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# Managing the COVID-19 emergency: A coordination framework to enhance response practices and actions

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## ABSTRACT

The global outbreak of the coronavirus pneumonia (COVID-19) showed how epidemics today can spread very rapidly, with potentially ruinous impact on economies and societies. Whereas medical research is crucial to define effective treatment protocols, technology innovation and social research can contribute by defining effective approaches to emergency management, especially to optimize the complex dynamics arising within actors and systems during the outbreak. The purpose of this article is to define a framework for modeling activities, actors and resources coordination in the epidemic management scenario, and to reflect on its use to enhance response practices and actions. We identify 25 types of resources and 8 activities involved in the management of epidemic, and study 29 “flow”, “fit”, and “share” dependencies among those resources and activities, along with purposeful management criteria. Next, we use a coordination framework to conceptualize an emergency management system encompassing practices and response actions. This study has the potential to impact a broad audience, and can opens avenues for follow up works at the intersection between technology and innovation management and societal challenges. The outcomes can have immediate applicability to an ongoing societal problem, as well as be generalized for application in future (possible although undesired) events.

## 1. Introduction

In late December 2019, several Chinese health facilities reported clusters of patients with pneumonia that were epidemiologically linked to a seafood and wet animal market in Wuhan (Hubei Province). On December 31, the Chinese Center for Disease Control and Prevention (China CDC) dispatched a response team to conduct an investigation, and the disease was labelled COVID-19 (*CoronaVirus Disease 2019*). The infection soon spread outside China, to reach other eastern Asian regions, Europe, USA, and then most world countries. The World Health Organization (WHO) on March 11 declared COVID-19 a pandemic, and as of 26 January 2021, the WHO reported about 98 M confirmed cases, about 2,1 M confirmed deaths and more than 200 countries, areas or territories with cases.

The COVID-19 outbreak has caused a global social and economic shock and stimulated a large stream of cross-disciplinary research investigating the impact of the pandemic on household income, savings and consumption (Martin et al., 2020), on economic output (Gharahgozli et al., 2020), and on consumers and digital sales (Kim, 2020). Other studies have been published with a more managerial and

sociological focus on aspects such as human resource management (Carnevale and Hatak, 2020), misinformation risks (Krause et al., 2020), self-restraint behavior (Katafuchi et al., 2020), and the role of open and distributed knowledge and innovation (Chesbrough, 2020).

Whereas a pandemic is always a threat for societies, many new factors contribute today to an increase in the transmissibility and severity of infectious disease. These include growing global mobility, the emergence of new lifestyles, the obsolescence of traditional control measures, the impact of charity actions, and the negative effects of communication rumors (WHO, 2018). Moreover, different countries adopt dissimilar risk management strategies, as well as diverse control and reporting criteria, thus causing unbalanced assessment of the number of infected people and the level of mortality as well (Giritli Nygren and Olofsson, 2020; Woodside, 2020). Recent epidemic outbreaks, such as MERS, Ebola and H1N1, have shown the vulnerability of industrial nations against the threat of unknown epidemics, and this has led to the development of various methods, protocol and agencies for mitigating negative effects.

Despite all these efforts, epidemic management has been plagued by mishaps and unforeseen problems. Such factors are driving the need to

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coordinate multilateral decisions and actions into a synergistic and systemic effort (Chen, 2020). There is a need to discuss frictions and interactions among agents and to consider an interdisciplinary approach to epidemic management as a complex and holistic endeavor (Colizza et al., 2007; Roca et al., 2015). Collaborative planning and shared decision making is essential in emergency response situations that are highly complex and volatile and involve competing priorities and conflicting interests amongst stakeholders (Perry and Laws, 2020). Whereas coordination is important in standardized situations, it is crucial in emergent, uncertain and complex scenarios which represent fertile fields for conducting research on coordination practices (Faraj and Xiao 2006). As emergency management typically involves complex networks of tasks, resources and actors, so coordination is critical to address the embedded interdependencies for smooth and efficient response operations (Turoff, 2002).

The coronavirus outbreak is requiring us to identify optimal decisions and actions for reducing the mortality and morbidity rate, and decrease the overall socioeconomic costs of epidemic. One big challenge that national and local governments face in dealing with the outbreak is effectively coordinating actors, resources and activities in a flexible way, i.e. to properly design and adopt effective responses. This is particularly crucial in emergent, uncertain and time-constrained scenarios. In such view, the approach of coordination science can provide an important contribution in relation to the management of the complexity generated by factors such as multi-stakeholder requirements, multi-level governance, and strong actors and resources interrelations. A clear investigation of activities involved in the emergency management is thus required to support single and coordinated actions. The research questions asked by this paper are twofold: a) *which activities, resources and actors are involved in the management of epidemic and how are they inter-related?* b) *How coordination principles can be applied to enhance decision making and emergency management?*

To address such research questions, this article presents a comprehensive analysis of resources, actors, activities, and dependencies involved in the management of epidemics. To the best of our knowledge, the article is among the first contributions in the literature to adopt a coordination science approach to analyze the articulated dynamics which characterize a pandemic and the integrated response to the same. The remainder of the paper is structured as follows. In the next section, we review the main studies on emergency and epidemic management. In Sections 3 and 4 we present a coordination framework including a study of activities and resources, and dependencies among the same. In Section 5, we conceptualize a system to support emergency management and present an illustrative scenario. Finally, in Section 6, we discuss the scholarly and practitioner impact of the paper, as well as the main limitations and avenues for further research.

## 2. Epidemic management as emergency management

Emergency management is concerned with ensuring evidence-based prevention or reduction of the probability of accidents, and dealing with the aftermath of an event to reduce the negative impact (McLoughlin, 1985; Petak, 1985). The academic interest on emergency management has developed along a number of research areas. Among these, the topic of resource and stakeholder management is particularly relevant in the scholarly discussion. In 2013, Turoff, Hiltz, Bañuls and Van Den Eede edited a special issue in *Technological Forecasting and Social Change* with the aim to gather relevant frameworks and experiences. Among such studies, Ryan (2013) investigated the importance of multi-stakeholder and multidisciplinary contributions in planning for emergency management, whereas Hernantes et al. (2013) proposed a combination of collaborative modeling and software simulation to identify the interrelationships and expertise sharing among stakeholders. Bañuls et al. (2013) focused on workgroup for scenario modeling to examine the consequences of assumptions about preparedness, plans, and the actions taken during a crisis.

More recently, and with reference to epidemic emergencies, Qiu et al. (2018) demonstrated how an open attitude and active engagement of stakeholders to address risk information needs can build trust and facilitate collaborations, whereas Perry and Laws (2020) developed a collaborative planning and shared decision making framework for risk informed decision making in biosecurity. A number of studies have also investigated the adoption of digital technologies to enhance emergency management (Gasmelseid, 2014; Luo et al., 2020; Misra et al., 2020; Yang et al., 2013).

With specific reference to epidemic outbreaks, a relevant area of scholarly interest is the evaluation of impacts generated by different interventions. Perlroth et al. (2010) represented an agent-based social network model to estimate the effectiveness of 48 different strategies based on six interventions. Results indicated that the strategy depends on the severity level of the epidemic, which can be mild, moderate or severe. Yañez et al. (2017) presented a visual analytics decision support tool that helps public health officers understand what is happening during an outbreak and the impact of potential actions/interventions. Araz and Jehn (2013) designed a simulation-driven exercise which allowed participants to respond to a hypothetical pandemic influenza scenario and make iterative policy decisions in a group setting.

With a focus on the approaches to action, whereas most of them are largely reactive, “pre-emptive” strategies have been discussed by Matua, van der Wal and Locsin (2015). The authors analyzed *post-outbreak* and *constant* interventions, and they provided a set of categories such as active disease surveillance, laboratory confirmation, case management, social mobilization, education and training, resource mobilization, and communication. Ferguson et al. (2006) focused on strategies for mitigating the influenza pandemic whereas Funk et al. (2010) modelled the influence of human behavior on the spread of infectious diseases. Hitchcock et al. (2007) discussed the insufficiencies which challenge the response to disease outbreaks. Among these, they classify health infrastructure, scientific methods, operations and international policies. Other studies focused on the integration of resilience considerations into disease prevention (DeWitte et al., 2017) and the relevance of a “dynamic health policy” capable to adapt to the evolution of the outbreak (Yaesoubi and Cohen, 2011).

A global pandemic holds most of the characteristics which are typical of emergencies. In the last fifteen years, the rapid spread of serious diseases such as SARS and H1N1 demonstrated the potential threat posed by infections in a closely interconnected world. The effective response to the earliest stages of an outbreak requires an array of synergic elements related to coordinating responders, managing health information, communicating risk, and ensuring health interventions (WHO, 2018). The COVID-19 crisis has significantly challenged the preparedness of local and national healthcare systems, and required urgent actions able to optimize the use of limited capabilities. At this regard, Cao et al. (2020) studied the importance to build contingency or emergency management plans to alleviate the workload of emergency departments. The COVID-19 outbreak is generating renewed interest in coordinating global responses to infectious threats, many of which could disrupt global health and commerce (Sands et al., 2016), and the importance of defining an international, independent, and multi-stakeholder expert center.

The crisis is requiring new research aimed at investigating new ways to coordinate actors, resources and processes at local and global scale, so to enhance networked cooperation and synergic actions. Our study intends to progress on the study of approaches to emergency management by adopting a coordination science approach. We address multiple stakeholders, resource requirements and activity interrelations through a study of coordination and dependencies, which is relatively new in the study of pandemic crisis. The approach adopted is novel and aims to contribute to the extant knowledge by providing a complex systems modeling view of epidemic management. Such view illustrates the dependencies and management mechanisms to improve coordination and more effective answers.

**Table 1**  
Activities involved in the epidemic management process.

N	Activity	Involved actors (alphabetical)	Description, including critical issues
A#1	<b>Infection containment</b>	<ul style="list-style-type: none"> <li>• Business organizations</li> <li>• Individual citizens</li> <li>• Institutions</li> <li>• Medical staff</li> <li>• Politicians, decision makers</li> <li>• Public administrators</li> <li>• Public officials</li> </ul>	Coordinated early detection, social distancing and prevention activities and norms aimed to avoid or reduce the probability of infection among individuals, and the related controls and sanctions for misbehaviors
A#2	<b>Information sharing</b>	<ul style="list-style-type: none"> <li>• Data analysts</li> <li>• Institutions and politicians</li> <li>• Opinion leaders</li> <li>• Social networks, communities</li> <li>• Traditional media operators</li> <li>• Web media agencies</li> </ul>	Multi-source gathering and multi-media distribution of data and information related to pandemic at local, national and global level, with implications in terms of veridicity, timeliness and consistency
A#3	<b>Medical treatment</b>	<ul style="list-style-type: none"> <li>• Experts and consultants</li> <li>• Health agencies</li> <li>• Health companies</li> <li>• Medical staff</li> <li>• Sanitary support staff</li> </ul>	Recognized therapies, treatment protocols and actions on exposed/infected individuals, with evaluation in terms of individual/population effectiveness and preliminary experimentation of alternative solutions
A#4	<b>Business operations</b>	<ul style="list-style-type: none"> <li>• Business organizations</li> <li>• Companies</li> <li>• Logistic organizations</li> <li>• Professionals</li> <li>• Trade companies</li> </ul>	Authorized business (production and service) activities undertaken by organizations and individuals considering the restrictions and cautions defined by purposeful norms on pandemic
A#5	<b>Public functions</b>	<ul style="list-style-type: none"> <li>• Public bodies</li> <li>• Public offices and agencies</li> <li>• Public services and activities</li> </ul>	Continuing public functions, services and operations by offices and entities which are executed by implementing the restrictions and cautions defined by purposeful norms on pandemic
A#6	<b>Private activities</b>	<ul style="list-style-type: none"> <li>• Families and aggregations</li> <li>• Formal groups, associations</li> <li>• Individual citizens</li> <li>• Informal citizen groups</li> </ul>	Regular personal, family and working activity by individuals and groups which are executed by implementing the restrictions and cautions defined by purposeful norms on pandemic
A#7	<b>Policy making</b>	<ul style="list-style-type: none"> <li>• International policy institutions</li> <li>• National institutions</li> <li>• Non-governmental institutions</li> <li>• Regional/local institutions</li> <li>• Supranational institutions</li> </ul>	Integrated public government, decision making and actions associated to the regulation of behaviors and activities of countries, regions and territories, with the implications on system continuity/resilience
A#8	<b>Scientific research</b>	<ul style="list-style-type: none"> <li>• International research entities</li> <li>• Research centers</li> <li>• Research laboratories</li> <li>• Scientists and experts</li> <li>• Universities</li> </ul>	Interdisciplinary and targeted research and development activities aiming to address/ solve pandemic and support policy and management decisions and actions through scientific evidence

### 3. A study of activities and resources in the epidemic management

helps to develop a comprehensive understanding of a system (Andersen et al., 1997; Bérard 2010). Whereas the study has significantly leveraged the authors' observation and direct experience on coordination theory, collective intelligence and complex systems modeling, some domain experts were consulted as key informants. In particular, we involved a pulmonologist operating in the ICU (Intensive Care Unit) of a public hospital, a hospital nurse involved in the triage unit, a sociologist, a psychologist, a civil engineer, an economist, a public manager and two management engineers with specific expertise in healthcare. The selection of experts was conducted following a purposive sampling approach (Etikan et al., 2016). This is a non-random technique, typically used in qualitative research, that allows researchers to identify and select individuals that are proficient and well-informed with a phenomenon of interest (Cresswell and Plano Clark, 2011), as well as available and willing to participate and communicate experiences and opinions in an articulate, expressive, and reflective manner (Bernard, 2002; Spradley, 1979).

Selection criteria for experts were an accumulated working experience of fifteen years, the involvement with COVID-19 issues in their current work, and the direct authors' acquaintance so to speed-up the involvement and interaction process. The combination of expertise was aimed to address the different disciplines involved in the management of a pandemic crisis. In particular, the two management engineers were involved to gather expertise on the modeling of complex socio-technical systems through a systemic view (Elia et al., 2020). The interaction with experts included a preliminary phase aimed to present the goals of the research, and a three-step process in which: a) we sketched concepts and definitions based on direct experience and the available literature; b) we shared with experts our drafts and asked to provide integrations; and c) we consolidated the feedback and improved our model.

We moved from the study of epidemic management as an articulated process, which includes five crucial stages (WHO, 2018): a) anticipation of new and re-emerging diseases to facilitate faster response; b) early detection of emergence in animal and human populations; c) containment of the disease at the early stages of transmission; d) control and mitigation of the epidemic during its amplification; and e) elimination of the risk of outbreak or eradication of the infectious disease. In particular, considering the purpose of our study, we focused on middle stages of disease containment (c) and epidemic control/mitigation (d), and identified 8 macro-activities. These were first sketched from the review of literature as well as from practitioner reports (e.g. WHO and the Italian Superior Institute for Health - ISS). Table 1 illustrates the eight activities, and provides a description of involved actors and a definition, including critical execution issues.

Whereas the eight activities are relevant *per se*, and it is important to understand how they are executed and how they can be designed and monitored, it is also crucial to reflect on the reciprocal interrelations. By applying a simple system dynamics approach, Fig. 1 shows the flow diagram of activities and the relations among the same. Such relations include "confirm", "enhance", "facilitate" "feed", "influence", "regulate" "restrict" and "support" types. The dynamic view integrates the more static inventory of process descriptions, and it is preparatory to the next steps of resource and dependency analysis.

We identified three categories of resources involved in the epidemic management process, i.e.: 1) *Knowledge-type Resources*; 2) *Person-type Resources*; and 3) *Object-type Resources*. *Knowledge-type* include data, information, knowledge and intellectual assets which are used or developed for managing epidemic or generated from the same. *Person-type* include the population of individuals and citizens, which can be divided using consolidated compartmental models. One of the most used models is the SEIR, which distinguishes individuals into Susceptible (S), Exposed (E), Infected (I), and Recovered (R). Since compartments are functions of time  $t$ , the total population  $N$  is calculated as  $N = S(t) + E(t) +$

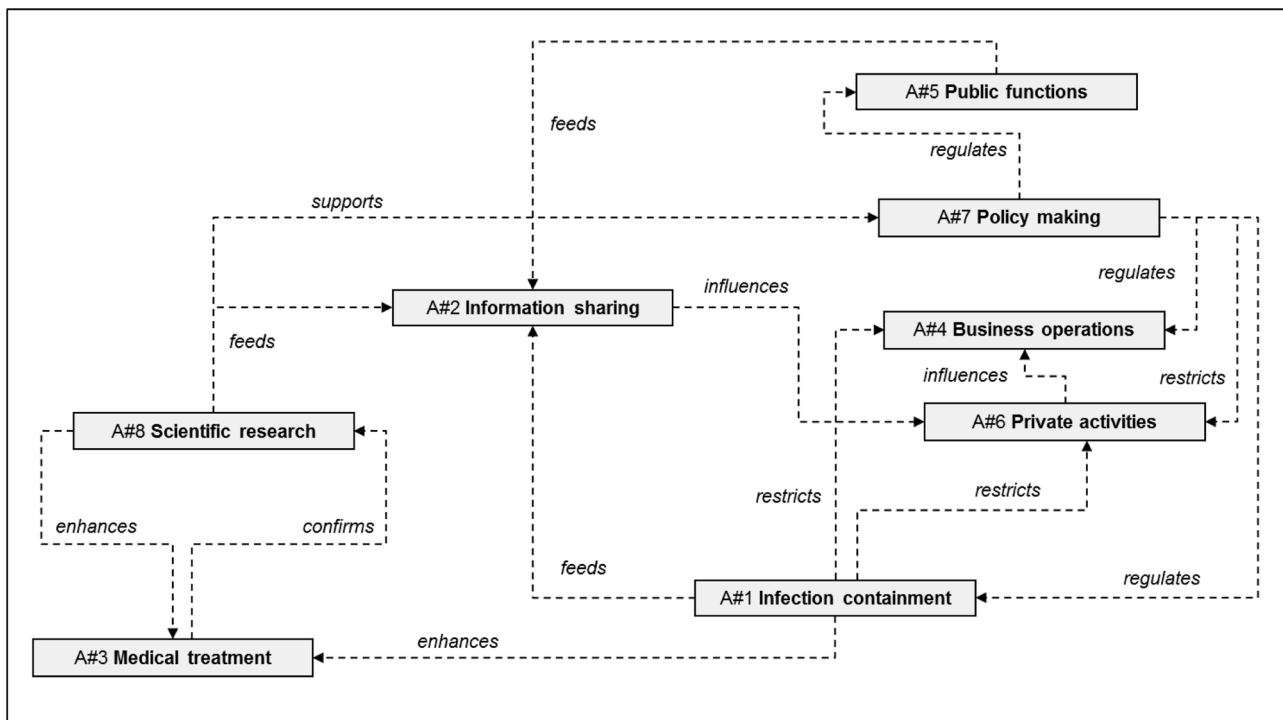


Fig. 1. Flow diagram of activities involved in the epidemic management process.

$I(t)+R(t)$ . Object-type include physical resources, assets, devices used in the different phases of epidemic management. Table 2 illustrates 25 resources (8 for Knowledge, 6 for Person and 11 for Object) completed by a description including relevant issues for the epidemic management.

#### 4. A study of dependencies in the epidemic management

Coordination has been at the center of organization theory ever since March and Simon (1958) suggested that work in organizations could be coordinated through pre-specified programs. In the late 80's and early 90's, the seminal work of Malone (Malone 1987; Malone 1988; Malone and Crowston 1993) has substantially advanced the understanding of coordination in the study of modern organizations.

Workflow coordination is the management of the flow of activities which build up the processes of an organization and are based on a progressive resource and responsibility hand-off. Coordination is the optimization of interdependencies among those processes, with particular reference to resource and output management, and the orchestration of critical process-to-process and process-to-resource dependencies. The optimal management of a process depends thus on the coordination mechanisms chosen to manage dependencies (Crowston 1997; Klein et al., 2003; Margherita et al., 2007).

There are three types of dependencies (Fig. 2). First, "flow" dependencies are related to common cases of activities generating outputs which are used as inputs by other activities. Managing a flow dependency involves thus ensuring that the "right thing" (usability principle or constraint) reaches the "right place" (accessibility) at the "right time" (prerequisite). "Fit" dependencies concern cases in which different activities produce one single output, whereas "share" dependencies are cases in which one single (limited) resource is used by different activities. Fit and share dependencies "include" flows, i.e. they add the problem of coordinating the aggregation issue (for fit) or the resource split issue (for share) to the usability, accessibility and prerequisite constraints.

We apply the three types of dependencies to the study of epidemic management. Whereas Fig. 1 shows general links among activities, the analysis of dependencies identifies relations in terms of output

generated and/or input used. Flow dependencies are schematized in Fig. 3. Since the first phases of the COVID-19 outbreak, a relevant area of complexity which arose has been represented by the orchestration of tangible and intangible flows within local and global systems, and the implementation of effective strategies to ensure fast, consistent and accurate generation of outcomes to be used in the epidemic management lifecycle. Examples include the production and distribution of standardized data about pandemic progress (intangible flows) or the adoption of safe procedures to transfer infected individuals into medical facilities (tangible flows).

In Tables 3–5, we report the flow, fit and share dependencies involved in the management of epidemic, along with constraints and management criteria (coordination mechanisms). The content of Tables was obtained through a three-step approach. First, we sketched the definition of dependencies and related attributes, based on authors' direct experience and the available literature on process coordination and emergency management. Second, we shared with the experts (via e-mail) our draft analysis, which was reported into a purposeful document with a rough representation of the dependency tables. We asked experts to integrate or amend the elements and related descriptions, and to send back the revised documents. Finally, we gathered and consolidated the expert feedback and used the same to improve and finalize the content reported in Tables 3–5. For each of the 12 dependencies, Table 3 provides ideas of criteria for managing accessibility, usability and prerequisite requirements, along with a more general management criteria for the identified dependency.

Next, we focus on share dependencies, which are represented in Fig. 4. In order to mitigate the impact of epidemics, a strong health, production and social system is needed. The sudden influx of large numbers of COVID-infected individuals to health facilities stretches the systems' capacity and resources, especially where resources are already scarce. The scarcity of resources in the short/medium term asks to optimize the design of sharing mechanisms and the allocation of resources according to an urgency criteria, and this is true for both person-type resources (e.g. medical doctors and nurses) and object-type resources (e.g. intensive care units). An illustrative example is the allocation of available pulmonary ventilators available nation-wide to many



**Table 2**  
Resources involved in the epidemic management process.

[1] Knowledge-type Resources		
Code	Resource	Description including critical issues
BP	Best practices/cases	Relevant experiences in the same field but in different time/place
CR	City and regional data	Local information about pandemic and effects of actions undertaken
DP	Discoveries and patents	Shared results of R&D and innovation processes
ED	Epidemiological data	Consolidated and scientifically validated information about pandemic
MI	Media and information	Updated news about contagion, public actions and system impacts
MP	Medical protocols	Recognized treatment methods applied to infected individuals
PR	Policies and regulations	Coordinated and communicated decisions and norms for public action
SA	Scientific articles	Publications and databases of scientific articles and research outcomes
[2] Person-type Resources		
Code	Resource	Description including critical issues
EC	Emergency telephone lines	Organizations dispatching assistance requests to sanitary staff
EI	Exposed individuals	Under risk or Infected but still not infectious people
II	Infected individuals	Sick and infectious people undergoing a treatment or isolation protocol
MS	Medical and sanitary staff	Trained professionals treating and assisting COVID patients
PO	Public officials	Professionals ensuring public order and respect of procedures/norms
RI	Recovered individuals	Isolated, immune, or dead people providing new evidence on epidemic
[3] Object-type Resources		
Code	Resource	Description including critical issues
AM	Ambulances	Purposeful bio-contained transportation means for infected individuals
AN	Antivirals and medicines	Treatments and authorized drugs able to reduce symptoms of COVID
FI	Funds and investments	Public money to support costs of epidemic and recovery investments
HB	Hospital rooms and beds	Locations to host sick individuals, ensure isolation and treatments
HO	Healthcare facilities	Facilities to host patients and medical staff into purposeful procedures
PD	Protection devices	Tools to reduce risk of direct individual to individual contagion
PM	Products and materials	Consumer and production products and resources, and related logistic flows
PT	Public transportation	Air, train, bus, metro, and other means supporting people mobility
ST	Support transportation	National and international sea/airline carriers for medical transfers and supplies
SW	Swabs	Medical devices able to identify infected people
VE	Ventilators	Machines supporting or replacing people breathing functions

ongoing “parallel” processes of medical treatment for sick individuals. **Table 4** provides ideas of criteria for managing accessibility, usability and prerequisite requirements, along with a more general management

criteria for the 10 share dependencies identified. Finally, we focus on fit dependencies, as showed in **Fig. 5**. In the COVID-19 outbreak, the management of fit relations is a substantial area of investigation, as it relates to the gathering and integration of different contributions to generate consistent outcomes. One clear example is the concomitant commitment of many researchers and laboratories worldwide in the attempt to develop significant discoveries and come up with a vaccine for the disease. Another example is the continuous formation of data related to new/total contagions, new/total deaths, and new/total recoveries, which have to be aggregated at local and global scale using homogeneous data acquisition, processing and monitoring approaches. **Table 5** provides ideas of criteria for managing accessibility, usability and prerequisite requirements, along with a more general management criteria for seven fit dependencies identified.

### 5. Applying the coordination framework

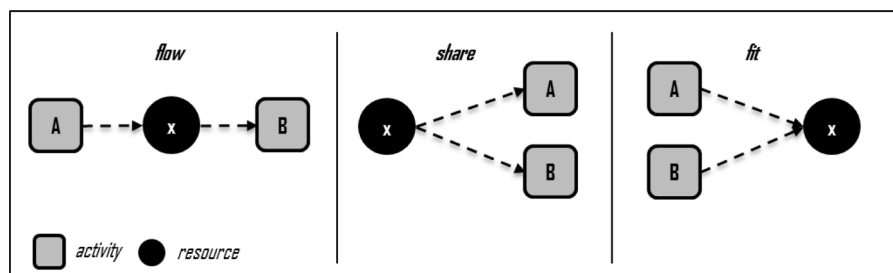
#### 5.1. A system to support epidemic management

The complexity of epidemic management is a challenging factor in the development of systems to support decisions and actions (Li and Mackaness, 2015). In **Sections 3** and **4**, we presented a comprehensive analysis of the processes and dependencies involved in the management of the COVID-19 emergency. The inventory of activities and interrelations represents a coordination framework that has a twofold value: a) it provides an ontology of epidemic management in terms of key activities, resources and dependencies; b) it defines a comprehensive checklist of resource and activity-related management items that are relevant for emergency managers.

The coordination framework can be operationalized into an emergency management system able to support two “types” of integration. First, integration of different coordination practices. Building on Faraj and Kiao (2006), such practices may be related to expertise and dialogic issues. Expertise coordination practices are essential to manage distributed expertise and ensure the timely application of necessary capabilities at the right time and the right place. Dialogic coordination practices are time-critical responses to novel events and ensure error-free operations.

The design of fast and effective responses is a key requirement in the COVID-19 emergence. At this purpose, the model of Faraj and Kiao (2006) is relevant to describe problem-independent “practices” in the management of emergencies and to integrate (conceptually) the dependency analysis (focused on specific “processes” in a specific problem scenario) with a view of actions and enabling behaviors. The two categories of practices, i.e. expertise coordination and dialogic coordination, are significant to facilitate the management of knowledge and expertise interdependencies, and the time-critical interventions urged by the pandemic crisis. **Table 6** applies the two categories of practices with reference to the management of epidemic.

Second, our framework can provide insights on the integration of different actions aimed to respond effectively to the pandemic. *Science-related actions* would include R&D actions aimed to advance the state of art knowledge in relevant fields (e.g. virology, biology, chemistry,



**Fig. 2.** General schema of dependencies among activities and resources.

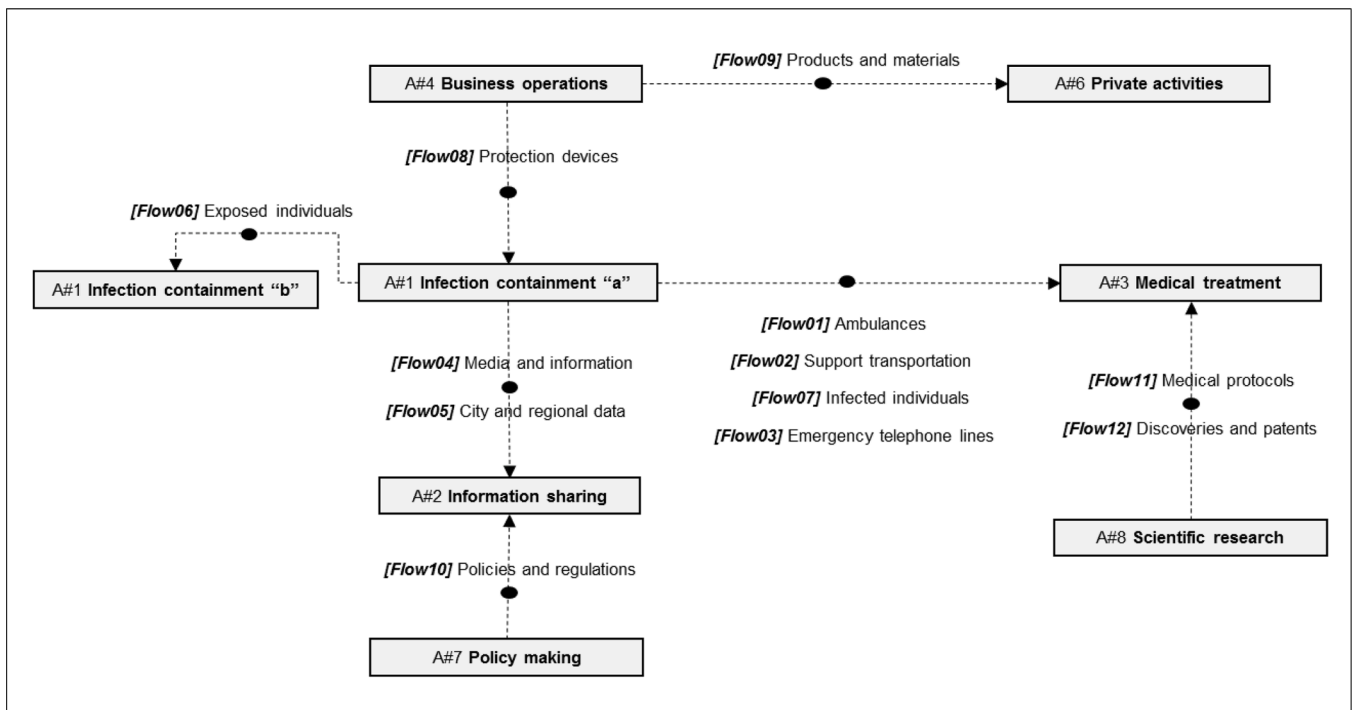


Fig. 3. Flow dependencies among activities and resources in epidemic management.

pharmacology). Second, *technology-related actions* are aimed to leverage existing/new technologies to improve treatment protocols (e.g. new ventilators), social mapping (e.g. digital tracking systems) or data analysis (e.g. artificial intelligence, big data).

*Business-related actions* include activities to support industries in recovering from the downturn and building new opportunities for value creation. *Policy-related actions* include public-led activities to define regulations, social distancing and behavioral norms, and policies of relevance for the public good. *Medical-related actions* are addressed to enhance treatment protocols, procedures, and the overall ability of the system to face pandemic through strengthened medical capabilities. Finally, *social-related actions* concern the activities to enhance social awareness and preparation for pandemic, to develop competencies, and to provide psychological and material support to communities.

Whereas actions refer to knowledge areas or fields of expertise, practices “cross” actions and refer to the micro-activities and related arguments which arise within specific response teams. Fig. 6 shows an emergency management system, with the described practices and actions, and the coordination framework including activities, resources and dependencies. The system should also include the goals to achieve, the success metrics, the potential exceptions, and the “handlers” to ensure the effective management of those exceptions (Dellarocas and Klein 2000). The representation is not a new research model or conceptual framework, but rather a visual synopsis of the key elements described. Moreover, the synthesis can provide some food-for-thought for defining new research efforts aimed to investigate, for example, the role and relevance of different practices in specific contexts, or the integration of multiple disciplines in wicked problem-solving scenarios.

## 5.2. An illustrative scenario of use

During the COVID-19 emergency, a number of emergency “agents” (e.g. institutional decision makers, emergency coordinators, and medical doctors operating within intensive care units) are involved into cross-disciplinary teams using/generating multiple information and physical resources. In such endeavor, what could be an illustrative application of the coordination system presented in the previous sections? How can

coordination principles be integrated within emergency management actions?

We focus on the case of a national government officer who communicates (to a plethora of stakeholders) crucial information on the status of the outbreak and the deriving policy decisions. The scenario has a number of implications related to the management of “flow”, “fit” and share “dependencies”, as well as with the integration of actions and coordination practices to ensure that the “right” information is distributed at the right time and in the right place.

The epidemic management system should first support or “check” that flows are properly managed, to ensure that the authorized (institutional) information providers communicate in a timely fashion (e.g. daily update) the data on the COVID emergency by detailing the multiple dimensions of the phenomenon (e.g. health, social, economic, institutional) and reach multiple targets (e.g. health care structures, municipalities, companies, schools, students, parents, aged people).

The information must be primarily verified to avoid the distribution of fake news. At this purpose, the system should ensure the integration (“fit”) of different bunches of information related to actions executed by actors operating in multiple domains. For example, *science* information will be shared with the public in relation to important scientific discoveries on new drugs or vaccines. *Technology* information will concern the development of tools such as contact tracing systems, swabs, serological tests, and protection devices. The *medical* domain will be involved in relation to aspects such as the robustness of emergency room procedures and the experimentation of alternative treatment protocols. Finally, the system should allow to integrate *business* expertise and information, such as industry-specific requirements to guarantee the security of workers and customers, and *social*-related information, such as awareness of communities and the respect of regulations.

The system “receives” the information generated in each domain by following an expertise coordination practice based on the implementation of a specific protocol. Moreover, in case of time-critical responses, the system should support a dialogic coordination based on joint sense-making to temporarily break the vertical sources of information and consider the phenomenon in its overall complexity. The interpretation of all the information received allows policy makers to elaborate their

**Table 3**  
Flow dependencies, constraints and management criteria (coordination mechanisms).

Code	Right Place (Accessibility)	Right Thing (Usability)	Right Time (Prerequisite)	Management Criteria
Flow01	Hospitals or temporary health facilities	Bio-contained and resuscitation units	Medical check on patient call	Emergency dispatch unit
Flow02	Hospitals or temporary health facilities	Bio-contained and authorized units	As needed, event-driven	Emergency coordination authority
Flow03	Hospitals or temporary health facilities	Authorized call dispatch units	User call	Call buffer, first-come first-serve
Flow04	Authorized information providers	Descriptive scenario information	Real-time broadcast	Veridicity and anti-fake news control
Flow05	Authorized information providers	Structured data in shared format	Daily or periodic updates	Veridicity and anti-fake news control
Flow06	Individuals' houses or health premises	Risky asymptomatic individuals	Prevention or upon medical check	Quarantine control and supervision
Flow07	Hospitals or temporary health facilities	Verified infected individuals	Medical check or patient self-reporting	Standard or experimental treatment protocol
Flow08	Authorized dealers or sellers	Industry or WHO standard-compliant	As available	Distribution or logistic authority
Flow09	Authorized sale or distribution points	Market or industry standards	On customer request	Market control authority
Flow10	Authorized information providers	Final approved documentation and decisions	As available	Institutional dispatching and control
Flow11	Hospitals or temporary health facilities	Scientific community standards	As available and authorized	WHO and national agency approval
Flow12	Hospitals or temporary health facilities	Scientific standard	As available and authorized	WHO and national agency approval

decisions and issue new regulations that are communicated to national stakeholders. The system can also control if target metrics (e.g. number of updates for each domain, number of authorized targets interested in receiving updates) are achieved through the implementation of activities, and support by suggesting proper alternatives in the case of arising exceptions (e.g. bandwidth problems, fake news).

The system should also address the problem of resource allocation ("share" dependencies). For example, in the described scenario, the information distribution and policy communication process uses a communication line (e.g. a national television channel) which can be used for multiple purposes. In this case, a priority criteria will drive the decision on how the limited resource will be used to optimize the process.

Whereas the case described may look as an "idealized" situation, there are many complexities which can generate exceptions or issues. For example, when it comes to political communication, there could be much deliberate ambiguity. Whereas, in relation to scientific communication, there is a relevant component of unexpected and emergent knowledge discovery. These aspects have implications on the nature of information distributed and how this is used by the "receivers". Complexities may derive in terms of managing flow, fit and share dependencies. For flow dependencies, a key issue is related to how much credible and authoritative is the "provider" of information. In this case,

the distribution (flow) of inappropriate data (e.g. not verified number of infected people) can generate a distortion in the emergency management mechanism. For fit dependencies, a problem is related to the ineffective process of merging inputs (fit) in order to generate socially-relevant knowledge (e.g. mistaken consolidation of regional data into national statistics). Finally, for share dependencies, a potential issue could be the arise of opportunistic behaviors which bring some actors to profit from the availability or access to a given resource by dis-advantaging other users (e.g. business use of public/open data).

### 5.3. "Positive" and "problematic" examples

We provide hereafter other three examples, two "positive" and one "problematic", i.e. situations in which coordination seems to have been (rather than not) properly managed. In order to provide different illustrative applications, the three cases cover an organizational perspective (focused on a "flow" dependency), a process perspective (focused on "share"), and an institutional/government perspective (focused on "fit").

One positive example is provided by most leading corporations, such as Amazon, Apple, BP, General Electric, Google, Walmart, and many others which have set up dedicated communication channels aimed to provide (flow) relevant information to customers (through public web-sites or Apps) and employees as well (through internal web portals and corporate Apps). In such cases, the information flow is managed directly by the company, which can oversee and guarantee the reliability of communication, and ensure that the right information is distributed at the right time and to the right users (efficiency and effectiveness).

A second positive example is the organization of the triage process outside the main buildings of big hospitals. A Swiss case (Peros et al., 2020) presents a system consisting of three areas, i.e. pre-triage, triage, and triage plus. The pre-triage check-points identify any potential COVID-19-infected patients and re-direct them to the main triage area where trained medical staff screen which patients undergo diagnostic testing. If testing is indicated, swabs are performed. If patients require further investigations, they are referred to triage plus. At this stage, patients are then discharged home after additional testing or admitted to the hospital for management. The case is an interesting example of co-ordination aimed to optimize the management (share) of limited resources represented by the hospital beds/rooms through a better three-level case management system.

The third example may be classified as problematic since it refers to a case in which the management of coordination can be optimized. The example refers to the many research entities, scientific bodies and private organizations which have worked worldwide to finalize and distribute a vaccine for the coronavirus. In such case, the existence of competitive dynamics can bring to partially un-coordinated efforts which may delay the development and global diffusion of the drug. Whereas the finalization and distribution of the vaccine should be a collaborative effort based on experience integration (fit), the partial communication of information on the diffusion of the virus and the lack of data on medical experimentations, can hinder the synergic effort aimed to generate an effective and safe drug for the global population.

## 6. Discussion and conclusions

A number of natural and human-related factors can today spread epidemics more widely and more quickly, potentially affecting ever-greater numbers of people and having ruinous impact on global societies (WHO 2018). Our study provides a comprehensive ontological analysis of activity coordination issues which are present in an effective emergency management system. We identified 8 activities and 25 resources involved in the COVID-19 outbreak. We described 29 flow, fit and share dependencies among resources and activities, along with insights for the design of an integrated management system.

The study is in line with the WHO's recommendations (WHO, 2018)



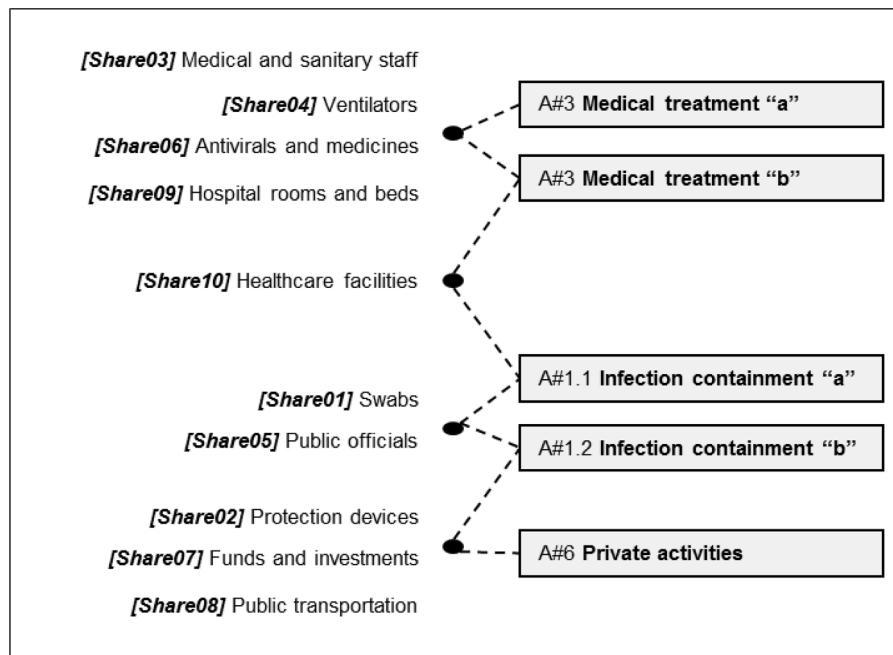


Fig. 4. Share dependencies among activities and resources in epidemic management.

to define comprehensive responses to outbreaks. Responses may influence the delicate equilibrium among government, business, and citizen issues, and they can have an impact on resilience of health systems (Leite et al., 2020), social systems (Giritli Nygren and Olofsson, 2020) and business systems (Kuckertz et al., 2020). In the paper, we highlighted the importance of managing exceptions and frictions (Draeger, 2017), and the role of activity and resource interactions in the study of complexities deriving from a highly contextualized and non-routine setting (Faraj and Xiao, 2006).

The present study is new in the management science literature, and can thus stimulate new contributions that attempt to adopt a process view in the analysis of how resources and agents interact in the management of epidemics. Our study advances the discussion on the relevance of multi-stakeholder views for emergency management, and on the crucial need for governments to improve investments in tangible and intangible infrastructures in the wide area of emergency preparedness and management (Turoff et al., 2013).

Our conceptual view of the epidemic management system addresses

the integration of citizens and public organizations into all the phases, which is a relevant aspect in the design of an emergency management system (Turoff et al., 2013). This contributes also to highlight the role of communication and coordination in overcoming the institutional gap created by decentralization (Zulean and Prelipcean, 2013) and the unclear chains of command (Araz and Jehn, 2013). The diffusion of such approach would also contribute to include numerous online communities of experts, known also as Virtual Operations Support Teams - VOSTs (Fathi et al., 2019), to provide their knowledge and expertise for emergency planning, thus increasing the effective of the emergency response (Turoff, 2002).

The proposed coordination framework that includes knowledge-type, person-type and object-type resources, multi-knowledge actions, dependencies mechanisms and coordination practices, allows to address the four specific challenges characterizing crisis management, including the heterogeneity of the actors and stakeholders involved, multi-dimension effects, the diversity of activities to build resiliency, and the centrality of knowledge transfer and sharing mechanisms

Table 4  
Share dependencies, constraints, management criteria (coordination mechanisms).

Code	Right Place ( <i>Accessibility</i> )	Right Thing ( <i>Usability</i> )	Right Time ( <i>Prerequisite</i> )	Management Criteria
Share01	Sanitary premises or health facilities	Industry or WHO standard-compliant	Prevention or upon medical request	First-come first-serve
Share02	Authorized dealers or sellers	Industry or WHO standard-compliant	Routine or as available	Degree of risks or exposition to information
Share03	Hospitals or temporary health facilities	Authorized trained health professionals	Continuous 24/7 availability	Local availability and number of infected individuals
Share04	Hospitals or temporary health facilities	Industry or WHO standard-compliant	Medical decision and protocol-based	Disease severity, patient age and general health conditions
Share05	Territorial distribution	Authorized trained professionals	Continuous 24/7 availability	Local availability and diffusion of contagion
Share06	Hospitals, temporary health facilities, patient houses	WHO Protocol	Medical decision and protocol-based	First-come first-served
Share07	Recognized beneficiaries	Authorized institutional funding	As available or authorized	Health vs. business/market priorities
Share08	Regular routing and scheduling	Disinfected means applying contagion restriction measures	On customer or user request	Trade-off between health vs. business needs
Share09	Hospitals or temporary health facilities	Industry standards	Medical decision on patient self-reporting	First-come first serve
Share10	Hospitals or temporary health facilities	Industry standards	As needed	Treatment vs. prevention priorities

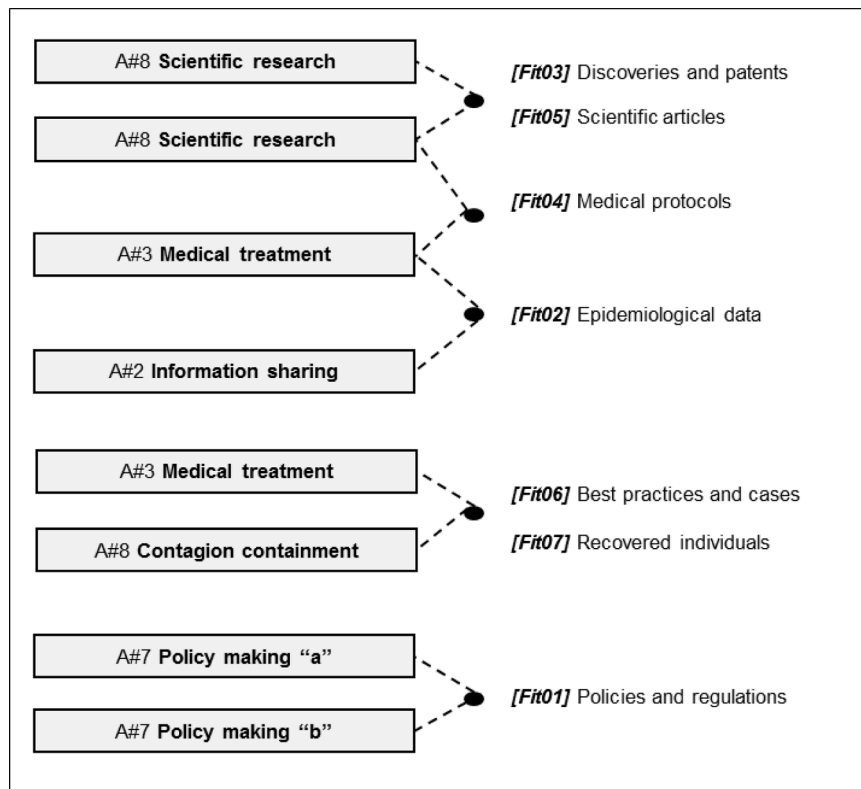


Fig. 5. Fit dependencies among activities and resources in epidemic management.

**Table 5**  
Fit dependencies, constraints and management criteria (coordination mechanisms).

Code	Right Place (Accessibility)	Right Thing (Usability)	Right Time (Prerequisite)	Management Criteria
Fit01	Supra-national, national and regional institutions	Shared format or template	Emergency-based, event-triggered or based on WHO request	Policy coordination authority
Fit02	WHO or national health agency or ministry	Shared format or data-collection template	Daily or other agreed frequency	Information coordination authority
Fit03	Global scientific community	Scientific standard and research protocols	Event-triggered or serendipity	Scientific coordination authority
Fit04	Hospitals or temporary health facilities	Scientific standard and research protocols	Emergency-based, event-triggered or based on WHO request	WHO and scientific coordination authority
Fit05	Global scientific community	Scientific standard and research protocols	Event-triggered or serendipity	Scientific coordination authority
Fit06	WHO and global scientific community	Formalized report or case study	As available	WHO and scientific coordination authority
Fit07	Individuals' houses or health premises	Official or experimentation protocol	As available	WHO and scientific coordination authority

**Table 6**  
Expertise and dialogic coordination practices in epidemic management.

Expertise coordination practices	
Practice	Definition (based on Faraj and Kiao, 2006)
<i>Reliance on protocols</i>	Adoption of standard procedures (to avoid ambiguities) integrated within a decision-making flow that regulates the treatment of a COVID-19 case or the execution of different analysis, management or response tasks
<i>Community of practice structuring</i>	Formation of specialty teams to coordinate operations and manage staffing interdependences and learning process, epistemological demarcation, hierarchy, policies and schedule
<i>Plug-and-play teaming</i>	Temporary role-based ad-hoc team formation, with ability of the group to split up in subunits, to work in parallel cases, and to return to its original form
<i>Knowledge sharing</i>	Data, information and knowledge flows among COVID-19 team members, to align awareness about status, discuss alternative plans, re-evaluate diagnosis, prevent errors and faulty cognitions
Dialogic coordination practices	
Practice	Definition (based on Faraj and Kiao, 2006)
<i>Epistemic contestation</i>	Conflicting perspectives of different specialties and communities as to which a treatment step or action is required, which roles and responsibilities should be involved and when/how
<i>Joint sense-making</i>	Temporary break of specialization boundaries, due to ineffective treatment or emergent complications of a COVID-19 case, and emergence of a dialog phase to support time-critical cross-disciplinary decision making
<i>Cross-boundary intervention</i>	Emergent cross-boundary corrective actions aimed to prevent or repair the negative effects of actions of a team member which may compromise the safety of patient
<i>Protocol breaking</i>	Risky but necessary deviation from protocol and best practices when the same slow down treatment and delays crucial intervention on a case, with upset of work plans and roles

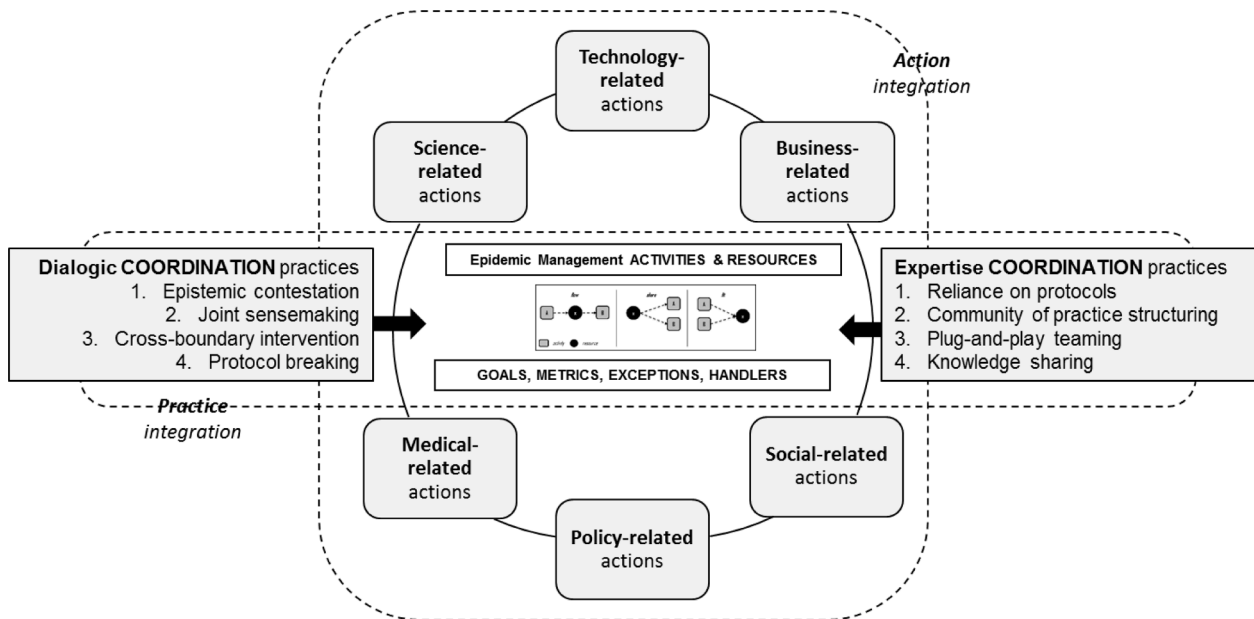


Fig. 6. Conceptual view of a system to support epidemic management.

(Hernantes et al., 2013).

Besides advancing the extant knowledge on emergency management and the use of coordination principles to build comprehensive response models, our article has a value for practitioners. Responding to an emergency is a distributed process which concerns: a) decision makers and institutional agents, defining policies and norms to contain contagion and regulate the behavior and activities of individuals and organizations; b) first response managers, coordinating medical and sanitary staff involved in saving endangered lives, and activating prevention actions. Our framework can be useful for emergency agents and coordinators, as it provides a structured checklist of management items to include in an emergency management plan or outline of purposeful actions.

The study has some limitations. First, an extended group building approach, and expert validation, can support a more robust version of this framework. Second, the model should be integrated with more analytical and computational efforts aimed at developing a decision support system able to apply the defined variables defined into an optimization algorithm. Third, prototyping the model by leveraging information systems and algorithms can help address and manage privacy concerns from a multidisciplinary perspective (Chen, 2020). The coordination framework may inspire further reflection and insights that help rethink trade policy agreements and conditions under pandemic circumstances (Evenett, 2020), and consequently reorganize the commercial supply chains (Ivanov, 2020) as well as reinterpret the meaning of resiliency, viability and robustness of the intertwined supply networks (Ivanov and Dolgui, 2020).

#### Declaration of Competing Interest

None. The authors whose names are listed below declare that they have NO affiliations with or involvement in any organization or entity with any financial or nonfinancial interest in the subject matter or materials discussed in this manuscript.

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