A NEW CONCEPT FOR DIMENSIONING SALT STORAGE FACILITIES IN GERMANY

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ABSTRACT

Differentiated specifications and recommendations for the dimensioning of the storage space for winter service spreading material have so far not existed in Germany. Therefore, in the framework of a research project, a concept for salt storage and logistics has been developed. The aim of this concept is a need-based and economic provisioning of spreading materials, so that even in extreme winter weather conditions, no shortages of spreading material supply occur and, at the same time, profitability remains guaranteed.

The principle of the used methodology for ascertaining the demand for spreading materials is the requirement that security of supply is provided for all maintenance centres to as similar a level as possible. For the necessary storage capacities of spreading material, three different concepts have been considered – when and to which scope spreading materials are purchased from suppliers. These concepts all exhibit the highest possible security of supply, but they differ in their profitability and the necessary investments. As there are different conditions, but also different storage needs in the individual federal states, the concepts to be implemented can therefore vary from state to state.

With the calculation models for ascertaining the need for spreading material and the necessary storage capacity for spreading material there is a calculation method available which guarantees a very high, consistent security of supply for spreading materials nationwide, which, however, considering the differentiated climatic conditions, makes this possible at economically acceptable costs.

1. INITIAL SITUATION

Efficient winter services on the German road network are a prerequisite for safe driving on the roads, also in wintery road conditions, and for the road network as an essential part of infrastructure to be efficient. Alongside efficient staff, vehicles and technology, sufficient spreading materials for clearing and preventing ice are necessary.

In Germany, spreading material halls and silos are generally available for the storage of spreading material. The selection and, above all, the dimensioning of the spreading material storage oriented itself strongly on experience, available funds and benchmarks in the past. Differentiated specifications and recommendations for establishing locations and dimensioning have so far unfortunately not existed. Long-lasting and especially also transregional wintery weather conditions in the past, however, led to the supply of spreading materials not being need-oriented and therefore creating shortages in the salt supply. Especially in the winter of 2009/10, as well as in December 2010, the long-lasting winter weather period led to massive shortages in salt supply in many parts of Germany.

As a reaction to the shortages in salt supply, the German Ministry of Transport, Building and Urban Development, as well as the Road Construction Administrations of the federal states took numerous measures to extend the existing salt storage capacities at short notice. This includes storing spreading materials as an emergency reserve of the state in buffer storage spaces, which, above all, should be used for the federal motorways. Furthermore, several federal states have also set up buffer storage spaces in their areas of responsibility, as well as extending storage capacities in motorway and road depots. These measures were accompanied by an extensive state survey at the beginning of 2011 about the road networks to be maintained, the existing storage capacities and the planned measures for capacity extension. The Federal States' Expert Committee on Road Operations (Länderfachgruppe Straßenbetrieb) created a strategic paper for optimising the salt supply during extreme winter conditions [1].

Therefore, in the framework of a research project, a new concept for dimensioning salt storage facilities was developed by the authors [2]. The aim of the developed concept is a need-oriented and economic stocking of spreading materials, so that even in extreme wintery weather conditions no shortages in the supply of spreading materials occur and, at the same time, the profitability of the storage spaces remains guaranteed.

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2. RESEARCH METHOD

For an extensive depiction of the current situation concerning the storage capacities for spreading material, the data supplied by the Road Administrations of the federal states by federal state survey were analysed and amended as needed. Through this, extensive information is available for all federal states about the following:

- the road network maintained
- the concept of spreading materials supply
- the existing salt storage capacities

Information about the concept of the supply of spreading materials was gathered through interviews in nine federal states and through a written survey in the other federal states.

The basis for the used methodology for ascertaining the demand for spreading materials is the requirement that security of supply is provided for all maintenance centres to as similar a level as possible. This means that the remaining risk that there is not enough of the existing capacity for spreading material storage is also the same in all maintenance centres, independent of the probability of certain weather scenarios. Therefore, depending on the acceptable remaining risk, the necessary storage capacity can be ascertained. This approach makes it possible to consider the different winter weather conditions in different regions of Germany, and, at the same time, to reach the same security of supply for all maintenance centres. This chosen approach corresponds to common calculation methods in the area of drainage and flood protection, where, for a defined region the intensity of rainfall is determined, which is not exceeded with a certain probability.

To ascertain the requirements for spreading material specific to the maintenance authorities, a model developed by BADELT [3] is used for all available climate stations of the German Weather Service (DWD). This is based on different spreading scenarios, and therefore the requirements for spreading material can be estimated per operating day depending on real weather data. However, to calculate the requirements for daily spreading material of the individual climate stations, departing from BADELT [3], wet salt FS30 is used as a spreading material. Therefore, the following quantities of dry spreading material arise for the different spreading scenarios set by BADELT [3]:

- Hard-packed snow (condition: snowfall):
  preventive 15.2 g/m², every 2 cm of fresh snow: 15.2 g/m², max. 121.6 g/m² per day
- Black ice or icy conditions (conditions: minimum air temperature < 0 °C & precipitation depth > 0 mm & no snowfall):
  generally 2 x 15.2 g/m² per day
- Slippery frost (conditions: minimum air temperature < 0 °C & no precipitation & rel. humidity > 90 %):
  1 x 7.6 g/m² per day.

These requirements for spreading material are valid for the area of the federal motorways, which are maintained 24 h. For the other trunk roads, BADELT [3] sets a requirement of 67 % for spreading material.

In order to ascertain the requirements for spreading material per day on this basis, the following five climate parameters are necessary, which are available at the climate stations of the German Weather Service for a long series of time:

- Relative humidity [%], as an arithmetic average of hourly values
- Minimum air temperature [°C]
- Precipitation depth [mm]
- Type of precipitation, differentiated in seven categories, e.g. snowfall
- Depth of snow [cm], measured once per day

Because, in practice and predominantly during longer-lasting winter events, problems occurred with the supply and additional delivery of spreading materials, the amount of needed spreading material is currently not ascertained for days of full operation. But this is ascertained for longer time spans. On the basis of variation calculations, 30 days are set as a normative time span. The amount of spreading material needed every day is added with the help of varying subtotals and from this the individual maximum sums of the subtotals are ascertained. As these subtotals are formed for longer time spans usually dating back at least 50 years, the maximum values of the subtotals and their probability of occurrence can be determined for the time span dating back to that point. With the setting of these described probabilities of occurrence, the desired security of supply can be set equally nationwide for all climate stations and therefore all maintenance authorities.

Depending on the local weather conditions, as well as the topographical conditions different requirements for specific spreading material arise, which, however, reflect the demanded security of supply for the respective climatic region. In consideration of the traffic areas currently being maintained, the absolute requirements of spreading material per maintenance authority and their probability of occurrence can be calculated with the help of the specific values.

As the storage capacities for spreading material do not only depend on the requirements for the spreading material, meaning the outward stock movement, but essentially are also influenced by additional supply, meaning the inward stock movement, different concepts, when and to what scope spreading materials are received from suppliers, are to be considered. On the basis of the concepts currently used in the federal states, three storage and logistics concepts have been developed:

1. Exclusively decentralised storage at the maintenance centres with additional deliveries during the winter,
2. Decentralised storage at the maintenance centres with additional deliveries during the winter, as well as central buffer storage spaces, which are only used during extreme weather conditions,
3. Decentralised storage at the maintenance centres, as well as central storage spaces, which are used for additional deliveries during the winter.

With the first two concepts additional deliveries from the spreading material supplier are necessary during the winter, whereas in Concept 3 the salt is exclusively purchased from the manufacturer in summer and the whole requirements for spreading material are stored in storage spaces of the Road Administration. What is decisive with Concept 1 and 2 are the requirements for spreading material, which, also during a 30-day extreme wintery weather period, is never exceeded. With Concept 2 a part of the requirements for spreading material is stored decentrally at the maintenance centres, which is exceeded on average every 5 years. The rest of the storage capacity is stored centrally in buffer storage spaces. With Concept 3, the whole requirement of spreading material needed during a winter is stored, whereby the storage capacity at the maintenance centres is oriented on the existing storage capacities. Further requirements are stored centrally. Depending on the concept, different assessment values are decisive for ascertaining the requirement for spreading material (s. Table 1):

$q_{30;0.2}$: Required spreading material for 30 days, which is exceeded every 5 years
This value is decisive for dimensioning spreading material storage capacities, which should be available in storage and logistics concept 2 at the maintenance centres.

$q_{30;max}$ Required spreading material for 30 days, which so far has not been exceeded
This value is decisive for dimensioning spreading material storage capacities, which should overall be available in storage and logistics concepts 1 and 2, in order to have sufficient amounts of spreading materials available even during extreme weather conditions. In consideration of this value a logistics concept is necessary, which plans for sufficient additional deliveries through suppliers also during winter.

$q_{180;max}$ Required spreading material for 180 days, which so far has not been exceeded
This value is decisive for dimensioning spreading material storage capacities, which should overall be available in order to have sufficient amounts of spreading materials available during the whole winter. This value is decisive for storage and logistics concept 3.

Table 1 – Compilation of assessment values and calculation approaches of the storage and logistics concepts

Storage and logistics concept	Storage capacity maintenance centre	Storage capacity central / buffer storage space	Overall storage capacity
Concept 1	$q_{30;max}$	-	$q_{30;max}$
Concept 2	$q_{30;0.2}$	$q_{30;max}$ - $q_{30;0.2}$	$q_{30;max}$
Concept 3	Current capacity	$q_{180;max}$ – current capacity	$q_{180;max}$

Apart from the requirements for spreading material to be covered in a certain time span, the security of supply in storage and logistics concepts 1 and 2 is also strongly dependent on the possibility of additional deliveries of spreading materials. Through regular additional deliveries, the security of supply can, if necessary, be increased via the security level considered in ascertaining the requirements for the spreading material, as the case may arise. Vice versa, in ascertaining the spreading material storage capacities it should be taken into account that in some climatic regions extreme winter weather events can also exceed the considered amount of days, so that higher storage capacities are necessary.

Therefore it is necessary to set the storage capacities for the spreading material in storage and logistics concepts 1 and 2 so that in consideration of set input quantities for additional delivery, a complete emptying of the storage spaces is excluded also for periods of time longer than 30 days. The storage capacities for the spreading material are therefore defined so that on the one hand the 30-day requirement for spreading material during extreme weather conditions and also further requirements for spreading material are considered.

In order to guarantee that the storage spaces for spreading material are never completely emptied, the specific inventory per day is calculated for the representative climate stations of every climatic region, on the basis of specific requirements for spreading material and additional delivery amounts over the whole period under observation. During this examination, the following entry parameters were set on the basis of practice currently prevailing in Germany:

- **Activating an order:** Level of remaining material in the storage space, at which a replenishment order is triggered; set at: 80 %
- **Delivery time:** Time span between activating the order and delivery; set at: 3 days, meaning that on the 4th day the spreading materials are delivered
- **Calculated quantity delivered:** Specific quantity delivered as a national average; set at: 15 g/m² per day

Requirements and storage capacity of spreading material are ascertained for every motorway and road maintenance centre, whereby the existing storage capacities at the maintenance centres are considered. Influences specific to the maintenance centre cannot be entirely considered in this, so that the calculated values might, in practice, have to be adapted to the level of the maintenance centres. The level of the federal state is, however, sufficiently accurate. For every maintenance centre depending on the underlying storage and logistics concept, it was checked that the inventory during the observation period was never negative. As the case may be, storage capacities were increased or higher delivery

quantities were set, which were compensated through lower delivery quantities in other maintenance centres of the observed federal state.

3. RESEARCH RESULTS

Nationally, mostly complete information is available about the storage spaces for the spreading material currently available per maintenance centre. Considering the spreading areas to be maintained per maintenance centre, so-called relative storage capacities per maintenance centre can be ascertained from this. The absolute storage capacities vary considerably between the federal states, but also within the federal states. On a national average, the storage capacity of a motorway maintenance centre amounts to about 2,000 t, which corresponds on average to 1,259 g/m² related to the road area. Per road maintenance centre 1,700 t or 826 g/m² are stored on average. Additionally there are considerable storage capacities in interim storage spaces, which serve as buffer storage spaces. Overall there are about 1.86 million t of storage capacity currently available for the motorways and trunk roads maintained by the road administrations of the federal states. Of these, 1/3 are apportioned to Bavaria, in a further 5 territorial states there are more than 100,000 t available for each state.

On the basis of data from 149 climate stations, as well as the information about the Road Weather Information System (RWIS) climate areas, altitude and topography, overall 39 climatic regions were formed nationally, for which assessment values are available for the specific requirements for spreading material. The specific requirements for spreading material for a 30-day winter weather time period varies between about 800 g/m² in the north-west of Germany and a maximum of 1,700 g/m² in the area of the Alpine foothills (s. Figure 1). For a whole winter period the values vary between 2,000 g/m² in the north-west and 5,000 g/m² in the Black Forest.

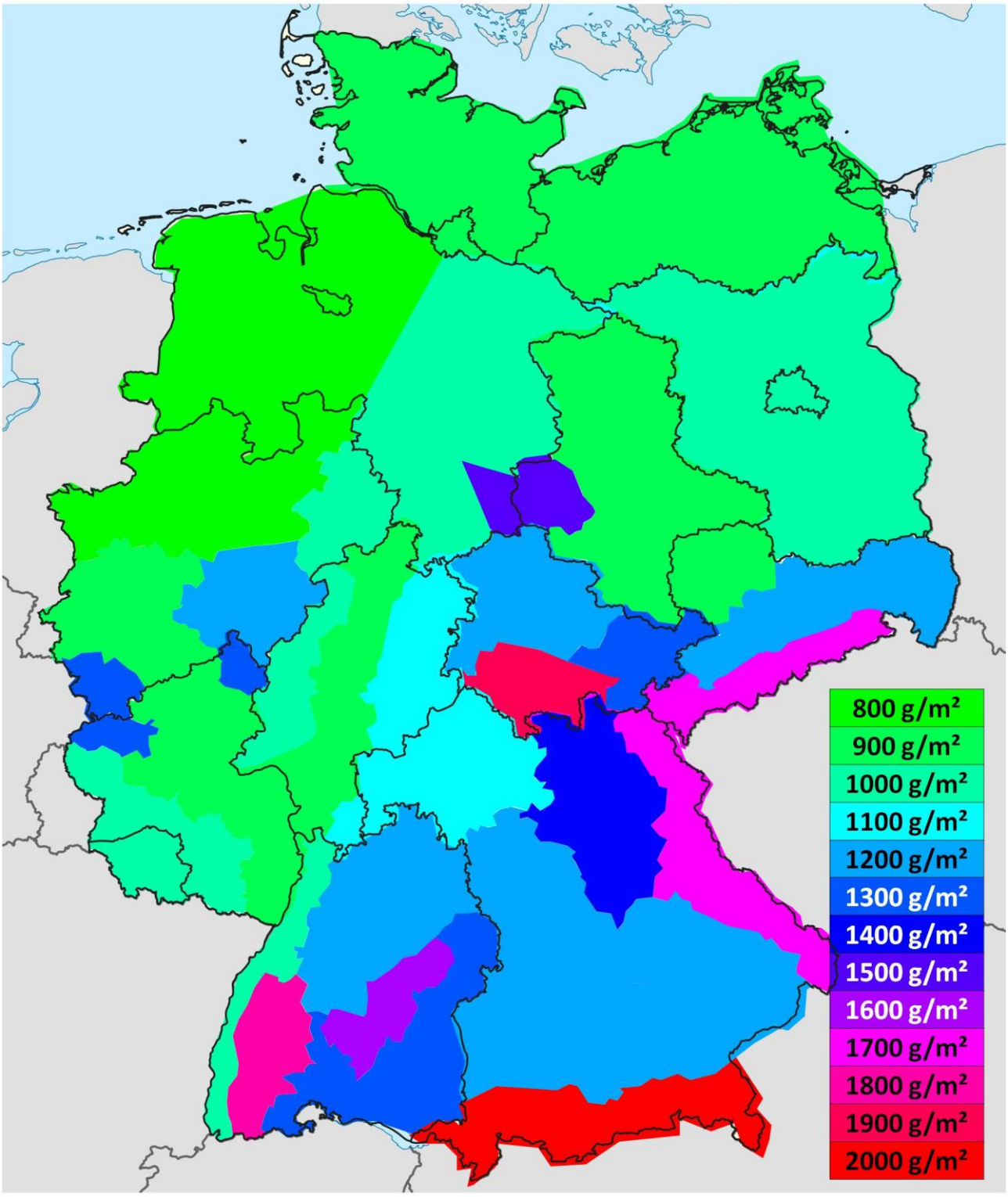

Figure 1 – Climatic regions for ascertaining storage capacities for spreading material and assessment values $q_{30;max}$

For storage and logistics concept 1 about 150,000 t of additional storage capacity are necessary. Lower Saxony has the biggest requirement for additional storage capacities (about 31,000 t), as well as Hessen (about 28,000 t). For storage and logistics concept 2 about 110,000 t of central buffer storage space and about 40,000 t of additional storage capacity at the maintenance centres are necessary. The requirements for buffer storage spaces are covered in many federal states by already rented storage spaces, often a clear reduction is possible. In order to realise storage and logistics concept 3, about 1.4 million t are neces-

sary as a central storage space nationally, for which overall about 900,000 t of additional central storage capacity have to be created, excluding Bavaria.

4. OBSERVATION OF PROFITABILITY

In the framework of a cost and profitability analysis, the three storage and logistics concepts were compared concerning their profitability and the needs for investment. Statements about which of the concepts is to be recommended for economic reasons, can be made on the basis of yearly costs, which occur for the average requirement for spreading material. Independent of profitability, the needs for investments are to be seen, which, however, also has to be considered for the overall evaluation of the concepts, as a high need of investments puts more strain on budgets.

Only the decision-relevant costs are considered. Decision-independent costs, like e.g. the costs for the spreading materials overall, are not included in the yearly costs. Therefore, the yearly costs are not to be seen as based on full cost accounting, but as subtotals for storage logistics. Yearly and investment costs are calculated according to the individual federal state, whereby the necessary storage capacities per maintenance authority are taken as a basis. To ascertain the average yearly costs, average requirements for spreading material are used. This is calculated with the same assessment approach, which is also used for ascertaining the maximum requirements for the spreading material.

The lowest yearly costs in all federal states accrue with storage and logistics concept 2, the savings compared to Concept 1 lie nationally at about 6 million EUR per year. Concept 3, on the other hand, has higher yearly costs in all federal states than the two other concepts. Compared to Concept 1, the additional costs amount to about 11 million EUR per year.

For additional storage capacities at maintenance centres, about 114 million EUR are necessary nationally for investments with storage and logistic concept 1; for storage and logistics concept 2 the needed investment only amounts to about 29 million EUR at the maintenance centres. This amount is increased by 17 million EUR, if the buffer storage spaces are built by the Road Administrations instead of being rented from external service providers. For Concept 3, no investments are necessary for the maintenance centres. The needed investments for the central storage spaces, however, would amount to more than 200 million EUR nationally, unless storage spaces are not rented, as is currently often the case.

5. CONCLUSIONS FOR PRACTICE

Due to the lowest yearly costs and also the low needed investment, storage and logistics concept 2 seems like the most advantageous concept for many federal states. However, profitability and real needed investment are dependent on numerous influences, which could not be examined in detail in the framework of the research project. Therefore, in the framework of state-specific implementation concepts on the basis of the ascertained necessary storage capacities per maintenance centre, these influences should be made more precise on a regional basis and specific to the location. Finding the right location for the buffer and central storage spaces and the connected costs and investments are essential with this. In the implementation concepts, the economic-organisational aspects, which are connected to the different storage and logistics concepts, should also be considered closely.

As all three developed storage and logistics concepts guarantee the same maximum security of supply, the concepts to be implemented can vary in the individual federal states. What is decisive is the state-specific yearly costs, investments and economic-organisational circumstances.

With the developed assessment model for ascertaining the requirements for spreading material and the necessary storage capacity for spreading material a calculated approach is available in Germany, which on the one hand guarantees a very high, nationally coherent security of supply for spreading materials, and on the other hand makes this possible due to the differentiated consideration of climatic conditions at economically reasonable costs.

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