Supporting Humanitarian Logistics with Intelligent Applications for Disaster Management

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***Abstract*—The management of humanitarian logistical operations was for many years the weak link in the relief chain. Within the advent of big data, this challenge has been changing life and the way of dealing in the humanitarian field. Data is increasing exponentially due to the growing digitization of modern life and the further evolution of data collection in combination with the digital technology. More and more humanitarian organizations designed numerous system with specific objectives in order to manage the massive amounts of data. Hereby, we propose an intelligent application scenario for disaster management. Here, we use the multi-source information correlation together with the implementation of our own approach based on sudoku principles for supporting humanitarian logistics. This paper aims to show how our system can alert and provide decision support for disaster response and recovery management through the integration of heterogeneous data sources from different organizations.**

***Keywords*–Data linkage; Disaster Information; Knowledge Base System.**

I. Introduction

The digital evolution of the humanitarian response in disaster relief brings new challenges for the systematic strategy to collect, store and retrieve digital information. These massive data have to be provided in a structured way and should be connected to the experience of humanitarians on the one side and to the experience of logistics experts on the other side. This process could help in distributing the knowledge to those who need it in a timely manner and in a clear structured way. In all stages of disaster relief, the decision makers need a large variety of information to react, such as disaster situation, availability and movement of relief supplies, population displacement, disease surveillance, relief expertise, and meteorological satellite images or maps, etc. In addition to that, during Humanitarian Assistance and Disaster Relief (HADR), it is also required the intervention and aid of various agencies in a concerted and timely manner. As a result, HADR operations involve dynamic information exchange, planning, coordination and all negotiation. The HADR mission goal is to work jointly with other national, UN and Non-governmental organization entities, bringing military speed and scale to the problem in a coordinated planned response as a force for good. The mission is to support military, etc., for planning processes to save lives, relieve suffering, limit damage and initially restore critical services where possible. This includes search and rescue operations, providing supplies such as food, water and shelter, bringing medical care and autonomous critical support facilities, providing planning and tactical coordination services with communications, building shelters, providing vehicles, restoring infrastructure such as power, communications, and transportation. The HADR mission also needs communication support and liaison between military and international government entities. The goal is to provide a rapid tailored response with consideration of all actions including physical, political, legal, and economic impacts on host populations and other supplying nations.

In all humanitarian organizations, there are numerous systems designed with specific tasks. In this paper, we propose objectives and with its own data sources. Each sources, and in general any archive containing information, both structured and unstructured responds and was produced in response to specific needs. What is often missing is a vision that is able to grasp phenomena that go beyond the vision that any single archive can provide. Each source, in general, provides different information of a same entity creating a partial point of view of that entity. Each of these data sources represents a “point of view” of reality, and the sum of these points of view can provide a more complete representation. The combination of multiple views of the same entity could bring out new knowledge. The search for an overview and cross meanings within this growing body of data in HADR, it is currently faced with methods known by the term big data management, namely through tools able to process large volumes of data with the aim of improving research processes or through the application of statistical methods of investigation and representation of financial highlights. The sources were not born either with the purpose to provide a formal semantics of the data, thus making the tools of automatic processing very difficult to apply to. Linked Data is about using the web to connect related data that wasn’t previously linked, or using the web to lower the barriers to linking data currently linked using other methods. Structuring Linked Data is to enable a wide range of applications to process the content contained in the datasets. It is extremely difficult to recognize, for example, that two records belonging to different sources are referring to the same logical object to improve the effectiveness and efficiency of the prediction of response for future disasters. Record linkage (RL) usually is used to find records in a data set that refer to the same entity across different data sources. RL is necessary when joining data sets based on entities that may or may not share a common identifier. It should be noted that, being in a multi source environment, the problem doesn’t deal only with the comparison of two tables, but the comparison of n tables from m different sources. To reduce the complexity of the RL approach that require to join all table of all sources, we propose correlations between the data directly in the databases of origin (sources), using record linking techniques and statistical algorithms for the identification of common elements between heterogeneous data sources using a approach sudoku. The idea of the proposed approach is to correlate only relevant candidates records of each source that have been produced by sudoku method heuristics. The proposed Records Linkage Approach uses the sudoku principles to reconcile the sources linear method instead of an exponential one because only certain candidates records of each source are compared.

In this paper, we propose a new knowledge management system, that allows to correlate heterogeneous data sources using sudoku approach to reduce record linking computation complexity, for support of the humanitarian logistic response to a natural or man-made disaster. The rest of the paper is organized as in the following: after the presentation of the related work (Section II), we firstly focus on our approach to combining logistics processes with knowledge management (Section III) and then we describe our HL-KMS framework (Section IV). Furthermore, we show a case of study (Section V). Finally, we draw some conclusions and describe shortly the future work (Section VI).

II. Related work

In the following we describe the related work, explaining in more details how humanitarian supply chains (see Section II-A) and Knowledge Management System to support HADR (see Section II-B).

A. Humanitarian supply chains

There are many organizational approaches looking for the best way of coordinating humanitarian supply chains. Humanitarian organizations have acquired an exemplary know-how with their numerous past experiences, but a number of stakeholders poses a problem of coordination, considering that the different actors, often widely different in nature, size and specialization, are also compartmentalized in their operating modes [1]. This coordination is a direct condition for successful aid. In order to improve the monitoring of humanitarian aid, actors will have to learn how to co-elaborate and co-manage relief chains. In other words, an efficient collective strategy will be able to improve the performance of humanitarian supply chains, while a lack of it has dramatic consequences for the stricken populations. Then, it is necessary to better define the logistical coordination difficulties throughout the complexity of humanitarian operations [2]. In a highly uncertain world, where the shortest possible timing will probably save thousands of victims, the issue is not only a matter of money, but also and above all a matter of human life. Saving lives will not be possible without developing a knowledge management approach, in other words learning from previous disasters by capturing, codifying and transferring knowledge about logistics operations [3]. There are systems like SUMA(Supply Management Project) [4], a management tool for post-disaster relief supplies, that use simple software on laptop computers to track and sort incoming donations and their destinations, allowing disaster managers to see what they have and send it where it is needed. Among the works dedicated to humanitarian logistics, we should note the place occupied by research focusing on transportation optimization issues, perhaps to the detriment of a wider reflection on the monitoring of all relief chains. These works tend to modelize the use of transport resources in disaster relief, by referring, for example, to models imported from the military context [5][6]. Although transport management remains a major concern in the literature on humanitarian logistics, it must be admitted that it is no longer the only one.

B. Knowledge Management Systems to support HADR

Today, more and more information technologies have been adopted in support of knowledge management however, Knowledge Management in Humanitarian Assistance and Disaster Relief (KM in HADR) is still in the early stage. KM in HADR is referred to the entire process of acquisition, management, and utilization of disaster information and knowledge for the support of HADR operations [7]. Managing past knowledge for reuse can expedite the process of disaster response and recovery management plays important role. Here we need the most important KMS reference that should be given. KMS is vital for disaster detection, response planning, and efficient and effective disaster response and management [8]. KMS plays important role in gathering and disseminating the natural disaster related information. Murphy and Jennex [9] explore the use of KMS with emergency information system concluded that KMS should be included in more crisis response. Mistilis and Sheldon [10] describe that knowledge is a powerful resource to help governments and organizations in order to plan and to manage disasters and crises. Groups have proposed and created KMS that allow for more efficient use of data and faster response. One example that has been proposed is the Information Management System for Hurricane disasters (IMASH) [11], an information management system based on an object-oriented database design, able to provide data for response to hurricanes. Wolz and Park [12] present another example of knowledge-based system, which serves as an electronic central repository to meet the information needs of the humanitarian relief community. There are other several KMS for the support of specific disaster such as in India [13], in Hurricane Katrina [8], in Malaysia [14], These systems have resulted in a step change in the efficiency and effectiveness of HADR chains, such improvements have the potential to achieve similar advances in humanitarian logistics. Humanitarian logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiarys requirements [15]. A first step towards the development of a broad HLKMS in [16], a conceptual model and an associated taxonomy are given to support the development of a body of knowledge in support of the logistic response to a natural or man-made disaster.

In the next sections we discuss our system that implements Knowledge Management System to support HADR in a logistic scenario.

III. Combining Logistics Processes with Knowledge Management

The humanitarian field has been forever changed by the advent of big data and the attendant challenges of dealing

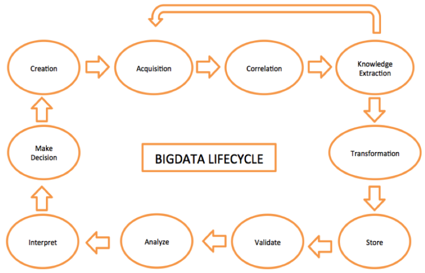

Figure 1. Knowledge lifecycle to support logistic

with it the disaster response. In order to utilize big data in humanitarian logistic organization response, there are multiple steps in the process that must be undertaken before being able to make decisions based on the information. This section tries to identify how big data can be used to support logistics, identify knowledge lifecycles, and assign responsibilities (see Fig. 1). The 10 well-known steps of such a lifecycle have to be developed for addressing 5 relief needs of decision makers:

1) Discover which critical information/knowledge is required by different disaster relief tasks.
2) Identify which organizations or agencies are the major information sources for each particular relief task.
3) Specify the standard structures for each kind of information and knowledge.
4) Determine how to acquire the relevant information from those authorized sources. The organizations that own information sources could submit the newly updated information to the knowledge base as soon as it is available.
5) Examine the acquisition process to make sure that it is manageable and can be aided by information systems and technologies.

In the following section, we presents a linear method to correlate data derived from the game of sudoku: at first certain numbers are entered. This process brings out less certain number. In our method, at first we aggregate certain records and store aggregated data into the KMS, than we use aggregated data into the KMS to aggregate less certain records.

IV. Applying Knowledge Management for Big Data HADR

The humanitarian field has been forever changed by the advent of big data and the attendant challenges of dealing with it the disaster response. In order to utilize big data in humanitarian logistic organization response, there are multiple steps in the process that must be undertaken before being able to make decisions based on the information.

The purpose of our approach is to identify the correct correlations between the data contained in the database. If you make the assumption that sources are able to provide their information in a table, you need an algorithm that is able to join the lines of the various tables sources, taking count of errors and inconsistencies that may occur. Moreover, sources may also be relevant to different moments and then it's necessary managing the execution of the transaction between the current state of knowledge base and the new source. To realize a diachronic multi source RL we propose to correlate only more certain candidates records of each source produced by sudoku method heuristics. The innovation of this reconciliation is also for the return entity and the associated knowledge. There is better accuracy of research. Furthermore there are more reliable results because the knowledge base is more rich and multidimensional.

The proposed solution is the connective substrate to collect and harmonize data coming from heterogeneous sources, thus integrated with business intelligence solutions for graphics and data analysis. In our method, at first we aggregate certain records and store aggregated data into the KMS, than we use aggregated data into the KMS to aggregate less certain records. We propose an Humanitarian Logistics Knowledge Management System (HL-KMS) able to acquire information sources where data coming from different sources are recovered. Our framework performs linkage operation between heterogeneous data from different information sources using a sudoku approach and performs data analysis generating new knowledge. In this way we guarantee validity of the information content by means of keeping a constant trade-off between data quality and the need of human help.

The uniqueness of our approach is the use of a knowledge management system explained by the combination of the following elements:

- "sudoku" approach, in which knowledge is consolidated from simple correlations and increasingly arriving to complex interrelationships.
- diachronicity: it follows the evolution of each source of information over time, recording not only the status of an entity but also all its subsequent changes.
- "Secularism" of the system with respect to the sources: no source is considered primary for data nor free from errors. The information is obtained from the correlation of data, not from a weighted importance scale.
- "Quality control" the module always uses a benchmark to verify the quality of the information produced.
- "cost-quality trade-off" the module is able to predict ex ante which will be the necessary cost to improve the quality of produced information.

HL-KMS framework is structured in 5 modules, as depicted in Fig. 2. Each of these modules populate the Knowledge Base. It provides a layered architecture for data management. The different modules can operate sequentially or independently one from each other. Each module can have one or more components. The first phase of the process consists in the acquisition of the data to solve, given heterogeneity problems, misalignment problems and inconsistency problems all due to the multiplicity of data sources (Data Acquisition module). Once the sources have been suitably normalized, it is possible to understand if two observations refer to the same entity by means of proceeding with an operation of linkage between certain candidate records with the sudoku heuristic (RL-Sudoku module). To discovery new knowledge, the reasoner module browses the relationship between the cross-linked data (Reasoner Relationship module). Validity of the information content (Quality control module) is guaranteed either keeping a constant trade-off between data quality and

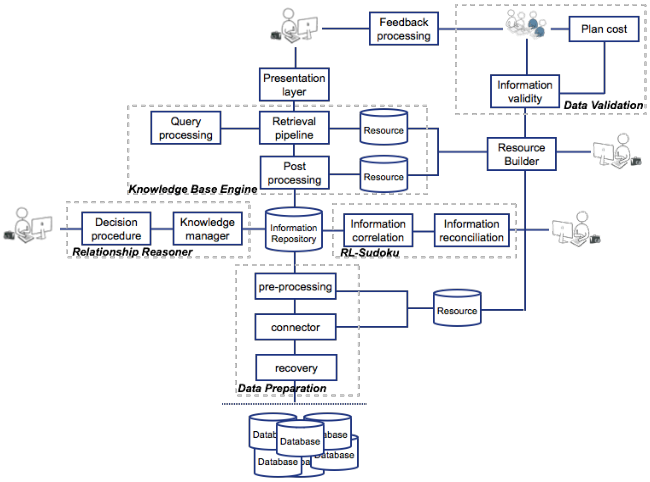

Figure 2. HL-KMS framework Functional Architecture

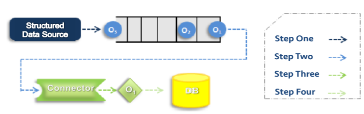

Figure 3. Data preparation module steps.

the need for human help (Cost quality trade-off module). Quality control is a process governed by predictable costs, in accordance to [17]. The HL-KMS framework has a series of dashboards that provide analysis of the data for decision support.

A. Data Acquisition

Before proceeding to entity correlation, Data Acquisition component is responsible of providing connectors to data sources. Each connector is itself responsible of normalizing data and structuring it in a format used by entity correlation component. Connectors do not change data: a connector merely transform input format producing a structured dataset that closely represent the input. We consider datasource to be both structured or unstructured. Data acquisition component and connectors are also responsible of the life cycle of information before data il correlated and imported within the KMS. The proposed system consider a data source as a set of observations relating to a specific phenomenon. An observation is made of records and each record may contains fields of data. These observations may refer to static phenomenon (that do not vary over time) or dynamics phenomenon. A dynamic phenomenon produces new observations or changes in existing ones. How a phenomenon varies over time is also an information. The Data Acquisition is also responsible of representing how diachronically data sources varies over time. Fig. 3 summarizes the steps of the Data Preparation module. In the following we describe them in more details:

- First step: recovery of the observations published by sources;
- Second step: sending observations to the connectors;
- Third step: normalization of the observations;
- Fourth step: normalized observations are submitted to Knowledge Base.

B. RL-Sudoku

This is the component responsible of data reconciliation, correlating data from connectors to the data stored into the KMS. As we said, the process of aggregating data is based upon a function that at first aggregate and store into the kms linked entities, extract the knowledge from newly imported and correlated data, used generated knowledge to aggregate less certain sources record. The RL-Sudoku function has the following features:

1) It is a linear function: each observation to be processed is compared only with a small subset of record from the KMS. This is possible thanks to a component responsible of selecting a small subset of data from the KMS eligible to possible candidate to data aggregation.
2) When comparing entities from the KMS with a new observation, it profit by using all the knowledge previously acquired. It is because entities stored within the KMS are the sum of already linked observation. Comparing to the Sudoku, we are using already entered numbers to enter new ones.
3) The RL-Sudoku method allow the operator (we use to call operator as the Oracle) to train the function to transmit specific knowledge about data sources to be used during data aggregation. This is especially when different data sources may offers different point of view of the same observation: fields that are relevant for a data source to describe an observation, should be insignificant when found in another data source. If it happens, such field should be unverified, affected from errors, aged, etc.
4) For each step of sudoku, the Oracle configures the function assigning weights and thresholds. Weight are used to evaluate how similar are to entities, thresholds are used to determine if similarity is certain. If not, the Sudoku-RL asks to the Oracle to suggest him if two entities can be aggregated. When it happens, the Oracle transfer knowledge to the Sudoku-RL. such knowledge will be used for future entity linking.

C. Relationship Reasoner

This section describes how we represent, extract, store knowledge within the kms. Once sources are reconciled, we can extract the information in the form of data using the the Relationship Reasoner module. Information is used to generate knowledge. We have classified knowledge in three categories:

1) Explicit knowledge: the knowledge clearly written within the source
2) Implicit or tacit knowledge. Tacit knowledge [18] as the kind of knowledge that is difficult to transfer to another person by means of writing it down or verbalizing it. We consider tacit knowledge as the knowledge that cannot be explicated and requires the creation of dedicated structures to be represented.
3) Inferred knowledge: the knowledge derived from the aggregation of the two sources.

Explicit knowledge is represented by linking entities within the KMS using one or more graph. A knowledge graph

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can be a weighted graph, weighted oriented graph, simple graph depending on the type of relation between entities. It is automatically handled by the Reasoner. Tacit knowledge requires a strategy to be extracted and represented. Our platform provides a programmable interface useful to add capabilities to the reasoner. Inferred knowledge derives from the correlation (Sudoku) and linkage (Reasoner) of entities. Inferred knowledge do not need to be represented. For example, in our experiment, the consequence of correlating data about people per municipalities, health infrastructure, geographical data, gives us a clear representation of the distribution of people per area and per hospital.

D. Data Validation

As highlighted a reconciliation process is difficult to achieve fully automatic and especially not guarantee the reliability that this problem requires. It is therefore necessary to develop a tool for the use of the algorithm by an operator to allow corrections, validations or additions needed to strengthen the process of reconciliation. The cost for manual control of the results of the algorithm must be supported. It should therefore be a tool that keeps a constant trade-off between data quality and the need for human intervention in fact optimizing costs and algorithms. If you accept a loss of performance it could therefore not be necessary to consult the oracle. This process has the following properties:

1) predict and, consequently, to plan the cost of human intervention needed to ensure a quality set;
2) to control, at run time, the cost of human intervention needed to maintain the agreed level of quality;
3) provide the ability to predict the minimum cost necessary to achieve the objectives of guaranteed quality.

According to our previous work done by M. Bianchi et al. [17], we extend the approach involving the identification of a range of indecision determined ex post, in which the performance of the automated systems are not considered appropriate, to identify ex ante the minimum set that must be processed by human intervention. The interval of indecision varies depending on the threshold values obtained ex post to the prediction, control and minimization of the cost of human intervention with a guaranteed quality of service. The proposed approach allows to apply automatic systems in the production chain, for example in industrial processes with constraints of guaranteed quality. In fact, the measurement system reduces costs in a real production chain, limiting the processing to manually necessary to ensure certain performance values taking into account a planned budget to correct errors of the automatic systems.

V. A CASE STUDY: MAPPING OF GEO-POLITICAL AND INFRASTRUCTURAL SITUATION IN ITALY

In this section, we explain how we incorporated and collected Big Data into a HADR framework basing upon a real use case which has been started since 2007. The main goal of the project was to create a Geo-Political and Economical map of Italy, using Big Data as a knowledge base, for future mapping and understanding of other HADR related knowledge domains. Approaching to the problem with a software platform would be restrictive because of multiple related issues (known or unknown). TABLE I lists issues to be addressed:

TABLE I. CRITICAL ITEMS TO BE ADDRESSED GROUPED BY DOMAIN

Data Source related issues
• How to identify data sources? Where the information is? • How to normalize structured and un-structured data-sources? • How to address data linkage? Can I re-use acquired knowledge to improve future data import and linkage? • How often does data need updated/refreshed? • How representative are datasets of a HADR specific domain?
Data Representation related issues
• How will data change over time and how long are datasets valid? • How to represent diachronic variation of data-sources? • What means knowledge? How to represent it?
Data Acquisition related issues
• What is the overall big data strategy? • Can big Data be used preventively?

To address all the items, we created a framework including of software libraries, best practices and strategies. In details:

- A strategy to address the problem of connecting and extracting data from data sources;
- A method together to a software library to approach to data-sources record linkage and a strategy to decide what data-source and when to import;
- A method to address to the problem of extracting explicit knowledge from data-sources and to extract implicit knowledge when two or more data sources are linked;
- A method to design a database suitable to import data and represent knowledge keeping in mind possible future growth and implementations.

In the following, we present some examples of questions that have impact on logistics.

TABLE II. PUBLIC ADMINISTRATION OPEN DATA

—Public Administration Open Data—		
Name	**Type**	**Contents**
IPA	Structured	Index of public administration covering PA, Public Security, Defense.
Ancitel/Ancitada	Structured	Containing data about municipalities in terms of resident population, extension of the territory.
LineAmica	Structured	Index of public administration covering PA, Public Security, Defense.
MinSanita	Structured	Covering health
MISE	Structured	Index of communication and internet service providers.
MIUR	Structured	Covering education.

TABLE III. ITALIAN COMPANIES DATA

—Italian Companies Data—		
Name	**Type**	**Contents**
http://www.guidamonaci.it	Unstructured	Italian Companies grouped by industry sector.
EPO (European Patent Office)	REST services	Information about filed patents per company and market product classification.

TABLE IV. OTHER RELEVANT BIG DATA DATA-SOURCES

—Other relevant big data data-sources—		
Name	**Type**	**Contents**
Google	Unstructured	An entry point to navigate the internet for specific contents.
World Wide Web	Unstructured	Information space where web resources are identified by URLs.
Open Street Map	Structured	Open Geo Data.
ICANN	Text-Unstructured	Index of ISP, domains, ip owners.

For the experimental phase we decided to trace the following scenarios:

- Presence of public administration and coverage area;
- Presence of civil protection and coverage area;
- Presence of infrastructures: barracks, health, education, warehouses, etc.;
- Population distribution and infrastructures coverage;
- Economical ecosystems and distribution of companies per market per area (thin can be also used to define strategies in the domain of cyber security);
- Capacity and independence for the supply of essential goods and technologies;
- Communication Service Providers.

Such knowledge base can be used to extract HADR relevant information and decision support. Knowledge generated can also be used to implement strategies to approach to a real scenario in terms of supporting decision and enhancement of the knowledge base (knowledge can be used to generate knowledge). The following table lists data sources used respectively in Public Administration Open Data TABLE II, in Italian Companies Data TABLE III, and in other relevant big data data-sources TABLE IV.

VI. Conclusion and Future Work

Disaster managers have realized the true potential of KMS to provide a more effective and rapid response in case of disaster. Disaster response requires the intervention and the coordination of a large number of organizations, people, and resources. Accessing to real time information is the key success for a real-time knowledge base decision making.

This paper proposed the implementation of a framework used to generate a KMS to create a Geo-Political and Economical map of Italy as a knowledge base for future mapping and understanding of other HADR related domains. The aim of the framework is to collect and to integrate information resources from different public and private organizations and from other and not institutional sources in order to create situation awareness and support decision maker to make the right decision within the timely manner. In this paper we have also shown how knowledge can be used as the basis for creating new knowledge and providing data analysis for a wide range of HADR scenarios.

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