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STRATEGIC SUPPLY CHAIN DESIGN FOR AN AUSTRIAN WINTER ROAD SERVICE PROVIDER

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ABSTRACT

Snowplow operations are critical for public safety and economic success in countries where difficult driving conditions occur in winter. Specifically, the salt supply ensuring good driving conditions is a crucial factor. In this paper, the strategic supply chain design of a winter service provider in Austria is investigated. Two research directions on the influence of bigger and fewer salt silos per depot and the logistic costs for a unique summer salt purchasing strategy are addressed applying two independent solution approaches. On the same data basis, a simulation model is developed and a mixed integer linear problem is applied to answer the respective research questions. The first study shows that the current depot availability is quite good but that bigger and fewer salt silos per depot could be a risk. Finally, the second study shows the logistic costs for the unique summer salt purchasing strategy and the optimal salt warehouse locations.

1 INTRODUCTION

In Austria snow plowing operations are usually performed in areas when there is frozen precipitation or significant snowfall. The snowplows remove ice and snow from the roads using either mechanical means or salt to melt the ice. Snow removal on roadways is important for public and industry to guarantee safe and on-time transportation. Therefore, the winter service is a critical service for the success of a society with harsh winter conditions. To manage the plowing operations, each of the nine Austria's federal states have a department of road construction and maintenance, which is responsible for the road conditions during the winter season in their federal state area. Each department further separates their geographical region into non-overlapping subareas, called districts, each including one or multiple salt depots at which the salt is stored in silos and a number of vehicles are based. Fixed routes for the maintenance service are assigned to the vehicles.

This paper describes a contract research of the University of Applied Sciences Upper Austria and the St. Pölten University of Applied Sciences for the department of road construction and maintenance of the Upper Austrian federal state. The department of road construction and maintenance is in charge of 32 highway districts managing 63 depots consisting of 106 salt silos that store the salt for the snowplows. The three salt suppliers, i.e. Salinen Austria AG from Ebensee (Austria), the company List Salzhandel GmbH from Hallein (Austria), and the SWS Winterdienst GmbH from Heilbronn (Germany) are responsible for refilling the salt silos. The orders are generated with an automatic ordering system via electronic data interchange (EDI) interface, following an (s,Q)-inventory management system. This means that an order of lot size Q is released whenever the echelon inventory falls below the reorder level s (Axsäter 2015). The lot size Q is the truck size of 30 t minus safety space which leads to an average lot size Q of 26 t per order. Almost all silos have a weighing system integrated and, therefore, the suppliers get live information about the actual inventories. The suppliers guarantee a maximal replenishment lead time of 72 hours.

The management of road construction and maintenance has identified a trend to bigger silos. Whereas in the past, silos with a capacity of 150 t and 250 t were bought, today usually 650 t or even 1150 t silos are purchased. Assuming that the annual salt demand per winter season will not increase (or even decrease through global warming effects), the trend to bigger silo sizes on the salt depots leads simultaneously to fewer silos per depot. Therefore, the federal state would like to know, how the trend of bigger and fewer silos per salt depot influences the salt availability per depot.

Additionally, the federal state is also interested in identifying the effects of a new order logic in a further independent investigation. Instead of the above-explained decentralized (s,Q)-reorder policy, where the suppliers automatically deliver according to the actual salt level, a centralized policy is evaluated. In the new approach the forecasted annual salt demand is purchased in the previous summer term and the salt is stored at new, big, and central salt warehouses. Significant economies of scale of the salt price are expected with this strategy. During the winter season, the refilling of their 106 salt silos would be self-organized, maybe with the help of an additional external logistic provider. For applying this new order and refill strategy, they would like to know where the central salt warehouse locations should be and how much the required logistic effort (traveled kilometers) for this new reorder policy would be. For the new order strategy, this study should deliver insights to evaluate the trade-off between the cost benefits for the unique summer salt purchasing logic in comparison to the logistic costs for the self-organized replenishment of the silos. Additionally, applying the new unique summer salt purchasing logic, the federal state hopes to reduce the dependence on their suppliers. In the last years, there were some situations where the suppliers reduced the priority of the federal state salt orders, even by accepting their contractually determined penalties. In these situations, the suppliers preferred to satisfy other customer orders first, where they could achieve better salt prices per ton.

The two research directions explained above lead us to the following research questions, which are addressed using a simulation model with geographic information system (GIS) integration (RQ1 and RQ2) and a warehouse location optimization model (RQ3 and RQ4).

- RQ1: What is the impact of the number of silos on the salt availability of the depots? (Subsection 5.1)
- RQ2: What is the trade-off between the infrastructure costs for different silo size specifications and the salt availability at the depots? (Subsection 5.1)
- RQ3: What is the impact of the number of centralized salt warehouses on the traveled kilometers of the salt supply chain? (Subsection 5.2)
- RQ4: Where are the optimal locations for the centralized salt warehouses with respect to their number? (Subsection 5.3)

The rest of the paper is organized as follows. Section 2 discusses relevant literature on winter road service, supply chain inventory management and the warehouse location problem. Section 3 provides an introduction to the studied problems and the solution methods used, while Section 4 offers the details of the investigated use case. Section 5 brings forth the results and answers the formulated research questions. Finally, Section 6 concludes the paper and discusses perspectives for future research.

2 LITERATURE REVIEW

In general, the study presented in this paper is related to supply chain inventory management, i.e. RQ1 and RQ2, and warehouse location problems, RQ3 and RQ4. For both, related literature is presented. However, the application domain of winter road service, and specifically the decisions to be taken in this domain, is as well introduced in this section to provide a comprehensive overview.

Literature focusing on the decision levels in ***road maintenance and service operations*** has been summarized in Perrier, Langevin, and Campbell (2006a), Perrier, Langevin, and Campbell (2006b), Perrier, Langevin, and Campbell (2007a), and Perrier, Langevin, and Campbell (2007b). These studies present the state of the art of decision-making problems in different planning levels for winter service providers. In line with Hopp and Spearman (2011), they also separate the planning levels into strategic, tactical, and operational decisions. In winter service the strategic decision making involves, e.g., the investment in resources such as warehouses or trucks intended to be used over a long period of time. This includes decisions related to splitting the road networks into districts or the location of warehouses or depots. Tactical decisions include medium-term decisions that are generally updated in rolling horizon in an interval of one or several months. For example, the assignment of districts to salt depots and the sizing of the snowplow fleet are contained. Operational decisions deal with regular tasks during the winter season that require monitoring on a daily basis. Such decisions involve the routing and scheduling of snowplows and the staffing of the fleet. Further work on the planning decisions of winter road maintenance operations is conducted by Perrier, Langevin, and Amaya (2008). Mohamed, Jafari, Siu, and AbouRizk (2017) also mention an additional planning level called real-time level decision-making. According to the authors, this involves situations in which operations must be undertaken immediately (e.g., minutes) in response to a sudden system change such as a breakdown or a weather change. They mention the modification of routes based on forecasted weather and traffic information as an example of the real-time decision level. Concerning the problems studied in this paper, RQ1 and RQ2 can be classified as tactical decisions, i.e. optimizing the re-order policy for a predefined network, and RQ3 and RQ4 are strategic decisions, i.e. defining a new network structure.

Strategic ***facility location decisions*** are critical in the strategic design of supply chain networks. Melo, Nickel, and Saldanha-Da-Gama (2009) provide a literature review of facility location models in the context of supply chain management. They identify basic features of supply chain design models and especially discuss the integration of facility location decisions with other decisions relevant to a supply chain network. Furthermore, aspects related to the structure of the supply chain network are also addressed. Planning of logistic networks is traditionally conducted by solving two separated and independent problems, where on the one hand the positions of the nodes representing the facilities of a network are defined and on the other hand the flow between the nodes is determined. The warehouse and facility location and the corresponding allocation problem, which defines the structure of the network, is introduced in Cooper (1963). For the location and allocation problem, the location of each destination, the requirements of each destination, and a set of shipping costs for the region of interest are given. The number of sources, the location of each source and the capacity of each source are determined. The customer-oriented network flow problem, where the edges between the nodes are observed in detail, has been introduced by Ford and Fulkerson (1956). Recent research is still paying attention to location and allocation problems (Atamtürk and Zhang 2007).

The practical problem discussed in RQ3 and RQ4 of this paper is as well investigated applying a mixed integer linear program (MILP) model on the same dataset available from the simulation study.

Academic research and literature regarding supply chain design and ***inventory management*** parameter optimization show that research usually focuses on optimal planning parameters, e.g. lot sizes and re-order level, assuming stochastic demand and static order costs (Kouki, Jemaï, and Minner 2015; Stadtler 2015; Bendavid, Herer, and Yücesan 2017; Güller, Uygun, and Noche 2015; Altendorfer 2015). The application of the results derived from analytical inventory management models to practical application is limited due to the streamlined settings, e.g. single-stage supply chains or single material; see the papers of Altendorfer, Felberbauer, and Jodlbauer (2016), Peirleitner, Altendorfer, and Felberbauer (2016) and Felberbauer, Altendorfer, and Peirleitner (2018) for a respective discussion of planning decisions within production and supply chain management. Therefore, the combination of innovative solution approaches to find a near-optimal planning parameter setting for a supply chain is necessary. In our study, we model the inventory management policy of the supply chain and evaluate how the depot availability changes with respect to different silo sizes. Here, the silo size defines the replenishment level s.

3 MODEL DEVELOPMENT

In this section, the general problem description from the use case is introduced and the application of two different solution methods, as well as their linkage, is motivated (see Subsection 3.1). Furthermore, the detailed models are introduced, i.e. simulation model in Subsection 3.2 and MILP model in Subsection 3.3.

3.1 Problem Description

In this paper, the four research questions introduced are related to two different problems solved with two independent solution methods. To investigate the trade-off between number and size of silos, i.e. defining the infrastructure costs, and the salt availability per depot, i.e. measuring the service quality, a simulation model is developed. Specifically, RQ1 and RQ2 are addressed with the simulation model including uncertainties in the replenishment process and silo availability. To evaluate the logistic costs and to determine the optimal warehouse location for a unique summer salt purchasing strategy, a MILP formulation of the facility location problem is applied on the federal state's data. This MILP solution provides answers to RQ3 and RQ4 and is a purely deterministic optimization model. Although independent models are applied to answer the research questions, a detailed analysis shows that the same data set can be applied for both models. The simulation model described in Subsection 3.2 and the MILP described in Subsection 3.3 both need information on the network structure, the demand, and the replenishment process. One contribution of this study is, therefore, to show how different methods, i.e. simulation and MILP modeling, can benefit from a joint data source and data processing. The problems stated in the practically use case further show that often a mix of methods is necessary to provide rigorous and practically relevant results.

The relevant data are exported from the two federal state's Enterprise Resource Planning systems (ERP), such as SAP® and Salzmanager®. The two independent solution approaches use the same data basis in an initial phase to build the salt supply chain models respectively. Basically, in this study we distinguish between master data and transaction data. The master data define the structure of the salt supply chain and consist of:

- supplier locations
- depot locations
- predefined supplier per depot
- number of silos and silo size per depot
- initial inventory of the silos

The transaction data are used to mimic the dynamic and stochastic supply chain behavior. The transaction data, partially stored in the ERP system, are analyzed in a previous step where the respective probability distributions are fitted (e.g. replenishment lead time) or the empirical data are used (e.g. salt demand of snowplows per depot). For the cases where there was limited data in ERP system available (e.g. silo failures), the knowledge of the maintenance experts was used to get a rough model of the failure probability distributions (Law and Kelton 1991). The following transaction data items have been analyzed:

- stochastic replenishment lead times of the suppliers
- stochastic silo failure behavior
- empirical demand of the snowplows

3.2 Geographic Information System Simulation Model

To answer research questions RQ1 and RQ2, we built a simulation model with AnyLogic® 7.6, by the use of the Geographic Information System (GIS) feature of the software. The simulation model is developed to be generic, according to the idea presented in Felberbauer, Altendorfer, and Hübl (2012), which means that the simulation modules, i.e. the suppliers and the salt depots are built based on the data stored in the integrated database. This enables to scale or adapt the model easily to different scenarios or situations. The simulation model imports the data from the database in an initial phase and builds the salt supply chain structure respectively. The analyzed transaction data are used during the simulation model to mimic the stochastic replenishment process, failure behavior and previous demand scenario.

3.3 Warehouse Location Problem

The optimization model formulation is provided in Equations 1-7. Let I be the set of locations for the salt depots. This set of salt depots I represents the depots to which the salt has to be delivered from the central salt warehouses. The set of central salt warehouse candidates is J from which an optimal subset should be chosen to be opened. The goal of the represented decision model is to decide the location of the central salt warehouses, i.e. decision vector x, and the assignment of the supply of the salt depots to the chosen central salt warehouses, i.e. decision matrix y. Therefore, the binary decision variables x_j are introduced. x_j is one if a warehouse at location $j \in J$ is opened and zero otherwise. The second decision variable y_{ij} defines which salt depot $i \in I$ is supplied from the central salt warehouse $j \in J$. Contrary to classical facility location problems, we do not have costs associated with the construction of a new central salt warehouse. The reason for this assumption is that the federal state predefined the possible number of central warehouses. Additionally, the construction costs could be calculated and discussed in a retrospective evaluation and their variation between the candidates are negligible. Nevertheless, in our model we denote by c_{ij} the annual transportation costs between central warehouse location j and the salt depots i. The costs are proportional to the distance, d_{ij}, between the central salt warehouse and the salt depots. Supply chain costs for serving salt depots i from central salt warehouse location j are calculated according to

$$c_{ij} = d_{ij}\lambda_i, \ \forall i \in I, j \in J. \tag{1}$$

In Equation 1 we weight the distances from salt warehouse location j to salt depots i, i.e. d_{ij}, with the annual salt demand λ_i of the salt depot i. In the objective function in Equation 2 we minimize the sum of the transportation costs. We define the predefined number of central warehouses N in the constraint of Equation 5. N is a parameter in our numerical study and we investigate how the transportation costs decrease with respect to the increase of N. The constraints in Equation 3 ensure that all salt depots $i \in I$ are assigned to one central salt warehouse location $j \in J$. Due to the binary decision variable y_{ij} it is not possible to cover the annual demand of salt depot i from multiple central salt warehouses j. The requirement that a salt depot $i \in I$ can only be supplied from an opened central salt warehouse location $j \in J$ is ensured through the constraints in Equation 4. Finally, the constraints in Equations 6 and 7 define the decision variables to be binary. For solving the above-described mixed-integer-linear-problem we use the heuristic solution algorithm implemented in the ArcGIS Network Analyst extension. For further details on this algorithm, we refer to the manual of ArcGIS (ESRI 2018).

$$\min_{y,x} \sum_{j \in J} \sum_{i \in I} c_{ij} y_{ij} \tag{2}$$

$$\text{s.t.} \sum_{j \in J} y_{ij} = 1, \ \forall i \in I \tag{3}$$

$$\sum_{i \in I} y_{ij} \leq x_j |I|, \ \forall j \in J \tag{4}$$

$$\sum_{j \in J} x_j = N \tag{5}$$

$$y_{ij} \in \{0,1\}, \ \forall i \in I, j \in J \tag{6}$$

$$x_j \in \{0,1\}, \ \forall j \in J \tag{7}$$

4 NUMERICAL STUDY

To run the simulation model and to solve the MILP problem, the locations of suppliers, salt depots, and warehouses are used. Additionally, the annual salt demand and daily salt consumption by snowplows are needed. Table 1 shows the annual salt demand of the federal state and already shows that there is a high variability in these data. The average annual salt demand over the last six years is 46,280 t, and the coefficient of variation is 0.35. Furthermore, a detailed analysis reveals that the daily salt consumption of snowplows has even higher uncertainties. Expert discussions showed that weather condition uncertainties cannot be approximated appropriately with statistical distributions and, therefore, an empirical-demand-scenario-based simulation study is conducted.

Table 1: Annual salt demand from winter season 2011/2012 to 2016/2017.

winter season	2011/2012	**2012/2013**	2013/2014	2014/2015	**2015/2016**	**2016/2017**
annual salt demand	44,100	**74,400**	26,200	43,800	**35,500**	**51,500**

The winter season 2016/2017 sets all records in terms of daily salt consumption, with 4,100 t of salt needed on the 31^{st} January. In comparison, the long-standing peak of the winter season 2009/2010 was 2,700 t per day. The reason for this high daily consumption was the freezing rain, which started on the evening of the 30^{th} January and lasted nearly 24 hours. For the investigated demand scenarios, we decided in consensus with the management of the road construction and maintenance department to use the three winter seasons 2012/2013, 2015/2016, and 2016/2017, for our numerical studies, due to their interesting demand characteristics.

- 2012/2013: Due to the high annual demand.
- 2015/2016: Because it represents a mild winter season.
- 2016/2017: Due to the moderate annual demand and the high variance in daily salt consumption.

For the experiment of the number of silos and the silo size per depot, i.e. RQ1 and RQ2, the management of the department of road construction and maintenance predefined realistic and interesting silo combinations that should be tested within our numerical study. They also provided the infrastructure costs per silo size according to offers of silo suppliers. For RQ1 and RQ2, the mild winter season 2015/2016 is not discussed in our results due to the fact that this scenario was not critical for the depot availability.

As already mentioned, we do not have infrastructure costs in the mixed integer model formulation of Section 3.3. Therefore, we predefined the investigated numbers of central salt warehouses. The range of the number of central warehouses was predefined in consensus with the management of the road construction and maintenance department. This leads to the following parameter set where $N \in \{1,2,3,4,5\}$ is investigated. To account for the stochastic behavior of the simulation model, we evaluated each simulation scenario for RQ1 and RQ2 with ten replications. Due to the fact that only the replenishment lead times and the silo failure behavior are stochastic, this low number of replications is sufficient to get significant results. For the validation of the simulation model, we used the historical demand data and discussed the KPIs (supply chain structure, shortages, silo availability, replenishment times, etc.) and the inventory charts of the whole depots and the single silos with the management of the department of road construction and maintenance.

The main assumptions in the conducted study are:

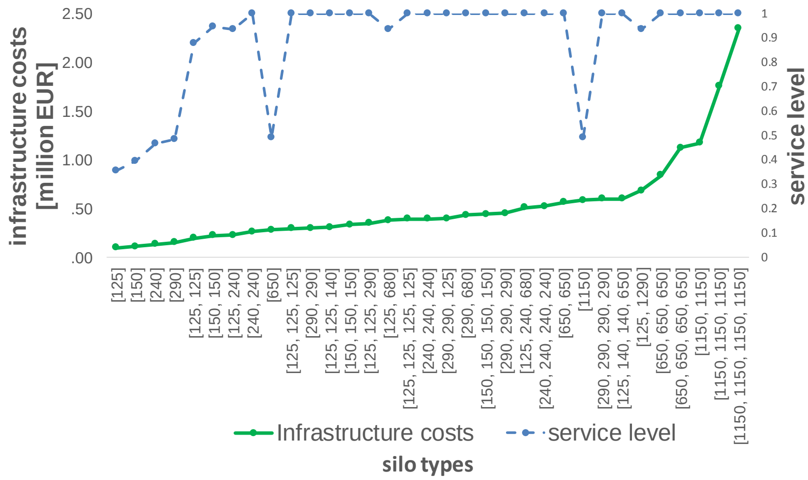
- In the simulation model we do not model the routes of the snowplows in detail, instead we use their historical demand (amount and date).
- The previously assigned snowplows are randomly routed to the silos of a depot.
- Silo failures are approximated from expert information since only limited data were available.
- The trucks which drive from the supplier to the salt depots are no bottleneck in the simulation model.
- Central salt warehouse candidate locations in the MILP are all salt depot locations.
- The number of central salt warehouse locations is not a decision variable in the MILP formulation but a design parameter for the experiment.

5 RESULTS

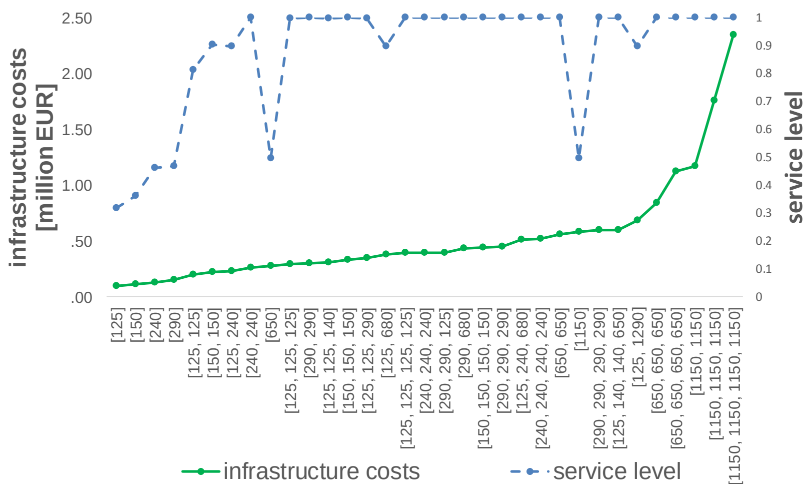
In this section, the research questions are investigated as follows. Subsection 5.1 investigates the impact of the silo size and the number of silos per depot on the trade-off between infrastructure costs and salt availability (see RQ1 and RQ2). To answer this research question, we use the GIS-simulation model presented in Section 3.2. For the contract research, we analyze the results for all 32 salt depots. For this paper, we picked one single location to discuss the results in detail. For the federal state we provide a data report, where all silo depots could be analyzed in the same manner as described in the following Subsection 5.1. Subsection 5.2 and Subsection 5.3 evaluate the optimal locations for the central salt warehouses and the sensitivity of the transportation efforts on the number of central salt warehouses N. (see RQ3 and RQ4). For RQ3 and RQ4 the warehouse location problem presented in Section 3.3 is used. Based on research questions RQ1 and RQ2, the current supply chain design concerning locations and delivery policy is predefined, which leads to an optimization of this current system with respect to silo sizes. This new optimized system design is the basis for the future purchasing strategy that is implemented in the next years since many salt silos are at the end of their lifetime and will be replaced in this time range. The research questions RQ3 and RQ4 have a more strategic dimension, i.e. one or more new central warehouses have to be built. To separate the effects of these two different decisions, a prerequisite of the project partner was to conduct the respective study based on the current system design. Additionally, the decision on one or more central warehouses has only minor effects on the silo size optimization and the insights are also valid for a new supply design.

5.1 Trade-off Between Infrastructure Costs and Salt Availability - RQ1 & RQ2

In Figure 1, the performance measures of the salt depot 'Altheim' are depicted for the winter seasons 2012/2013, and 2016/2017. On the x-axis you see the different silo combinations ordered with respect to ascending infrastructure costs (solid line), which are shown on the primary y-axis. On the secondary y-axis, the service level (dashed line) is quoted. From the perspective of the department of road construction and maintenance, the best silo combination would be the one with the lowest infrastructure cost and service level of one. In both scenarios, the combination with the best trade-off between infrastructure costs and salt availability would be the combination of two 240 t silos. We found that providing only one silo per facility reduces service level significantly. Penalizing the delivery problem incidents, i.e. changing the objective function by including tardiness costs, might lead to an optimal solution in which some delivery problem incidents, i.e. a service level value below one, are accepted. We see a similar characteristic of service level performance with respect to silo combinations for both winter seasons 2012/2013, and 2016/2017. Nevertheless, the number of delivery problem incidents is approximately twice for the winter season with the higher annual salt demand. In detail, one 1150 t silo leads to ≈ 700 delivery problem incidents in the winter season 2012/2013 whereas only ≈ 400 delivery problem incidents would occur in a winter season following the demand characteristics of 2016/2017. In both scenarios, the service level would be ≈ 0.5. The insight that only one silo per facility is not sufficient holds for all other salt depots. The optimal silo combination varies between depots and mainly depends on the empirical demand of the respective depot.



(a) Depot Altheim, winter season 2012 / 2013



(b) Depot Altheim, winter season 2016 / 2017

Figure 1: Infrastructure costs and the number of delivery problem incidents with respect to the different silo combinations.

5.2 Trade-off Between Number of Centralized salt warehouses and Traveling Effort - RQ3

In this subsection, we study the impact of the number of centralized salt warehouses N on the traveled kilometers of the salt supply chain. The results of this study enable the federal state to calculate the extra logistic costs caused by the new unique summer salt purchasing strategy, by weighting the reported supply chain kilometers by the cost per kilometer of a 30 t truck.

Table 2 illustrates the influence of the number of central salt warehouses N on the traveled truck kilometers with respect to the different demand scenarios 2012/2013, 2015/2016, and 2016/2017. The reported truck kilometers refer to the kilometers needed to accomplish the supply of the salt depots from the central salt warehouses. The overall kilometers report the sum of the truck kilometers over all three winter seasons. The more salt warehouses are installed, the less truck kilometers are needed to do the supply. The savings of kilometers (logistic costs) by an additional central salt warehouse can be counterbalanced with the investment and service efforts for it. Additionally, the department of road constructions and maintenance could consider other facts, such as the maximum salt storage capacity or transport connection for the warehouse location decision.

Table 2: Influence of the number of central salt warehouses on the traveled truck kilometers with respect to the demand scenarios of the winter seasons 2012/2013, 2015/2016, and 2016/2017.

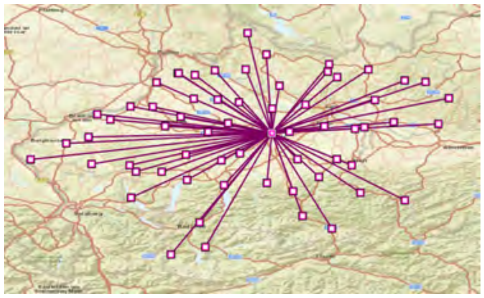
number of central salt warehouses	1	2	3	4	5
truck kilometers 2012/2013	160,445	127,274	104,950	86,877	74,862
truck kilometers 2015/2016	79,021	62,242	50,333	43,180	38,670
truck kilometers 2016/2017	104,468	82,042	67,178	56,162	48,668
overall kilometers	343,934	271,559	222,461	186,219	162,200

The results of Table 2 show that an increase of the number of central salt warehouses of one leads in average over all demand scenarios to $\approx 17\%$ reduction potential of the logistic effort. This reduction potential by an additional salt warehouse varies in a range between 10.4% and 21.5% considering all three winter seasons and the varied number of salt warehouses $N \in 1,2,3,4,5$. The highest reduction potential arises when the number of salt warehouses is increased from one to two with 21.1%, averaging over all three winter seasons. Also, the variance of kilometers with respect to the three demand scenarios is visible in Table 2. For one central salt warehouse the logistic effort varies between 160,445 km for a strong winter season (2012/2013) or 79,021 km for a mild winter season. The required truck kilometers for the winter season 2012/2013 reduce from 160,445 km with one salt warehouse to 74,862 km for five salt warehouses.

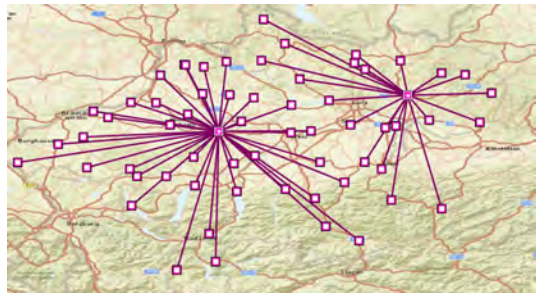
5.3 Optimal Locations for the salt warehouses with Respect to the Number of Centralized salt warehouses N - RQ4

For the optimal location candidates it has been assumed that central salt warehouses can only be placed at locations where already salt depots exist. These results only report the optimal location which satisfies the constrains according to the model formulation in Subsection 3.3. Other important factors such as transport-connection of the depot or the possibility of upgrading a salt depot to a central salt warehouse are neglected. Figures 2a-2e visualize the optimal salt warehouse locations and the assigned salt depots for the federal state with respect to a varying number of central salt warehouses.

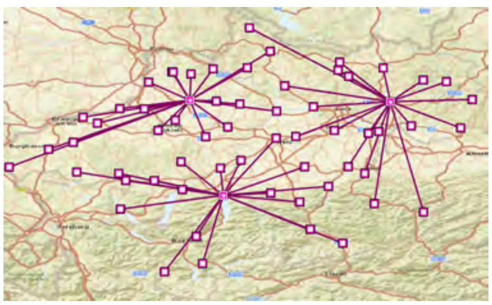
It is interesting that the depot in 'Pregarten' is in the optimal set for multiple experiments where $N \in 2,3,4,5$. Also 'Gmunden' points out as interesting location in multiple experiments when $N \in 3,4,5$. For the scenario where $N = 1$, 'Wels' in the center of the federal state would be an optimal choice for the central salt warehouse. The warehouse capacity for this solution must be $\approx 75,000$ t salt according to the annual demand of the strong winter season 2012/2013. Choosing two possible central salt warehouses, the optimal position would be 'Pregarten' in the east and 'Weibern' in the west of the federal state. In this scenario, according to the depot assignment the central salt warehouses 'Pregarten' would need a warehouse capacity of $29,500$ t (39%) and 'Weibern' would need a capacity of $46,000$ t (61%) analyzing winter season 2012/2013. In the experiment with $N = 3$, 'Gmunden', 'Pregarten', and 'Raab' would supply 23,073 t (31%), 28,146 t (37%) and 24,300 t (32%) of the annual demand of winter season 2012/2013. 'Altheim', 'Eferding', 'Gmunden', and 'Pregarten' are the location for four central salt warehouses. 'Altheim' would need a warehouse capcity of 13,431 t (18%), 'Eferding' of 22,452 t (30%), 'Gmunden' 18,369 t (24%) and 'Pregarten' 21,268 t (28%). For the experiment with five central salt warehouses, 'Gmunden', 'Kremsmünster', 'Peuerbach', 'Pregarten', and 'Uttendorf' are the optimal warehouse locations. In the latter scenario, according to the derived depot assignment, 12,542 t (17%) of the annual demand 2012/2013 should be stored in 'Gmunden', 15,989 t (21%) in 'Kremsmünster', 18,763 t (25%) in 'Peuerbach', 17,365 t (23%) in 'Pregarten', and 10,860 t (14%) in 'Uttendorf'. The above-presented study results represent a good input for the final decision of the federal state on the possible unique summer purchasing strategy. Also, in the case that no unique summer purchasing strategy is implemented, the federal state got insights from the study where strategic important depot locations are.



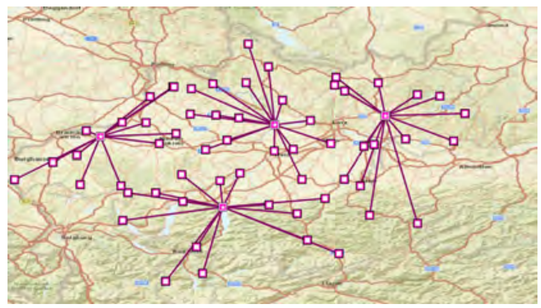
(a) One central salt warehouse: Wels



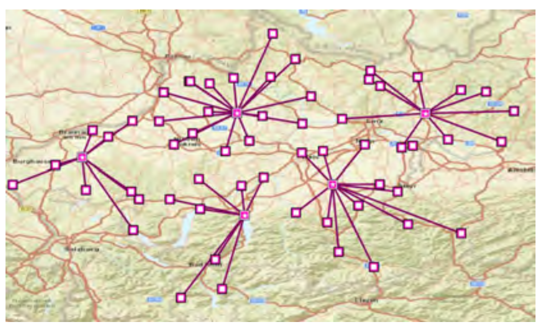
(b) Two central warehouses: Pregarten, and Weibern



(c) Three central warehouses: Gmunden, Pregarten, and Raab



(d) Four central warehouses: Altheim, Eferding, Gmunden, and Pregarten



(e) Five central warehouses: Gmunden, Kremsmünster, Peuerbach, Pregarten, and Uttendorf

Figure 2: Optimal locations for central warehouses.

6 CONCLUSION

Winter road service is important for public and industry to guarantee safe and on-time transportation. Therefore, in countries with harsh winter conditions the winter service provider plays an important role. Nevertheless, also the winter service provider looks for innovative ways to reduce operational costs. In this paper, strategic design decisions on a supply chain for an Austrian department of road construction and maintenance are investigated. In the scope of a contract research two independent research directions are studied. First, the influence of bigger and fewer salt silos per depot is investigated. Second, the logistic costs for a unique summer salt purchasing strategy with central salt warehouses are evaluated. Using a joint data source and data processing, a generic GIS simulation model is built to answer the question on the influence of bigger and fewer salt silos per depot and a MILP is applied to answer the research questions on the best salt warehouse location for a unique summer salt purchasing strategy. The study on the influence of bigger and fewer silos per depot shows that generally the current depot availability in the federal state is quite good. Nevertheless, the trend of decreasing number of silos per depot and the simultaneously increasing silo sizes threatens their service level. The results of the warehouse location problem show that an increase of the number of central salt warehouses of one leads to a logistic efforts reduction potential of $\approx 13\%$. Additionally, the study shows that the depots in 'Gmunden' and 'Pregarten' point out to be an interesting salt warehouse location for multiple scenarios varying the number of central salt warehouses. For further research, additional constraints, e.g., concerning transportation connections, or property costs for depots could be integrated within the mixed integer linear warehouse location problem. Additionally, the generic GIS-simulation model could be extended to be able to answer also short-term decisions. Therefore, a salt forecasting algorithm could be integrated in the simulation model to predict salt bottlenecks at certain depots. This information could be used to pro-actively change the assignment of snowplows to the depots.

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