Context-Aware Customizable Routing Solution for Fleet Management

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Abstract: Vehicle routing solutions delivered to companies as packaged applications combine vehicle routing decision-making models and supporting services for data integration, presentation and other functionality. The packaged applications often are tailored to specific needs of their users thought customization methods and mainly focus on the supporting services rather than on modification of the routing models. This paper proposes a method for customization of the routing model as a part of the routing application. The customization method enables companies to incorporate their specific decision-making goals and context into the routing model without redesigning the model itself. The routing model is also capable of adapting its behaviour according to observed interdependencies among decision-making goals and routing context. An illustrative example is provided to demonstrate customization of the routing solution and to highlight multi-objective and context-dependent characteristics of the vehicle routing problem.

1 INTRODUCTION

Recent developments in information technology such as services, sensor technologies, advanced data analytics and cloud computing have allowed to reconsider solutions of well-known operations management problems. New data sources can be incorporated in problem solving and larger computational resources can be used for searching solutions. That allows developing models of higher sophistication providing more realistic solutions. A vehicle routing (VR) problem is one of such problems benefiting from the new technological capabilities (Keming, 2015; Wan et al., 2016).

To make operations managements models available to users, they are delivered as a part of various enterprise applications such as decision-support systems and ERP systems (Madapusi and D'Souza, 2012; Carton et al., 2016). These enterprise applications are provided by their vendors and often require customization to fit needs of particular users. In the case of the VR problem, the users are companies providing logistics services. While customization of enterprise applications is frequently considered (e.g. Parthasarathy and Sharma, 2016), traditional methods provide limited guidance for customization of decision-making components of these applications and modification of operations management models used, in particular.

The VR problem also depends on a number of company specific requirements and circumstances. The traditional models allocate client requests to vehicles to minimize traveling costs, and there are generic formulations of the problem solving model available (Eksioglu et al., 2009). However, there are many possible variations. Companies providing logistics services have different objectives, deliveries are affected by local circumstances and there are specific delivery constraints. Developing a customized solution for every user is resource intensive for software vendors. One of the possible solutions is development of operations management models on the basis of a common reference model (RM), which consists of generic and customizable parts. The generic part incorporates the most common aspects of the VR model shared by many users, and the customizable part incorporates user specific aspects of the VR problem.

The objective of the paper is to elaborate a method for customization of the VR service on the basis of the RM. The method focuses on customization of the VR model underlying the service. It allows to incorporate company specific

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objectives in the model without structural modification of the routing model. It also allows to represent specific operational circumstances faced by the company. These circumstances are referred as to context (Abowd, 1999). At this stage of the research, customization does not address specific internal constraints because these might require more comprehensive changes in the model structure and model solving procedure. Customization is performed on the basis of the RM, which defines typical VR objectives and context factors as described in literature.

The paper describes modules of the customizable VR service and the customization process. The main contributions of the paper are a proposal for separating generic and customizable parts of the VR model and methods for RM based modification of this customizable part. The paper is also an initial step towards a method for developing customizable operations management applications not only in VR. It relates to research by Giaglis et al. (2004) and Cordoso et al. (2016) in its emphasis on addressing of the routing problem as a part of the overall information system.

The rest of the paper is organized as follows. Section 2 provides an overview of the routing solution. The customization process is described in Section 3. This section also elaborates key features of the process including the RM, routing model and adaption. The vehicles routing results obtained using the proposed solution are provided in Section 4. Section 5 concludes.

2 SOLUTION OVERVIEW

The solution is developed for the vehicles routing problem. A company operates fleet of vehicles and provides transportation services for its clients. Given a set of client requests, the routing problem finds a set of routes starting and ending at a depot that serves all clients. Typically, there are specific time windows when the service should be provided.

Requirements are established according to literature review, evaluation of similar solutions and interviews with companies.

2.1 Requirements

The VR solution should satisfy all traditional requirements such as defined in Solomon (1987) and Laporte (1992). There are several specific requirements identified in literature and practice that are not fully satisfied by existing VR solutions.

R1. Multi-objective decision-making – typical objectives of VR are minimization of costs, time and travelling distance (Jozefowiez et al., 2008). Environmental issues, safety concerns and other factors are often mentioned as relevant.

R2. Customer service requirements should be met - time windows is a typical way to define customer service requirements.

R3. Customer priorities should be considered - if customer requirements cannot be fully satisfied due to capacity constraints priority should be given to the most important customers.

R4. Robust and risk aversion is preferable - some of potential routes exhibit large variations in travelling time and companies often prefer routes, which are longer on average but their traversal time is more predictable.

R5. System level special events should be accounted for - travel time strongly depends on special events such as street closures and public holidays. The system should provide predictive capabilities to estimate impact of such events.

R6. Route specific exceptional events should be considered - during the route execution, exceptional events (e.g., traffic accidents) occur and the impact of these events on the route planning should be evaluated.

R7. Location specific requirements should be taken into account - routing is affected by different factors depending on location (Cattaruzza et al., 2014). Additionally, data sources characterizing routing situations also vary across locations.

R8. Routes should be updated during their execution in response to customer requests, exceptional events and other circumstances (Haghani and Jung, 2005; Ghannadpour et al., 2013).

R9. The solution ramp-up time should to short and modifications could be introduced in an expedite manner (Prindezis et al., 2003).

2.2 Key Modules

A complete VR solution consists of routing service, context platform and transportation management application (Figure 1). The routing service is the focal part of this investigation and it is responsible for generating routes for every vehicle in the company's fleet to serve client requests in the given situation. The transportation management application provides a wide range of functions to logistics and transportation companies (Speranza, 2016). It provides input data to the routing service and consumes routing results. From the routing perspective, its main function is route execution (i.e., assignment of client requests to drivers, tracking of deliveries, performance evaluation). The context platform is responsible for gathering and pre-processing of context data from different external sources. The context data characterize particular route planning and execution circumstances.

Functionality of the VR service and transportation management application overlaps depending on needs of the particular company. If a company does not possess route execution functionality then that is provided as modules of the VR service.

The core part of the routing service is the route calculation module. It implements route an optimization model and finds a solution of the VR problem. The service is packaged as a web service, which acts as a wrapper for invoking a specific model solver. This way different model solving procedures can be used if necessary. The service also includes additional functions such as model's adaptation functions according to the performance evaluation feedback (see Section 3.4).

The routing model is a mathematical programming model specified. The model consists of its generic part and customizable part (see Section 3.3). The generic part is the traditional VR model while the customizable part represents company's specific requirements. The customizable part is configured according to the VR business model, which defines unique requirements of the company.

The business model consists of goal and context models. The goal model specifies company's VR and fleet management objectives. It enables meeting requirement R1 concerning capturing multi-objective nature of the VR problem. The context model describes various factors affecting route planning and execution. It enables meeting requirements R5 and R6. The business model is derived from the routing RM. The RM captures the common VR knowledge and allows sharing the model development effort among multiple service consumers. The customer specific model is developed by extracting relevant features from the RM or adding unique goals and context factors.

The data integration model is responsible for supplying the route calculation module with all necessary input data. It gathers data from sources, transforms these data and passes them to the route calculation module. The main input data are: 1) client demand data provided by the transportation management application; 2) context data provided by the context calculation module; 3) performance evaluation data provided by the transportation management application. These input data are pre-processed, aggregated and transformed by the module.

The context calculation module specifically deals with processing of context data because context data providers change dynamically and provide data of different quality and granularity. The context platform receives data directly from various sensors. These data are fed to the context calculation module, which transform, for instance, raw traffic intensity data into traffic intensity categories such as light, medium or heavy traffic. This transformation allows to decouple volatile data providers from business interpretation of context data. The context calculation module is configured according to data from the context model.

Currently, the prototype of the VR solution uses OPL to define the routing model and CPLEX to solve the routing model. The goal and context

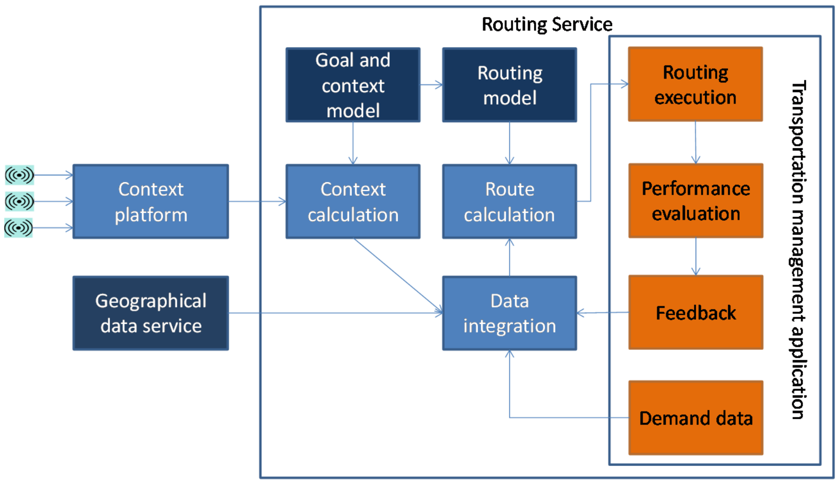

Figure 1: Key modules of the vehicle routing solutions.

models are formally specified in the XMI format. Data from the XMI file are extracted to add necessary elements to the routing model.

3 CUSTOMIZATION

The key requirement is an ability to customize the solution for a particular company and the customization should be done in a cost-efficient manner. The proposed approach addresses the customization issue during the solution design as well as during the solution execution.

3.1 Process

The customization process defines activities performed to develop a company specific VR solution. This solution is created on the basis of the common reference goal and context model and generic route optimization model. The final result is a complete routing solution. The customization process focuses on tailoring the routing model while development/integration of the transportation management application is performed using an engineering process traditionally used by the service provide and service consumer.

The first activity of the process is development of the business model consisting of the goal and context model (Figure 2). The consumer specific model is derived from the RM. The RM is maintained by the service provider and contains all relevant VR goals and context factors affecting the route planning and execution. It is a result of knowledge accumulated from providing routing services to multiple customers. The business model is used to create a company specific route optimization model, which is again derived from the generic routing model. The generic routing model is augmented by including goals and context factors important for a particular company as specified in the business model.

The data integration model is configured by establishing data bindings. That includes specification of context data sources, which could be specific for every company, and integration with the transportation management system. The route optimization model includes multiple parameters steering the route planning and execution activity. Initial values of these parameters are set for initial runs of the routing model. The customized model is tested and deployed as a part of the routing solution for productive usage.

The route planning and execution activity includes tasks on generating routes, tracking route execution, measuring performance and providing feedback. This activity is executed continuously whereas routing performance is monitored. If performance objectives are not met then the routing solution should be updated. The model parameters are changed in an adaptive manner (see Section 3.4), and these changes can be made without redeploying the solution in run-time. If adaptation is insufficient to improve routing performance, changes in the route optimization model or business model might be required. A typical change in the route optimization model is introduction of additional constraints. A typical change in the business model is updating of the relevant routing objectives or context factors. These changes require re-testing and re-deployment of the routing solution.

The main benefits provided by the proposed customization process are availability of routing knowledge, reduction of customization effort and the feedback loop.

3.2 Reference Model

The RM is maintained by routing service provider and it contains the most common routing goals used by different logistics companies and frequently observed context factors affecting routing activities. The RM is developed according to scientific literature and professional experiences while detailed discussion of the RM is beyond scope of this paper and it is not attended that this RM is accepted across the industry (i.e., its scope may be

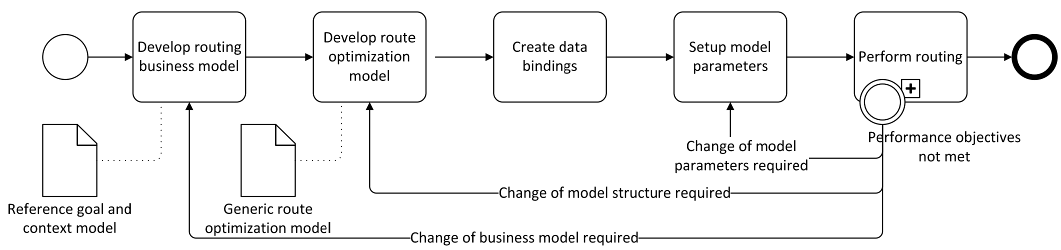

Figure 2: Customization process.

restricted to a single routing service provider). The RM is developed using the goal and context modelling methods used in the CDD methodology (Bērziša et al., 2015).

Figure 3 shows a fragment of the goal model (elements in the model will be used in Section 4). This model names relevant routing goals and there could be relationships among the goals. From the routing model customization perspective, it is important that the goal model also contains KPI for measuring the goals. These KPI can be incorporated in the optimization model to account for specific decision-making needs for a particular routing service client.

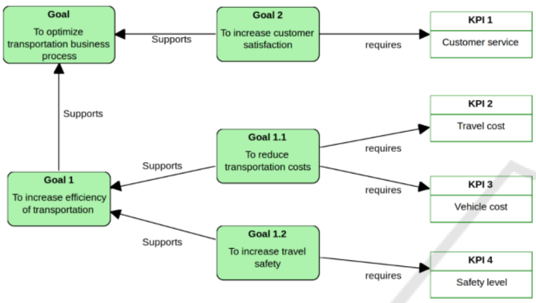

Figure 3: A fragment of the goal model.

A fragment of the context model is given in Figure 4. The model names context elements affecting routing. In the CDD methodology, a context element represents already processed raw context information, which is provided by measurable properties. The measurable properties are actual observations gathered from sensors while the context element already represent domain specific interpretation of the context measurements (e.g., measureable property counts cars while context interpretation defines what does account for a traffic jam). Measurements are transformed into context elements using context calculations. This kind of context processing allows using customer specific data sources by changing data bindings for measurable properties without affecting definition of the context elements.

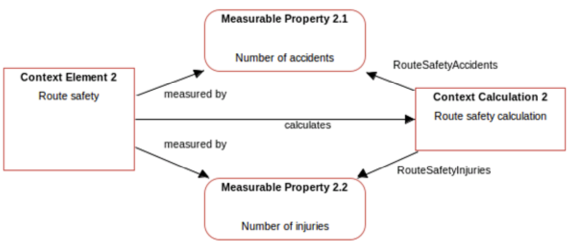

Figure 4: A fragment of the context model.

3.3 Routing Model

The routing model is a mathematical programming model (Table 1). The generic model is a typical formulation of the VR model (e.g. Solomon 1987). It optimizes routing cost and its main decision-making variable is a binary variable indicating whether a vehicle travels from one client to another. This decision variable is denoted by **X**. The main constraints are that each client is visited exactly once, vehicles have finite capacity, customer service time windows, routes start and finish at a depot, if vehicle arrives at a client it also must leave and departure, transit and arrival time dependences.

The vector **c** represents expense of taking a particular path between two clients. This expense can be expressed in different ways, e.g., actual travel costs, travel distance or travel time. In the generic formulation this expense equals to **d**, which represents travel distance. Vectors **a** and **b** are parameters used to specify constraints.

The generic model is augmented by a customizable part. That includes customization of the objective function by adding a term **v'P**, where **P** is a vector of penalties for not meeting company's specific goals and **v** is a vector of weights indicating a relative importance of each goal. A corresponding set of constraints (Eq. 4) is also added to the model. These constraints represent relationships among target values of KPI and values estimated by the model. $\mathbf{kpi}^T$ are target values set by decision-makers and $\mathbf{KPI}^C$ is a KPI value estimated using the routing model. This estimated value depends on the decision variable **X**. The constraint implies that if the target KPI value is not achieved then a positive penalty is added to the objective function. The penalty term in the objective function and the KPI constraint are added according to the goals and their measurements specified in the goal model.

Table 1: Generic and customizable parts of the routing model.

Core part	Customizable part	
$\min Z = \mathbf{c}'\mathbf{X}$	$+ \ \mathbf{v}'\mathbf{P}$	(1)
$\mathbf{aX} \le \mathbf{b}$		(2)
$\mathbf{c} = \mathbf{d}$	$+ \ \mathbf{ctx} \times \mathbf{w}$	(3)
$\mathbf{KPI}^C(\mathbf{X}) + \mathbf{P} \ge \mathbf{kpi}^T$		(4)

Additionally, constraint Eq. 3 is also modified. The cost of the route is now calculated as a sum of the distance and the weighted impact of context factors (the weight vector **w**). This modification implies that the cost parameters characterize different aspects of the route. For instance, there is a short route where accidents frequently occur; the aggregated cost parameter captures these characteristics. The aggregated cost parameter is defined as c_{ijk} implying that there are k different routes leading from i to j. These different routes are obtained by finding the best path from i to j using different sets of **w**. For instance, one set of **w** favours the shortest path while another set of **w** favours the safest path.

Changing the goal and context models in the business model automatically changes the routing model thus enabling customization of the solution according to specific requirements. That is performed in a similar manner as described in (Chandra and Grabis, 2009).

The routing model depends on a number of weighting parameters. The initial values of these parameters are specified in a judgmental manner. Subsequently, they are continuously updated to improve routing performance. The adaption is performed periodically once information about route execution is accumulated in the transportation planning application. Adaptation is also one of the mechanisms used to customize the solution.

4 ROUTING EXAMPLE

The customization approach is explored using an example. The objectives of the experimental studies are: 1) to demonstrate impact of company specific goals on the routing results; 2) to illustrate context-dependency of the routing results; and 3) to outline adaptive behaviour of the routing model.

The routing solution is set-up for a logistics services provider. The provider receives client requests on the daily bases and must visit these clients during specified time windows. This provider has identified that its primary KPI are KPI1) customer service measured as a percentage of the clients served during the specified time windows; KPI2) travel cost calculated as time spent on deliveries times hourly rate; KPI3) vehicle operating cost incurred for every vehicle used on a given day regardless of distance travelled; and KPI4) safety aimed at avoiding traversal of accident prone routes measured by an index characterizing frequency of the accidents. The provider also indicates that two major context elements affecting its operations are: CTX1) route variability measured as variation of driving time from day to day; and CTX2) route safety measured as a number of accidents observed for the given route. These goals and context factors are shown in the business model (see Figure 3 and Figure 4, respectively). There are hypothesis that the CTX1 affects KPI1 and CTX2 affects KPI4.

The route optimization model is customized according to the business model. As the result, a constraint $\mathrm{KPI1}^C + P_1 \geq kpi_1^T$ is added to the model to represent KPI1. The corresponding constraints are added for other KPI as well. Similarly, the expense calculation is update and now the cost is expressed as a weighted sum of distance and two context factors, namely, CTX1 and CTX2

$$c_{ijk} = w_{1k} d_{ij} + w_{2k} CTX1_{ij} + w_{3k} CTX2_{ij} \, ,$$

where subscripts ij denote distance or context values or the path between i and j and subscript k denotes type of the path.

Routing is performed for 20 client requests received for a single day. The travel distance and time data are retrieved from OpenStreetMap (https://www.openstreetmap.org). The accident data are gathered from a web mapping service. For every pair of customers, three different paths are obtained by varying the context dependency weights (Table 2). The path type is referred as Short because the best route between two customers is found giving the most importance to the distance minimization. The path type is referred as Safe because the largest weight is given to the context factors including the safety context element CTX2.

Table 2: The weights used to find the best path between two customers.

Path type	w_1	w_2	w_3
Short	0.8	0.1	0.1
Safe	0.1	0.1	0.8
Balanced	0.34	0.33	0.33

The optimization is performed by allowing to select any of the paths (EXP1), only the shortest path (EXP2), only the safe path (EXP3) and only the balanced path (EXP4). The values of KPI obtained for these four experiments are reported in Table 3. These values are reported relative to EXP1 or the optimal case but Z, which is the actual objective value observed and is a weighted sum of all criteria. It can be observed that EXP2 yields the best result in term of actual costs but neglects the impact of context factors (high value of the cost) and delivers weak customer service performance. Similarly, EXP3 selects safe paths and scores the best according to the safety KPI4. Selecting balanced path (EPX4) expectedly yields results close to the optimal. None of the experiments yields satisfactory customer service performance (KPI1). The actual values recorded were 65 to 75% while the KPI target was 100%.

Table 3: Values of KPI

Expe-riment	Z	Cost	KPI1	KPI2	KPI3	KPI4
EXP1	0.28	1.00	1.00	1.00	1.00	1.00
EXP2	0.40	1.76	1.00	0.75	0.50	0.95
EXP3	0.72	3.41	1.00	1.85	1.50	0.38
EXP4	0.30	1.10	1.07	1.08	1.00	0.97

Figure 5 illustrates differences between routing results in EXP1 and EXP2. It can be observed that different paths are selected on several occasions. EXP2 favours path length over other characteristics. As a result, the whole route can be performed by a single driver. In the EXP1 other paths are taken to choose routes with better safety and variability characteristics. That indicates context-dependency in path selection.

As mentioned before KPI1 did not yield satisfactory performance (other KPI target values were satisfied). Therefore, weights **v** are changed adaptively, to find a better balance among the goals. Initially the weight for **c'X** in Eq. 1 was set to v_0=0.4 and v_3=0.2 for KPI1(remaining 0.4 are equally split among other KPI). The weight of KPI1 is gradually increase by 0.1 and the weights for other KPI1 are decreased accordingly (EXP1a has v_3=0.2 and EXP1b has v_3=0.4). The adaption results are reported in Table 4. One can observe that initially the adaptation improves customer service though the result is not improved in the next step when KPI1 and KPI4 values worsen. Therefore, the adaption should be reversed and the importance of KPI4 should be increased.

Table 4: Impact of the weights adaptation on KPI.

Expe-riment	Z	Cost	KPI1	KPI2	KPI3	KPI4
EXP1	0.28	1.00	1.00	1.00	1.00	1.00
EXP1a	0.33	1.01	1.07	1.02	1.00	1.01
EXP1b	0.37	0.99	1.07	1.02	1.00	0.56

5 CONCLUSION

The paper developed a method for customization of VR solutions. The customization is done in a model driven manner making easier to involve company's representatives in the customization process. The model driven customization of the VR model is made possible by distinguishing generic and customizable parts of the mathematical model. Additionally, customization is achieved by considering case specific data sources for measuring context and adaptation of the model's parameters during its execution.

The proposed model depends on availability of contextual data. Some of these data can be accumulated during route execution while other can be obtained from external sources. Sharing of data among users of the VR service would be beneficial. The model is computationally hard and model solving time could be reduced by possibly employing non-parametric optimization techniques.

Currently, the business model defines goals and context. Business rules could be added to the business model and these could be used to specify constraints in the routing model. However,

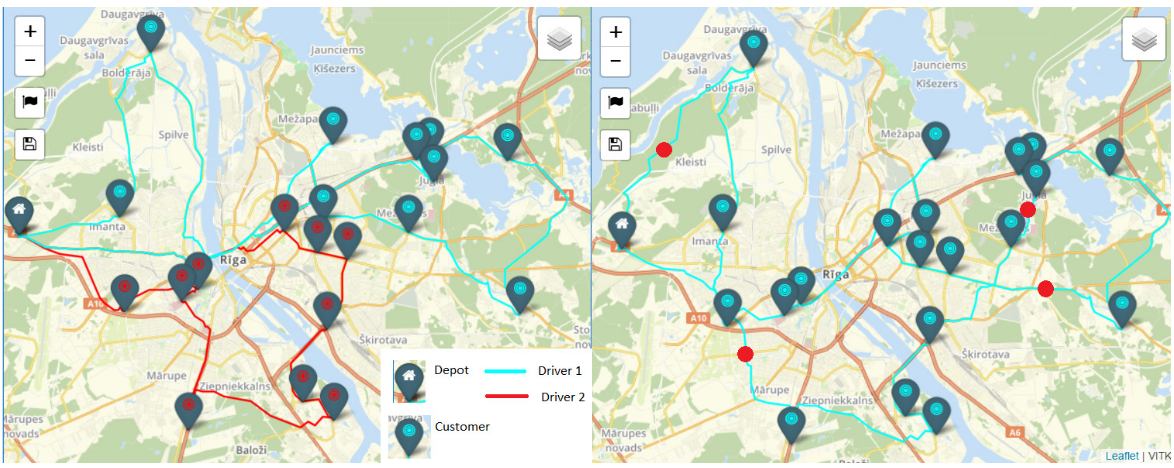

Figure 5: Routing results for EXP1 (left panel) and EPX2 (right panel). Notable differences are marked with red dots.

translation of business rules into the constraints would impose specific requirements towards specification of rules hard to fulfil in practice (i.e., requiring a mathematical modelling expert participation in business model development).

Detailed numerical analysis of relationships among context and routing goals and efficiency of the adaptation procedure is beyond scope of this paper and is subject of further research.

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