EQ#wpro(w)):Fin(f,t))=
            Winv(w,t)+@sum(Flow(f)|(fori(f)#EQ#wid(w))             #AND#
            (fpro(f)#EQ#wpro(w)):Fout(f,t)));
```

```
! warehouse contingency stock constraint;

      @for(MatWT(w,t): Winv(w,t)-wreq(w)=Wove(w,t)-Wsto(w,t));

      @for(MatWT(w,t): Winv(w,NT)=wreq(w));

! CUSTOMERS;
      ! Total needs value over the periode:;
      @for(Customer(c): ctqua(c)=@sum(Times(t):cqua(c,t))*cunc(c));

      ! Total received value:;
      @for(Customer(c): Ctrec(c)=@sum(Times(t):Cin(c,t))*cunc(c));

      ! Total stockout value over the periode:;
      @for(Customer(c): ctsto(c)=@sum(Times(t):csto(c,t))*cunc(c));

      ! Customer balance
      @for(MatCT(c,t):Cin(c,t)=
      @sum(Flow(f)|(fdes(f)#EQ#cid(c))     #AND#     (fpro(f)#EQ#cpro(c)):
Fin(f,t)));

      @for(MatCT(c,t)|t#EQ#1:Cin(c,1)+Csto(c,1)=Cqua(c,1)+Cove(c,1));
      @for(MatCT(c,t)|t#GT#1:Cin(c,t)+Csto(c,t)=Cqua(c,t)+Cove(c,t)+Csto
      (c,t-1)-Cove(c,t-1));

      @for(Customer(c): Ctqua(c)=@sum(Times(t):Cin(c,t)*cunc(c)));

! EQUITY CONSTRAINT;
      @for(Customer(c)|(cpen(c)#EQ#1.5) :
      Ctsto(c)/ctqua(c)<(@sum(Customer(c):Ctsto(c))/@sum(Customer(c):ctqu
      a(c)))+0.1);

      @for(Customer(c)|(cpen(c)#EQ#1.5) :

      Ctsto(c)/ctqua(c)>(@sum(Customer(c):Ctsto(c))/@sum(Customer(c):ctq
ua(c)))-0.1);

! OBJECTIVE FUNCTIONS CONSTRAINTS;

!effectiveness:

!Ctpen calculation _ Penalty of the stockout par customer and product;
```

```
@for(Customer(c):Ctpen(c)=@sum(Times(t):((Cpen(c)*Csto(c,t))+Cove(c,t))*
cunc(c)));

!Wtpen calculation _ Penalty of the stockout par warehouse and product;
@for(Warehouse(w):Wtpen(w)=@sum(Times(t):(Wsto(w,t)+Wove(w,t))*wunc(w)))
;
EndSubModel

SubModel Indicators:

Effective=@sum(Customer(c):Ctqua(c)*cpen(c))-
@sum(Customer(c):Ctpen(c)/NT)+@sum(Warehouse(w):Wreq(w)*wunc(w))-
@sum(Warehouse(w):Wtpen(w)/NT);

! Maximize local suppliers volume, considering the expected commands
(fin);
Social=@sum(MatFT(f,t):(Fin(f,t)*fsoc(f)*fcost(f)));

Environment=@sum(MatFT(f,t):(Fin(f,t)*fenv(f)));

Economy=@sum(MatFT(f,t):(Fin(f,t)*fcost(f)));

EndSubModel

!*********** 2. EFFECTIVENESS OPTIMIZATION *****************;

SubModel EffectOpt:

max=Effective;

EndSubModel

!********* 3. SOCIAL IMPACT OPTIMIZATION ****************;

SubModel SocialOpt:

max=Social;

EndSubModel

!********* 4. ECONOMY IMPACT OPTIMIZATION ****************;
```

```
SubModel EconomyOpt:

min=Economy;

EndSubModel

!********* 5. ENVIRONMENT IMPACT OPTIMIZATION ***************;

SubModel EnvironmentOpt:

min=Environment;

EndSubModel

!********* 6. EFFECTIVENESS CONSTRAINT ***************************;

SubModel EffConstraint:

Effective>=eff_cons(1,6)-(eff_cons(1,6)*eff_tol(testn));

EndSubModel

!********* 7. SOCIAL CONSTRAINT ***************************;

SubModel SocConstraint:

Social>=soc_cons(testn,ord)-(soc_cons(testn,ord)*soc_tol(testn));

EndSubModel

!********* 8. ECONOMY CONSTRAINT ***************************;

SubModel EcoConstraint:

Economy<=eco_cons(testn,ord)*(1+eco_tol(testn));

EndSubModel

!********* 9. ENVIRONMENT CONSTRAINT *************************;
```

```
SubModel EnvConstraint:
!equal or lower than the constraint;

Environment<=1+@floor(env_cons(testn,ord)*(1+env_tol(testn)));

EndSubModel

SubModel vide:

EndSubModel
```

Towards a Sustainable Humanitarian Supply Chain: Characterization, Assessment and Decision-support

Abstract. The Humanitarian supply Chain is a key element to enhance a performing response to humanitarian crisis. Because of the internal and external pressure, Humanitarian Organizations (HO) has done efforts during last decades to improve the crisis response in terms of effectiveness and efficiency. However, the performance is challenged by the increasing gap between funding and needs. The main donors ask for more transparency and accountability. Moreover, the pressure from the international community is pushing HO to integrate Sustainability challenges on a near future. Is in this context, and field research results, that the difficulties to consider sustainability on HSC decision-making. The lack of Decision Support Systems and a sustainability culture specific to the HSC have been identified as break to improve the planning of sustainable humanitarian operations. This research work seeks to introduce the sustainability notion to the management of the HSC. The approach followed is the development of a decision support system based on performance, to plan the HSC operations. Three research directions have been explored:

(a) How to gather an exhaustive knowledge of a HSC, for both field research and development of DSS? The proposed contribution is a Meta-Model of the HSC, for field research porpoise and for developing adequate Decision Support Systems.

(b) What sustainability means in HSC context? Based on a literature review and field research, a framework is established to define the HSC sustainable performance.

(c) How to make sustainable decisions during humanitarian response? This contribution is based on an Operational Research Algorithm, which permits to integrate the sustainable performance on decision making with an interactive approach. The thesis illustrates the three contributions with use cases based on the International Federation of the Red Cross (IFRC).

Keywords. Humanitarian Supply Chains, Decision-support, Tactical planning, Crisis management, Sustainability

Vers une chaîne logistique humanitaire durable : caractérisation, évaluation et aide à la décision

Résumé. La chaîne logistique humanitaire (CLH) est essentielle pour assurer une réponse performante aux crises humanitaires. Les Organisations Humanitaires (OH) ont fait des efforts pendant les dernières décennies afin d'améliorer la réponse à la crise en termes d'efficience et d'efficacité. Tout de même, la performance est mise à l'épreuve dû au manque de fonds, et à l'augmentation des besoins humanitaires, le delta ne cessant pas de s'accroître. Les principaux donateurs exigent de plus en plus de transparence et de justification des dépenses. De plus, la pression de l'opinion publique et de la communauté internationale amène les OH à prendre en compte les enjeux du développement durable dans un futur proche. C'est dans ce contexte, et avec des études au terrain, qu'on a pu constater les difficultés pour intégrer le développent durable dans la prise de décision de la CLH. Le manque d'outils d'aide à la décision ainsi qu'une culture du développement durable spécifique à la CLH sont identifiés comme des freins pour améliorer la planification durable des opérations humanitaires. Le travail de recherche cherche à introduire la notion de développement durable dans la gestion des réseaux logistiques humanitaires. L'approche retenue est le développement d'un système d'aide à la décision basé sur la performance pour planifier les opérations de la CLH. Dans ce sens, trois directions de recherche ont été explorées :

(a) Comment recueillir une connaissance exhaustive de la CLH pour la recherche terrain ainsi que pour développer des Systèmes d'Aide à la Décision adéquats ? La contribution proposée est une méthodologie pour la recherche terrain qui s'appuie sur un Meta-Modèle de la CLH.

(b) Qu'est-ce que la durabilité signifie dans le contexte de CLH ? En base à une revue littéraire ainsi qu'aux recherches terrain, on a établi un cadre pour définir la performance durable d'une CLH.

(c) Comment prendre des décisions durables au cours de la réponse humanitaire ? Cette contribution est basée sur un algorithme de Recherche Opérationnelle qui permet d'intégrer la performance durable dans la prise de décision avec une approche interactive.

La thèse illustre les trois contributions avec des études de cas basées sur la CLH de la IFRC.

Mots-clés. Chaîne d'approvisionnement humanitaire, Aide à la décision, Planification tactique, Gestion des crises, Développement durable