Applying Simulation and Mathematical Programming on a Business Case Analysis for Setting up a Spare Part Logistics in the Construction Supply Industry

A Case Study

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***Abstract*— This paper describes how methods and techniques from different fields of research can be combined to evaluate cost-intensive and business-critical decisions regarding future market development. In their concrete application a leading company from the construction supply industry has to make a decision on setting up of a spare part logistic. Three future alternatives (negative, constant, positive market growth) on market trends are simulated with a Monte Carlo simulation by considering a given demand history and possible locations for storage facilities were isolated by applying the Steiner-Weber method. Finally solving a mixed-integer formulation of the Uncapacitated-Facility-Location-Problem gives information on opening/closing new/existing storage facilities by minimizing all relevant costs. The results of this approach, containing information about a cost-based evaluation of all business related decision criteria, were examined with a sensitivity analysis.**

Keywords: spare parts logistics, Monte Carlo simulation, Steiner Weber iteration, mixed-integer programming, Uncapacitated Facility Location Problem, sensitivity analyses

I. INTRODUCTION

With the help of simulation, this case study analyzes the options for a German construction supplier to set up a spare part logistic. The company had an enormous growth during the last years - especially regarding the distribution of solar systems. Since these systems support the heating circuit of the ultimate customers, the company is in duty for delivering spare parts within a short time. Up to this date the company was able to serve these requests with the help of the general stocks but due to the enormous growth new options need to be developed. The first idea was to delegate this task to a service provider and some offers were invited. A comparison showed that the best offer was 460€ for delivering a single spare part to the customer. These high costs are the main reason for developing an own strategy with own storage facilities.

A possible scenario was developed to cover all requirements. The first step was done by analyzing the demand history of the last year. Due to the fact that these won’t reflect the future development correctly, new market demands were created by using simulation. The second requirement within this scenario is the concrete location decision, based on geographic features. The last part of the basic consideration is the facility location problem, which solves the problem on making a cost-optimal decision regarding facility opening. The first assumptions were solved with the help of mathematical programming.

In order to include the unpredictable requirements of the market, a sensitivity analysis was applied. The scenario has been modified towards a positive and negative price trend of the element of costs for different market growth options.

II. SCENARIO ANALYSIS

The present business case contains a lot of requirements which need to be considered. This section will define the restrictions which cause the analytic procedure.

A. The Market

The solar market experienced a strong growth during the last years. One reason is that the German government subsidized the setting up of solar systems until 2011. This discontinuation makes the market unpredictable for a broad consideration. Another aspect is that the demand is fluctuant during the year. There are peaks with 20% of the yearly demand and troughs with 2% of the yearly demand. To cover all of these deficits the demand has been forecasted for three different cases. The first case assumes a negative market growth with 70% of the former demand. This is named as the worst case. The next assumption covers up a faltering market growth by using 100% of the former demand. This approach comprises the average (avg) case. A positive market growth is coped by calculating with 130% of the former demand and is called the best case. These three scenarios should meet the requirements of the market.

B. Conditions of supply

Due to the fact that the spare parts need to be delivered within 12 hours, there are challenging requirements towards

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the transportation. This accomplishment could be ensured by using a courier service during the workday (69%) and a cap during the weekend and national German holidays (31%). Therefore the transportation costs are higher than using a shipping company. The used price for a kilometer is 1.00€. As a vendor of systems for using renewal energy the company focuses on reducing the CO2 emission for the transportation. This is one of the reasons why this work considers spread storage.

C. Range of spare parts

For using new storage capacities the space requirements need to be analyzed. The former sales are used for a forecasting. There are 24 articles within the assortment. The smallest one measures 17cm x 17cm x 1cm (length x width x height). The biggest one measures 40cm x 43cm x 7cm. All articles have the size of standardizes parcels. There are no special needs for the transportation. Due to the fact that even articles with a low sales figure need to be stored in each location, the spacial amount will be higher than with the use of one location. The needed storage area of the last year sales would be 358,2m². Regarding to this fact, 442,8m² would be needed for the spread storage.

In order to classify the articles, an ABC-Analysis has been done. One of those spare parts could be classified with A and two of them as B. The other 21 parts are within the range of C parts.

D. Existing depots

The company owns three storage facilities. One of them is located in the northwest of Germany at the postal-zip-code area beginning with the number three. The other two are located in the southwest very close to each other. Their postal-zip-code starts with the number six.

Those warehouses should be involved within this work as potential spare part storage locations. Due to the fact, that they have to be considered as privileged, the costs are termed as zero, because they exist even though they are not in use as a spare part storage facility.

III. APPROACH

This section will introduce the used approach to solve each of the tasks. At first the simulation of future demands has to b done. After that, the location decision is explained. In the end the uncapacitated facility location problem will be introduced which is formulated with a mixed-integer program (MIP).

A. Simulation of the demand

As described in section two, the forecast of demands is not easy. Simulation became a favored and important method for solving problems within the field of production and logistics [1]. That is the reason for using a simulative method for this fraught decision with risk. This approach sets up the different scenarios for the market growth and the possible consequences could be deduced.

Our decision went to the Monte-Carlo simulation as an approved method of choice for the task to generate randomized demands within a given planning horizon. This approach uses the aspects that all results have the same chance and are independent from each other [2].

Because of the named characteristics this method is used for risk analysis very often. It is in use for complex processes which could not be solved directly. The unsteady demand could be simulated through this method, which is presented by a normal curve of distribution with the range of 70% till 130% of the former demand. To cover up a negative market growth the simulated demands were multiplied by 70%. The same was done for the positive market growth of 130%

The five-figure postal-zip-code system is used to separate different areas of Germany. The first number of the code goes from 0 to 9. Therefore 10 markets could be pointed out. Fig. 1 shows the demand of the year 2010 separated for the postal-zip-code areas.

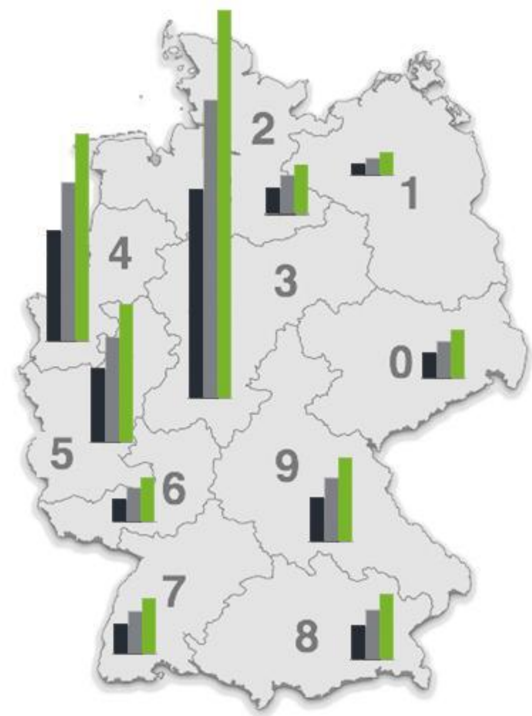

Figure 1. Separated demands (70%, 100% and 130%) by postal-zip-code

It is obvious that the demand of the market 3 is much higher than the demand at the area number 1. The different density of population is one of the reasons. The area one has 71-87 inhabitants per km² and the area 3 has 524 inhabitants per km². However the customers within Germany need to be delivered with taking into account the transportation restriction.

These demands are the basic approach for the normally distributed randomized demand within the given range. The numbers were computed with Minitab for each area.

TABLE I. Interval [Min; Max] of the Monte-Carlo Simulation results

	Worst-case	AVG-case	Best-case
Market 0	[130; 187]	[173; 255]	[247; 334]
Market 1	[59; 81]	[85; 115]	[102; 168]
Market 2	[115; 179]	[155; 270]	[206; 322]
Market 3	[987; 1394]	[1396; 2005]	[1639; 2601]
Market 4	[532; 798]	[720; 1110]	[850; 1333]
Market 5	[360; 545]	[443; 798]	[644; 899]
Market 6	[111; 169]	[162; 238]	[197; 323]
Market 7	[135; 218]	[200; 321]	[250; 382]
Market 8	[163; 250]	[231; 349]	[334; 447]
Market 9	[203; 333]	[296; 433]	[338; 595]

Table 1 gives a short overview about the results of the Monte-Carlo Simulation of the demand within a min./max.-interval out of the result series. These results are used for the third step where mathematical programming has to be applied but at first the decision on facility location has to be made. Its result will be used within the mixed-integer program as well.

B. Location decision

After determining the demand, it is necessary to consider the location decision problem. The separation of 10 areas leads to the idea to set up a single storage facility per market. A traditional method for solving this task is the Steiner-Weber location approach [3]. This technique is based on three assumptions:

- n customer with j= 1, …, n are supplied with a homogenous area. The position of the customer j is located at coordinates (u_j, v_j) with a demand of b_j.
- each position is a potential location and
- the transportation costs $c_{i,j}$ between two positions are proportional towards the transported amount and distance. The costs are consistent for each unit. For the distance measurement the Euclidean meter will be used.

The goal of this method is to discover the position which ensures an inexpensive supply to all customers. This problem could be formulated as minimizing problem:

$$K(x_s, y_s) = c \cdot \sum_{j=1}^{n} b_j \cdot d_j \quad (1)$$

$$K(x_s, y_s) = c \cdot \sum_{j=1}^{n} b_j \cdot \sqrt{\left(x_s - u_j\right)^2 + \left(y_s - v_j\right)^2} \quad (2)$$

One way to solve this equation is to split up the process into two steps. The first step is to calculate the weighted focus of all customer positions and their demands. This result will be improved with an approximate procedure until the result is almost optimal. This process is called the scheme of Miehle [6].

In order to use this method, the markets have been separated by the second number of their postal-zip-code. The focuses of these areas are used as the demand spots. Each location sums up all demands within this area

This method results in having 10 potential locations for setting up spare part storage locations as shown in Fig. 2. These locations are the basic approach for the next step during the whole analysis.

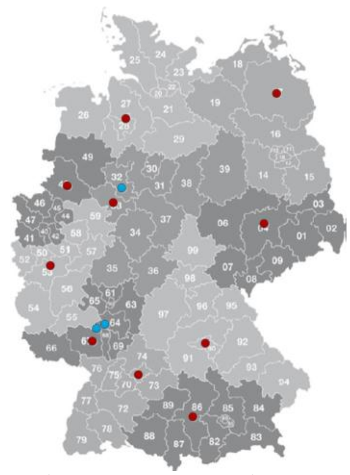

Figure 2. Results of the location decision after iterations of the Steiner-Weber method

C. Facility Location Problem

After nominating locations for new facilities, these have to be analyzed regarding the costs. Each of them causes costs for being operated and on the other hand reduces transportation costs to the customer due to shorter delivery routes. This class of problems is called facility location problem and covers all problems were a selection of different locations has to be made. The proceeding is based on graphs where the nodes are representing the locations and the edges are representing the distance between them. All nodes have a certain demand. These models are named as finitely discrete. Furthermore, a differentiation regarding the overall goal could be done. The minmax locations problem tries to minimize the largest distances between the locations. The other type is the minsum location problem and tries to minimize the sum of all distances [7]. A special model of this class is the Uncapacitated-Facility-Location-Problem (UFLP). This problem is also called Simple-Plant-Location- or Uncapacitated-Warehouse-Location-Problem. As given in the name there are no restrictions regarding the capacities since all location are new as in this present business case. The model contains the following parameters:

- n locations denoted as S_i with i=1, …, n,
- m customer denoted as K_j with j=1, …, m with a demand of D_j,
- fix costs F_i for opening up a location
- the transportation costs are between two locations with c_{ij}.

The objective function is:

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} \cdot z_{ij} + \sum_{i=1}^{n} F_i \cdot y_i \quad (3)$$

Under the constraints:

$$\sum_{i=1}^{n} z_{ij} = D_j \qquad j = 1, \dots, m \qquad (4)$$
$$z_{ij} \leq y_i D_j \qquad i = 1, \dots, n, \;\; j = 1, \dots, m \qquad (5)$$
$$z_{ij} \geq 0 \qquad i = 1, \dots, n, \;\; j = 1, \dots, \mathrm{m} \qquad (6)$$
$$y_i \in \{0, 1\} \qquad i = 1, \dots, n \qquad (7)$$

This model contains two decision variables within the constraints. One of them is y_i. It is a binary variable to decide either if a location is opened (y_i=1) or not (y_i=0). This is necessary because of the fixed cost for the facilities. The other variable is z_{ij} which stands for the available parts within this location for fulfilling the customer demands. The objective function minimizes the costs consisting of the sum of transportations cost in the first part and the cost for setting up the facility in the second part. These constrains make sure that all demands are covered (4) and that the demand is delivered by a location which exists (5).

The model was implemented with the tool IBM ILOG OPL Optimization studio in version 12. Due to the fact that this model does not consider variable costs the fixed costs include all fees like the rental fee for the storage space (different for each area), the picking fees (15€ per pick), the fix salary of the employee (3600€ per year) and costs for the material and equipment (1200€ per year). Those costs were calculated for the three scenarios with 70%, 100% and 130% of the former demand. The costs are shown in table 2.

TABLE II. Overview of the used fix costs

	Worst-case	AVG-case	Best-case
Market 0	9.280,58 €	10.275,12€	11.269,65€
Market 1	8.055,61 €	8.525,15€	8.994,70€
Market 2	9.540,94 €	10.647,06€	11.753,18€
Market 3	25.065,92 €	32.825,60€	40.585,28€
Market 4	16.667,09 €	20.827,27€	24.987,46€
Market 5	13.477,10 €	16.270,14€	19.063,18€
Market 6	9.084,49 €	9.994,98€	10.905,48€
Market 7	10.019,50 €	11.330,72€	12.641,93€
Market 8	10.204,99 €	11.595,70€	12.986,41€
Market 9	11.015,03 €	12.752,91€	14.490,78€

After analyzing the market, the occurred costs and computing the results, these outcomes need to be summed up and compared with the service provider.

IV. Results of the Basic Approach

After implementing the model and the data to the tool a clear result occurs. The results of the first assumption are explicit

A. Average case results

This case studied a continuous demand in referring to the former demand. For this case 30 different demands were proofed. The facilities of the markets 0, 1, 2, 3, 4, 5, 7, 8 and 9 were opened. In addition to this both existing facilities at the market 6 were used to deliver the spare parts. The facility of the market 3 was not in use. This result occurs for each demand. Summing these up costs 403.339,80€ per year could be expected.

B. Worst case results

An equal result as in the average case showed up in this case. The new facilities of all markets besides the market 6 are in use and in addition to this both existing facilities of the market 6. The location of the market 3 is not in use again. This effect was shown by all demands. The average cost of all iteration is 300.149,47€.

C. Best case results

For two demands out of this 30 series, another results showed up and new facility of the market 6 were opened up. The other new locations were opened too and the existing storage facilities were use too, besides of the market 3. The average cost are 502.542,73€ per year.

D. Comparison to a service provider

The most interesting investigation for the company within is the comparison of the costs referring to the fees of a service provider. This assumption has been done for the three market growth scenarios.

a) Average Case

The costs for delivering the spare parts to the facility differ about 69%. The company has to pay more because they have to deliver more facilities for storage. On the other hand the company does have less cost for delivering the parts to the customer. The company just would need pay 10,72% of the charged fees if they would do it by their self.

This could be shown summed up with the unit costs. One unit would cost 460,24€ with the service provider and 82,33€ with the introduced scenario.

TABLE III. Comparison of costs: service provider vs. the avg. case

	Service Provider	AVG-Case
Demand	4899 pcs.	4899 pcs.
Rental fee	1.201,46€	1.924,67€
Salary	152.284,65€	122.325,00€
Equipment	- €	10.800,00€
Transport to customer	2.097.969,81€	263.647,49€
Transport to facilities	3.257,50€	4.642,64€
Costs	2.254.713,41€	403.339,80€
Costs per piece	460,24€	82,33€

b) Worst Case

The first compared component is the delivery for the storage facilities. As shown before in this case the costs for the company are even higher too. They would pay 65% more. Even for this case the cost are higher if they would choose the service provider. The delivering could be realized for 15,31% of the offered price.

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The unit cost are 460,74 € for the service provider and 87,52€ for the own concept. The reduction of costs per unit is 0,093% for the offered service and 6,45% for own facilities for considering the worst and the avg case.

TABLE IV. Comparison of costs: service provider and the worst case

	Service Provider	Worst-Case
Demand	3429,3 pcs.	3429,3 pcs.
Rental fee	841,02€	1.347,27€
Salary	107.679,26€	101.179,50€
Equipment	- €	10.800,00€
Transport to customer	1.468.578,86€	184.553,25€
Transport to facility	2.906,05€	2.269,45€
Costs	1.580.005,19€	300.149,47€
Costs per piece	460,74€	87,52€

c) Best Case

If the company would deliver the parts to the stocks by themselves they have to pay 64% more towards the offered service. But on the other hand they would save 89,28% by delivering the parts to the customers from the spread locations.

For the offered service a fee per unit would be 459,77€ and for the alternative 78,91€. Comparing this result to the average case it shows that the reduction of costs per unit would be 3,82% for the company option and 0,048% for the service provider.

TABLE V.Comparison of costs: service provider and the best-case

	Service Provider	Best-Case
Demand	6368,7 pcs.	6368,7pcs.
Rental fee	1.561,89€	2502,07€
Salary	196.890,05€	143.470,50€
Equipment	- €	10.800,00€
Transport to customer	2.727.360,75€	340.105,27€
Transport to facility	3.608,95€	5.664,89€
Costs	2.929.421,64€	502.542,73€
Costs per piece	459,97€	78,91€

Summarizing up the scenario is even more important if the company decides to enlarge the article range or if there would be a positive market growth.

V. SENSITIVITY ANALYSIS

In order to verify these results a sensitivity analysis was done for each scenario of market growth. In order to find out about the impact of the components within the fixed costs, they have been changed. As shown in table 6 the fees are studied with three different characteristics.

TABLE VI. Changed fees for the fixed costs

Fee			
Transportation costs	0,80 €	1,00 €	1,50 €
Fix salary	300,00 €	500,00 €	800,00 €
Pick fee	12,00 €	15,00 €	18,00 €

The new combinations of fixed costs have been implemented to the OPL model. For each case 10 different demand series were studied to show up the relationship between the elements. Another aspect which was observed is the rate of opening for each new facility.

The further proceeding is separated into two parts. The first one will consider the opening rate in correlation with costs. The results are represented in cubes for each scenario. The x-axis represents the costs per km, the y-axis shows the fix salary and the z-axis displays the picking fee. The average costs of the 10 series are presented by the number at each node.

A surprising aspect of the basic approach was that the new location of the market 3 was in use. The sensitivity analysis shows that this fact changes. The red line at the Fig. 3, 4 and 5 indicates that the normal stock location of 3 is in use, instead of the new one for more than 50% of the results. By comparing the three scenarios, it shows up that the surface at the dices is getting smaller with an increased market growth as shown up in Fig. 5. This led to the realization that if the market achieves a positive growth, the costs, especially the transportation costs, need to grow much more for using the basic stock location of the market 3 than it would be for the negative case.

Another aspect could be pointed out for the new facility at the market 5. The results for all market growth scenarios show a recommendation of 100% for most of the combinations. An exception occurs for all combinations with the transportation costs of 1,50€ per km. This new facility should be considered if the transportation costs are lower than this.

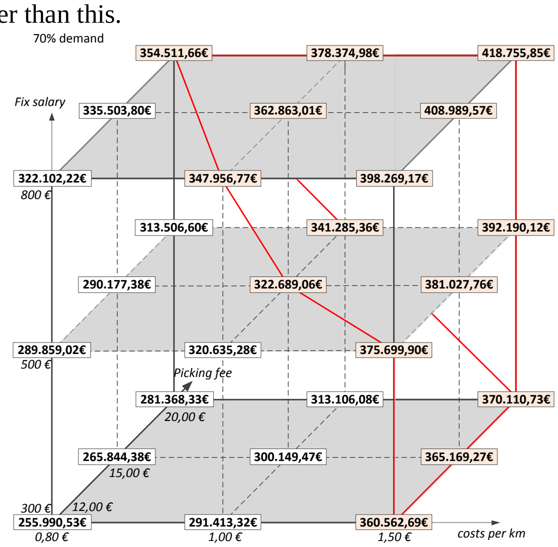

Figure 3. Cube illustrating the worst case results

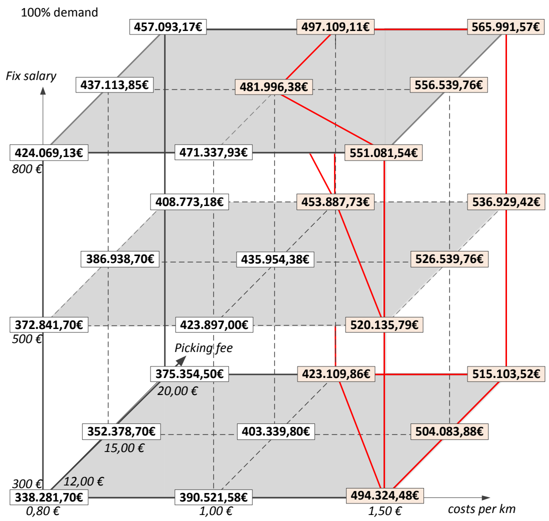

Figure 4. Cube illustrating the avg. case results

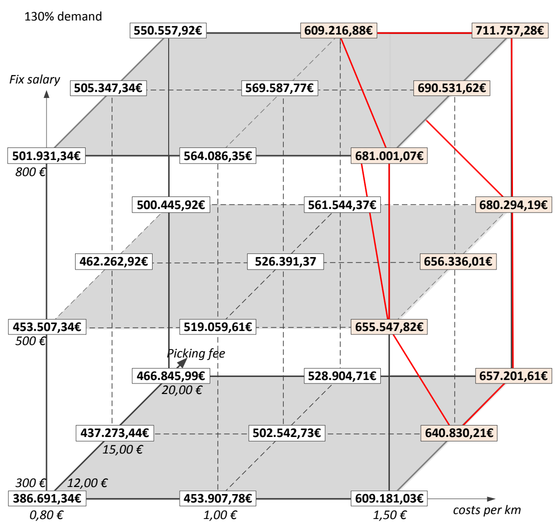

Figure 5. Cube illustrating the best case results

The new stock for the market 7 shows variations in recommendations too. Within the study of the lowest demand it shows up that this location was not in use for each combination of the transportation rate 1,50€ and for a fix salary 800€ and most of 500€. As for the market 3 with an increased demand this changes and more often this location is recommended. The average scenario shows that it would not be profitable to open up the stock for all combinations with a transportation rate of 1,50€, besides with a fix salary of 300€. The best case recommends this new facility not for all cases with a transportation rate of 1,50€. The costs per km are the most influential factor for this location. An equal observation could be made for the new facility of the market 8.

Moreover, the statistical analysis of the designed experiments allows the derivation of a mathematical meta-model for the resulting cost with a forecast quality of more than 98%. It's just based on the above mentioned input factors. Fig. 6 shows the relevance of each of the three input factors. It can be seen, that the fixed salary has the most significant influence on the resulting cost.

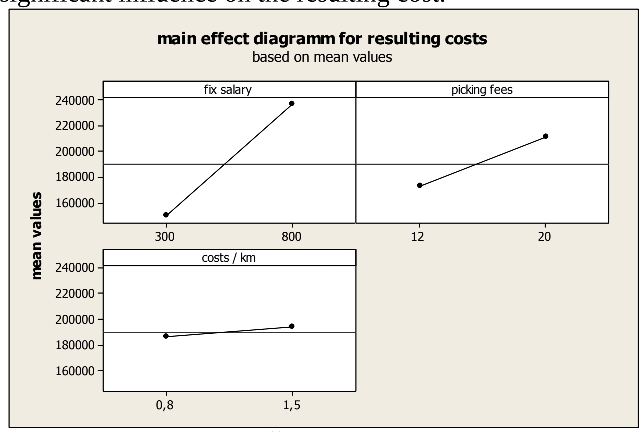

Figure 6. Main effect diagram on resulting costs

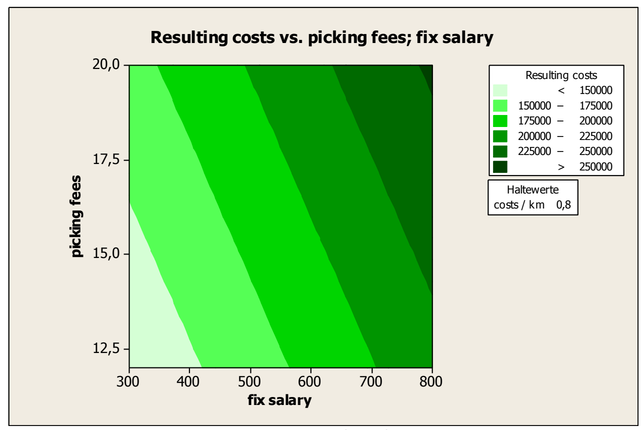

Figure 7. Response surface for resulting costs

Fig. 7 shows a derived response surface for the resulting costs of this model based on the derived meta-model. For each combination of fixed salary and picking fees, the resulting cost structure can be directly derived.

VI. CONCLUSION

This present business study shows how scientific methods can be applied to the real world and how they can support the decision making regarding real business problems. With this approach, using basic methods and implying real costs, we developed a framework which makes considering various alternatives possible. Furthermore the responsible management now has a basis for argumentation in cold print, since all parameters are given by the company and based on the company-wide costs.

For completeness of the results, the sensitivity analysis showed that the transportation cost and the fix salary have an enormous influence on the outcome calculated with the facility location problem. A possible recommendation for the company, based on the pure results could be to use new facilities within the markets 0, 1, 2, 4 and 9, as well as all basic stocks too, until the market growth could be estimated concretely. But the realistic orientation of these results needs to be considered too, since decisions within companies are made often in more difficult and elusive ways. Realistic options would probably be opening a single stock facility because of the unsafe market growth or maybe supply contracts with authorized premium dealer, which have available storage capacity and which are already familiar with the products.

Based on the more complex simulation and optimization models, a statistical meta-model could be derived via an experimental design study on the three input factors. It allows a forecast quality of the resulting cost structure of more than 98%, and thereby, can be used for further cost analysis, if some input factors change to a level, that has not been regarded during the here described study yet. Furthermore and referring to current discussions on sustainability and environmentally-conscious behavior, it could be of interest to investigate on the impact and influence of decision making towards reducing the emission of CO^2 in transport options.

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