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Data challenges in dynamic, large-scale resource allocation in remote regions

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ABSTRACT

Resource allocation is difficult in large-scale systems in remote locations with sparse infrastructure and dynamic, demanding requirements, as can be the case in disaster management, emergency and oil spill response, and search and rescue operations. Resource allocation challenges are particularly acute in Arctic oil spill response, where the lack of infrastructure makes logistics challenging and heightens the need for comprehensive and thoughtful resource allocation models. This paper describes data challenges associated with the development of resource allocation models for dynamic network scheduling in support of Arctic oil spill response. A marine transportation traffic analysis and an Arctic resource allocation database, developed to support the resource allocation model development described, were developed using public and private information sources. This paper outlines the challenges associated with the data acquisition and analysis efforts, and provides recommendations for addressing the data challenges, which are similar to those in other complex, safety–critical resource allocation problem settings.

1. Introduction

Resource allocation is a critical function in large-scale human-technology systems in which resources – including people, technology, funds, living resources, equipment and/or supplies-must be deployed, often in response to safety – and time-critical requirements. Resource allocation decisions in large-scale, dynamic systems can have significant impacts on the environment, economic systems, organizations and social systems, and on the safety and preservation of life, living resources and property. Examples of large-scale dynamic resource allocation systems include those in emergency relief and disaster management (Sheu, 2010), global high speed network development and incident response (Buyya et al., 2000), hazardous material routing and traffic management (Zografos and Androutsopoulos, 2008), oil spill response (Garrett et al., 2014), search and rescue (Gelenbe and Wu, 2012), and water resource management (Gleick, 2003), among others. Resource allocation is difficult in large-scale remote locations with sparse infrastructure and dynamic, demanding requirements, as can be the case in disaster management, emergency and oil spill response, and search and rescue operations (Reynolds, 2014). Effective resource allocation therefore requires logistics – the procurement, maintenance and transportation of materials, equipment, facilities, funding and personnel – and is dependent on existing infrastructure.

Access to shared repositories of accurate, consistent, timely, reliable information is critical in large-scale resource allocation systems. Absent such information sources, planners, decision-makers, regulators and operational managers face significant hurdles in planning, assessing operational situations and making crucial decisions (Waugh and Straub, 2006; Odlund, 2010). In addition, the development of common portrayals of operational situations that inform decision-makers in real-time--the development of a knowledge commons—is a long-standing research challenge in many safety- and time-critical settings where access to that information can mean the difference between a successful or

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unsuccessful mission, and lives lost, economies disrupted and populations and ecosystems at risk (Bannon and Bødker, 1997).

Access to shared, reliable information sources for resource allocation is particularly important in remote settings, such as in Arctic oil spill response, where the lack of infrastructure and need for careful planning in a fragile, pristine and rapidly-changing ecosystem (Abel, 2015) make logistics challenging, and information scarce and difficult to acquire. In the Arctic, the lack of information, communications and transportation infrastructure, and enormous distances between sparsely populated villages, coupled with the unpredictability of weather and the magnitude and power of sea states and environmental conditions, complicate access, deployment and supply of critical resources. In the absence of Arctic shore-based infrastructure, long-range planning and reliable information for resource allocation, refueling and replenishment are required. Public expectations for four-season response capability in the event of an incident in the Arctic also increase the need for thoughtful planning, reliable information, and robust resource allocation models (Arctic Council, 2009; Pew Charitable Trust, 2013; National Academies, 2014).

Data about resources to be allocated are at the center of resource allocation models. Information about equipment, supplies, deliveries, locations, personnel, technologies, incidents, hazards, environmental considerations, and data about constraints that influence resource allocation, are important inputs to resource allocation decisions. Aggregating, integrating, cleaning and analyzing this data for Arctic resource allocation are difficult and time-consuming tasks, particularly since the data are collected and managed by different public and private organizations who do not share common data definition, metadata or data management standards. This difficulty is by no means unique today, especially with the proliferation of large-scale, dynamic data sets (National Academies, 2015).

This paper describes data challenges associated with the development of large-scale resource allocation models for dynamic network scheduling in remote locations, particularly for Arctic oil spill response. These data challenges create difficulties for effective resource allocation, and for developing a common operational picture for large-scale resource allocation responsibilities in remote and infrastructure-poor settings. The paper outlines the challenges associated with the data acquisition and analysis efforts, highlights a case study of Arctic oil spill response resource allocation data challenges, and discusses future research needed in large-scale resource-constrained, remote systems.

2. Information needs for dynamic resource allocation

Information needs for dynamic resource allocation center on equipment, material, personnel, budgets, technology and shipments delivered to locations in support of events or incidents, and information about changes and trends in the system, data and allocations. Information about events includes location, timing, duration, severity, trends or changes, as well as resources deployed and timing and effectiveness information about the resource allocation effort. Resources have costs, locations, shelf lives, optimal deployment periods, transit times, constraints about their use and maintenance, as well as weight, height, transportation and storage considerations, among others. Resource allocation decisions support tasks to be accomplished to complete a mission, respond to an incident, or prepare for an event.

Common data definitions and common data capture standards are critical for robust modeling efforts, including those for large-scale resource allocation, particularly when high levels of performance and reliability are required (Grabowski and Roberts, 1996, 2011), as participants are geographically scattered, with varying degrees of access to and understanding of the on-the-ground operational picture. Distributed decision-makers in large-scale safety–critical systems often rely on standard data definitions and classifications to ensure that all members are using the same data to develop shared mental models of the system and to make decisions. In addition, modelers and analysts rely on standard data definitions and ontologies to insure that data that has been captured, represented, labeled or stored with consistent data descriptions, and nomenclature, and that data dictionaries represent and store the same data. Absent standard data definitions and standard ontologies and classification schemes, decision-makers, regulators, analysts and modelers have difficulties relying on critical data, and significant data cleansing, reconciliation and management efforts are required. Thus, efforts to improve global capabilities for Arctic oil spill response must include efforts to improve operations, logistics, technology and science, as well as to improve data definition, storage and interface standards, and to improve processes ensuring data integrity and accuracy (Pew Charitable Trust, 2013; National Academies, 2014).

Resource allocation therefore requires coordinated and synchronized data sources, analytical tools and methods for assessing data and identifying trends, in support of real-time response or preparatory planning. Efforts to aggregate, integrate, synchronize, clean and assess such data have often been undertaken in the context of the development of a knowledge commons, an information repository of disparate data and metadata from public and private organizations that supports collaborative work (Bannon and Bødker, 1997). Such repositories have tremendous utility and appeal in settings where information, communications and transportation infrastructure are light, and the cost of competing, uncoordinated and duplicative data efforts are prohibitive (Seppänen et al., 2013).

Large scale resource allocation efforts thus require reliable information repositories (National Research Council, 2013), as they can create the opportunity to develop a shared sense of an event or scenario, or situational awareness (Endsley et al., 2003). Resource allocation requires collaborative goal setting, problem solving and decision solutions, all of which require that participants have a compatible understanding of the situation or shared situation awareness (Endsley et al., 2003). Such shared situation awareness can promote the development of trust, which can have a positive impact on communication, information sharing, and interorganizational performance (Grabowski and Roberts, 1996, 2011; Weick and Roberts, 1993; Virrantaus et al., 2009).

Designing, developing, maintaining and securing shared information repositories is a substantial challenge in large-scale systems, and the massive data analysis efforts required to parse and make inferences from such data are similarly challenging (National Research Council, 2013; National Academies, 2015). Providing accurate, consistent and reliable information in support of large-scale dynamic resource allocation efforts, particularly in remote locations, therefore, presents a number of challenges. In the following section, we explore the data challenges associated with dynamic resource allocation models for oil spill response in remote regions, focusing particularly on models developed for the Arctic (see Table 1).

3. Case study: resource allocation for Arctic oil spill response

The Arctic is an environmentally sensitive area with little commercial, maritime or safety infrastructure, and great distances that must be covered to access resources in the case of a maritime event, personnel casualty or an oil spill incident (National Academies, 2014; National Petroleum Council, 2015). The Arctic marine environment is also rich in oil and gas. The Arctic holds