oDMN: An Integrated Model to Connect Decision-Making Needs to Emerging Data Sources in Disaster Management

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Abstract

Disaster managers depend on timely and accurate information for task-related decision-making in highly complex and dynamic environments. New data sources, like online social media provide an increasing volume of data that promises improvements in situation awareness. But it remains difficult to focus data collection on information needs and integrate relevant information back into decision-making. In this paper, we present the observation-aware Decision Model and Notation (oDMN), which connects tasks, decisions, information and data sources based on standardized models and notations as well as on domain-specific information models. The oDMN allows for deriving information requirements and determining the impact of incoming observations on relevant tasks and decisions. To demonstrate its usefulness, we apply oDMN to a case centered on logistics operations during the 2015 Nepal earthquake response. The results show that oDMN is indeed able to formally connect tasks, decisions, information and data sources, and thus support better decision-making.

1. Introduction

The number of people vulnerable and affected by disasters has increased substantially since the 1970s and will probably continue to do so [8]. In the immediate aftermath of a disaster, decision makers have to assure that action is prompt and targeted although required information about the situation at hand is least available and there is great time pressure [3]. Various decision models support decision makers in these situations, but they rely on fundamental data about the situation, whose collection is often sacrificed by humanitarian staff in favor of life-saving activities [32].

New data sources are emerging to gather more complete, accurate and timely information about the situation [10]. They include online social media, [1, 35], collaborative platforms [33, 22, 39] or in-situ and mobile sensors [34, 9]. However, the increasing volume of available data, lack of targeted analysis and integration into practical workflows results in valuable information going unused – or worse – contributes to information overload, adversely impacting decision-making.

Against this background, it comes as no surprise that practice calls for better targeted data collection [25, 15, 4]. At the same time, researchers understand the importance of integrating identified information into decision-making processes, so that more valuable insights may be considered in disaster relief – but have unfortunately not yet succeeded [36, 5, 38]. There remains a need for the bidirectional connection between decision-making and data collection, especially considering the use of new data sources, like online social media.

To address this issue, we offer the observation-aware Decision Model and Notation (oDMN), which connects tasks, decisions, information and data sources. This allows to formally derive information needs from decisions and tasks and determine suitable data sources to better target data collection. It also allows to determine the impact of new information on decisions and tasks. For easier adoption and application in practice, oDMN is based on and related to popular standards for the modelling of processes, decisions and observations as well as on domain-specific information models that add knowledge about concrete tasks, decisions and information needs.

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To demonstrate oDMN's applicability and usefulness, we instantiate it in a case that is based on humanitarian logistics operations during the 2015 Nepal earthquake response. From the various sub-domains involved in humanitarian response, we focus on logistics. The reason is that logistics takes a central role for the delivery of relief items that it incurs for humanitarian organizations [3].

The remainder of this paper is structured as follows. We first present the relevant state of the art. Next, we describe how the foundational standards are incorporated and – where necessary – extended. The subsequent section describes the application case. Eventually we summarize this work, draw conclusions and suggest directions for future research.

2. State of the Art

2.1. Integration of Data Collection and Decision-Making in Disaster Management

Data collection activities fundamentally depend on an appropriate understanding of decision-makers' information needs and ways of working, so that information products can effectively contribute to decision-making and operational excellence. For example, knowledge of the main points of entry into an affected area, like ports and roads, are essential for planning transport modes and routes, which is vital for getting relief items delivered from foreign countries. Related information can be collected by local staff using publicly available rapid assessment forms. A lack of sufficiently in-depth understanding can not only lead to valuable information going unnoticed but has been observed to increase information overload and adversely affect decision-making [5].

Various researchers have elucidated information needs in disaster management. Vieweg et al. [38] analyze the use of social media data in decision-making, based on interviews with employees of a non-operational agency. Gralla et al. [7] present a broad and categorized set of information requirements and types of decisions that are more directly connected to field operations. The gap towards applicable insights is still wide, which is partly due to the complexity of the landscape of decision-makers [7] and their individual information requirements (depending on their specific tasks and related decisions).

Some recent works use an increased domain focus to more specifically identify decision-making roles, which leads to information requirements that can be satisfied using certain data sources and methods of analysis [19, 11, 38, 14]. Within this group, Horita et al. [11] present a conceptual framework that links supply chain processes of humanitarian organizations with volunteered geographic information (VGI) but do not explicitly describe the relationship between tasks, decisions and information. Link et al. [19] describe a keyword-based method for information extraction, which uses reference tasks and information categories to identify relevant information in social media data but, too, do not explicitly connect information to decisions. To the best of our knowledge, no publication systematically connects tasks and decisions with information needs and data sources.

2.2. Foundational Models and Notations

To deliver services or products, organizations employ business processes. A business process can be understood as "*a chain of functionally connected activities using information and communication technologies, which lead to a closed outcome providing a measureable benefit for a customer*", and a task represents a single unit of work [3]. A widely adopted standard for modelling business processes is the Business Process Model and Notation (BPMN) developed by the Object Management Group (OMG) [23]. To provide more detail on the processes that should be modelled, the notion of process models can be combined with the notion of reference information models, which aim to describe the universal elements of a system to provide a point of reference for application system or organization developers [3]. One example for such a combined model is Blecken's reference task model for the supply chain processes of humanitarian organizations [3].

Business processes are intimately linked to decision-making. Since BPMN's capabilities to model decisions are limited, OMG has recently released a first public version of the Decision Model and Notation (DMN), which *"creates a standardized bridge for the gap between the business decision design and decision implementation. DMN notation is designed to be useable alongside the standard BPMN business process notation*" [24, 17]. Overviews of decision models in disaster management are readily available, e.g. for disaster operations management in general [6] or humanitarian logistics in particular [31].

While there are many ways to model business processes and decisions, we found BPMN and DMN the best choice for the integrated modelling of business processes and decisions. One important reason is the tight integration of BPMN and DMN.

DMN includes elements related to the modelling of information as input to decisions, which can act as interfaces to detailed information models. Several such information models (or: application schemas, ontologies) have been constructed for the disaster management domain [21]. One example is the Humanitarian Logistics Infrastructure and Resource Model [11].

To provide an abstract view on observations that originate from various data sources and can be contextualized to satisfy information needs, the Open Geospatial Consortium (OGC) and the International Organization for Standardization (ISO) offer the Observations and Measurements (O&M) standard. O&M "*defines a conceptual schema for observations, and for features involved in sampling when making observations.*" [30].

3. The observation-aware Model and Notation (oDMN)

In this section we present the *observation-aware Decision Model and Notation* (oDMN), which consists of a model that systematically connects BPMN, DMN and O&M and of a graphical notation.

3.1. Description of the Model

The oDMN model extends the DMN meta-model [24], as shown in Figure 1, so that it integrates the properties of observations in O&M [30]. It also utilizes O&M's interface to domain-specific information models. BPMN is connected via the element Task.

Following a top-down approach from operations to data collection, the model's starting point is the element Task, which represents a single unit of work in a business process (e.g. *Select Transport Route*) [24]. A Task can be associated with zero or more decisions, e.g. finding the shortest route in the road network. Each decision is described by two elements: (a) Expression, which defines information items as input variables (e.g. road condition) and decision rules (e.g. specifying the impact of road conditions); and (b) required information, which is provided by Input Data (e.g. *Ground Team Reports* about the condition of roads). Except the element Task, all aforementioned elements are part of the DMN meta-model.

In order to connect decisions' information requirements (in the form of Input Data) to data sources, the model attaches to the O&M specification via a Provided Observation, which links to Observations originating from data sources; see the bottom right of Figure 1. O&M defines an observation as "*the act of measuring or determining the value of a property*" [25], wherein the property of a feature (as an abstraction of a real-world phenomenon [30]) simultaneously characterizes an observation. In other words, one has to be clear on which property to observe and what feature's state to estimate from the observed property, in order to be able to define a specific observation at any given location and time. A property is thus intimately related to an application domain, which gives meaning to an observation. For example, the

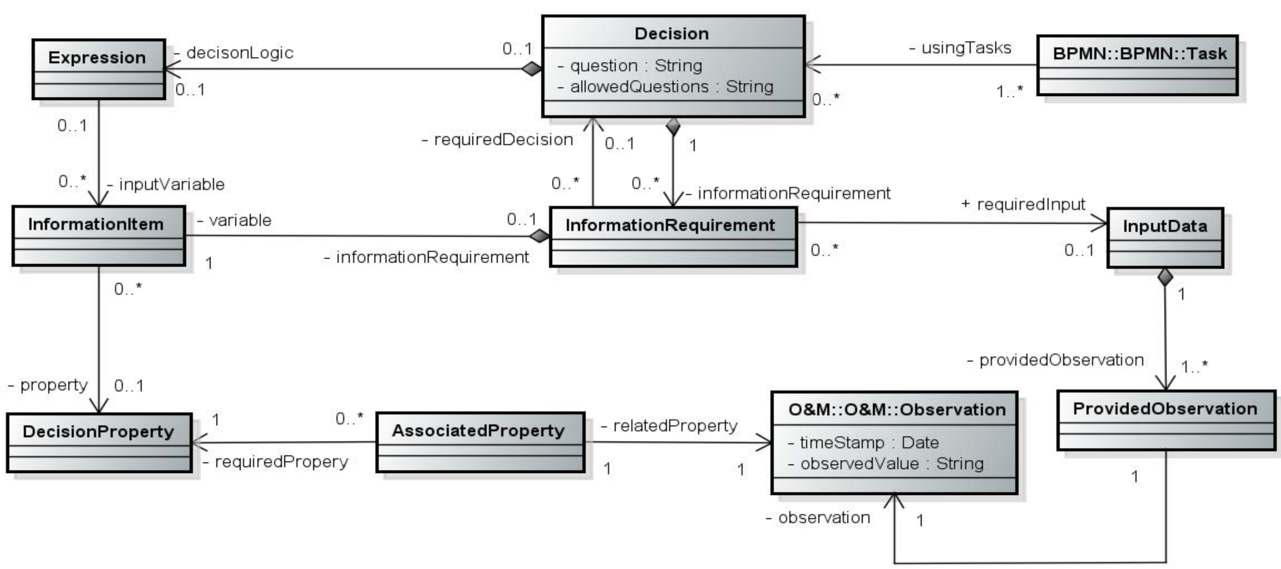

Figure 1. The observation-aware Decision Model

condition (property) of a building (feature) has different significance for a logistician, who is looking for a warehouse location, than for a medical team that seeks to establish a field hospital or for a shelter expert in the recovery phase of a disaster. Consequently, in order to associate an observation with a decision, one does not only have to specify an observation as Input Data, but it has to be clear how the observed property relates to the logic of a decision. This is reflected in the model by adding a Decision Property element that relates to the Information Items in DMN's Expressions (i.e. decision logic) and to an Associated Property in an Observation. For example, a ground team (data source) may submit a report (Observation) about the road network (Information Item/Feature of Interest), which contains information about a road's condition (Observation Property/Decision Property). In turn, this condition is associated with a vector of feasible routes (Information Requirement) in the decision logic (Expression) for finding an optimal vehicle route (Decision). Simultaneously, the report (Observation) represents a Provided Observation that links to the Input Data satisfying an Information Requirement of the Decision, which links to the corresponding Information Item in its Expression.

Since Decision Properties are so intimately linked with domain knowledge, there should be a way to relate them to domain-specific information models. Fortunately, O&M already provides an interface to incorporate domain knowledge via domain-dependent information models (in O&M terminology: Domain Application Schemas; e.g. [11, 21]). These information models provide catalogues of Domain Features, which are specific types of O&M's generic Feature element. In turn, Features can be associated with observable Properties, of whom Decision Properties are a certain type. This way, Decision Properties can make use of O&M's consideration of domain-specific information models. Figure 2 illustrates the aforementioned elements and their relationships.

Based on these definitions, it is possible to model business processes (using BPMN and reference tasks) and related decisions (with DMN). Associating properties with information items in decision models requires reflection on the features of interest in a decision model's logic (Expression) and on these features' observable properties. Having modeled the properties associated with information items and matching Input Data, it becomes possible to translate information needs into specific types of observations, and to identify the impact of incoming observations from fitting data sources onto decision-making.

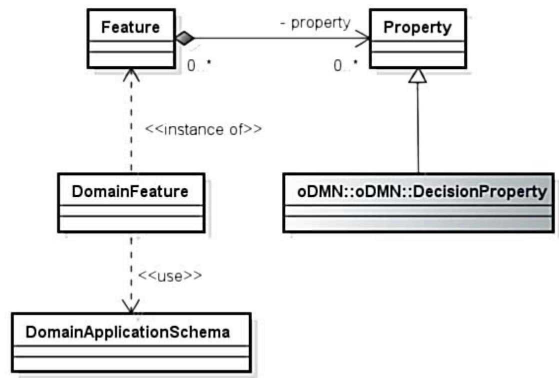

Figure 2. Relationship between Decision Properties in oDMN and Domain Knowledge in O&M

3.2. Description of the Notation

In an effort to support the creation of observation-aware decision models, we extend the DMN notation with new components and their respective notation, as summarized in Table 1.

Table 1. New Components in the oDMN Notation

Component		Description
Elements	(a) Observation	Denotes an observation (or data) that is provided by an input data element
	(b) Property	Denotes a characteristic that belongs to an observation element
Connectors	(c) Provided Observation	Indicates the observation provided by an input data element
	(d) Associated Property	Denotes a property associated with an observation element

Figure 3 displays an example of how to use these new components. On the left side, a business process and its tasks are modelled using the BPMN notation. Therein, a specific task (Task 1) involves a decision (Decision 1), which is modelled on the right side using the newly extended DMN notation. The decision requires information from an external source (Input data 1) and from another decision (Decision 2). It further employs a decision table (Business Knowledge 1) for processing required information. The decision table associates information items with properties, which relate to the properties defining the observations that deliver input data.

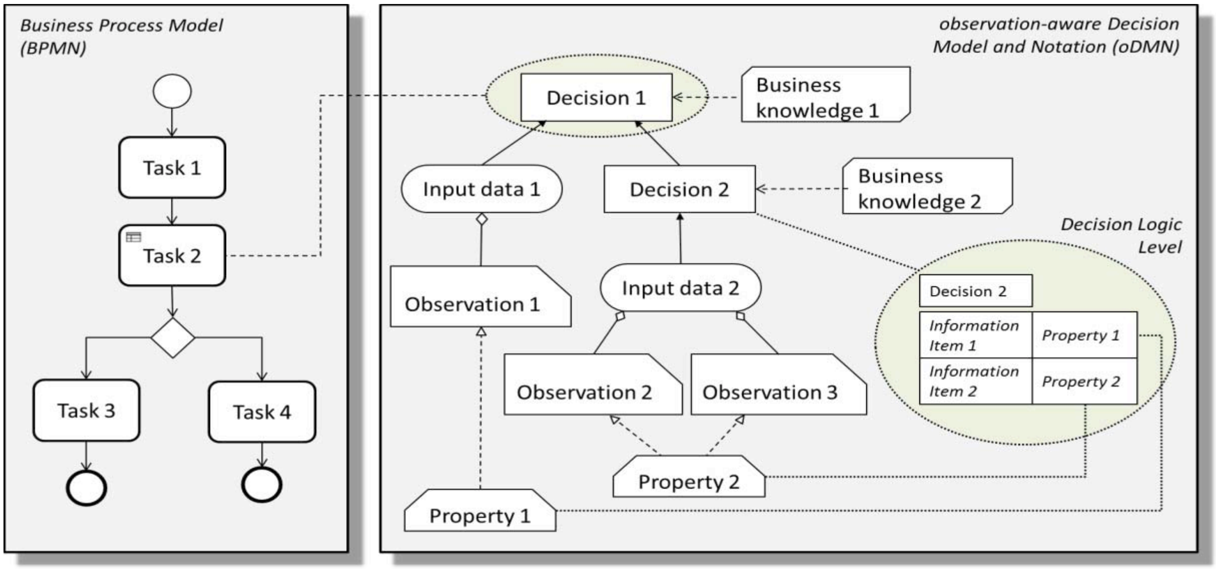

Figure 3. Example of Usage

4. Application of the Model and Notation

To demonstrate the model's applicability and its usefulness, we apply it to a case study centered on logistics operations during the 2015 Nepal earthquake response.

4.1. Methodology for Building the Case

The case results from a three-step analysis of the 2015 Nepal earthquake response:

1. ***Analysis of situation reports:*** To gain a general understanding of practical challenges, we analyzed situation reports published by OCHA and Humanity Road.
2. ***Interviews with practitioners:*** To deepen our understanding of domain-specific constraints, we conducted seven semi-structured interviews with employees of different organizations (e.g. UNICEF), who were involved in logistics operations during the 2015 Nepal earthquake response.
3. ***Modelling of the case study:*** Based on the gathered data and knowledge extracted from domain-specific information models (reference task model, information categories), we modelled business processes, decisions, information requirements, and data sources using oDMN.

4.2. Description of the 2015 Nepal Earthquake

On 25. April 2015, a 7.8 magnitude earthquake struck Nepal, triggering several avalanches and aftershocks in different parts of the country. The situation worsened when another earthquake of 7.3 magnitude struck the country only a few weeks later on 12. May 2015. OCHA estimates 8,700 fatalities, thousands of injured people, and almost 800,000 buildings affected [29]. Neighboring communities in India, China and Bangladesh were affected as well, although with lower intensity. When the government requested international aid and assistance, aid organizations from different countries began delivering various goods (e.g. medicine, equipment, vehicles), financial support, and staff to Nepal; providing relief services like search-and-rescue and medical assistance [27].

As mentioned in the introduction, we focus on logistics, as it can be considered the backbone of relief operations. During the Nepal response, logisticians faced numerous challenges. Among these were transportation issues[1], like too many aircraft targeting Kathmandu airport, while other airfields in

[1] Another important issue was procurement. As in many disaster contexts, it was difficult to assess the location, availability and capacity of local suppliers of relief goods in Nepal, so that the initial response heavily relied on the import of items from India, China and other countries. An issue related to limited information about local market capacity is the import of goods that could have been procured locally, which increases delivery time, drives transportation costs and may further disrupt stressed local markets. Consider what happens to local companies that are still intact when aid organizations begin flooding the market with cheap or free goods. A current approach to combat this problem are hybrid supply chains, which heavily relies on information on local market capacity [16].

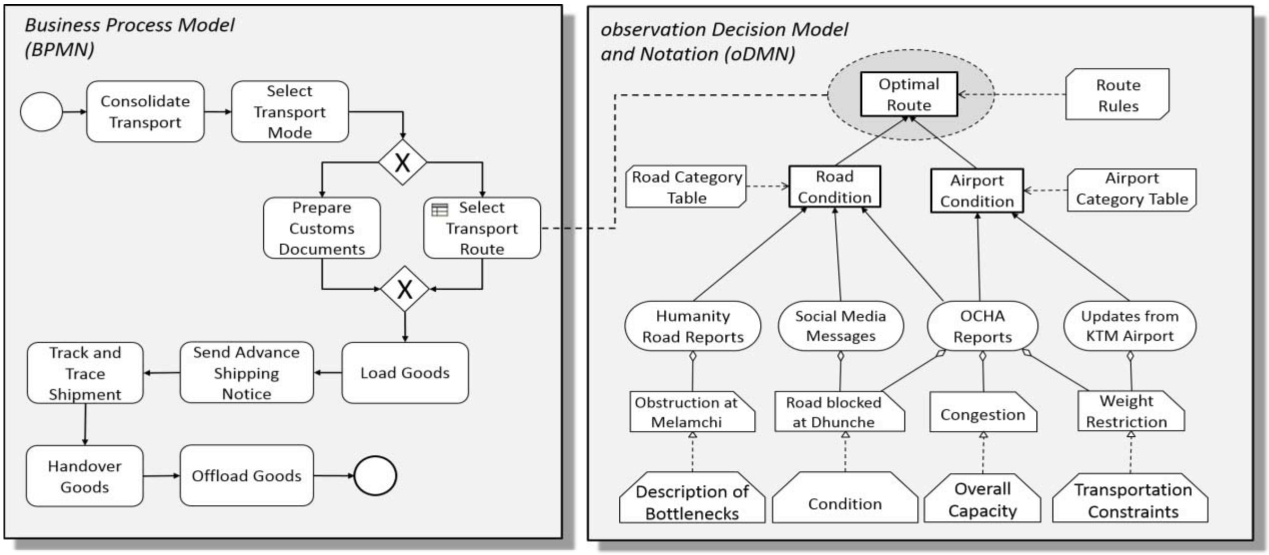

Figure 4. Model Application for the 2015 Nepal Earthquake

the country went unused. The airport became a bottleneck, also because its (previously sub-optimal) condition worsened after the earthquake, to a degree where the weight of incoming aircraft had to be restricted. One aid worker mentioned that his organization was lucky to learn about this restriction from a ground team just before a bigger airplane was about to be sent to Nepal. They could consequently switch to a smaller model. As another way of circumventing issues of airport access, logisticians used alternative points of entry, like road transportation from Delhi to Kathmandu, where first transports encountered constraints.

Regarding data sources, ground teams supplied important information for making sure that deliveries matched local needs as well as infrastructure and resource constraints. This is in line with previous findings that field staff is the main source of information for logisticians [37]. Practitioners issued several requests for specific information about local infrastructure and resources to digital volunteer communities, which once more suggests the perceived potential of online social media (e.g. Twitter and Facebook) and crisis mapping (e.g. by the Humanitarian OpenStreetMap Team) for supplying relevant information.

4.3. Domain-specific Information Models

Blecken offers a reference task model for the supply chain processes of humanitarian organizations [3] that features six functional areas: assessment, procurement, warehousing, transport, operation support, and reporting. For example, the operational / transport category contains 15 tasks, such as *Select Transport Route*[2]. Various decision models exist that support the planning of transport routes [31]. For instance, a set of all possible routes between all pairs of supply and demand nodes can be represented as an input vector and then used to optimally assign vehicles [2]. Descriptions of infrastructure and resources that are relevant for humanitarian logistics are available as information categories, including characteristics of airports and road networks and respective attributes [19]. For example, the category *Airport* contains sub-categories like *Current Condition of Facilities*, *Runway Characteristics* and *Cost of Airport Usage*.

4.4. Model Application

In this case, a logistician initiates a transportation process (modelled in BPMN) with the task *Consolidate Transport*, as displayed on the left side of Figure 4. Knowing the types and volume of goods to be transported, the logistician proceeds to *Select Transport Mode*, e.g. airplane or road transportation. Once the transport mode is clear, the next task is *Select Transport Route*, which involves a decision (modelled in oDMN; see right side of Figure 4). Parallel to selecting a transport route, it is possible to *Prepare Customs Documents* necessary for exporting goods to the affected country. When the transport

[2] The task *Select Transport Route* has the following description: "*When selecting a transport route, several factors such as security of staff, assets, and goods need to be taken into account. Transport routes should be easily adaptable in case of unexpected events. In case of an unforeseen event, transport routes may need to be re-planned*" [3].

route is clear and customs documents are ready, the logistician may issue to *Load Goods* as well as *Send Advance Shipping Notice* to inform the recipient, and subsequently *Track and Trace Shipment*. Upon arrival, *Offload Goods* and *Handover Goods* conclude the transport process. The task *Select Transport Route* involves the decision *Optimal Route*, which employs business knowledge (*Route Rules*) and requires data from other decisions (*Road Situation* and *Airport Situation*). These decisions, in turn, require further business knowledge (*Road Category Table* and *Airport Category Table*), which describe information requirements (features) and their respective decision properties. *Humanity Road Reports*, *Social Media Messages*, *OCHA Reports*, and *Updates from KTM Airport* (Tribhuvan International Airport in Kathmandu) have been selected as suitable input data to satisfy the decisions' information requirements.

Observations about the affected area can be considered relevant when their properties match the properties defined in the decisions' business knowledge; e.g. observations coming in via *Social Media Messages* and *Humanity Road Reports* could raise awareness of the *Road Situation* by pointing out an *Obstruction at Melamchi* and an *Obstruction at Dhunche* [12, 13]. Similarly, *Updates from KTM Airport* notify that all incoming aircraft need to obey a *Weight Restriction* [28], while OCHA reports *Congestion* at the airport [26]. Taking these limitations into account, Table 2 presents the data of the decision "*Airport Condition*", which adopts specific business knowledge (*Airport Category Table*) with two information requirements: *Aircraft Slots* and *Weight Limitations.* These decision's information requirements are then associated with the decision properties: *Overall Capacity* and *Transportation Constraints*. Matching the properties of observation and decision reveal that the observation (*Airport Congestion* and *Weight Restriction*) provided by the input data (OCHA Reports and Updates from KTM Airport) can fulfill the decision's information requirements (*Aircraft Slots* and *Weight Limitations*).

Table 2. Data of the Decision "Airport Condition"

***Decision:* Airport Condition**	
Airport category table	
Aircraft Slots	Overall Capacity
Weight Limitations	Transportation Constraints

Table 3 presents the decision logic of the *Airport Category Table*. The situation of the airport is defined by cross-comparing information requirements. For example, when there is slots available and the aircraft fits in the weight limitation (e.g. < 100 MT), the aircraft is allowed to land at the airport.

Table 3. Decision Logic of the Business Knowledge "Airport Category Table"

Airport Category Table			
O	**Aircraft Slots**	***Weight Limitations***	***Situation***
1	Available	< 100 MT	Available
2		[101..200]	Available
3		< 201 MT	Limited
4	Limited	< 100 MT	Available
5		[101..200]	Limited
6		< 201 MT	Congested
7	None	< 100 MT	Congested
8		[101..200]	Congested
9		< 201 MT	Congested

5. Discussion

oDMN aims to clarify and systematically connect tasks, decisions, information, and data sources. This has been achieved by utilizing standardized models and notations (BPMN, DMN, O&M) as well as domain-specific information models (reference tasks, information categories) and extending them where needed. The utilized abstract and generic concepts allow for modularized customization via the domain feature class as the central interface. Still, the approach's generalization will benefit from application to other domains, like monitoring and early warning in disaster preparedness.

On one hand, the integrated model allows to formally derive information needs from decisions and tasks. This elucidates information requirements resulting from practitioners' tasks and decisions, which, in turn, can better focus data collection for identifying relevant information. On the other hand, the integrated model makes it possible to determine the impact of new information on decisions and tasks. This can be considered as an extension of previous studies [38, 14, 7]. Insofar it enables the integration identified information into decision-making.

Basing oDMN on popular standards favors adoption and application in practice. The use of

BPMN and DMN, however, has inherent limitations. For example, BPMN offers limited capabilities for modelling information flows, and the current version of DMN still focuses on routine decisions.

For oDMN development we have relied on published decision models. which might be based on unrealistic assumptions [6]. While this is important to note, it does not affect our approach, since the considered models can easily be replaced with more complete or practical versions in the future.

Currently, data sources are considered in the integrated model through a combination of input data and observations, but there is no explicit modelling of their characteristics. There remains a need to match properties with data source characteristics, which is highly domain-dependent due to the specifics of relevant properties.

Information in input data (e.g. *OCHA Reports*) can be automatically matched with decisions' information requirements if the contained observations are tagged with pre-defined properties. Currently this is hardly the case in written reports, although public data sets (see e.g. www.crisis.net), including social media data, are increasingly tagged and thus semantically enriched with information categories. Achieving a seamless information supply from data collection to decision support systems would benefit from information categories being applied during data collection itself, as it is done in the data collection system GDACSmobile, for example [18].

oDMN can drive interoperability by serving as a holistic framework for data collection and decision support systems. Moving beyond conceptual integration towards data integration requires systems to communicate with fitting semantics and syntax. Existing data exchange standards, like the Emergency Data Exchange Language (EXDL) or the Humanitarian eXchange Language (HXL), can support interoperability by providing the necessary clarity. If domain-specific models are used, as in our case, these languages may need to be extended.

Although it is useful to incorporate individual observations into decision-making, it remains a challenge to integrate them into baseline data. For example, the observation that a certain road is blocked at a given location should result in an update of maps. Doing this automatically for a high volume of incoming observations is still difficult.

6. Conclusions

This paper presents the *observation-aware Decision Model and Notation* (oDMN), which aims to systematically link tasks, decisions, information, and data sources. oDMN is based on popular standards for the modelling of processes, decisions and observations, as well as on domain-specific information models that further describe tasks, decisions and information needs. Applying oDMN to a case centered on logistics operations during the 2015 Nepal earthquake shows that it achieves its objectives.

oDMN can improve decision-making of disaster management organizations by improving the understanding of information requirements and data sources, and thus support targeted data collection. Furthermore, decision-makers are aided in the integration of information provided by different data sources; for instance, their configuration can consider collaborative mapping to provide information about the road network, while social media messages provide updates about the condition of the road network. Moreover, oDMN enables its users to determine the impact of new information on decisions and tasks, which can improve decision-making without increasing information overload. In addition, it can lead to higher degrees of automation, effectively reducing information overload.

Future work should be done to apply oDMN to other domains, like environmental monitoring and early warning, in order to support its generalization. In addition, oDMN should be adopted in the design of data collection and decision support systems, e.g. leading to the consideration of decision-related properties in observations, higher degrees of automation during processing of observations, improved interoperability between data collection and decision support systems, and more seamless integration of incoming observations into decision-making. Last but not least, the resulting systems should be evaluated; ideally in exercises (e.g. serious games [20]) and with practitioners, like assessment experts and decision-makers from headquarters and from the field.

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