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Simulating Incident Management Team Response and Performance

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Abstract

Recent research has shown the power of large-scale regional traffic simulations—such as MATSim—to model the systemic impacts and costs of capacity-reducing incidents. At the same time, observational studies have illustrated the potential for traffic Incident Management Teams (IMTs) to reduce these impacts and costs on a local scale; mathematical optimization models have also attempted to scale or locate these programs. In this research, we connect these two separate lines of scholarly inquiry by simulating the dynamic response of an IMT fleet to incidents arising on a metropolitan highway network. We introduce a MATSim module that handles stochastically-generated incidents of varying severity, dispatches IMT to clear the incidents based on path distance and availability, and measures excess user costs based on the incidents. We apply this module in a scenario with data from the Salt Lake City, Utah metropolitan region. We demonstrate the potential use of the module through an illustrative experiment increasing the IMT fleet size with a collection of simulated incident days.

Keywords: Incident Management Teams; Incident Simulation; Transportation Modeling

1. Introduction

In recent years, the deployment of Incident Management Teams (IMTs) across the United States has emerged as a key strategy in traffic incident management, notably reducing congestion and traffic-related costs [18, 3, 4, 16]. These teams, operated by departments of transportation and collaborating with emergency services, respond promptly to traffic incidents, improving overall traffic efficiency by clearing lanes and restoring roadway capacity. However, the effectiveness of these programs significantly depends on the response time of the vehicles [3]. Accordingly, much scholarly attention has gone towards optimization models that seek to site and size the IMT fleets and thereby improve response time [9, 14].

Previous research on IMTs has been necessarily limited: observational studies cannot fully capture the systemic response of motorists to incidents, and the objective functions used in the optimization studies are necessarily limited.

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The potential to study incidents and agency response to them with a regional traffic model — such as MATSim [2] — presents an opportunity to explore both sides of this problem: both evaluate the effectiveness of IMT programs and analyze potential policy responses related to their deployment and use.

In this paper, we present a MATSim extension to assess the performance of IMT programs. This extension handles capacity-reducing traffic incidents, dispatches IMT vehicles to incident sites to restore partial roadway capacity, and calculates incident-related delay. We also present a case study employing this extension to evaluate the effectiveness of IMTs in Utah's Wasatch Front Region, demonstrating the practical implications of our research for future IMT strategies and traffic management studies.

2. Literature Review

The foundation of our study lies in understanding the role of traffic incident management in maintaining efficient and safe roadways. The Federal Highway Administration defines incident management as a coordinated approach to managing traffic incidents, aiming to minimize their duration and impact while ensuring the safety of all road users [13]. Advances in technology and traffic dynamics research have led to the evolution of strategies, which vary across regions and contexts. A critical element of effecting incident management is IMTs, which have been demonstrated to significantly reduce roadway clearance time (RCT) and excess user costs (EUC) [6, 18]. The efficiency of these IMTs, as highlighted by Bennett et al. [3], is directly influenced by their response time, underscoring the importance of strategic fleet size and deployment locations [9, 14].

Efforts to enhance IMT efficiency have seen researchers exploring various methods, ranging from statistical models to heuristic algorithms. For example, Ozbay et al. [14] developed a mixed-integer programming model for strategic IMT resource allocation in New Jersey to optimize incident management efficiency and reduce costs. Similarly, Lou et al. [11] proposed a theoretical model to minimize IMT response times to improve deployment strategies. Parallel to these developments in IMT optimization, Dynamic Traffic Assignment (DTA) models have played a critical role in shaping incident management strategy by evaluating the impacts of traffic incidents. Utilizing the Visual Interactive System for Transport Algorithms (VISTA), Sisiopiku et al. [17] demonstrated the capabilities of DTA models in simulating traffic incident unpredictability and evaluating management strategies. Their findings indicated that providing post-incident information to drivers could substantially reduce travel times and congestion. Despite this, critiques by Wirtz et al. [19] of the VISTA model, such as its assumption of perfect driver information, underscore the need for more realistic models.

Despite these advancements in both IMT optimization and incident impact assessment, there remains a significant gap: the lack of an integrated, large-scale simulation model that encompasses both aspects. The MATSim toolkit offers a promising solution for detailed, large-scale incident simulations. Research by Kaddoura and Nagel [8] and Li and Ferguson [10] employed MATSim for thorough traffic incident analyses, demonstrating its ability to integrate real-world data and authentically represent driver behavior in response to unexpected incidents. However, these studies did not fully explore the direct impact of IMT programs or their effectiveness in reducing delays and costs.

While previous research has highlighted the crucial role of IMTs in reducing incident duration and related costs, a comprehensive understanding of their impact on regional traffic networks, particularly in dynamic scenarios, remains incomplete. To address this, we have leveraged the MATSim framework to develop a specialized tool designed to simulate incident scenarios and evaluate IMT performance across regional networks. This tool is specifically engineered to measure the impact of IMTs on delays and EUC and to facilitate the assessment of different IMT strategies and modifications. The development of this MATSim-based tool marks an advancement in traffic management research. It provides a platform for researchers and policymakers to explore and optimize IMT deployment and operational efficiency. By offering this tool, we aim to encourage the incorporation of incident management strategies into broader simulation studies, thereby enhancing the capacity for informed decision-making and policy development in traffic incident management.

3. Methodology

Our study involves a custom MATSim extension, referred to as the "IMT module," designed to simulate traffic incidents and IMT responses to evaluate their efficiency in mitigating delays and costs.

The IMT module integrates advanced incident simulation techniques, including Demand Rapid Transit (DRT) systems, event handling, and vehicle dispatch algorithms [5]. This integration enhances MATSim's existing capabilities, enabling more precise and realistic traffic simulations. We have adapted key MATSim features, such as scoring and replanning, network change events, and IMT assignments, to construct a comprehensive model. These components work in tandem to increase the authenticity and accuracy of our traffic simulations, particularly in managing roadway incidents, ensuring reliable results from our model.

3.1. Scoring and Replanning

In MATSim, simulated agents follow daily routines involving various activities and transport methods [12]. Their behaviors are evaluated using a scoring system, accounting for travel details. This system awards points for timely arrivals and deducts them for delays. Different transportation modes are also given utility scores that may influence the agents' travel choices. Agents within MATSim modify their plans via replanning between iterations [7]; strategies for replanning include choosing the best-scoring plan among those in memory, changing routes, or altering activity timings. The simulation aims to steer agents towards stable travel patterns, ensuring minimal variation in their plans across iterations. This method is essential for generating realistic travel plans. In the context of regional simulations, achieving this behavioral convergence often requires numerous iterations.

The strategy for modeling incidents is necessarily different, however, as agents cannot plan around randomly arising incidents while considering departure times or travel modes [5]. In this case, agents should strictly follow their set plans and not change them, with the exception of potential route changes indicated by within-trip or within-day notification of incident delays. This approach of creating a baseline of travel behavior with iterative modeling first and then using within-day replanning for dynamic situations provides a balanced and realistic traffic simulation method. It captures both the predictability of daily travel and drivers' reactions to unexpected changes, making it a comprehensive tool for traffic management and emergency response planning.

3.2. Network Change Events and Incidents

In MATSim networks, links are characterized by attributes such as type, length, lane count, free-flow speed, and capacity. To simulate unexpected traffic events realistically, these attributes can be dynamically altered using time-dependent networks [15]. Network Change Events (NCEs) in these networks enable the modification of link attributes, affecting traffic flow by changing link characteristics like speed and capacity. Our study uses NCEs to simulate the impact of incidents and IMT response on network dynamics.

Our IMT module is designed to incorporate incidents into the simulation effectively. The user supplies a list of incident coordinates, alongside a severity index indicating separately how many IMT units should respond to the incident, what percent of capacity the incident closes, and how long the incident will take to clear.

3.3. IMT Assignment and Response

When an incident occurs, the IMT module dispatches one or more teams to the site based on the incident severity. Utilizing a least-cost path algorithm, the module selects the IMT(s) capable of reaching the incident most quickly that are not already occupied. This selection considers current traffic conditions, such as congestion and varying speeds on different road links. In scenarios where all IMTs are occupied, the system queues the incident, assigning an available team as soon as possible.

Figure 1 demonstrates how traffic incidents affect road capacity and the role of IMT in decreasing this impact in the IMT module. The figure depicts a situation where a road link's capacity drops to 20 percent for 60 minutes due to an incident. Without any IMT response, this reduced capacity would remain unchanged throughout the 60-minute incident. With IMT intervention, the dynamics change: the arrival of the first IMT 15 minutes into the incident raises the link capacity to 40 percent of its pre-incident value, and a second team arriving 15 minutes later further increases it to 55 percent. This response was based on conversations with IMT operating agency, but could be improved with greater data availability.

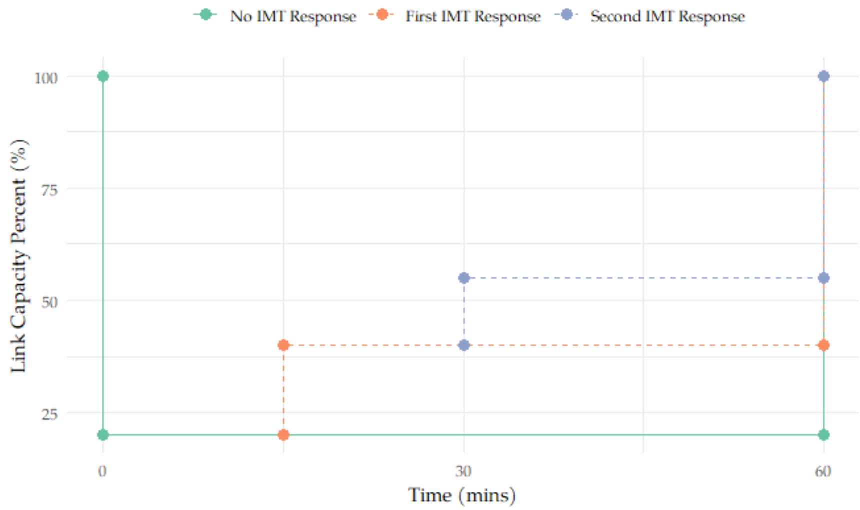

Fig. 1. IMT capacity restoration upon arrival example.

3.4. Model Implementation

The IMT extension is designed to facilitate the analysis of IMT efficiency across various simulation contexts. To effectively integrate and run the MATSim model with this extension, operators need several key input resources:

- A plans file detailing the agents to be modeled and their activity.
- A network file with interconnected links, enabling travel for the agents specified in the plans file.
- A configuration file outlining the scoring parameters of the simulation.
- An incident file containing the necessary data to affect NCEs within the simulation.
- An IMT file outlining starting locations and hours of operation for each IMT.

With these essential files, operators can integrate the IMT module into their MATSim simulations to assess the dynamics of incidents and the effectiveness of IMT interventions. In our case study conducted in the Salt Lake City, Utah USA metropolitan area, this MATSim model and IMT module combination provided valuable insights into the efficiency and impact of IMT deployment in a real-world urban simulation.

4. Case Study - Salt Lake City, Utah

This case study focuses on the effectiveness of Incident IMTs in Salt Lake City, particularly in reducing vehicle hours of delay (VHD) and improving incident response times. In collaboration with the Utah Department of Transportation (UDOT), Utah Highway Patrol (UHP), and building on previous research [16], we analyzed extensive data from 2022 on motorway incidents and IMT operations.

For instance, our study ran 350 iterations of a MATSim without incorporating incidents or IMT interventions to establish stable travel behaviors. The travel plans obtained from this baseline scenario then served as a baseline from which to evaluate the effects of incidents and IMT interventions. Using this data, we constructed and simulated 60 scenarios reflecting various numbers of incidents and IMT fleet sizes, thereby assessing the impact of IMTs on network efficiency. These scenarios were designed to mirror the range of daily incidents in 2022, varying from 4 to 21 per day. Our primary focus was on evaluating the current UDOT fleet of 20 IMTs and exploring the potential advantages of increasing the fleet to 30 units. This analysis aimed to understand the scalability of the IMT program and its potential for future enhancements.

The effectiveness of IMTs was measured in terms of their ability to reduce VHD on motorway links and improve arrival times at incident sites. We compared scenarios without IMT support to those with 20 and 30 IMT units. The findings, presented in Table 1, indicate a significant decrease in average motorway VHD with the presence of IMTs, particularly when the fleet size is increased to 30 units. This reduction, amounting to an 18 percent decrease with 20 IMTs and a 23 percent reduction with 30 IMTs relative to the baseline condition with no IMT units, suggests benefits for daily traffic flow and overall network efficiency. The data generated by the simulation clearly shows that IMTs are effective in reducing VHD, with a fleet of 20 IMTs reducing VHD by 18 percent relative to the scenario with no IMTs. Increasing the fleet size by an additional 10 IMTs further reduces simulated VHD, though the marginal impact of the next 10 is somewhat diminished.

Table 1. Average VHD of Motorway Links

Group	Average VHD	Change from No IMTs	Change from 20 IMTs
No IMTs	23280	-	-
20 IMTs	19050	-18%	-
30 IMTs	17950	-23%	-6%

Table 2. Average IMT Arrival Times [mins]

Group	All IMTs	1st Arrival	2nd Arrival	3rd Arrival
20 IMTs	15.0	11.1	21.1	28.9
30 IMTs	11.0	8.9	13.2	21.2

As a validation measure, we compared the average IMT response time — the elapsed time from when an incident occurs and when the first IMT arrives on the scene — in the 20 IMT scenario with the response times reported in a 2022 observational study of the IMT system in the same region [16]. In examining average IMT arrival times, we found that the current fleet of 20 IMTs had an average response time of 15.0 minutes, compared to the observed value of 13.9 minutes. The simulation reveals that expanding the IMT fleet to 30 teams could decrease this time by approximately 4 minutes, as indicated in Table 2. Such improvements in response times could lead to significant savings in travel time and associated costs for motorists. Previous research in Utah demonstrated that a one-minute increase in IMT response time results in a 34.6-minute increase in total travel time and an additional $925 in EUC [6]. Given these findings, the outcomes of our IMT performance case study could inform policy recommendations and cost-benefit analyses to enhance IMT operations, not only in the Salt Lake region but potentially in other areas as well.

5. Conclusions

IMTs have been operational in various regions across the United States, recognized for their role in improving roadway conditions. Despite their widespread use, research into their effectiveness has often been limited in scope and depth [16, 17]. One significant limitation has been the lack of robust analysis of the impacts of incidents and management strategies on a regional scale. This gap is addressed in our research, utilizing MATSim, a powerful simulation tool, to analyze the impact and performance of IMTs.

Our research led to the creation of a new MATSim add-on module designed explicitly for IMT performance analysis. This module was leveraged to evaluate the effectiveness of the IMT program in the Salt Lake City metro region of Utah. The findings from this evaluation demonstrate the module's potential as a versatile tool for future IMT analyses, not only within Utah but also in other regions. Future data collection could improve the model's fidelity to incident simulation; for example, additional data collection could inform a more realistic depiction of how IMT units restore capacity or reduce roadway clearance time beyond the crude assumptions pursued in this initial investigation.

The utility of this MATSim add-on extends beyond performance assessment. It offers a platform for advancing IMT performance studies, providing valuable insights into various aspects of incident management. This includes evaluating the impact of changes in fleet size, operating hours, and initial deployment strategies of IMTs. Additionally, the tool holds significant promise for conducting cost-benefit analyses, aiding in the decision-making process for future IMT proposals and optimization strategies. Future research should consider fine-tuning the behavioral response of agents in short- and long-term incident duration scenarios. For example, understanding when agents can learn of the existence of an incidents [8] or whether they decide to alter their daily plans in response to a larger incident, canceling or substantially modifying trips or activities. A link with an activity-based model, such as the POLARIS framework [1], could be beneficial for this analysis.

In conclusion, this research contributes to the existing body of knowledge on IMT performance and paves the way for a more informed, data-driven approach to managing roadway incidents. By combining the insights from real-world IMT operations with the analytical capabilities of MATSim, we have developed a tool that can significantly influence the future of incident management strategy and evaluation.

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