Formalization and Improvement of Ambulance Dispatching in Brabant-Zuidoost

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Throughout the last years, performance of ambulance services in the Netherlands has been consistently below the nationally-set target (response time of less than 15 minutes for at least 95% of highly urgent requests). As an industry where performance improvements can literally save lives, but resources are often scarce, *emergency medical services (EMS)* providers are continuously looking for ways to deploy available resources more efficiently. In this thesis we developed an alternative dispatch policy with the objective to improve the on-time performance of highly urgent ambulance requests, given the available ambulance capacity. We used machine learning to capture current dispatch practices in the Dutch EMS region 'Brabant-Zuidoost' (BZO) by extracting human decision rules from historic data and refining them with domain knowledge in a unique post-processing phase. This effort resulted in a formal model that is both concise and able to accurately predict current dispatch decisions. Subsequently, we leveraged the captured dispatch process as a practically relevant basis to improve upon and evaluated the resulting alternative policy in an advanced simulation. Results show that complementing the captured current dispatch policy with two enhancements yields a significant improvement of the on-time performance of highly urgent ambulance requests, without the need for increasing ambulance capacity. Our main contributions are the following:

- We are the first to formally capture current ambulance dispatch practices using machine learning. We apply decision tree induction to obtain a transparent representation of the current decision process in the BZO region, such that it can be used to create insights into current practices, as a basis to improve upon, and as a benchmark to fairly evaluate alternative policies.
- We apply a unique post-processing phase combining knowledge from the domain and literature with the fitted decision tree to further improve the performance of the resulting model, as well as make it more concise.
- We illustrate an application of the captured current dispatch policy by proposing four enhancements to it and evaluating these in a simulation using the captured policy as a practically relevant benchmark.

Approach While the limited number of existing studies aiming to improve performance through alternative dispatch policies either alter the commonly assumed closest-idle dispatch policy or develop a policy from scratch, we formally

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captured how dispatch decisions are currently made, with the goal of using this policy as a practically relevant basis to build upon. An instance set containing over 5000 historic dispatch decisions, including a wide range of features representing all information available to the dispatch agent at the time of the decision, was constructed. Our extensive feature engineering efforts entailed using domain knowledge to transform the data available in multiple databases into relevant features relating to each decision's concerned ambulance request (e.g. urgency), available ambulance options (e.g. driving times, status), and coverage-related features (e.g. region coverage reduction associated with each dispatch option).

On this data set we fitted a decision tree and compared its predictive performance to the commonly assumed closest-idle policy. While the performance of the fitted model is similar to the closest-idle policy for the majority of dispatch decisions, i.e. in case of sufficient capacity, it strongly outperforms this commonly assumed policy in case of scarce capacity. We used these insights to propose a concise, penalty-based policy that is able to accurately predict the dispatch decisions made by BZO's dispatch agents. The resulting model enriches the commonly assumed closest-idle dispatch policy through the use of penalty values that reflect the risk associated with certain ambulance characteristics, such as its status, region and time until the end of its shift.

Subsequently, four potential enhancements to the current dispatch policy were formulated based on insights from the captured current practices, discussions with dispatch agents and available literature. To evaluate these potential enhancements, a realistic simulation was developed that is able to accurately capture the complex dynamics of a life size ambulance system, facilitating dynamic request arrivals of multiple urgency levels, dynamic ambulance capacity, realistic relocation decisions and a wide range of practical considerations. The captured current dispatch process allowed us to be the first to evaluate alternative dispatch policies relative to a benchmark that resembles current practices.

Results Evaluation showed that two enhancements are expected to yield an on-time performance improvement equivalent to over seven extra weekly eight-hour shifts. These two enhancements entail redispatching ambulances that are currently on its way to less urgent requests and the reevaluation of active dispatch decisions upon service completion of an ambulance. The enhancements especially benefit areas that are currently underperforming due to them not being reachable in time from any, or most, ambulance stations. Therefore, especially for rural areas, similar performance gains are expected. Adjusting the dispatch process to better utilize available capacity is both virtually free and instantaneous, contrary to the expansion of capacity. Furthermore, the evaluated enhancements complementing, rather than replacing, the current dispatch policy is expected to foster adoption in practice. BZO dispatch agents have indicated to see serious potential in the proposed enhancements and intend to test them in practice.

References Theeuwes, N.B.J.M.: Formalization and Improvement of Ambulance Dispatching in Brabant-Zuidoost. Master dissertation, Eindhoven University of Technology (2019). Available: https://tinyurl.com/thesisTheeuwes