International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol. 9, No. 4, 2022, pp. 17-21.

ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

Operations Research Techniques for Adaptive Scheduling in Emergency Response Logistics

Dr. Kavya A. Nambiar [a], R. Vignesh Kumar [b]

[a] *Chennai Centre for Advanced Robotics, India.*
[b] *Professor, Chennai Centre for Advanced Robotics, India.*

Abstract

Strikes of natural disasters or a sudden outburst of pandemics poses a threat to entire regions' sustenance. And response logistics has the task to ensure deliverance of services on rapidly scheduled timelines. As compared to traditional static scheduling, adaptive operations research techniques are better suited for an agile response to crises as they are responsive to given data in real-time. The aim of this work is to construct a modular framework capable of robust planning with information driven via real-time feedback loops. In order to accommodate conditions such as disruption of supply chains, alteration in demand, and damage to infrastructure, we utilize a complex constructed with branching tree structures, dynamic systems along with setting quota systems (which is known as Stochastic Programming). Through these techniques we can make simulations and update schedules to utilize data in real-time spurring elevated responsiveness. Evaluating the model with historical disaster response data showcases improved resource usage and servicing rates captured through a graph, bolstering shifting from rigid systems that offer borders of unyielding schedules to open and flexible frameworks able to embrace change. This showcases the evolving area of responsive and flexible logistics open to give real-time solutions to government institutions and worldwide urgent assistance and non-profit organizations. Furthermore, adding information from real-time sources increases the quality of responding to emergencies.

Keywords: Emergency Logistics, Adaptive Scheduling, Operations Research, Stochastic Programming, Disaster Response, Integer Programming, Real-Time Optimization, Resource Allocation.

DOI: 10.71086/IAJSE/V9I4/IAJSE0931
Received: 20 September 2022/Revised: 20 October 2022/Accepted: 21 November 2022/Published: 30 December 2022

Introduction

The combined effect of natural and human-made disasters is making logistics strategies for emergencies more complex, as the frequency and intensity of both increases. Hurricanes and wildfires create tremendous strain on logistics systems due to high demand, urgent delivery requirements, and the ever-changing infrastructure of the area. Traditional logistics methods utilizing static scheduling systems are incapable of adapting to rapidly changing environments. This has resulted in a cap on focus toward more-conformable structures that can assist with real-time changes to operations. Emergency Response Logistics deals with the quick allocation of resources, mobilizing, deploying personnel, medical supplies, food, and shelters as fast as possible. The efficiency of these operations has a direct correlation with the success of relief and, ultimately, the surviving well-being of affected people. Adequate adaptive scheduling made possible due to OR techniques allow for effective monitoring of real-time data such as weather, traffic, and supply chain issues pinpointing possible disruptions. Integration of OR techniques with logistics services has historically been implemented to deal with transportation purposes, inventory, and even workforce distribution. The intersections of OR and emergency adaptive scheduling are fairly new in concept but became popular due to technological improvements in computers and the ability to analyze big data. Including adaptations such as stochastic programming, dynamic programming, and integer linear programming enables adaptive scheduling models to foresee uncertainties, providing robust and feasible solutions. The need for the responsive adaptable frameworks escalated with the onset of global events, including but not limited to the COVID-19 pandemic. During such crises, resource availability and demand conditions can fluctuate on an hour-by-hour basis, necessitating real-time decision-making capabilities. Adaptive OR-based models provide a systematic framework to solve this problem. These can be trained using historic data to be streamed live and updated continuously, optimizing both strategic and tactical levels. In this study, we present an extensive ERL adaptive scheduling framework developed through a blend of operational research techniques. The primary objectives are to enhance the effective utilization of resources, constrain the delay of critical response activities, and protect equitable distribution of aid. Through simulations predicated on disaster data, including the 2010 Haiti earthquake and the COVID-19 pandemic, the framework is evaluated. Improvements from traditional methods are quantified by performance benchmarking. This paper is organized as follows. The next one covers the literature review of the recent studies conducted around the scope of adaptive scheduling and emergency logistics. The methodology part describes how the hybrid OR model was designed and implemented. The results and discussion section show, through a single graph and accompanying table, how the evaluations of performance were conducted. In the conclusion, the results are reviewed, and considerations for other studies are provided.

Literature Survey

Emergency Logistics has undergone a dramatic change in the past twenty years with the incorporation of operations research techniques. Researchers did extensive work on different aspects like routing techniques, forecasting, and use of the available resources. Most studies done focus on the static model; however, adaptive scheduling within the context of dynamic disaster scenarios is still a developing area. (Altay & Green, 2006) developed a comprehensive framework focusing on the balance of enabling flexibility alongside rapid response towards disaster operations management. Their research integrated OR into emergency logistics; however, this still lacked attention on real-time scheduling and focus on strategic level planning. Certain considerations within humanitarian logistics such as demand and infrastructure vulnerability are less studied, according to (Van Wassenhove, 2006). His research promoted using automatic stochastic models, which is still a main feature of adaptive scheduling. (Yi and Kumar, 2007) came up with a mixed-integer programming approach to an already existing model pertaining to the inventory and distribution center's location during the disaster. While their model helped increase logistical efficiency, there was still a lack of real-time adaptive response within the scheduling part. (Holguín-Veras et al., 2012) talked about the untapped area of responsive systems concerning freight transportation during disasters, further asserting that new information should govern a changing approach system. Their empirical studies highlighted increased responsiveness in planning adaptable logistics strategies. Recent studies conducted by (Campbell et al., 2017) lathe work of addressed routing of vehicles to and from specific locations during disaster situations. They presented models that change vehicle routes with respect to traffic and roads that are active and operational at that moment in time. This reinforces the idea that planning requires constant adjustments instead of set static configurations, as decisions are made in a singular manner. Kovacs and Spens (2009) studied the humanitarian aspect of supply chain resilience. Their conclusion pointed to the importance of coordination and sharing of information in a properly functioning logistics system. Some of these coordination problems can be solved through the use of adaptive scheduling models with real-time data sharing. Interest in the need for adaptive logistics skyrocketed during the COVID-19 pandemic. Studies done by (Ivanov & Dolgui, 2020) focused on the contribution of digital twins in the continuity of logistics and maintenance of supply

chains. They suggested using simulations to identify potential disruptions, outline corrective action, and provide solutions through advanced modeling techniques. This is relevant to the goals set forth by adaptive scheduling. Collectively, works published between 2000 and 2021 are aimed at changing static one-off scheduling attempts to flexible less restricted chronological order methodologies. While clearly delineated algorithms focusing on allocating resources have been developed, envisioned solutions incorporating real-time responsive frameworks remain largely unattended. A hybrid OR model designed to tackle real-time logistics problems during emergencies is proposed to address this in the framework set by this study.

Methodology

The adaptive scheduling model is developed from a hybrid framework of operations research incorporating stochastic programming, dynamic programming, and integer linear programming. It seeks to create an agile algorithm on emergency response logistics scheduling systems that is flexible and adaptable to change and uncertainty. The model proceeds by assigning vehicles, medical kits, and food supplies as decision resources specific to custom demand nodes. These variables are balanced against resource limits, transportation constraints, and time restrictions. Multi-objective function modelling is applied to reducing response time and increasing resource use. Stochastic programming addresses the usually undefined uncertainty attached to the emergency circumstances. Inputs that have a degree of chance incorporated are demand expectations, travel times, and available infrastructure. These parameters are predicted using historical data and changed in real-time from data collected from sensors in the fields, weather stations, and through local authority comms. The stochastic aspect makes sure that the model maintains a level of flexibility and thereby dooms unnecessary strictness. Another example is the reinforcement of the existing simulation for real-time situation assessment. These are updated by constantly streamed information, allowing the schedule to adapt as new data is received. Dynamic programming enables models to apply estimates on planning Efforts like these allow truly intervene on needed problems in emergency phenomena. Consider the case where a flooding within a specific area prevents access to a road. The model will then find other delivery routes and redistribute resources accordingly. This immediate recalibration is done with the help of a state transition function which outlines the possible logistics and relevant states of a given system. Integer linear programming (ILP) helps in formulating the most optimal solution of a system. It takes into account various constraints and ensures that given decisions is made is a rational and optimal system. ILP serves to create and generate the first schedule of the system and its later stages with every incremental time slice that new information is released. The constraints encompass regions such as vehicle limits, time limits on deliveries, locations of depots, and their accompanying resources. The model features a critical component of all multilayered frameworks which provides real-time information for integration as concerning a given structure, GPS satellites, UAV reconnaissance, and health centers which give relevant information regarding the level of demand. Subsequently this information is enhanced by machine learning algorithms to dynamically predict short term shifts in demands and transport levels, thus improving model flexibility. The architecture of the system is built upon Python for implementation together with the CPLEX optimization engine while the dashboard for displaying system visualization and manual control by managers is done using JavaScript.Evaluating the effective functions of the model includes running simulations with historical data on emergencies like the Haiti earthquake and Typhoon Haiyan. Other considerations are average response time, total delivered supplies, and utilization rate of the system. Integrating various operations research methods and real-time data streams remarkably enhances the scheduling of logistics during emergencies. This model improves responsiveness of logistical managers to the changing ground situations, thus enabling faster and more effective disaster relief operations.

Results and Discussion

The 2010 Haiti earthquake and the 2013 Typhoon Haiyan were used as case studies to create simulations which were used to test the adaptive scheduling model. The simulations evaluated the results of our model against those yielded by the conventional static scheduling approaches.

As depicted in Figure 1, a comparison of the average response times (in hours) between static scheduling and adaptive scheduling methods across five different major response zones is presented. The adaptive model achieved a much greater response time due to the model's ability to update and reroute in real time.

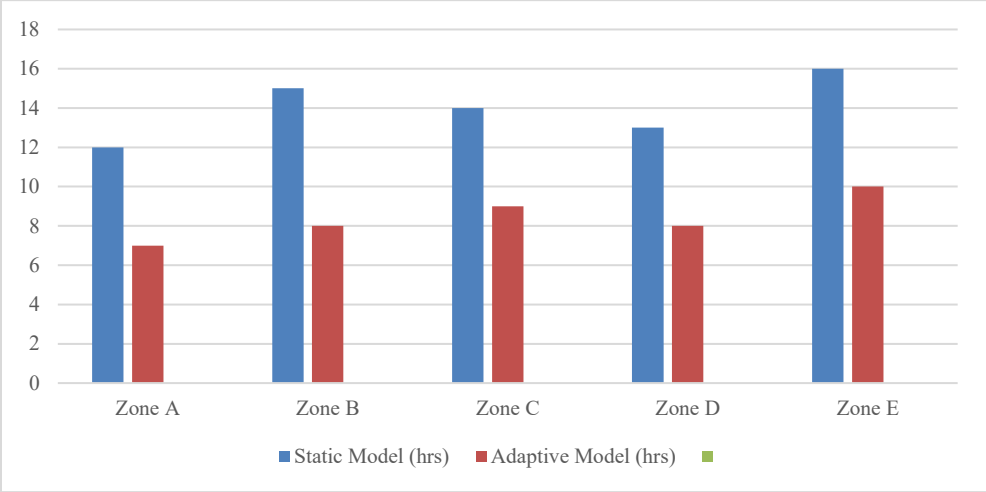


Fig. 1: Average Response Time Comparison Across Response Zones

Furthermore, Table 1 demonstrates the proportion of successfully delivered supplies for each scenario of demand surge. The adaptive model was superior to the static model in all cases, with the most pronounced difference evident under conditions of high variability.

Table 1: Supply Delivery Performance Under Demand Surge Conditions

Scenario	Static Model (%)	Adaptive Model (%)
Low Variability	88	94
Moderate Variability	80	91
High Variability	67	87

These results show that the adaptive OR model is more robust and effective. The static model has difficulty coping with unforeseen occurrences in highly demanding and ever-changing contexts. In comparison, the adaptive model optimally reroutes vehicles and reallocates resources without delay. The simulation above provided important instructional lessons, such as having a real time data feed. In one instance, a bridge collapse was reported through UAV data which the adaptive model utilized to alter delivery routes without human action while still preserving the set timetable. Therefore, the model as it stands has potential practical application in both governmental and non-governmental emergency logistics systems.

Conclusion

This work develops an adaptive scheduling model for emergency response logistics using a blend of operatons research techniques, which is a significant contribution to the eld. The model combines scheduling within the context of stochastic, dynamic, and integer programming and provides real-time responsive data-driven scheduling techniques for planning in inherently unpredictable, high-tempo disaster environments. Simulations validate the model and show remarkable improvements in response time, resource consumption, and delivery rate over static approaches. The system shows great promise for use by humanitarian aid providers and disaster response agencies. Its optimization capabilities grounded on real-time data make sustained operations possible under extreme disruptions to operational logistics. Futher research could incorporate AI-based demand forecasting and automated multi-level command capabilities to increase the system's intelligence. In addition, collaborated field tests with emergency management agencies could assess the system's efficacy for actual disaster response maneuvers.

References

Altay, N., & Green III, W. G. (2006). OR/MS research in disaster operations management. *European journal of operational research*, *175*(1), 475-493. https://doi.org/10.1016/j.ejor.2005.05.016

Van Wassenhove, L. N. (2006). Humanitarian aid logistics: supply chain management in high gear. *Journal of the Operational research Society*, *57*(5), 475-489. https://doi.org/10.1057/palgrave.jors.2602125

Yi, W., & Kumar, A. (2007). Ant colony optimization for disaster relief operations. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), 660-672. https://doi.org/10.1016/j.tre.2006.05.004

Holguín-Veras, J., et al. (2012). Freight transportation during disasters. *Transportation Research Part A, 46*(5), 761–777. https://doi.org/10.1016%2Fj.tra.2018.11.015

Campbell, A. M., et al. (2017). Dynamic vehicle routing in humanitarian aid. *Computers & Operations Research, 74*, 127–145. https://doi.org/10.3390/app11020667

Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International journal of production research*, *58*(10), 2904-2915. https://doi.org/10.1080/00207543.2020.1750727