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An activity theory analysis of boundary objects in cross-border information systems development for disaster management

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Abstract

One of the main challenges in cross-border disaster management is the development and use of information systems that cater the needs of heterogeneous relief agencies, policies, activities and cultures. Drawing upon activity theory, this paper examines cross-border information systems development for disaster management. We infuse the concept of boundary objects into activity theory by the characterization of the artifacts. This allows articulating how the socio-technical objects are meshed with the process of cross-border collaboration for systems development. Our longitudinal ethnographic field study on a cross-border flood management project, VIKING, revealed how the project was empowered and developed by four key boundary objects, i.e. the governance structure of the program, two information systems (a disaster management information system and an online collaboration portal), and recurring cross-border exercises as an evaluation and feedback mechanism. The selective institutionalizations of these key boundary objects helped the participants overcome various contradictions existed in the systems development. The study results also show that both goal-oriented actions and boundary objects can affect the outcomes of long-term large-scale disaster management systems development.

Keywords: Disaster management, Information systems development, Cross-border collaboration, Activity theory, Boundary objects

Background

Disaster management (DM) entails a range of complex interdependent activities involving many collaborating organizations. It is particularly so if the disaster affects multiple countries as we have seen in the 2004 Indian Ocean tsunami or multiple regions in a single country as has been seen in the floods of Oct-November 2011 in Thailand. Although information systems are often adopted to expand the scope of management in both private and public sectors, information system development (ISD) is by itself a complicated endeavor, especially in inter-organizational and international settings where organizations with different goals, existing technologies and cultural backgrounds have to collaborate [1-3]. DM organizations (DMOs) have attempted to leverage information systems (IS) in an effort to effectively coordinate various disaster management efforts. Developing an IS to support complex cross-border DM activities, however, is an overwhelming task even for most capable government authorities for a number of reasons.

First, the development of such a disaster management information system (DMIS) requires cross-organizational collaboration between multiple autonomous organizations. These organizations often have incompatible responsibilities, procedures and objects [4], highlighting the diverse requirements for cross-organizational information sharing systems that must accommodate a wide range of information needs and flows [5]. Second, the relational ties between many DMOs are often temporary and weak as inter-organizational collaboration is not necessary in their day-to-day operations during non-disaster periods [5]. Most DMOs rarely need cross-organizational information sharing, and thus it is hard to keep them interested and committed to the development of a DMIS for occasional use. The special systems requirements for cross-

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organizational and cross-border DMIS, such as reliability, interoperability, functionality, and accessibility, present yet another reason that makes it a daunting task. Accordingly, we conceptualize a cross-border DM ISD as a complex collaborative process in which many stakeholders conduct a wide range of activities centered around various socio-technical artifact (e.g., inter-organizational structure, shared systems development environment, communication channels, etc.), some of which may change as the development process evolves.

Due to the importance of effective disaster management, there are an increasing number of scholars picking up on the challenges of cross-organizational DM ISD e.g., [6-8]. While some contributions have been made on understanding cross-organizational ISD [9], studies on cross-border collaboration for DM ISD are scarce, with only a few exceptions e.g., [1,10]. This research aims to understand the nature of boundary objects that facilitate long term cross-border DM ISD process. For this purpose, a collaborative DM ISD project between Germany and the Netherlands, entitled Program VIKING, is investigated. Employing an ethnographic field study approach, this study identifies the collaborative activities and boundary objects that have made substantial positive effects on the cross-border DM ISD process. The field study was conducted using three data collection techniques: (1) semi-structured, face-to-face interviews, (2) participatory observations, and (3) document analysis. We draw on activity theory (AT) to frame the interactions among the activities, objects, and advances in the DM ISD.

In the next section, we discuss about activity theory and boundary objects that provide a theoretical foundation for our study of cross-border DM collaborations. Then we present our research design and methodology along with a brief introduction to the studied cross-border DM collaboration case. Next, the boundary objects that play a pivotal role in the success of the collaboration activity are identified. We conclude the paper with key research findings and discussions on the theoretical and practical implications of the findings.

Theoretical foundation

Activity theory

To understand the critical success factors for a cross-border ISD, the collaboration activities must be systematically specified, and the mechanisms through which the critical factors influence the collaboration must be articulated. Activity Theory (AT) [11,12] fits well with our research objectives. AT portrays a social system as a group of individuals engaging and interacting with their environment [13], which will result in output objects (a.k.a. artifacts) [14,15]. The number of interactions and resulting artifacts can increase as the social system persists over time, while some of the artifacts can affect the future activities and structure of the system. AT underlines the role of emergent artifacts in relation to the activity system and can untangle human-object relationships to observe the unfolding of the activity system (e.g., cross-border DM ISD project group) over time. As such, AT provides us with a useful analytical framework to examine the activities and artifacts of a cross-border DM collaboration system that can facilitate and prolong the system.

AT defines a social system as an activity system that consists of various components, including the subject (i.e., agent or actors), objectives (i.e., purposes of actions), tools, rules, community, and division of labor [11]. A subject is a person or a group of people engaged in an activity. Acting as subjects, actors can take a set of collated or extended actions in order to achieve a goal (i.e., a desirable outcome at the individual action-level), which should collectively contribute to the system-level activity. An objective is the desired outcome [16] held by the subject and motivates the activity, giving it a specific direction [13]. Transforming the objective (e.g., reduction of flood damage) into an outcome (e.g., cross-border DM initiative, development of DMIS, effective disaster response) motivates the existence of an activity system. There can be a multiplicity of objectives that may be revised or evolve over time in a long-term DM project. Community refers to the group of subjects that share the objectives of an activity system. In the context of cross-border ISD collaboration for DM, a large number of DMOs and IS vendors/consultants from the participating countries will comprise the community of the activity system. The relationships between subject, objectives and community are mediated by tools, rules and division of labor. An activity achieves an objective via a development process that typically has multiple steps or phases [17]. A "tool" can be anything used in the development process, including both material tools (e.g., servers, workstations) and tools for thinking (e.g., online forums, pressure); "rules" cover both explicit and implicit norms, conventions and social relations within the community, while "division of labor" refers to the explicit and implicit organization of the community of an activity system as the subjects are involved in the transformation process [17]. In the cross-border DM context, the rules and division of labor include institutionalized business processes and (inter-)organizational structures (e.g., national incident management system) that can widely vary from one country to another as well as among different types of collaborating organizations (e.g., firefighters vs. law enforcement vs. domain experts/hazmat).

AT was initially adopted in the IS field to understand human-computer interaction [13,16], and has also proved to be valuable in analyzing complex processes

such as cross-organizational data model development i.e., [18,19]. Shankar et al. [20] outline five fundamental principles of AT based on [11].

1. The prime unit of analysis is an activity system, where an activity system refers to a collective, artifact-mediated, and object-oriented system of actions, which exists in a network of related activity systems.
2. Every activity system is subject to multiple perspectives and beliefs (i.e., multi-voicedness). The division of labor in an activity system induces diverse positions for the diverse groups of actors involved in the activity. The division of labor is a primary component of any activity system, impressed with the rules and conventions.
3. The issues and capabilities of an activity system can only be analyzed by their own history (i.e., historicity). Thus, AT implicitly incorporates the structurational view of organizational transformation where human actions and institutional structures can mutually influence each other [21-23].
4. Contradictions are the sources of changes and developments. Contradictions amass structural tensions within and between activity systems.
5. An activity system can expand its capability (i.e., expansive transformations). Expansive transformation refers to a process through which an activity system expands its capability by redesigning its own structure and changing its actions in order to resolve a challenging contradiction. As suggested in the previous (4^{th}) principle, activity systems generally enter lengthy phases of fundamental transformations when a contradiction cannot be resolved by existing structure and practice. Such fundamental transformation, if successful, will results in a reoriented activity system [24] with an expanded capability required in the new environment.

The principles stated above make AT appropriate for examining cross-border DM ISD characterized by collective actions, historicity, contradictions and expansive transformations.

Boundary objects

AT recognizes the influences of both existing structure (i.e., rules, community, and division of labor) and human agents (e.g., human subjects using instruments or initiating an expansive transformation) [11]. Furthermore, AT appreciates shared understanding (e.g., expansive learning by the community members) as a means to improve social structures [25,26]. In relation to shared understanding, it is essential to understand the concept and role of boundary objects in cross-border collaboration activities.

Boundary objects are referred to as conceptual or physical artifacts that reside in the interfaces among organizations [27]. From a functional perspective, a boundary object is an artifact shared by a community of subjects (e.g., DMOs in cross-border collaboration) that work together to reach their individual goals. Such an object can be a material thing, but it can also be less tangible or totally intangible (e.g., plans, common ideas) as long as it can be shared for manipulation and transformation by the participants of the activity. For an object to serve as a boundary object, it must be "both plastic enough to morph to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" p. 393 [28]. Boundary objects help interacting organizations facilitate cross-organizational communication and form an organizational identity [27], while they can also act as gatekeepers that selectively filter information between the organizations. Hussenot and Missionier [29] depict them as bearers of compromises that promote cooperation between the stakeholders (p.274). Therefore, boundary objects should be able to bear various meanings assigned by different organizations while serving as a common reference point to the members of multiple organizations when they engage in mutual practice [28].

IS researchers have recognized the potential of IS as a boundary object that can facilitate boundary spanning [30,31]. Accordingly, boundary objects may include physical product prototypes, design drawings, shared IT applications, standard business forms, or even shared abstract constructs such as product yield [32].

For a boundary object to emerge, a new joint field of practice must be produced [25]. For example, a shared information system can be a joint field of practice. However, not every IS becomes a boundary object in reality because human agents in some organizations may not see its local usefulness or the IS may fail to establish a common identity across all organizations [25]. The VIKING alliance was originally an outcome object (a.k.a. artifact), but it became a part of the structure and influenced the transformation process of ISD. Hence it served as a boundary object that developed a shared identity and functioned as a communication hub.

Research design & methodology

This study adopts a qualitative, ethnographic field study approach in order to identify important factors (e.g., conditions and actions) for successful development of cross-border DM ISD. We chose a qualitative research methodology to develop a comprehensive understanding from rich field data. Qualitative methodologies are more appropriate where the research question is exploratory

in nature and exists within a broader sociological context, thus necessitates rich descriptions of the social environment [33]. Furthermore, such an approach allows the exploration of unforeseen relationships and offers better insights into the inter-dependencies among the factors captured in the study [34]. Research on the evolution of a partnership, the controversies and compromises between organizations across a national border requires data that is both rich in contextual information and deep in understanding [35]. The field study was conducted over a 9-month period, covering over 4 years of cross-border collaboration that developed a DMIS at the Dutch-German border, dubbed Program VIKING. This program is described in a later section in details. Both the process of the DM ISD and the use of the DMIS in a cross-border exercise were investigated.

This field study has employed three data collection techniques: (1) semi-structured, face-to-face interviews, (2) participatory observations, and (3) document analysis. A series of semi-structured face-to-face interviews [36] were conducted with representatives of the first responder and water management agencies, the lead IT developers, and technical and managerial staff of Program VIKING. The interview protocol contained questions concerning the project initiation (e.g., history, scope, leadership), the technological solutions developed and their development process (e.g., participants, negotiation, objectives, conflicts), and factors affecting the success of the project. In the formal interviews, subjects were asked a series of open-ended and unstructured questions, augmented by follow-up questions for clarification. This procedure allowed the respondents to elaborate on the issues and ask for clarifications from the interviewees to ensure a better understanding of the context and concepts in the study [37]. Informants also discussed their motivations for participation in the program, key milestones, and technical and non-technical challenges that they had encountered thus far. Formal interviews were conducted during a cross-border DM exercise (a.k.a. ROAR). Twelve formal interviews were completed with nine key informants; three of them were interviewed twice. All formal interviews were recorded and transcribed for data analyses.

In addition to the formal interviews, we observed the use of the DMISs developed by the VIKING alliance during the three-day ROAR exercise. Participatory observations allows researchers to collect rich data in a direct way [38] while distortion of the results can be reduced to a minimum through direct interaction with research objects [39]. In total, three days of training with approximately 500 participants from both nations was observed. At least one member of the research team observed each training run, and one member attended three full days of the ROAR exercise. The data collection criteria that guided the interviews also guided the observations. In addition, the observations allowed us to conduct opportunity-based informal interviews with DMIS users. Thanks to the cooperation and support of the Program VIKING committee, we were allowed unrestricted access to the VIKING file sharing system that hosts internal documents generated during Program VIKING. We analyzed both Dutch and German documents to enrich our understanding of the program and to clarify our interpretations of the interview and observation data. Examples of documents include project meeting reports, software requirements specification and DM ISD schedules. The lists of interviewees and full document corpus are included in the Tables 1 and 2.

Analytical framework

The literature in the field of organization studies argues that organizations, collective activities, and organizational processes are all constructed through the relationship between agencies (i.e., subjects) and objects [30]. To better understand the relationships between agencies and objects, we must observe their entanglement over time. As Hussenot & Missionier [29] have demonstrated, boundary objects evolve over time. Although the transformation and nature of boundary objects have been researched in cross-organizational environments e.g., [27,40], previous contributions have not clarified the relationships among activities and boundary objects nor the implications of changes in boundary objects for the agencies that use them. This calls for more careful consideration of how the material and social objects become "entangled" in the process of collaboration. We propose an analytical framework (Figure 1) that augments previous studies by analysing boundary objects from an AT perspective.

The proposed framework suggests that boundary objects can be synthesized by an activity system, which

Table 1 The subjects of formal interviews – the primary affiliation and the role in Program VIKING

ID	Organization	Role
1	Wateboard Gelderland	Coordinator water board
2	Decis Lab	Project manager Exercise Integration
3	Geonovum	Project manager system development and maintenance
4	Province Gelderland	Program coordinator for the Netherlands
5	Fire department	(former) Chief of the regional Fire department
6	FLIWAS	Application developer
7	Justice department	Auditor
8	Police Academy	Coordinator control room
9	Busy to	Program VIKING evaluator

Table 2 Corpus of Analyzed Documents

• Notes of the steering committee meetings from 2004–2006
• Annual project plans from 2004–2009
• Internal reviews of the cross-border exercises (both in Dutch and German), including user satisfaction with the information sharing systems
• ICT architecture planning and development documentation
• Helpdesk log files of the ISs used during cross-border exercises
• Observation notes of IS use during exercises
• Cross-border exercise scenario and scripts
• Analysis and description of the available information systems for flood management in both countries
• Analysis and description of the necessary cross-border information flows
• User manuals for FLIWAS
• Maintenance reports of FLIWAS
• Service level agreements on FLIWAS and outsourcing plans for 2009
• The education and training program for VIKING
• Functional requirements of the FLIWAS components

can in turn be morphed into the system and act as expansive solutions for subsequent cross-border DM ISD collaboration. The framework embraces AT elements such as agencies (subjects), instruments (tools), artifacts (outcomes), and environments, while environments encompasses the concepts of rules, community, and division of duties. As an activity system starts (t0 in Figure 1), it continues to exist for an extended period of time, some artifacts of its actions become boundary objects (t1). Such boundary objects transform the structure and behaviors of the activity system (t2), helping the system achieve its goals (t3). This framework emphasizes the pivotal role of boundary objects and delineates the dynamics among the structure of an activity system, the actions of its actors, and its environments.

Our framework can be directly applied to a transforming cross-boundary collaboration system (i.e., cross-border DM ISD program), captured over time. In such a system, the desires of the subject(s), instruments and actions in the given environment shape recursive transformation processes. Some, but not all, artifacts resulting from the subject's purposeful action (i.e., outcomes) at one point of time (t1) may become a part of the structure for actions at a subsequent time (t2). Such a structure would include subjects, instruments, and environments, while the environments encompass the concepts of rules, community, and division of duties. Whether an artifact becomes a part of the system structure or not depends on the attributes of the artifacts, thus we dub "a selective institutionalization process". We posit that the acceptability of these attributes to the various stakeholders in the system (i.e., community) is the key determinant of the selective institutionalization process. Artifacts that possess the characteristics of boundary objects, i.e., well accepted and shared by the stakeholders [32,41], are very likely to become a part of the activity system's structure and exert significant impacts on subsequent activities, especially when the community of the system includes a large number of stakeholders (e.g., cross-border DM ISD). Accordingly, we pay special attention to the selective institutionalization processes in Program VIKING, where some artifacts become formal boundary objects in the system. This will enable us to identify the conditions (e.g., existing rules, available instruments, imposed division of labor) and actions (i.e., creation, institutionalization, and utilization of the artifacts) that can help achieve a desirable state of the system. The focus on institutionalized artifacts will also suggest why the conditions and actions are important in view of the internal contradictions addressed via the boundary objects, and how the expansive learning and solutions that addressed the contradictions are implemented (e.g., the subject, object, instruments, action) [42]. We use the analysis framework as a guideline for our data encoding and analysis activities.

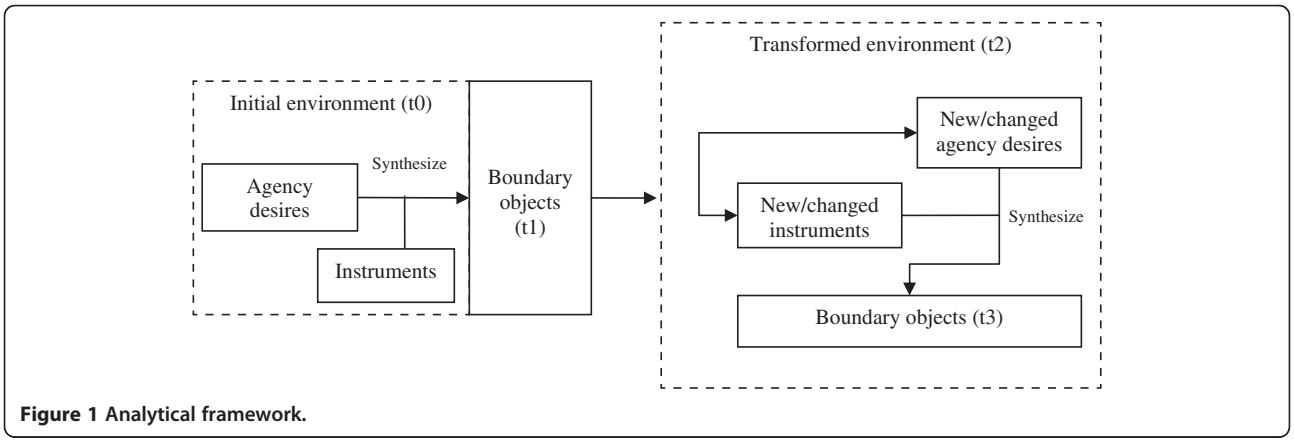

Figure 1 Analytical framework.

Coding scheme and analysis process

Collected interview data were coded using a coding scheme keyed to conventional terms used to specify the conceptual or physical objects in the program (e.g., Viking alliance, User group, Waterboard, FLIWAS, Viking Cockpit, ROAR, EU guidelines, program manager). Each instance of the objects was associated with an element of activity (i.e., actor, instrument, environment, and artifact) according to the analysis framework shown in (Figure 1) The association was recorded at instance level (i.e., each appearance in the data) because one object could be categorized into more than one element, depending on the context where the object was mentioned. For example, the Viking alliance was an artifact in the context of alliance formation activity, but it played a role of an actor, an instrument, and an environment in a later stage as it became a central part of the structure of Program VIKING.

We operationalized boundary objects as the objects mentioned by multiple data sources (i.e., interviewees from different organizations). With this operationalization, we searched for the key boundary objects that once emerged as artifacts and later appear again as another element (e.g., actors, instruments, environment), assuming that they were the (enablers of) expansive solutions that significantly facilitated the cross-border DM ISD activity. Upon the identification of the expansive solutions, other objects and theoretical antecedents of collaboration factors were related to the solutions. This analysis was to clearly understand the conditions and actions that triggered (or were triggered by) the emergence of expansive solutions. As expected, some of the identified boundary objects had a large number of connections to other coded objects, suggesting that they played critical roles in Program VIKING. (Figure 2) is a visual representation of the concept coding scheme. The results of the analysis are described in details in the research findings section. While this research is designed as a qualitative study, this coding scheme confers some level of objectivity on the analysis procedure. The results of the interview data analysis were triangulated with the researchers' insights derived from observations of the IS use, discussions with users (DMOs)

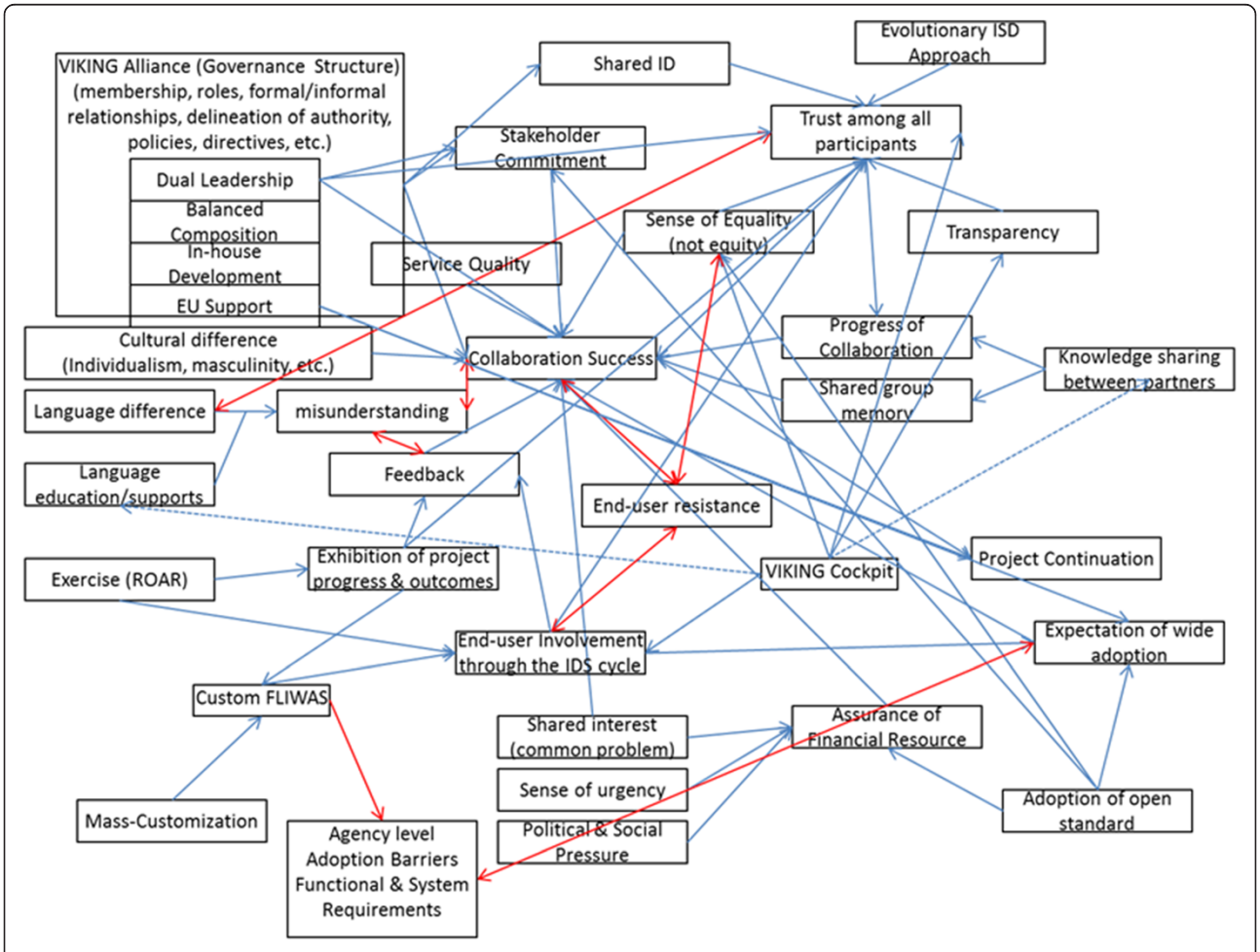

Figure 2 Concept coding scheme.

during the exercises and analyses of archival data, which enabled us to build a clear, in-depth understanding of the studied case from the compiled qualitative data [43].

Case background: program viking

In 1993 and 1995, the area surrounding Rijn River across the border of the Netherlands and Germany was affected by major floods. This area belongs to the Province of Gelderland, the Netherlands and the Province of Nordrhein-Westfalen, Germany. Both sides of the border together, this area has over 1.7 million inhabitants spread over 56 municipalities. During the floods, cattle and over 250,000 people had to be evacuated for 5–20 days. Fortunately, the dikes did hold the floods, but if they were destroyed, some parts of the area would have been submerged under 5 meters of water. This area is particularly prone to major floods as the Rijn River flows through Germany into the Netherlands before it meets the North Sea. A flood of the Rijn in one area may result in a flooding in another area as far as 40 kilometers away, which will not stop at the countries' border. In preparation for major floods, the local and regional governments in both countries have heightened dikes and stimulated development of information systems for flood management. After a myriad of agency specific, local and regional projects, an inspection of safety and flood management in the area called for integration and collaboration between Dutch and German counterparts in both water and disaster management. This led to the instantiation of Program VIKING. Program VIKING focuses on improving four aspects of flood and disaster management capability: (1) the operational processes, (2) the information sharing systems (architecture and maintenance), (3) cross-border collaboration between DMOs, and (4) the education and training of multi-disciplinary DM teams.

There are some noticeable differences between the DM environments of the two countries (see Table 3). The differences can be understood on different levels, including the cultural, technological, and institutional levels. On a cultural level Hofstede's [44] study revealed that the Germans are generally more formal than the Dutch in their ways of interactions. On the technological level we found that the two countries use totally different sets of information systems for flood management. On the institutional level, the main difference between Germany and the Netherlands is the division of duties and jurisdictions. In Germany, municipalities have their own police, fire brigade and ambulance services, whereas in the Netherlands these DMOs are organized around 25 safety regions, each of which covers 10–20 municipalities.

As a result, various DMOs are coordinated by the mayor of the largest municipality in the safety region in the Netherlands, whereas in Germany the coordination is distributed over three levels: districts, regions and states. The province of Gelderland and the Regional Government (Bezirksregiering) of Düsseldorf have no direct operational role in this, and are primarily responsible for coordination with entities outside of their jurisdictions (e.g., the national disaster coordination center, foreign governments). With regard to the program's emphasis on improving information sharing systems, both countries have a common motive to support the program: to quickly exchange flood related information in a major flood. In the past, different municipalities and provinces were using different flood management systems and could not share information even within the

Table 3 Differences between two nations

Level	Aspect	The Netherlands	Germany
Cultural	Main language	Dutch	German
	Cultural differences	Small power distance, informal, flexible, modest, individualistic	Big power distance, formal, inflexible, strict, collectivistic-committed to institutional structure
Technological	Flood information systems	1. PoldEvac,	1. HZG,
		2. Hoogwater InformatieSysteem (HIS),	2. X-border GDI,
		3. Geautomatiseerd Draaiboek Hoogwater (GDH),	3. Deichinformationssystem,
		5. POIRE,	4. HOWISS,
		6. SHERPA	5. COBRA,
			6. DISMA
Institutional	Institutional structure	Decentralized relief agencies with high autonomy	Centralized relief agencies, moderate autonomy
	Government standards for IS development	NORA	INSPIRE
	Disaster classification and coordination structure	GRIP structure containing four levels, flood is immediately GRIP 4 (highest level)	Stuffe structure (1,2,3)

same country. The initial project budget for Program VIKING was 1.6 million Euros. Because the program is partly financed by European funds, the products of the project (e.g., reports, software) are available for government agencies of other EU countries. So far, Ireland, Scotland, England, Poland, Czechia, Slovakia and Hungary have expressed interest in the products.

Program VIKING has been a successful project, according to multiple evaluation reports from both Dutch and German sides. Every stakeholder the research team has interviewed also considered it a successful project. For example, one of the project managers noted that they could obtain continued commitment from the participating agencies and additional funding to extend the collaboration efforts after the original project term (~2006) because their cross-border collaboration and DM ISD were successful. The program managers also believed that the collaboration between the Netherlands and Germany had significantly improved since Program VIKING started.

Another indicator of the success is the prestigious National Safety Award bestowed upon Program VIKING in 2006. In addition, several countries including Slovakia and Romania have decided to adopt FLIWAS [45]. Therefore, at least as of the time this study was conducted, Program VIKING was viewed as a good exemplar of successful cross-border DM and DM ISD project.

Analysis results

To keep our research manageable, we demarcated the beginning of Program VIKING as the starting point of our analysis when the VIKING Alliance was first formed and took the leading position in the cross-border collaboration project. The alliance originally included only a small number of partners including the regional fire departments, the water boards, and some other organizations in the province of Gelderland, the Netherlands. On the German side, only one agency, Regional Government of Düsseldorf, participated in the initial alliance, resulting in an unbalanced alliance structure skewed toward the Netherlands. The Province of Gelderland was coordinating the Dutch partners, while the Region of Düsseldorf that recently took over the water management in Germany was representing various German municipalities and DMOs. The first project meetings clearly pointed out that a wider range of partnership that includes regional police departments, municipalities, and ambulance services is required in order to develop a more sustainable program and gain regional commitment for further collaboration. Some of the major contradictions in the initial Program VIKING structure existed between:

- The budget and work to be done (instrument vs. outcomes)
- Political/economic power and the wider range of stakeholders to be mobilized (instrument vs. community/rules)
- The potential partners to be included and the hierarchical structure of the organizations (stakeholders vs. community/division of duties)

The alliance responded to these challenges by actively lobbying high level officials (action) in the hierarchies of DMOs in both countries, in an effort to expand the alliance partnership (action-level goal). Although the action-level goal of the lobbying actions may not look relevant to the system-level objective (i.e., facilitating cross-border DM) of Program VIKING, it turned out to be an important step that helped the alliance build its capacity to cope with the pressure in the cross-border collaboration environment (e.g., different cultures, institutional rules, & technological preferences) and effectively utilize distributed organizational knowledge [46] to achieve intended outcomes in the subsequent actions, which eventually led to successful system-level activity of the program.

Program VIKING can be viewed as a social structure created by a cross-border DM initiative, and thus the pre-existing environments in the Netherlands and Germany, as well as the purposeful strategic decision making of the initiative, determined the initial fate of how the program was to be governed, operated, and concluded. Nevertheless, the program, as an evolving activity system, justified its existence and extended its lifespan by serving the needs of the DM communities in both countries. Our analytical framework identified four key boundary objects: the governance structure of the program (i.e., VIKING Alliance), two information systems (i.e., FLIWAS and VIKING Cockpit), and cross-border DM exercise (e.g., HAGAR, HELGA, and ROAR). These were once artifacts of Program VIKING's activities, but became parts of the program itself and played pivotal roles in the successful development and continuation of the program. Using the AT terms, Table 4 outlines the significant activities from which the key boundary objects emerged and resolved contradictions in Program VIKING. More detailed descriptions of the key boundary objects are presented in the following subsections.

Governance boundary object: cross-border governance structure

One of the first actions taken by the VIKING alliance was the installment of governance structure in itself. (Figure 3) illustrates the governance structure of Program VIKING. According to the project meeting notes, two requirements were initially set for this governance structure. The first requirement was that the representatives of the water management agencies should have a

Table 4 Analysis results of key activities

Activity Contradictions to be resolved	Subject	Instruments	Environments (i.e., Community, Division of labor, Rule)	Outcome (Later became B.O.)
Transformation of cross-border governance structure (2001–2004)	Initial partners of VIKING Alliance	Project meetings (physical)	Dutch side: The Province of Gelderland and some regional agencies (e.g., fire depts., water boards, etc.)	New governance structure of VIKING Alliance (2004, February)
		Lobbying		
→Participation and resources to perform all expected collaboration activities			German side: The Region of Düsseldorf.	→Expanded & mandated participation
→Authority to mobilized all stakeholders			The Province of Gelderland coordinates other Dutch partners, while Region of Düsseldorf represents Water Mgmt. and (non-member) German agencies in the region.	→Symmetric distribution of authority and control across the border
			The roles of Police, municipalities, and ambulance services cannot be covered by the initial partners.	
			Agencies in one country must be controlled by a higher authority in the same country, but there was no clear hierarchy set for the Alliance.	
Development of IS for DM collaboration (2005, May-November)	Transformed VIKING Alliance (esp. steering committee)	Project meetings (physical) with the end-user groups and key stakeholders	An expanded set of alliance partners with incompatible IS.	FLIWAS (version 1 was first released in November 2005)
→Exceedingly fragmented ISs		Decentralized/unorganized info sharing	All partners in one country are now under the leadership of a single program manager in that country.	-First possibility of cross-boundary information sharing
→Need to support agencies in two countries/languages		EU Funding secured by the transparent governance structure		-Awareness of the potential of DMIS for effective flood management
→The deployment, access, and use of the IS must be easy for the large number of partners		ISD feasibility study		-VIKING Cockpit (first online release in June 2006)
Development of IS for ISD Collaboration	〃	〃	Increasing number of alliance partners (e.g., the Dutch National Ministry of Internal Affairs)	→Efficient cross-border info sharing, knowledge/project management for collaborative ISD
(2006, January-June)		+	Prospect of extended funding by the European commission	Easy access to & evaluation of DM IS (FLIWAS online version)
→Inadequacy of physical project meetings for the large stakeholders		Advanced knowledge/project management technologies		
→Inadequacy of decentralized information sharing among the large stakeholders		Existing Internet infrastructure		
→Need easier access to FLIWAS		FLIWAS (web-invoked light version)		
Institutionalization of regular field exercises (November 2005-May 2009)	〃	〃	Increasing number of alliance partners & other stakeholders (spectators, potential partners/adopters/investors)	Cross-border DM

Table 4 Analysis results of key activities *(Continued)*

→Need to evaluate the performance of cross-border DM collaboration, information sharing, and DMIS	+	Prospect of commercialization (consultation and software delivery) to other countries in Europe	Exercises (HAGAR exercises in 2005, HELGA exercises in 2006 ROAR exercises in 2008)
Need to demonstrate and promote the program for continued support	FLIWAS		→Demonstration of the successful progress & justification of the collaboration program
	VIKING Cockpit		→Empirical test and improvement of collaborative DM IS (FLIWAS) & DM performance
	Performance metrics		→Stronger sense of community/partnership
	Independent consultants		
	Academic researchers		
	Exercise planning, advertisement, promotion		

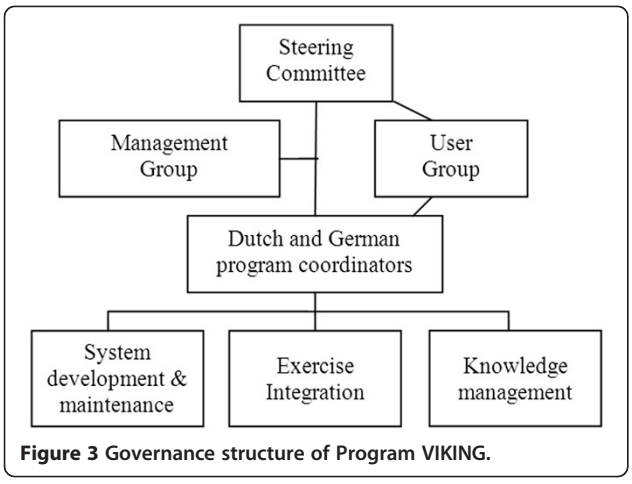

Figure 3 Governance structure of Program VIKING.

formal position in the governance structure. According to one of the informants, the motive behind this was "without the representation of the end-user group in the governance structure the program would not attain the necessary level of commitment of all the necessary partners. Moreover, we had to incorporate the end-users in our group meetings in order to understand their information needs". The second requirement for the cross-border governance structure was that it should equally distribute the authority and control between Dutch and German partners. Consequently, the alliance appointed two program managers, one for the Dutch partners and one for the German partners, to mediate the partners at the national level. One of the program managers stated that "we needed to have two program managers because we wanted to gain full commitment of all the agencies involved. It would be very difficult for a Dutch program coordinator to organize and lead German program teams... the [dual-head] leadership was also expected to better appreciate the cultural differences and promote the trust in the program, in addition to securing commitments, from the both sides".

The creation of governance structure for the VIKING alliance can be interpreted as a goal-oriented purposeful action, from the AT perspective. VIKING alliance was the subject of the action that formalized their structure (outcome) by using various instruments like requirement analyses and project meetings. This action and the resulting outcome addressed a contradiction between the alliance partners (subject) and the (absence of) rules and specification of duties to coordinate them. The design of this governance structure was influenced by the existing structure (e.g., the organizational hierarchies among the alliance partners, power structure in the cross-border context) and yet could influence the following actions as an added structural factor of Program VIKING. According to the analysis framework, this is because the outcome became a boundary object for the stakeholders while it was transforming the structure to resolve the internal contradiction. In addition to developing a shared identity among the alliance partners-a necessary condition for a boundary object [41]-the dual-head leadership prevented potential conflicts emerging from cultural differences by separating control over the partners on each side of the border. The two program managers acted as spokespersons for partners in each country to ensure the internal consistency of the alliance within and across the border. The governance structure also assured commitments of key stakeholders by mandating their involvement in the governance structure. As a result, partners could understand their roles in cross-border DM operations and had a good overview of what was expected from them and from the other partners. In general, the governance structure promoted a high level of trust among the alliance partners by providing a sense of equality and transparency. Especially, the high level of transparency developed through the governance structure was critical for obtaining further EU funding for Program VIKING. Mandated participation of key stakeholders and dual-head leadership are two distinctive attributes of the self-evolved governance structure. In terms of authority, the appointed program managers were well known and experienced leaders in the DM community and provided with the legal authority to mobilize all alliance partners in each side of the border. As a result, the governance structure could successfully coordinate the roles, responsibilities and resources of the alliance partners without explicit rules and policies.

IS boundary object: information systems for collaborative disaster response

As one of the original focus areas of Program VIKING was cross-border information sharing, one deliverable expected from the program was an architecture that would interconnect existing ISs of various DMOs across the border. Nevertheless, development of a new IS was not planned in the project proposal. The steering committee conducted a study of the existing DMIS in both countries, in an effort to find the best way to integrate the ISs already in place. However, the analysis reports revealed that the existing IS not only lacked the functionality for flood management, but also were exceedingly fragmented with overlapping functionalities. Based on the analysis reports, the steering committee concluded that it would be more viable for the partners to develop an entirely new IS for cross-border DM, which was later named FLIWAS. The purpose of FLIWAS was to "ensure that all relief workers on both sides of the border have access to the same information systems and make decisions based on real-time data in a disaster situation." Thus, FLIWAS has strong a characteristic of decision support solutions with the capability to

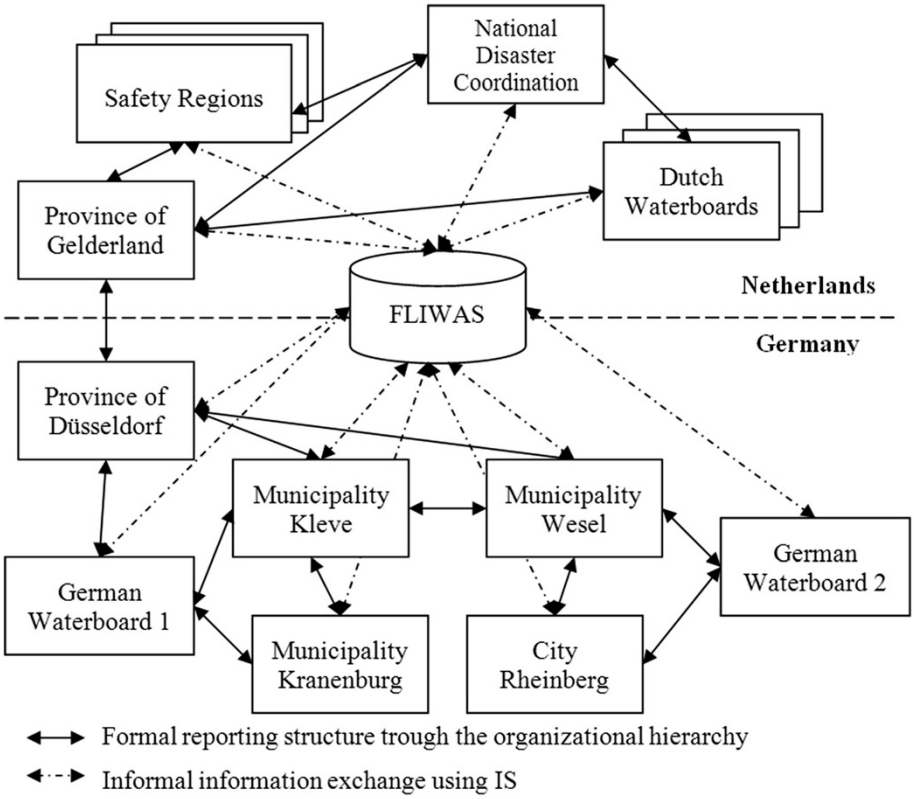

Figure 4 Information flows.

integrate data from heterogeneous sources and run simulations to predict possible flood scenarios. The FLIWAS design guidelines specify that: the application (1) must be multilingual (Dutch, German and English), (2) accessible on the web (invocation via a browser), (3) come in multiple versions (e.g., full vs. light, installable vs. online) with a modular-architecture, and (4) comply with open standards. Major functional modules developed to date include: flood visualization, flood level and risks prediction, evacuation scenario simulation, and emailing.

FLIWAS is designed to make use of existing measurement and flood forecast systems, flood warning plans, flood risk maps and disaster scenarios, as well as various geographical information systems (GIS) data [47]. Users can selectively install the modular components of FLIWAS to meet their specific needs, while their access to the different functions is controlled by a role based authentication system [47,48]. The system uses a client–server architecture, where an Internet browser or installed software agent can be used to access FLIWAS services running on a Linux-based server [45]. The GIS module is built on UMN-MapServer, and the databases can be built on PostgreSQL or Oracle [48,49]. (Figure 4) illustrates the FLIWAS-aided information flows between different Dutch and German DMOs.

As shown in the figure, only one formal communication channel existed between province of Gelderland and Region of Düsseldorf at the international level, which had to mediate all cross-border information flows from/to the waterboards and regional DMOs. Even within a country, not every DMO had a direct formal connection with every other DMO. FLIWAS enabled DMOs to bypass the clogged formal communication channel and instantly exchange information with each other, achieving a shared situational awareness of the status of dikes, water level, and pumps during a flood.

IS boundary object: information portal for collaborative project management

Similar to the case of FLIWAS, the initial proposal for Program VIKING did not include any plan to develop an IS for the collaborative program itself. In the early stages of the program, the alliance partners shared information with each other via physical group meetings and presentations, printed documents, and emails. However, as the number of partners steadily increased, these means of information sharing quickly turned inefficient, and issues such as document versioning, format compatibility and security started to gain priority on the meeting agendum. After multiple requests from partners for a shared document repository, the steering committee decided to

initiate the development of a collaboration portal, which resulted in a new IS named VIKING Cockpit. VIKING Cockpit collects and provides access to all essential information of Program VIKING. There were three initial requirements for the VIKING cockpit. First, this cockpit should be able to store a large amount of data in various formats, ranging from geographical maps to meeting reports. Second, access to this portal should be secured as the stored data may contain sensitive information. Finally, the portal should be available in both Dutch and German. Later, another requirement was added to the list: the portal should be able to invoke FLIWAS. Consequently, the VIKING Cockpit now has a link to a light version of FLIWAS and thus can play the role of a DMIS during disaster, in addition to the role of a collaboration portal for the program during a non-disaster time.

FLIWAS and the VIKING cockpit are two major, but originally unplanned IS artifacts of Program VIKING. Development of FLIWAS was initiated by an expansive learning-a realization that the original plan of action (i.e., interconnecting existing ISs) was not a good solution, given the available economic, organizational, and technical resources (instruments), for the system level activity (i.e., facilitate cross-border DM). Similarly, the VIKING Cockpit was developed to better fulfill the alliance partners' managerial needs for the collaborative project, rather than for cross-border DM operations. Since both ISs are expansive solutions designed to solve eminent contradictions in the existing structure (e.g., the large number of stakeholders and their legacy systems incapable of effective information sharing), many alliance partners quickly accepted these solutions. For example, while FLIWAS was still in the beta stage, two out of three Dutch Waterboards had already adopted it to exchange information with their neighboring German Waterboards. Such proactive early adoptions accelerated the IS-led transformation of the cross-border DM communication structure, as the practice instated an efficient direct information sharing network across the two countries, in addition to the existing hierarchical and formal reporting channel [46]. The link to FLIWAS in the VIKING Cockpit further boosted the responders' adoption of both ISs and secured their places in the institutional structure. Even though many DMOs have not officially adopted FLIWAS yet, they still can try FLIWAS via VIKING Cockpit anytime anywhere, which has made the learning and feedback structure of Program VIKING radically easy and simple. The enforced involvement of key stakeholders and use of open standard in the IS development process also helped lower resistance to the ISs and cultivated the emergence of a common identity among the alliance partners as they engaged in a common set of practices (i.e., development, evaluation, and revision of the ISs) [25]. Note that FLIWAS and VIKING Cockpit have gone through a cyclic process of evaluation and revision, through which the cross-border DM and DM ISD structures have also been transformed along the ISs.

Feedback boundary object: cross-border exercises

The other key boundary object that we have found is a series of large scale cross-border DM exercises. Three major exercises are: HAGAR (2005), HELGA (2006), and ROAR (2008). The explicit goals of the exercises were to improve (1) multi-agency collaboration between relief agencies on different echelons (strategic, tactical and operational levels) of response, (2) cross-border information sharing between the Dutch and German relief agencies, (3) information provisioning to the operational units during floods, and (4) developments of skills in using information systems for flood control. Apparently, the primary contradiction addressed by the exercises is the fact that cross-border DM structure, including the institutional rules, coordination plans, and operational procedures, cannot be examined under the normal condition due to the distributed DM responsibilities (division of duties). VIKING Alliance used its political and relational power in order to mobilize alliance partners and resources to conduct full-scale exercises, which provided the participants with chances to get acquainted with the cross-border DM structure, surrounding environments, and available ISs. ROAR had an additional objective to evaluate whether or not the newly developed DMIS (i.e., FLIWAS) were successful in meeting the requirements of the DMOs. One software developer stated that: "Even though we knew FLIWAS was not yet fully functional, we had to show our sponsors and users that FLIWAS was on a path to success, in order to build a foundation for survival of the program and prevent partners from exiting the alliance". Hence, ROAR was also used as a showcase and a test bed that allowed a large number of stakeholders to experience and evaluate the new DMIS.

The cross-border exercises made significant impacts on the collaborative DM activities in several ways. Since the exercises were recursive and large in scale, they became a widely recognized institutional mechanism for training and evaluation by mid-2007. Through the exercises, end-users of the newly developed FLIWAS could try the system in a simulated disaster environment, share their ideas with other end-users, and provide feedback to DMIS developers. In doing so, they could also improve their understanding of the roles and interdependencies of various DMOs in the larger context of cross-border DM operations. Thus, the institutionalized exercises became a knowledge creation and sharing mechanism, significantly improving the expansive learning capacity of Program VIKING. Cross-border

Table 5 Attributes and effects of key boundary objects

Key boundary object*	Attributes	Consequences (factors)
1. VIKING Alliance Governance Structure	•Expanded partnership	•Assured commitments of key stakeholders
	→Covers the full spectrum of necessary functions for collaborative DM & ISD.	•Improved understanding on the division of duties.
	•Mandated participation	•Prevented cultural conflicts
	→Institutionalized positions for key stakeholders (e.g., end-user groups) in the governance structure	•Ensured national-level consistency
	•Dual-head leadership	•Ensured political power to mobilize all alliance partners
	→Appoint an authoritative leader.	•Provided a sense of equality and transparency
	→Confer enough legal authority.	→Promote trust among partners
		→Secure further funding
2. Information Systems	•Convenient & secure access to all partners	•Created a new layer of direct communication links for DMOs.
A. FLIWAS	→Web-based	→Bypass hierarchical controls
B. VIKING Cockpit (Knowledge/Project Mgmt.)	•Modular multi-version	→Remove stove-piping
	→Flexible implementation options	→Remove bottleneck at the border
	•Multi-lingual	•Increase knowledge sharing/creation for ISD
	•Neutral design	•Lowered adoption barrier
	→Use open standards	•Interested other EU states
	→Independent of national DMO structure.	•Increased acceptance of IS
	•Mandated involvement of all key stakeholders	•Increased interoperability
3. Feedback mechanism (Cross-border DM Exercises)	•Large scale to involve the full spectrum of	•Improved individuals' understanding of cross-border DM operations.
	→Partners	•Provided a built-in feedback mechanism
	•Recurrent exercise	→Offer DMIS evaluation opportunities
	•Invite potential stakeholders	→Encourage expansive learning
		•Demonstrated the progress of the ISD
		→Showcase for FLIWAS to EU states
		→Revamp internal interests, involvement, and commitment
		→Keep EU/external supports

* Conditions for a key boundary object in the analysis framework: 1) developed as an expansive solution, meaning it is adaptable and scalable to changing stakeholder needs, and 2) become an influential part of the activity system structure.

exercises have also been great places to exhibit the progress of the project, as the exercise organizers invited not only the current alliance partners but also members of a wider community including media, academics, investors, and DM managers in other regions and countries. By demonstrating the progress of the exercise, the program could earn trust from its stakeholders and secure further involvements and commitments (e.g., partnership & budget) for the program activity. Table 5 summarizes the attributes and positive effects of the key boundary objects, which can answer not only "what" influenced the successful cross-border DM collaborative but also "how" and "why" those success factors were enacted in the particular social structure.

Conclusions

This research developed and applied an AT-based analytical framework to investigate key boundary objects in cross-border ISD for disaster management. We identified three types of boundaries objects that greatly contributed to the cross-border collaboration: 1) governance structure, 2) information systems and 3) recurring evaluation/feedback opportunities. The information systems category included two boundary objects: an easily accessible DMIS prototype and an online portal for project management. The selective institutionalizations of these key boundary objects helped the participants to overcome various contradictions existed in the socio-technical system of collaborative cross-border disaster management.

Specifically, the uncertainty about the collaboration project's future (i.e., lifespan), the limited information sharing capability in the DM community, and the wide geographic and functional dispersions of the collaboration partners were alleviated by the key boundary objects.

Provided the circumstances are similar, managers of cross-border DM projects are recommended to take a strategy that develops and institutionalizes the above mentioned key boundary objects. It is not the creation of boundary objects however, but the attributes possessed by those boundary objects that actually determine the fate of a project. For example, each participating country must have an authoritative and trusted representative in a trans-national governance structure, if the governance structure were to play a key role in the cross-border DM project. For an information system to be a key boundary object, it should allow all potential users convenient and secure access, flexible implementation options, and power to overcome the limitation in the existing DMO structure (e.g., formal reporting channels in the national incident management system). DM exercises can also be a key boundary object if they involve the full spectrum of stakeholders and offer evaluation and feedback opportunities in regular bases. The managers of cross-border DM projects are also expected to constantly monitor and analyze, using our analytical framework, the socio-technical structure of their project. They should look for structural contradictions and devise a solution that can be implemented with existing means and resources. If such a solution has the characteristics of boundary objects, the managers should promote the solution to be a more permanent part of the project structure even after the target contradictions are eliminated. Adding a clear and useful boundary objects will further improve cross-organizational interactions, commitments and appreciation of the project activities and outcomes.

This study also contributes to the academic community by developing a framework that analyzes the process through which material and social objects become interwoven in a cross-border DM collaboration system. This AT-based framework can help researchers identify important key boundary objects that can overcome the structural limitations and challenging conditions of large-scale DM collaboration projects. This research is, to our best knowledge, the first to employ AT for an investigation of cross-border DM ISD. The principles of AT (e.g., mediation by objects, historicity and expansion) make this theory suitable for studying a cross-border DM ISD context. By accounting for the time component (i.e., historicity) in AT, our analytical framework recognizes the possible feedback loop between pre-existing social structure and goal-oriented purposeful actions. Accordingly, the proposed analytical framework can suggest potential causal links between the success factors for cross-border DM collaboration and the attributes of key boundary objects

While this study examines a cross-border ISD in the DM domain, the findings can provide useful insights to researchers in other domains as well. Many private-sector companies seek to establish collaborative relationships for new opportunities or threats. When such a collaborative relationship spans across multiple cultures, legal jurisdictions, and an extended period of time, the key boundary objects identified in this paper can be developed to induce a similar positive influence in a new context. Our framework will be particularly useful when the system being analyzed is a complex and persistent social structure that involves a large number of stakeholders. This study is based on a single ethnographic study and presents only a partial view of cross-border DM ISD collaboration. Since we studied two countries in Western Europe, some cultural similarities might have affected our findings. Future research may examine relationships between cultural distance and collaboration success in cross-border DM ISD. Although our qualitative approach provides a deep understanding of the processes and issues in question, the findings require quantitative validation. Therefore, developing and validating a quantitatively testable model of cross-border DM ISD success will be the next step of this research stream. Of course, more qualitative studies in the cross-border DM ISD collaboration area will enrich the small pool of testable hypotheses.

Abbreviations

AT: Activity Theory; DM: Disaster management; DMIS: Disaster management information system; DMO: Disaster management organization; IS: Information systems; ISD: Information system development.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All four authors equally contributed to this study. They were deeply involved in every step of the study including research design, literature review, data collection & analysis, paper write-up, and multiple cycles of internal revisions phases. All authors read and approved the final manuscript.

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