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Concealment measurement and flow distribution of military supply transportation: A double-entropy model

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ABSTRACT

To address the issues of military supply distribution and transportation under the restrictions of concealment during war preparation and warfare periods, this study proposes a double-entropy model to measure the degree of the comprehensive concealment of military supply transportation from the perspectives of transportation and detection. With respect to the real road conditions, we further develop this double-entropy model with consideration of the width and length of roads and introduction of the limitations of average transportation. The reasonability of this model and its related definitions are then demonstrated by theoretical analysis and mathematical proof. Subsequently, three distinctive properties of military supply transportation via a road or a road network, namely unordering, scalability, and directionality, are investigated. Based on the double-entropy model and the above properties, a flow distribution model of military supply is designed, which addresses a vital issue in the event of a military confrontation or regional war. Finally, we provide an example that calculates an optimal flow distribution schedule to carry out a regional military drill in the Jiangsu Province of China to demonstrate the proposed concepts and approaches.

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1. Introduction

Military supply transportation has become an indispensable part of national defense capabilities. Normally, military supply transportation is used mainly to provide supplies for army training and warfare (Geisler & Karr, 1956). The capacity to conceal the transport of military supplies from the "enemy" is not only strongly related to the efficiency of supply delivery, but can also determine the outcome of warfare (Woodworth, 1998). Therefore, during the periods of war preparation and warfare, efficient military supply transportation is critical. Unlike general supply transportation that focuses on cost and time, the military supply transportation should closely consider its degree of concealment. In this paper, we focus on this vital issue and propose the concealment measurement of military supply transportation, and then construct the corresponding flow distribution model.

Generally, the military transportation studies follow two perspectives: The first perspective is the theoretical research, such as Flood (1954) applied the transportation theory to design an optimal approach for the military tanker fleet, which was an early study of military transportation; Liu and Huang (2009) investigated the shortest path of military transportation based on a simulation algorithm; however, in our opinion, the shortest path should not be considered as the most important factor in military transportation. Moreover, Gong et al. (2014) constructed an information support system for military transportation, which is a practical and automatic distribution system used to reasonably transport military supply. It is pointed out that these theoretical methods are not suitable for military supply transportation with respect to transportation concealment and detection degrees. The second perspective is the applied research on military transportation by introducing real backgrounds, such as Montana et al. (2000) and Burke, Love, and Macal (2004) applied military transportation theory to address some real problems where Montana built a proof-of-concept automated system for scheduling all US military transportation in detail, and Burke et al. (2004) presented a transportation system capability model to simulate the deployment of forces from Army bases. Similarly, Jain and Saksena (2012) studied the time minimizing transportation problem with a fractional bottleneck objective function, and applied it to an example of military transportation from the Indian Army. In addition, some recent research, such as Dagge and Filgueiras (2015) constructed a military weight transportation system which is a development of the information support system for military

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transportation provided by Gong et al. (2014) and Tsadikovich, Levner, Tell, and Werner (2016) provided a model for transportation operations in military supply chains by integrating demand and response. Most of these studies, however, are limited to time, costs, road network evaluation, and numerical simulations, which cannot be applied to military supply transportation with respect to concealment. Essentially, concealment is a vital factor in military supply transportation, which also is the main objective of this study.

On the other hand, the research of the flow distribution of transportation has obtained many results. It is obvious that the time, cost and method are three key factors for the flow distribution of transportation. First, based on the condition of least time, Ziliaskopoulos, Kotzinos, and Mahmassani (1997) designed a least time path algorithm for intelligent transportation systems; Miller-Hooks and Mahmassani (2000) studied the least expected time paths in stochastic transportation networks, from which Wang, Gao, and Yang (2015) analyzed the least expected time paths in fuzzy and time-variant transportation networks. The element of least time could be further considered in military supply transportation to improve the proposed models in this study. Second, according to the minimum cost principle, Klingman, Napier, and Stutz (1974) designed the code “NETGEN” to address minimum cost flow network problems; Lawrence, Randolph, Dennis, and Carlos (1985) provided distribution strategies that minimize transportation and inventory costs by classifying the transportation costs. In different research based on these constraints, Reynolds-Feighan (2001) presented a model for low-cost and full-service traffic distribution for the US air transportation carrier networks. Moreover, many other studies, such as Ding and Zhang (2011), Flisberg, Frisk, Rönnqvist, and Guajardo (2015), Tsao and Lu (2012), and Xie, Butt, Li, and Zhu (2016), focused on this issue. However, cost is not a vital element for military supply transportation during periods of war preparation and warfare. Third, regarding the transportation model, Ambrosino and Scutellà (2005) proposed two mathematical programming formulas for the transportation distribution network; Ramezani, Haddad, and Geroliminis (2013) developed a macroscopic traffic model; Song, Yin, Lawphongpanich, and Yang (2014) presented mathematical formulations for developing Pareto-improving pure road space rationing schemes and other approaches (Blank, Kuznetsov, Pekkér, & Veldman, 2016). These transportation models cannot be used in this study because they mainly focused on the time, cost, path, and other objectives of military supply transportation, which are the typical issues in the general transportation fields. These studies cannot be used to address the concealment issue. As previously mentioned, concealment is a vital element in military supply transportation and should be considered in the modeling and calculation process.

Moreover, additional studies addressing other transportation technologies, such as for radioactive supply transportation (Evangeliou et al., 2015; McClure & Tyron-Hopko, 1986), resource supply transportation (Etemadnia, Goetz, Canning, & Tavallali, 2015; Lee, Bardunias, & Su, 2007), emergency supply transportation (Gun, Pel, & Arem, 2016; Tang, Chen, & Zhang, 2008), bulk supply transportation (Ristic & Jeftenic, 2012), soil supply transportation (Farsang et al., 2013), and hazardous supply transportation (Ardjmand, Ii, & Weckman, 2016; Kang, Batta, & Kwon, 2014, 2014b), are developed. However, these studies also cannot be used to address concealment issues.

Based on the literature review, we find that military supply transportation is an important issue; however, there are few related studies focused on its martial properties and practical requirements. Thus, this study proposes a double-entropy model to measure the comprehensive concealment of military supply transportation under the restrictions of maximum concealment and minimum detection degrees during the war preparation and warfare periods. Furthermore, a flow distribution model of military supply is developed to apply these models to real military transportation, and then, an example is provided to demonstrate the feasibility and effectiveness of these new approaches.

The remainder of this paper is organized as follows: We first analyze the relationship between the entropy theory and the concealment of military supply transportation in Section 2, which is the theoretical basis of this study. In Section 3, we respectively propose the transportation entropy model, the detection entropy model, and the double-entropy model to measure the concealment, detection, and comprehensive concealment degrees of military supply transportation. Some properties of the double-entropy model are investigated in Section 4, from which a flow distribution model of military supply transportation is constructed. In Section 5, an example is given to demonstrate the application of the models. The paper ends in Section 6 with conclusions.

2. Entropy theory and concealment measure

In this study, we investigate the flow distribution model of military supply from the perspective of maximum concealment. To reasonably measure the concealment degree of military supply transportation, the entropy theory is introduced because it can be used to calculate the degree to which the transportation disorder in a road network corresponds to the degree of concealment against the “enemy.” The flow distribution model of military supply transportation can then be constructed based on the maximum concealment principle with real road conditions, and the optimal transportation schedule can be obtained. To do this, the detail theoretical analysis of combining the concealment of military supply transportation with entropy theory is presented as follows:

Entropy, a concept that was proposed by Clausius in 1850, has been used as a measure of disorder in the special distribution of energy (Baron, 1983). A higher level of entropy indicates a greater degree of disorder in an energy distribution. Shannon (1948) introduced the concept of entropy to information theory, and proposed the concept of information entropy, which refers to the probability of discrete random events. A greater uncertainty of random events can result in greater entropy. To reasonably apply this idea, Jaynes (1957) summarized the maximum entropy principle, and then Lazo and Rathie (1978) developed entropies with different continuous probability distributions based on the maximum entropy principle. By setting the upper and lower limits of the moment constraint, Thomas (1979) proposed a generalized maximum entropy principle for decision-making problems under uncertainties. Based on these studies, Majlender (2005) proposed a class of parametric order weighted averaging (OWA) operators with the maximal Rényi entropy; the maximal Rényi entropy is obtained by introducing the max function for entropy values and solving the corresponding nonlinear programming. Moreover, Abbas (2006) proposed a new method of determining the utility value using the maximum entropy principle. Through continuous improvements in entropy theory, this concept has been widely used in the natural and social sciences with reasonably good practical results. It is pointed out that the maximum entropy is a common technology, and is the basic principle used in this study to construct the following distribution model.

Moreover, a study closely related to our research is the risk measure of the military transportation system (Yang & Qiu, 2005), in which an expected utility-entropy decision-making model is proposed. The theoretical basis to apply the entropy to military transportation is demonstrated in this study. However, this risk measure differs from the concealment measure proposed in this study, and the corresponding decision-making model cannot be used in the flow distribution of military supply transportation. Therefore, based on the entropy theory and Yang's study, this

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