A Framework for the Integration of Volunteered Geographic Information into Humanitarian Logistics

Completed Research Paper

Flávio E. A. Horita
Department of Computer Systems, ICMC
University of São Paulo
São Carlos/SP, Brazil
horita@icmc.usp.br

Daniel Link
European Research Center for Information Systems, ERCIS
University of Münster
Münster, Germany
daniel.link@ercis.uni-munster.de

João Porto de Albuquerque
Department of Computer Systems, ICMC, University of São Paulo, Brazil
GIScience Chair, Institute Geography, Heidelberg University, Germany
jporto@icmc.usp.br

Bernd Hellingrath
European Research Center for Information Systems, ERCIS
University of Münster
Münster, Germany
bernd.hellingrath@ercis.uni-munster.de

Abstract

Humanitarian logistics is a major factor for the success of humanitarian operations, making use of a broad range of infrastructure and resources in highly unstable and volatile environments. Due to the need for accuracy and timeliness, the information must be updated and related to the real variables of the affected area. In this context, volunteered geographic information (VGI), providedby local members of non-governmental organizations or individual citizens,emerges as an important information source. This paper presents a conceptual framework to link supply chain management (SCM) processes of humanitarian organizations with VGI, in order to assist the identification of information about infrastructure and resources that are needed by humanitarian SCM processes, and to supply better sources of information fulfilling the needs. The framework's central component is the Humanitarian Logistics Infrastructure and Resource Model, which can be used to encapsulate information and facilitate the cross-linking of SCM and VGI systems.

Keywords

Volunteered Geographic Information, Humanitarian Logistics, Logistics Infrastructure, Resource Model, Supply Chain Management.

Introduction

"Humanitarian logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods, materials and equipment as well as related information, from point of

origin to point of consumption for the purpose of meeting the beneficiary's requirements" (Blecken, 2010). To fulfill its tasks, humanitarian logistics makes use of a broad range of infrastructure and resources, such as roads or trucks. It is vital for the success of humanitarian logistics operations that the condition of required infrastructure is sufficient and that the needed resources are available. For instance, an airplane might arrive at its destination and find it cannot be unloaded because it does not have a ramp and there is no high-loader available; or an arterial road turns out to be blockedduring the delivery of relief goods, resulting in a detour and thus a higher delivery time.

So-called assessments aim to collect timely and accurate information about the disaster site, in order to minimize the likelihood of the aforementioned problems and to provide a decision base for planning(Tufinkgi, 2006; Blecken, 2010). The geographic context of the information is essential, e.g. when non-paved roads become muddy and impassable during the rainy season. Much of this information is hard to come by from afar, and the capacity of field assessment teams is limited. The emergence of Web 2.0 and the evolution of mobile devices haveled to the rise of Volunteered geographic information (VGI), where local members of non-governmental organizations or individual citizens act as sensors. VGI generally has proved to be more detailed, updated and faster than information provided by official and traditional ways(Goodchild 2007; Elwood 2008; De Longueville et al. 2010; Gill and Bunker 2012). In the domain of humanitarian logistics, a volunteer may report, for instance, that an airport is becoming congested. A humanitarian logistician receives this information and investigates whether a flight should be re-routed to another airport.

Systems like Ushahidi[1] or GDACSmobile (Link et al., 2013) support the generation of geographic information by volunteers and also allow the information to be exported for further analysis. Unfortunately, current supply chain management (SCM) systems lack the ability to automatically import and make direct use of data from VGI systems during a disaster that requires rapid decision-making. Before the VGI and SCM system can be effectively cross-linked, the relations between humanitarian logistics processes and theirinformation needs have to be made more explicit. Thatmeans, it has to become clear which information needs of processes can be fulfilled by VGI and which processes benefit from certain information. To achieve this, process modeling appears to be a suitable technique, especially when the process models are able to integrate resources or infrastructure.

The goalof this paper is to present a conceptual framework that associates humanitarian supply chain processes with VGI. The framework maysimplify the specification ofinformation about infrastructure and resources that areneeded inhumanitarian supply chain processes, thus enabling the identification of better information products fulfilling the needs. The informationmaybe encapsulated in one component of the framework, i.e. the Humanitarian Logistics Infrastructure and Resource Model, which enables the modeling of processes with an integrated infrastructure and resource view and which supports the development of an integrated SCM and VGI system.

The paper is structured as follows. First, we present design science research as our research method. Next, wereviewliterature to introduce the fundamental concepts of the framework and present the framework itself, which is followed by an evaluation. Eventually we conclude the paper with a summary andour research agenda.

Research Method

We chose design science research (DSR) as our research method, because this approach has been successfully applied to achieve practical solutions with the development of new artifacts, in some cases with a high degree of abstraction (Gregor and Hevner, 2013). Generally, these artifacts aim to describe, explain, and get a better understanding in relation to an object (e.g. model and instantiation) or process (e.g. method and software) which, in some cases, can be transformed into a material existence such as algorithms (Sein et al. 2011; Gregor and Hevner, 2013). We thus understand our conceptual framework as an abstract artifact that outlines the integration of SCM and VGI systems and helps to analyze the conceptual and practical benefits of VGI for humanitarian logistics.

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[1]http://www.ushahidi.com

According to Peffers et al. (2007), DSR has six activities: problem identification, objectives, artifact design, demonstration, evaluation, and communication. At the time of writing, this work has completed demonstration and is approaching evaluation. For the demonstration of the framework's usefulness we employed the case study approach presented by Pries-Heje et al. (2008), focusing on the 2007 Uganda floods (Blecken, 2010), as described in the demonstration section.

The development of the framework has been grounded in the information needs of practitioners from the humanitarian sector. The information needs and the categories that they fall into have been taken from Link et al. (2013) which useMayring's(2010) Inductive Category Development as a research method. The categories have been further analysed regarding their fit to Schuster's definition of resources. The categories that did not fit the resource definition have been analysed once more regarding their fit to our definition of infrastructure. Both definitions can be found below in the corresponding literature review sections.

Literature Review

Integration of Resources into Process Models with the Resource Modeling Language

Schuster (2012) defines resources as objects that can be allocated to an activity; with resources being material or immaterial, human or non-human.He further identifies a gap in process modeling approaches, like event-driven process chains or the business process model and notation (BPMN), regarding the proper integration of resources. Consequently,he developed the Resource Modeling Language (RML) (Schuster 2012). RML includes the Resource Meta-Model (RMM) as a reusable meta-model to describe resources, allowing for domain-specific extensions. The meta-modeling approach enables precise specification, making it possible to formally define, and automatically transform and interpret instantiated models, while conforming to the Meta Object Facility (MOF) standard for model-driven engineering (OMG, 2003; OMG, 2006; Petrasch and Meimberg, 2006; Schuster, 2007). The detailed definition ofabstract syntax, semantics and rules of RML can be found in (Schuster 2012). Figure 1 depicts the Resource Meta-Model (RMM).
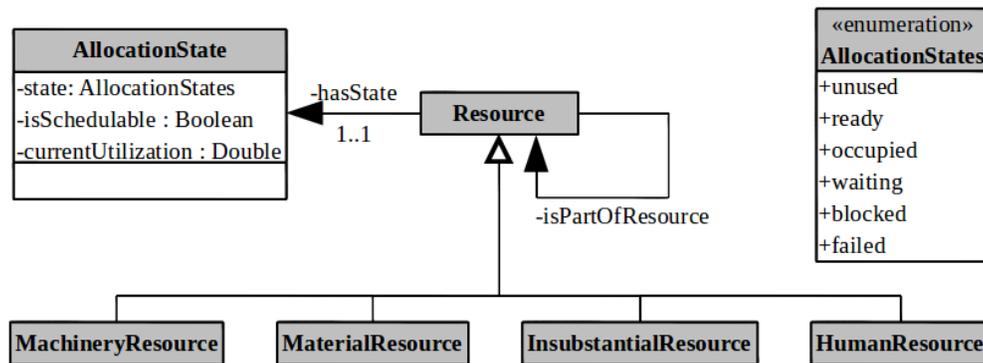

Figure 1. Resource Meta-Model (RMM) (Schuster, 2012)

The central component of the RMM is the abstract class Resource, which encapsulates the common attributes of concrete resources (OMG, 2010). According to the RMM, resources do not have to be viewed completely separately but can in turn be included in other resources; e.g. the resource "radio receiver" can be part of the resource "truck". Resources can assume a number of allocation states, from being unused (new), to being ready, occupied, waiting or blocked, and failed. In addition, resources can be schedulable and utilized to a certain degree. They can be of the types: machinery resource (e.g. truck), material resource (e.g. fuel), insubstantial resource (e.g. software) and human resource (e.g. driver).

Infrastructure and Resources in Humanitarian Logistics

Although the term "infrastructure" is widely used in both academic and non-academic publications, there is no generally accepted definition (Buhr, 2003). To the best of our knowledge, the most in-depth investigation on infrastructure describes it as a public good and distinguishes types of material, institutionaland personnel infrastructure (Jochimsen, 1966). Material infrastructure is understood to represent capital goods in the form of transportation, education, and health facilities, equipment of energy and water provision, facilities for sewage, garbage disposal, and air purification, building and housing stock, facilities for administrative purposesandfor the conservation of natural resources. Institutional infrastructure is the sum of all customaryand established rules of the community as well as the facilities and procedures for guaranteeing and implementingthese rules by the state. Personnel infrastructure comprehends the number and the relevant properties of the working population (for example, general and special education, qualification in different functions).

Following Hellingrath et al. (2011), Link et al. (2013) understand infrastructure astraditional supply networks, such as roads and electricity. In their work about information categories for infrastructure and logistic resource assessments in humanitarian logistics, they employ Mayring's (2010) Inductive Category Development as a method for qualitative content analysis to curatepractical knowledge about infrastructure and logistic resources.

The sources areassessment tools and guidelines ofhumanitarian aid organizations. The knowledge contained in them falls into main categories:airport, seaport, road transportation, railwaytransportation, inland waterway transportation, warehouse, customs, local suppliers of relief goods, flour mill, fuel supply, electric power supply, telecommunications, additional handling equipment, staff accommodation, and country overview.The main categories contain various sub-categories e.g. the sub-categories: current condition of facilities, runway characteristicsand cost of airport usage, are sub-categories of main category *airport*. In total, the category gives an overview of the information about infrastructure and logistics resources that humanitarian organizations consider to be most important, as pertheir handbooks and guidelines.

In this paper, the terms "infrastructure" and "resource" are being distinguished by defining infrastructure astraditional supply networks and their immobile elements, such as roads and warehouses. In contrast, resources are defined as any kind of mobile equipment, e.g. handling equipment and vehicles, or persons that are substantial forcarrying out logistic operations, complementing infrastructure. This conforms to Schuster's definition of resources, as equipment and persons canbe directly allocated toactivities, while infrastructure is indirectly used by resources.

Volunteered Geographic Information

For years, the growth of spatial data was limited to activities carried out by specialist organizations (Goodchild and Glennon, 2010). Following the emergence of Web 2.0 and the improvement of mobile devices to provide data related to their location, people began to be more involved in this area, not just by examining it, but also by providing data and information. This was in many cases, more detailed and of a higher quality than that provided by official institutions (Goodchild, 2007; De Longueville et al. 2010).

Goodchild (2007) coined the term Volunteered Geographic Information (VGI) to describe this phenomenon, which was defined as a collection of digital spatial data produced by individuals and non-formal institutions, i.e. by ordinary citizens using appropriate tools to gather and disseminate their views and geographical knowledge on the web. According to Coleman et al. (2009), this volunteerism has a highpotential to expand and qualify the amount of information available about the events and experiences of the community members.

In the context of disasters, this approach has been adopted to assist the activities of emergency agencies and facilitate community organizations. Moreover, there has been a sharp rise in the use of VGI for disaster preparedness and response in recent years (Goodchild, 2007; Gill and Bunker, 2012; Horita et al. 2013). Among them, there are several approaches that analyze the impacts of the disasters by making use of volunteered information (Poser and Dransch, 2010). In addition, there are studies that are related with the development of frameworks for processing and sharing VGI(Goodchild and Glennon, 2010) and

others which aim to evaluatethe use of data generated by social media (Kaewkitipong et al. 2012; Erskine and Gregg, 2012).

Framework for Information Assessment

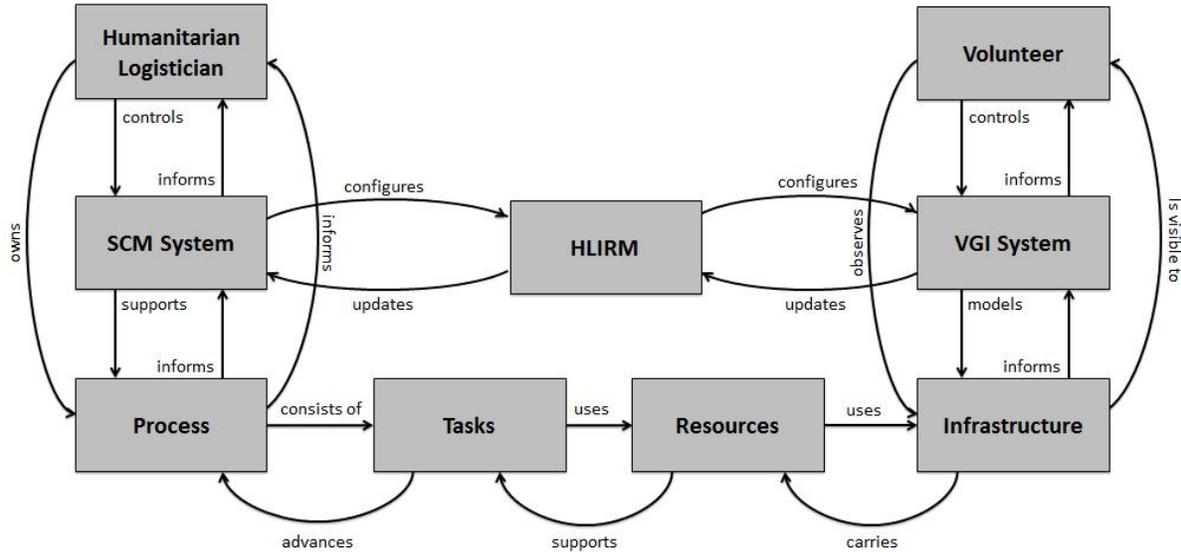Figure 2 depicts the conceptual framework proposed herein.

Figure 2. Conceptual Framework

We can begin by examining the figure at the top left corner, where the humanitarian logistician is located. This person owns processes, having the responsibility to organize, e.g. the transport of aid goods from their storage in a regional warehouse in Dubai to a local warehouse in the affected area in South Sudan. While the process is being executed the humanitarian logistician may receive information about the status of the process activities, e.g. by receiving a phone call from a truck driver. The humanitarian logistician controls an SCM system that supports the process and receives informationfrom the process, feeding it backto the humanitarian logistician, e.g. by giving a unifiedview onstock levels to the humanitarian logistician and to the local warehouse manager.A process consists of individual tasks, i.e. tasks are the building blocks of a process andmove it forward. Tasks need resources, such as trucks for transportation. Resources, in turn,rely uponinfrastructures, such as trucks rely upon theroad network.

If the relevant infrastructure can be seen physically by volunteers, they may deliberately observe it and control a VGI system, such as Ushahidi, to model the infrastructure. If the infrastructure is equipped with networked sensors then the VGI system may receive status information and feed this information back to volunteers. For instance, the water levels of waterways or amounts of rainfall in areas with non-paved roads could be monitored.

The central part of the framework is the Humanitarian Logistics Infrastructure and Resource Model (HLIRM). Its function is to cross-link the SCM system and the VGI system by describing the informationneeds tothe VGI system and byproviding the needed information tothe SCM system. The SCM system derives information needs from models of the processes it supports and configures the HLIRM accordingly. For instance, the SCM system declares that airports and the road network are relevant to operations and includes them in the HLIRM configuration. The VGI system receives the configured model and informs volunteers about the information needs,in order to guide observations towards relevant infrastructure. The volunteers enter their observations into the VGI system and thus update the infrastructure model. By using the HLIRM as an exchange format, the VGI system is able to update the SCM system. The SCM system investigates if any supported processes are critically affected by the updates and informs the humanitarian logistician, who may take immediate action. Coming back to the example from the introduction: Avolunteer reports that an airport is becoming congested. The SCM system alerts

the humanitarian logistician, who investigates the situation and decides to re-route a flight to another airport. Because volunteers have reported road blocks, the SCM system is capable to alert the humanitarian logistician that several land routes from the new destination airport to the local warehouse are blocked. The humanitarian logistician thus includes specific instructions regarding the possible land routes in his transport request to a local freight forwarder.

Due to its central position in the framework and its innovative character, we will describe the HLIRM in greater detail.

Humanitarian Logistics and Resource Model

Figure 3 depicts the Humanitarian Logistics Infrastructure and Resource Model (HLIRM), which connects the Infrastructure and Resource Meta-Models.
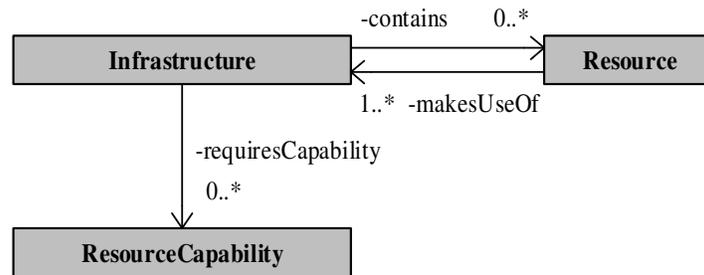

Figure 3. Humanitarian Logistics Infrastructure and Resource Model (HLIRM)

Infrastructure may contain resources in the same way as an airport contains parked aircraft or a warehouse contains cranes. In turn, resources always make use of infrastructures. For instance, aircraft use airports to take off and landing, and field logisticians use their organization to coordinate operations. Schuster (2012) did not distinguish between resources and infrastructure, as we do. It is thus necessary to complement Schuster's Resource Meta-Model with an Infrastructure Meta-Model, as depicted in Figure 4. On this foundation, the resources and infrastructure that are relevantfor humanitarian logistics can be described with theHumanitarian Logistics Resource Model (HLRM) (Figure 5) and the Humanitarian Logistics Infrastructure Model (HLIM) (Figure 6).
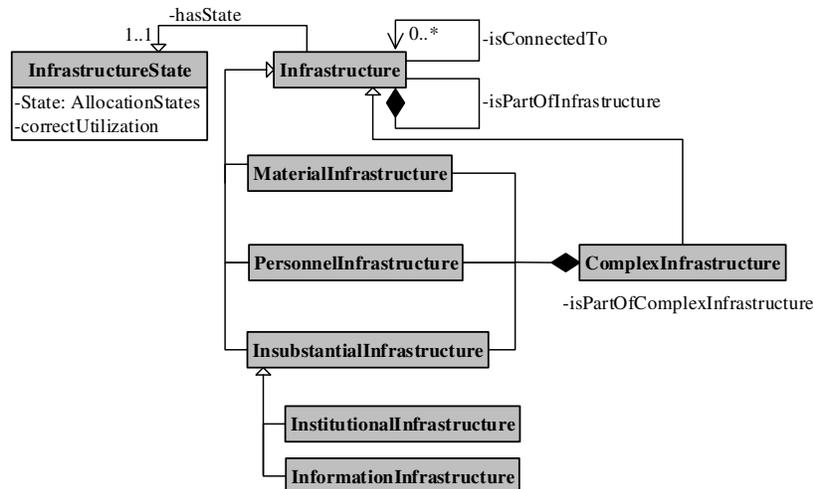

Figure 4. Infrastructure Meta-Model (IMM)

The central component of the IMM is the abstract class Infrastructure, which encapsulates the common attributes of concrete infrastructures. As resources in the RMM, infrastructures can be included in other

infrastructures; e.g. the infrastructure "warehouse" can bepart of the infrastructure "airport". Just likeresources, infrastructure can assume a number of allocation states and can also be utilized to a certain degree.

In addition to theability of beingpart of another infrastructure, infrastructures are interconnected; e.g. an airport is connected to a road network, which in turn connects to a variety of other infrastructures. This implies that infrastructures can only interact if there exists a connection between them. Infrastructures can be of the types described by Jochimsen (1966): material, personnel and institutional.

To pay tribute tothe advances in Information and Communication Technology (ICT) since Jochimsen's publication in the 1960s, information infrastructure is added, being placed under the class of insubstantial (immaterial) infrastructures, together with institutional infrastructures. To indicate that infrastructures can be of a complex type, which consists of the material, personnel and insubstantial infrastructures,complex infrastructure has been added as an additional type. An example forsuch a complex infrastructure can again be seen in airports, making use of landing strips (material), air traffic controllers (personnel), an operating company (institutional) and various kinds of software(information).

It should be noted that the distinction between infrastructures and resources is not absolute but relative. For someone who uses the airport as a customer, the air traffic controllers are part of the infrastructure, and are normally of no more special concern during own operations than the power plants that provide the electricity that is used to light the departures hall. For the company that operates the airport, in contrast, theair traffic controllers are essential human resources with a broad range of attributes like skills and competencies.
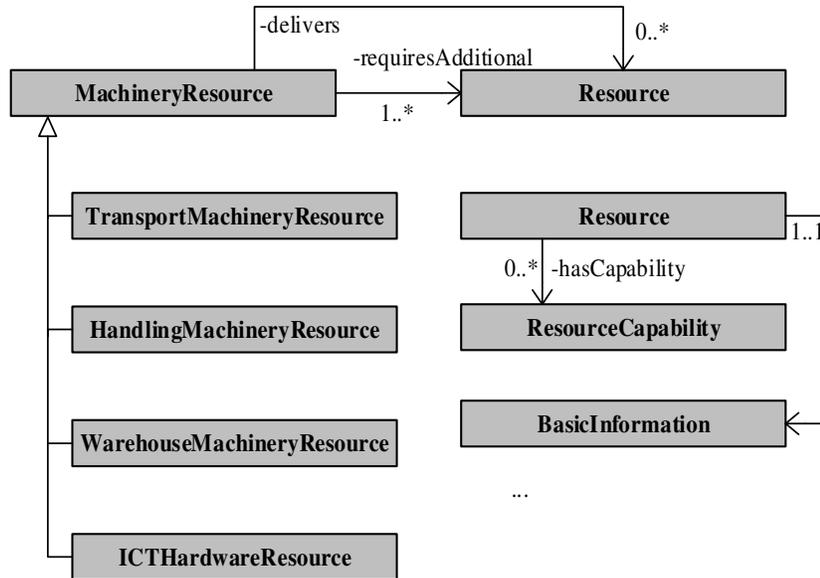

Figure 5. Humanitarian Logistics Resource Model (HLRM)

The essential component of the HLRM is the machinery resource. Machinery resources can be of the types: transport machinery resource (e.g. a truck), handling machinery resource (e.g. a high-loader), warehouse machinery resource (e.g.a crane) and ICT hardware resource (e.g. a computer). The main distinction between handling and warehouse machinery lies in their area of application; warehouse machinery is specificto warehouses.Machinery resources that are important to humanitarian logistics optionally deliver other resources (e.g. cargo aircraft transportingtrucks) and require additional resources for their operation (e.g. fuel). Furthermore, resources have specific resource capabilities (e.g. 4-wheel-drive) and are associated with a dataset of basic information (e.g. location). This part can be considered as a placeholderfor later,detailed specification of significant resource attributes and constraints.
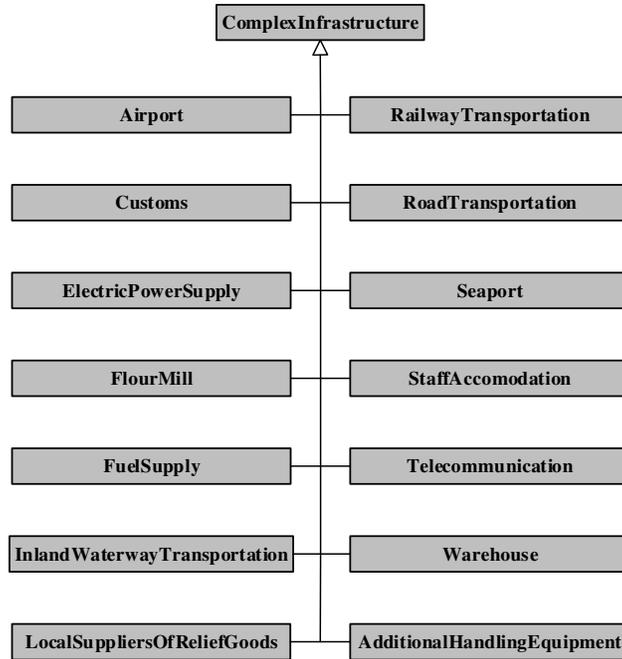
Figure 6. Humanitarian Logistics Infrastructure Model (HLIM)

Figure 6 depicts the Humanitarian Logistics Infrastructure Model (HLIM) composed of themain categories defined in Link et al. (2013). All relevantinfrastructuresare described as types of complex infrastructure comprisedof material, personnel and insubstantial infrastructures. The *Airport* refers to international and national airports for commercial flights and *Seaport* covers any type of landing site for overseas shipments. *Road Transportation* covers roads and trans-loading points for intra-modal transhipment while the*Railway Transportation* covers tracks and stations and *Inland Waterway Transportation* covers waterways and jetties. *Warehouse* refers to suitable buildings as well as to any area that can be used for storing relief goods intentionally. *Customs* covers regulations, procedures and restrictions for shipping relief goods to the affected country or a transit country. A *Local Supplier of Relief Goods* is an independent market agent, external to any humanitarian organization. *Flour* refers to the milling infrastructure that humanitarian organizations might utilize to produce flour from grain. *Fuel Supply* is crucial to running supply chains. *Electric Power Supply* is essential for operating transhipment points, warehouses and communication equipment, and also covers power generation. *Telecommunications* is required for intra-organizational as well as for inter-organizational coordination, and covers both general telecommunication issues and different technologies that arepotentially used.*Additional Handling Equipment* covers any handling equipment that does not belong to one of the above main categories, and *Staff Accommodation* covers the accommodation for the staff of humanitarian organizations during operations. Staffs include field logisticians, although it is not limitedto them.

Demonstration

Case Description

The framework's usefulness was demonstrated by adopting the approach outlined by Pries-Heje et al. (2008), with a focus on the 2007 Uganda floods (Blecken, 2010) as an illustrative example. Since it caused around 300,000 victims,the floodswere "the most serious flooding in decades"(Blecken, 2010). Humanitarian aid operations occurred in a rural context with few activities executed in distant areas. The major concern for humanitarian organizations was the provision of clear drinking water to the affected communities. The activities to provide potable water involved several organizations at local and regional levels and encompassed assessment, procurement, management, and transportation(Blecken, 2010). The

transportation process, as shown in Figure 6, is triggered when there is a need to transport goods into an affected area.
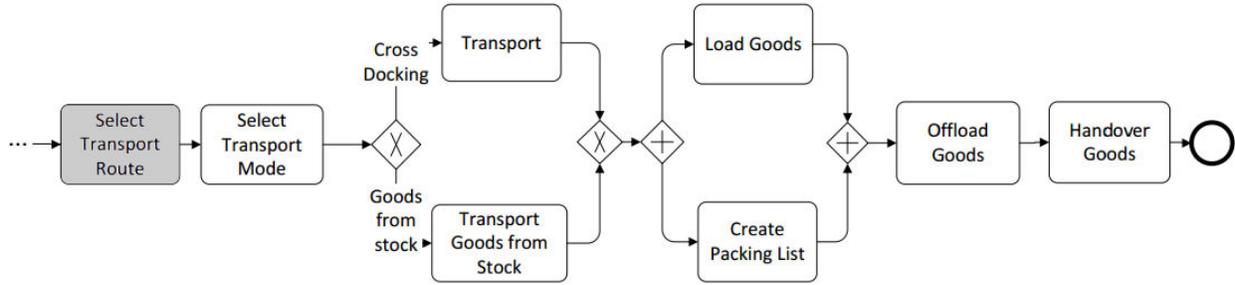

Figure 6. Transportation Process at flood in Uganda (Blecken, 2010)

As shown in Figure 6, the first and second tasks aim to select the best route and transport mode (e.g. truck) to deliver the goods. After the decision has been made whether to transport the goods from stock or via Cross Docking, the goods can be loaded while a packing list is produced. When the goods finally arrive at the affected area they are offloaded and handed over to their recipients. The first task, *Select Transport Route*, is crucial because its accuracy and efficiency have a directimpact on the performance of the entire process. It needs information about various resources and infrastructure to lead to good decisions that affect the following tasks like *Transport*.

Application of the Framework

In our case,we assume thata SahanaSCM system works with an UshahidiVGI system. Figure 7 presents a customized instance ofthe conceptual framework, which matches the route selection in the case study.
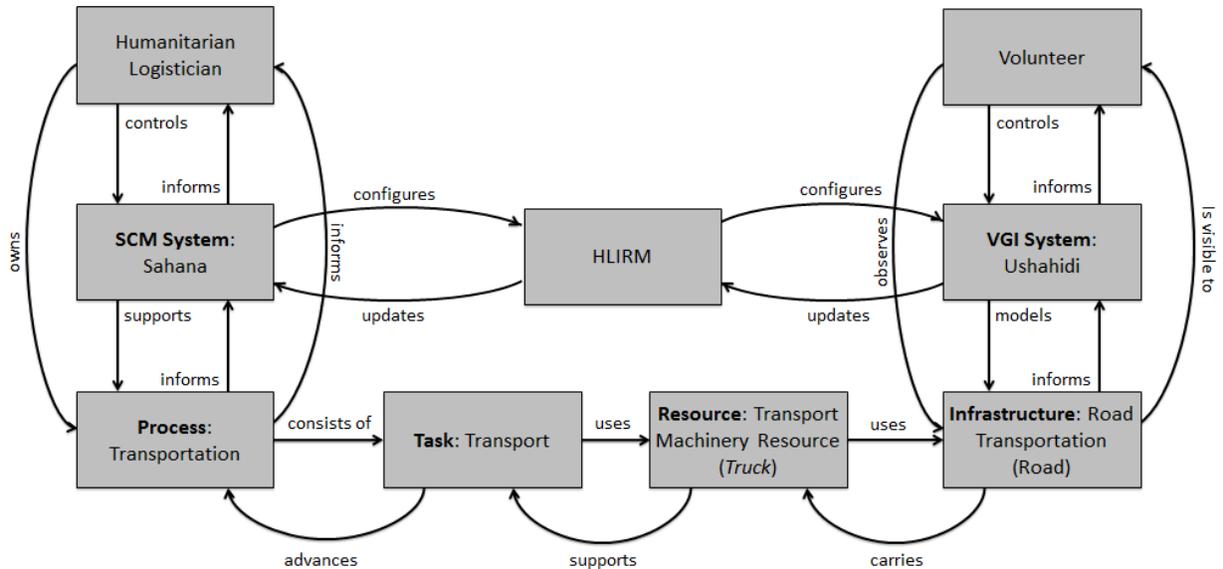

Figure 7. Instance of the framework for transportation at Flood in Uganda.

As shown in Figure 7, the Sahana SCM system supports the processes ownedby the humanitarian logistician, while volunteers use the Ushahidi platform to manage their observations of the disaster area. The supply chain process in focus is theTransportation, and the task in question is *Transport*. *Transport* needs trucks as resources, which in turn depend onRoad Transportation infrastructure. When the humanitarian logistician decides to transport potable water into a particular area and uses Sahana to support the process, Sahana configures the HLIRM (see Figure 8) and uses it to specify the information needs with regard to transport capabilities (e.g. road condition, volume of traffic and constraints) to the Ushahidi platform. Ushahidi receives the information needs, sets up the corresponding categories and

informs its volunteers. By means of the platform, they create reports with relevant information and update HLIRM, which as a result, updates Sahana. On the basis of this new information, the SCM system checks if the selected route is still appropriate for the transportation. If it isnot the case,the humanitarian logistician is triggered to make appropriate changes (e.g. change the route, the transportation mode or choose direct transportation from another location). Figure 8 shows the instance of HLIRM for the case study.
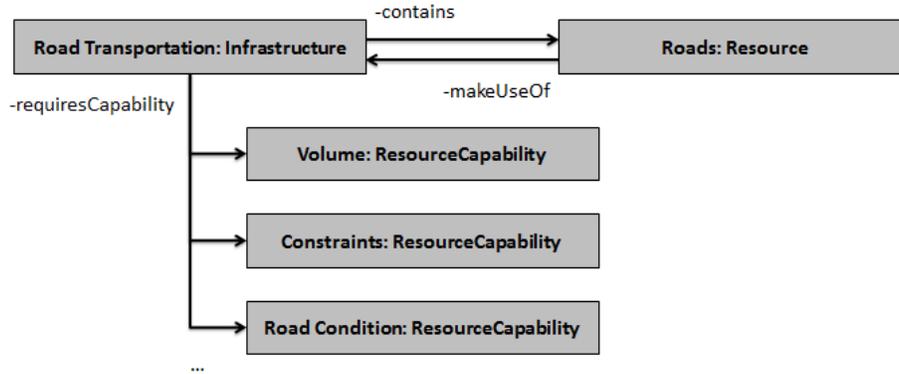

Figure 8. Instance of HLIRM for transportation atFlood in Uganda

As an illustrative example, Figure 8 showsthe HLIRM instantiation for our case.Sahanacan configure the HLIRM to request information about resources (trucks) that use road transportation infrastructure, so that better routes for the transportationof potable water into the affected areas may be selected. According to Link et al. (2013), this infrastructure covers roads, vehicles and trans-loading points for intramodaltranshipment, i.e. it can be used to transfergoods nationally or internationally. Through the model, Ushahidi identifies information needs (ResourceCapability), e.g. traffic volume, roadconstraints, and road conditions; and communicates them to volunteers, which insert therelevant information into the Ushahidi system.

The case study demonstrates that the framework can be used to integrate VGI into the supply chain processes of humanitarian organizations through an infrastructure and resource model. Through HLIRM, the framework creates an easy way for the SCM system to request information about infrastructure and resources, and thus increasethe timeliness and accuracy of the incoming information, while reducing information overload.

Conclusion

This paper has outlined a framework that integrates volunteered geographic information (VGI) into humanitarian supply chain processes, including the definition of supported processes, the specification of corresponding information needs and the impact of particular pieces of information on running processes. The humanitarian logistics infrastructure and resource model (HLIRM) may be used to effectively link supply chain management (SCM) systems and VGI systems. The resulting models are by no way complete in the sense of containing every possible element. Since they are grounded in the information categories, however, they docontain the elements that play outstandingroles in humanitarian operations, i.e. the elements that need to be considered during targeted assessment support and SCM systems development.

Given that *Airport*, *Warehouse* and *Flour Mill* are on the same level of abstraction, the structure of the category system may appear to be counter-intuitive. This is understandable from a researcher's perspective, but it has to be kept in mind that practitioners and the rigorous application of Mayring's method dictatethis structure. We argue that researchers should not superimpose their own structure, lest it reduces both relevance and rigor in exchange for a purely aestheticalimprovement.

The exemplary instantiation for the case of the 2007 Uganda floods demonstrated the framework's usefulness and its applicability as a complete artifact. It may betransformed intoa material object by implementing interfaces betweenSCM and VGI systems.

In future design cycles, we intendto detail parts of the framework, create a software instantiation from the conceptual framework (i.e. interfaces) andevaluate the software instantiation with end users, i.e. humanitarian logisticians and volunteers.

Acknowledgment

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