Optimal Location Planning for Self-Storage Enterprises

by

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Abstract

Self-storage enterprises offer an innovative service in a new market. They offer storehouse capacities to private persons or enterprises for long and short term. The access to the storehouse is not limited to time. The service is often used due to insufficient warehouse capacities or the outsourcing of peak loads. Because of the innovative character of this service there are only a few competitors and the "product" itself is quite unknown to potential users. Therefore, it is advisable to quickly penetrate the market in order to get a big market share. Finding the optimal the expansion strategy for the next years is not trivial: Each investment decision has an impact on the market and therefore influences the decisions in the following periods. We construct a dynamic binary optimization model for this problem that determines when (which period) and where (which locations) how many storehouses should be put on stream within the planning horizon. The market is subdivided into a set of locations where storehouses can be built. Because of the long-term character the objective is to maximize the net present value of the related expansion strategy. Of course one has to consider the given budget and the constraints of the market situation and volume. Because of the high complexity of the problem structure, optimizing algorithms based on decision trees work only for small models. Practice-oriented problem sizes demand another solution procedure. Therefore, we concept and implement a genetic algorithm that handles any large problem size in acceptable time with good results.

Keywords: Location Planning, Self-Storage, Decision Model, Genetic Algorithm

1. Introduction

In the past decade, an innovative concept for storehouses evolved with its origin in the USA (Self Storage Association 2007). For outsourcing purposes, service providers offer storage capacities for individuals as well as for business users. The market is promising because the investment in storehouses, the operating costs and the market penetration are relatively low while the potential demand is high (Duffy/Kliebenstein, 2005). The basic idea is as follows: The service provider procures standardized storage room for a short period of time, the storage equipment (roller shutter, fork lift etc.) and administers the storehouse, but stockpiling and stock removal have to be done by the customers themselves. Due to an electronic entry system customers can access their rented storage capacities at every time independent of the presence of warehouse employees. For renters, this concept allows to reduce fixed storage costs that can now be replaced by usage dependent variable costs (see Mark 2005).

Because of the innovative character of the service and the developmentally chances many new sites will emerge in the next few years (Duffy/Kliebenstein, 2005). Therefore, it is very important in this stage to choose appropriate locations. Densely populated areas are attractive because of the restricted catchment area of a storehouse and the closeness to the potential target group. But the competitive situation and the investment costs in these areas are normally inauspicious. Thus, we are facing a complex long term site planning problem: How to choose the site that is the economically favorable one for the next years? (Fleischmann/Klose, 2004) In the following we present a multi periodic optimization model for this problem and show how this problem can be solved.

2. Development of the Optimization Model

Characteristics and Goal

The characteristics of self-storage storehouses (SSS) are (Duffy/Kliebenstein, 2005): (1) Construction and equipment of SSS are considered as a medium-/long-term investment. (2) Once a decision on investment and location is made, a revision can't be taken without greater loss. (3) SSS provide a certain capacity of storage space. (4) The offered product »storage possibility« isn't affected by usage concerning its quality and life expectancy. (5) Operating costs of an SSS aren't constrained by use and load. They just ensure the disposability (availability fees). Thus, the marginal costs of an additional contract, if it lies within the capacity limits, matches 0. Non-use of storage capacity doesn't diminish the operating costs. (6) The sales market of an SSS is locally bounded to the location of choice. Main target group are individuals and craftsmen. (7) Even if the rental contracts allow flexible durations, most of the contracts are on a long term basis. To convince a customer once is important for the »natural« customer loyalty.

The location planning for self-storage enterprises is a multi-periodic dynamic decision problem. The planning horizon amounts to T years, scaled in t=1,2,...,T periods. Opening of storehouses takes place at period begin. The present point in time is $t = 0$. The goal is the maximization of the net present value that is determined by all site decisions made within the planning horizon. The decision concerns the expansion strategy. That is if and when storehouses should be built at a location within the planning horizon.

Optimization Model

1) Site Alternatives and their Characteristics

The investigation area shall be split into equal grid boxes (e.g. 5*5 km), each regarded as an »atomic« location element. A location will be determined by its x- and y-coordinates (x,y). Let x=1,…,X and y=1,…,Y be the relevant coordinates of all locations, so that the complete surface of the investigation area can be covered. Irrelevant locations that lie outside the grid because of the irregular shape of the investigation area are initially kept for an easier, formal description even if they fall apart later on. Each location is characterized by a set of attributes. Depending on their values a location rating can be computed. The relevant attributes of a location (x,y) for period $t = 0,\dots,T$ are:

1. Outpayment: Land prices $GP_{x,y,t}$ [$]; storehouse equipment costs $LEQ_{x,y,t}$ [$]; labor costs index $LNIV_{x,y,t}$; annual outpayment-effective operating costs $K_{x,y,t}$ [$/period].
2. In-payment: Population $POP_{x,y,t}$ measured in 1.000; purchasing power of population, measured by purchasing power index $KKI_{x,y,t}$; market range of coverage, attainable price per square meter

$P_{x,y,t}$ [$/sqm]; average rented storage space per contract [sqm]; life cycle curve of »salable« storage space (contracts or rather rented space) conditioned by age of the storehouse; competitive situation (foreign as well as one's own SSS in catchment area); economic trend

2) Prerequisites and Decision Variables

For the optimization, the following conditions shall hold: (V1) At each location should be built a maximum of one storehouse. Locations with an already existing storehouse aren't considered any further (see further V2). (V2) Shutting down of storehouses won't be allowed. (V3) There exist competitors on the market. (V4) Due to financial shortage or other bottlenecks only Bt storage houses can be built in one period t. (V5) Each storehouse provides a certain maximum capacity of storage space KAPx,y (e.g. 4200 sqm). (V6) The periods aren't subdivided any further. All payments, except acquisition payments, occur at the period-end.

The decision variables consist of binary variables differenced after the locations and the construction periods (Vahrenkamp, 2007). Because of condition V1, only the values 0 (no construction) and 1 (construction of an storehouse) can occur so that the optimization model is a binary decision problem with the decision variables $S_{x,y,t}$:

$$S_{x,y,t} = \begin{cases} 1 \text{ if a storehouse is built at } (x,y) \text{ in } t \\ 0 \text{ else} \end{cases}$$

with $x \in \{1,\ldots,X\}, y \in \{1,\ldots,Y\}, t \in \{1,\ldots,T\}$

At the start of planning, already existing storehouse locations are such $(x,y) \in X \times Y$ with $S_{x,y,0} = 1$. Because of condition V1 and V4 it applies formula (1) and (2):

$$\text{(1)} \qquad \sum_{t=0}^{T} S_{x,y,t} \le 1 \text{ for all } (x,y) \in X \cdot Y$$

$$\text{(2)} \qquad \sum_{x=1}^{X} \sum_{y=1}^{Y} S_{x,y,t} \le B_t \text{ for all } t=1,\ldots,T$$

2.1 Determination of Outpayments for Equipment and Operation of a Storehouse

With regard to the outpayment, we have to consider site specific land prices $GP_{x,y,t}$ and site neutral payments for storage equipment $LEQ_{x,y,t}$ (e.g. 2 Mio $). Furthermore, there occur operating costs which are almost fixed costs. With approximately 50%, labor costs are the biggest cost pool as surveys are showing. That means the annual site neutral costs affecting payments are K_t [$/year] and the site specific costs – affected by the labor costs index $LNIV_{x,y,t}$ – are represented by $K_t \cdot LNIV_{x,y,t}$. The labor costs index $LNIV_{x,y,t}$ indicates the multiplier referring to a base salary (e.g. 1.07). From this, the annual costs affecting payments for the location (x,y) result in: $K_t \cdot (1 + LNIV_{x,y,t})$.

2.2 Determination of In-Payments

Calculation of Market Potential

A storehouse's market range of coverage is determined by its catchment area. It may reaches beyond its own location (x,y) and can also contain the ones nearby. Therefore, we define a degree of proximity $1 \ge Ng((x_1,y_1),(x_2,y_2)) \ge 0$ for all pairs of locations in such way, that they decrease with increasing distance from the observed location. It indicates which share of the population in (x_2,y_2) can be reached by a storehouse in (x_1,y_1) due to distance and transportation infrastructure. The degree of proximity of one's own location obviously is 1. Symmetry shall always apply. All locations in the neighbourhood with a positive degree of proximity are relevant for the site decision. With the help of this environment information the potential reachable customers $KUZ_{x,y,t}$ of a location $(x,y) \in X \times Y$ in period t=1,…T is determined as:

$$(3) \qquad KUZ_{x,y,t} = \sum_{i=1}^{X} \sum_{j=1}^{Y} POP_{i,j,t} \cdot Ng\left((x,y),(i,j)\right)$$

with $POP_{i,j,t}$ is the population of location grid box (i,j) in period t. If there are competing storehouses (own or foreign) that have access to the same market potential then the market potential has to be split. It has to be noted that not only storehouses of competitors but also own storehouses may reduce the market potential of a location (cannibalization effects). Let $L_{i,j,t}$ be the number of storehouses at the beginning of period t in location (i,j) without differencing of own and foreign storehouses. Thus, the starting situation is described by $L_{i,j,1}$ with $L_{i,j,1} \geq S_{i,j,0}$ because of the competing storehouses. Then, considering the starting situation and the site decisions within the planning horizon the value of $L_{i,j,t}$ (t>1) can be computed as:

$$(4) \qquad L_{i,j,t} = L_{i,j,1} + \sum_{t'=1}^{t-1} S_{i,j,t'} \quad \text{with } (i,j) \in X \times Y;\ t=2,3,\ldots,T$$

The »access intensity« $ZUG_{i,j,t}$ that describes how many customers can be reached in period t by the storehouse in location (i,j) can be defined as:

$$(5) \qquad ZUG_{i,j,t} = \sum_{k=1}^{X} \sum_{l=1}^{Y} Ng\left((k,l),(i,j)\right) \cdot L_{k,l,t} \quad \text{with } (i,j) \in X \times Y;\ t=1,2,\ldots,T$$

Consequently, in period t the relevant market potential (in thousand inhabitants) of a storehouse to be built in location (x,y) is determined by:

$$(6) \qquad MP_{x,y,t} = \sum_{i=1}^{X} \sum_{j=1}^{Y} POP_{i,j,t} \cdot \frac{Ng\left((x,y),(i,j)\right)}{\max\left\{Ng\left((x,y),(i,j)\right) + ZUG_{i,j,t};1\right\}}$$

In a bottleneck situation, the market potential is distributed proportionally in accordance to the degree of proximity.

Attainable Price and Quantity of Sales

Empirical studies have shown that the price per sqm $P_{x,y,t}$ correlates positively with the purchasing power index $KKI_{x,y,t}$. The capacity utilization depends except for the market potential $MP_{x,y,t}$ on the the age of a storehouse. Thus, there is a »life cycle curve« that can be described with the age dependent success rate $SUCCESS_s$ ($s=1,\ldots,T_L$) measured in contracts per 1.000 reachable customers. T_L is the lifetime of a storehouse. In its beginning a storehouse becomes known and gets used until the capacity limit is reached. The typical curve is first ascending continuously up to a certain absorption point and then stagnating. Practical experiences have shown that this point usually is reached after six years. The reason for this phenomenon is that many customers are storing goods during a long period of time. Once a storehouse has gained a customer he most likely will rent his storage box over the next years. This effect is enhanced by relatively high costs for stock transfer if another storehouse will be chosen for rental. Therefore, the number of contracts $AK_{x,y,t}$ is determined by (t is the storehouse's building time):

$$(7) \qquad AK_{x,y,\tau} = SUCCESS_{\tau-t+1} \cdot MP_{x,y,\tau} \quad \tau = t, t+1, \ldots T$$

Additionally, the number of contracts is limited by the capacity of a storehouse. Let $LF_{x,y,t} = f_L(KKI_{x,y,t})$ with $dLF/dKKI_{x,y,t} \geq 0$ be the averaged storage space per contract. Then, the demand is determined by the number of contracts multiplied with the averaged storage space per contract.

The Investment's Residual Value

Let $RW_{x,y,t}$ be the residual value of a storehouse built in period t at location (x,y). This value represents a storehouse's value at the end of the planning horizon T. It is needed because the revenue of such an investment takes place after a certain period of time that might lie beyond the planning horizon. If $RW_{x,y,t}$ wouldn't be taken into account investments at the end of the planning horizon would be monetarily misinterpreted.

2.3 Objective Function

The acquisition value $AW_{x,y,t}$ of a storehouse at location (x,y) at the beginning of period t has two components: The site specific land price $GP_{x,y,t}$ as well as the site neutral payments for the storehouse equipment $LEQ_{x,y,t}$:

(8) $AW_{x,y,t} = GP_{x,y,t} + LEQ_{x,y,t}$

Then, the net present value $CV_{x,y,t}$ of a storehouse in location (x,y) built at the beginning of period t ($x \in X$, $y \in Y$, und t=1,…,T) will be:

(9) $$CV_{x,y,t} = \ AW_{x,y,t} \ (1+i)^{(t\ 1)} + RW_{x,y,t} \ (1+i)^{T} + \sum_{=t}^{T} \left(AK_{x,y,} \ \ LF_{x,y,} \ \ P_{x,y,} \ \ K_{x,y,} \ \left(1+LNIV_{x,y,}\right)\right) (1+i)$$

The discounting always is for the planning horizon begin, i.e. t=0. The acquisition payments accrue at period begin, all other payments at period-end. Naturally, the following condition must hold:

(10) $CV_{x,y,t} \geq 0$ with $(x,y) \in X \times Y$; t=1,2,…,T

Now, the objective function consists in the maximization of the total net present value:

(Z) $$\text{Max} \sum_{t=1}^{T} \sum_{k=1}^{X} \sum_{l=1}^{Y} CV_{x,y,t} \ S_{x,y,t}$$

Because $S_{x,y,t}$ are binary variables we are facing a binary decision model. The number of decision variables is $X \ Y \ T$. In order to compute the access intensity $ZUG_{i,j,t}$ all existent storehouses in t plus those storehouses to be built (represented by $S_{x,y,t}$) including the proximity index have to be considered. Additionally, the access intensity is a determination factor of the market potential. Thus, the decision model is NP-hard and cannot be solved in an acceptable calculation period. Even commonly known optimization algorithms like e.g. branch and bound have to compute all solutions in order to find the optimal solution. Only with proximity index 0 for all neighbour grid boxes a classical binary optimization algorithm could succeed because then, the access intensity only depends on the known starting situation at the beginning of the planning horizon.

3. Case Study

Let us now apply the presented model to Germany. Figure 1 shows a map of Germany on the left side. On the right side we can see the grid boxes the investigation area is split into. The grey grid boxes indicate the six areas with the highest population density: Hamburg, Berlin, Munich, Frankfurt, Cologne and the Ruhr. These are the regions the model is coping firstly. Due to the relatively low outpayments in Berlin and the Ruhr, storehouses are first of all built in respectively beside these regions. The chosen locations depend on the values we are using for each grid box and the access intensity. If the outpayments of the white boxes are low in comparison to the grey boxes and the access intensity is not zero the chosen locations lie outside the six areas. Otherwise, if each region consists homogenously of boxes with equal values the chosen locations lie in the center of each region.

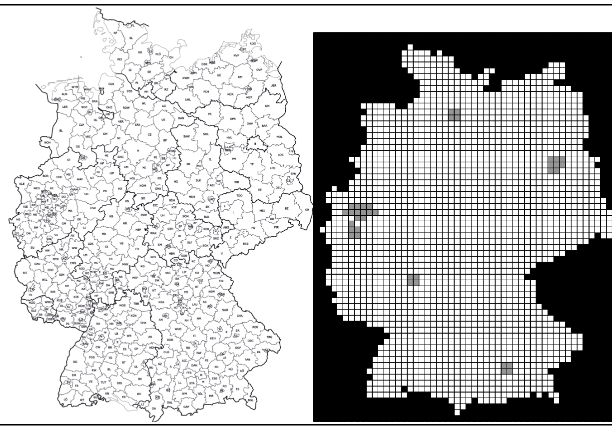

Figure 1 Investigation Area Germany

The calculation for Germany could only be done because we reduced the number of grid boxes without empty values and the number of periods so that the number of possible solutions was decreased enormously. If we use a totally filled grid the calculation period explodes: With five periods and a 100×100 grid the solution space consists of 9,5 billion elements that have to be computed. Therefore, we will use a genetic algorithm in order to find good solutions in an acceptable time.

4. A Generic Algorithm As Approach

Individuals

In the following we assume $B_t = 1$ for simplification. A solution can be described via a 3D-cube with the location coordinates and the periods as dimensions (Mitchell, 1998, Vose, 1999). Then, an individual of the genetic algorithm is one solution alternative that can be defined as follows: The individuals can be represented as a X×Y-matrix M. The matrix contains a maximum of T values between 1 and T whereas no value occurs twice. The other values of the matrix are 0. A value $M_{x,y} > 0$ in the matrix indicates that a new storehouse is built at site (x,y) in period $M_{x,y}$. The value 0 indicates that no storehouse is built at site (x,y). The net present value is used as fitness to choose the individuals for crossover and the selection of the next generation.

Mutation

The mutation operator can be defined as follows: Randomly choose two cells of an individual M with different values and swap the two values. Because of the crossover we are discussing later on some values might be lost during the calculation. In order to reproduce those missing values between 1 and T we can insert them instead of swapping two values.

Crossover

Let M and N be individuals of the genetic algorithm. Then, the crossover operator exchanges parts of the two individuals as follows: Randomly choose the bounds of a rectangle in the matrix. Then the rectangles are cut out of M and N and implanted into the other solution. This operation may lead to invalid individuals: The number of values between 1 and T may now be greater than T (case

1). Values between 1 and T may occur twice but there are only T values greater than 0 (case 2). Therefore, a repair mechanism has to be installed. In the first case, we randomly choose a cell with a value that occurs twice and set the value of the cell to 0 until there are only T values greater than 0. In the second case there are doublets as well as missing values. Therefore, we randomly choose a cell with a doublet value and set the cell's value to one of the missing value until no value occurs twice.

5. Conclusion and Further Enhancements

In this paper we presented an optimization model for the location planning of self-storage enterprises concerning the expansion strategy. As this problem is a binary decision problem with many decision variables it can hardly be solved with deterministic algorithms. As genetic algorithms rapidly find good solutions (Koza, 1993) we designed a genetic algorithm that finds a good solution in an acceptable computation time.

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