# A Spatial Interaction Model to Assess Urban Scenarios and Policies in Almelo – the Netherlands

# Utilização de um Modelo de Interação Espacial para Avaliação de Políticas e Cenários Urbanos em Almelo - Holanda

**João Borba**
jmopborba@uac.pt
University of the Azores, Portugal

**Koen Staals**
koen.staals@wur.nl
Wageningen University, The Netherlands

**Tomaz Dentinho**
tomazdentinho@uac.pt
University of the Azores, Portugal

## Abstract/Resumo

The aim of this paper is to develop an urban decision support system to assess the complexity of the impacts that result from urban policy measures and outside driven shocks in the economic dynamics of a region. This is performed by the development of a spatial interaction model that was coded and integrated in MATLAB 2013a as a user-friendly tool that supports both model calibration and simulation functions, unlocks spatial constraints regarding matrix operations, speeds up the iterative processes and allows the export of outputs to spreadsheet format for further analytical and graphical analysis. The model's attrition parameters are calibrated until the model average costs are similar to real average costs, and bid-rents are calculated according to the offer and demand for space in each zone. Data respective to employment, population and real average costs in Almelo territory was collected for six different municipalities. An external zone was added to act as a buffer for the model. Four different future scenarios regarding new allocations of basic employment and space for employment and/or population in these zones are conceptualized with the Shell Method. Differences between *status quo* and hypothesized scenarios in terms of residence-employment and population-services interactions are assessed

O objetivo deste artigo será o desenvolvimento de um sistema urbano de suporte à decisão de forma a avaliar a complexidade dos impactos resultantes de medidas políticas e influências externas nas dinâmicas económicas de uma região. Isto é realizado pelo desenvolvimento de um modelo de interação espacial codificado e integrado em MATLAB 2013a como uma ferramenta intuitiva para qualquer utilizador e que suporta funções de calibração e simulação, desbloqueia os constrangimentos em relação a operações matriciais, acelera o processo iterativo e permite a exportação dos outputs para um formato de folha de cálculo para uma análise numérica e/ou gráfica posterior. Os parâmetros de atrito são calibrados até que os custos médios estimados pelo modelo sejam iguais aos custos médios reais, e as rendas são calculadas de acordo com a oferta e a procura pelo espaço em cada uma das zonas. Os dados respetivos ao emprego, população e custos médios reais no território foram adquiridos para seis zonas. Uma zona externa foi adicionada. Quatro cenários diferentes em termos de alocação de emprego básico e espaço para emprego e/ou população nas zonas consideradas foram concetualizados com o Método da Shell. As diferenças entre o estado inicial e os cenários hipotéticos relativamente às interações residência-emprego and bid-rent variations are calculated to determine the impact of each future scenario in the dynamics of a region. The spatial interaction model has ultimately proven its usefulness and effectiveness in accurately predicting the outcome of future scenarios and policies on the local economy and its respective spatial structure and dynamics. A future combination of the developed spatial interaction model with a land use aspect and subsequent integration with specialized geographic information system tools might prove itself as a milestone in the field of impact measuring methodologies for efficient spatial planning.

*Keywords: MATLAB, Spatial Interaction Model, Scenario Building, Spatial Planning, Impact Measurement*

*JEL Codes:* C3, C8, E2

e população-serviços foi aferida e as variações das rendas calculadas para determinar o impacto de cada cenário nas dinâmicas da região. O modelo de interação espacial demonstrou a sua utilidade e eficácia na previsão de políticas futuras não só na economia local, mas também nas dinâmicas de estrutura espacial. Uma combinação futura do modelo desenvolvido com o uso do solo e subsequente integração com ferramentas de informação geográfica especializadas poderá representar um marco importante no ramo do ordenamento do território através de metodologias de mensuração de impactos.

*Palavras-Chave: MATLAB, Modelo de Interação Espacial, Construção de Cenários, Mensuração de impacto, Ordenamento do Território*

*Códigos JEL:* C3, C8, E2

## 1. INTRODUCTION

The aim of this paper is to develop an urban decision support system to assess the complexity of the impacts that result from urban policy measures and outside driven shocks. We do that by formulating, implementing and calibrating a spatial interaction model (SIM) for Almelo area in The Netherlands to subsequently perform simulation of impact scenarios that result from urban policy measures and outside driven shocks. This approach swiftly responds to the increasing demand for scientific tools in the field of regional planning that support the sustainable management and development by estimating the impact of policies and scenarios such as territorial planning, energy management, water management, climate change and biodiversity conservation in the flows of people and goods of a considered region, which could ultimately change the dynamics of the economy of that region (Wegener, 2001; Engelen et al., 2010).

Gravity models of spatial interaction are built to describe and predict the flow of people, goods and information across space (Sen & Smith, 1995). Applications of gravity models to analyze spatial interactions are long reported in the literature (Carey, 1858; Reilley, 1932; Stewart, 1948; Carrothers, 1956; Schneider, 1959). These studies have contributed to the development of analytical tools that are commonly used in land use planning, geography and regional science (Wilson, 1967; Isard, 1975; Batty, 1976; Anderson, 1979; Haynes & Fotheringham, 1984; Fotheringham & O'Kelly, 1989; Millonen & Luoma, 1999), transports (Hyman, 1969; Evans, 1971; Evans, 1976; Erlander & Stewart, 1990), commerce and marketing (Huff, 1964; Bergstrand, 1985; Deardorff, 1998) and demography migration (Plane, 1984). A review of the evolution of the theoretical bases of these models is undertaken by Roy and Thill (2004), while a review of these theoretical bases with a larger scope on various economic fields is performed by Roy (2004).

The relationship between the central place theory and SIMs has been subject of research and past efforts were performed in incorporating the central place theory in SIMs. A number of studies by Wilson proposed that the variables usually employed in SIMs are capable of providing an implicit representation of several aspects of the central place system (Wilson, 1976; 1977; 1981a; Wilson & Senior, 1974). Indeed, central place theory is now regarded as being consolidated in SIMs, as the information about the number of centers at each level of a hierarchy and the spacing of these centers is contained in the attraction term from the shopping model and, indirectly, in an inter-zonal generalized cost matrix (Wilson, 1977).

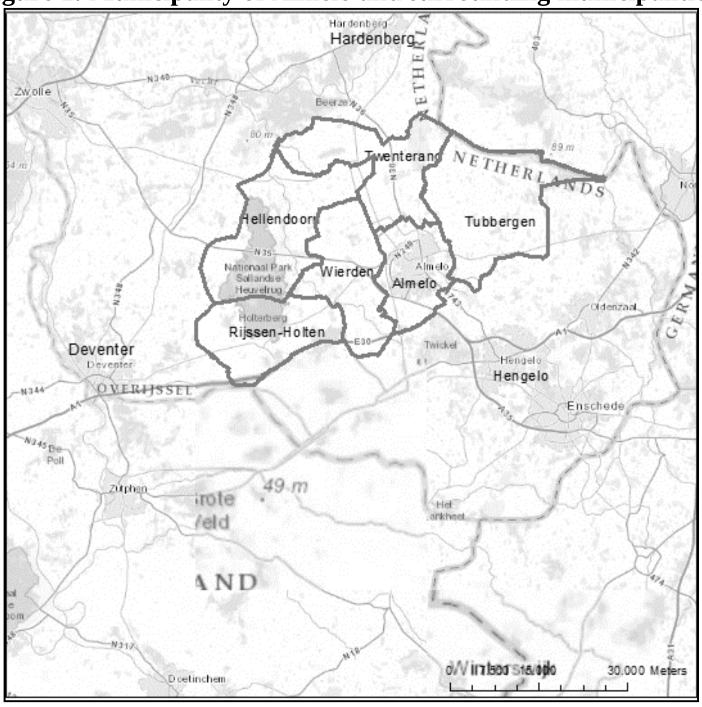
When successfully developed, integrated and validated, SIMs can act as decision support systems that envision the behavior of large populations regarding possible threats to local and regional environment and economy, which enables the possibility of subsequently developing impact measuring methodologies in order to create sustainable local and regional plans (Couclelis, 2005).

The second chapter of this paper makes a brief introduction to the studied area. The third chapter fully explains the SIM methodology and describes how it was implemented in MATLAB environment. The calculations behind some of the important parameters that are necessary to run the model are also described. Afterwards, we approach the scenario building theory and apply the method of Shell (Schoemaker, 1992) to construct different forecasting scenarios. The following chapter exhibits and analyzes the outcomes of each of the considered scenarios and the variations between the *status quo* and the specified scenarios. In the last chapter, a conclusion is outlined and future work insights are briefly proposed and discussed.

## 2. THE AREA

The area that will be studied in the current paper is located in the eastern part of the Netherlands in the province of Overijssel and contains the city of Almelo and surroundings. Six municipalities are included to the research-area and it is assumed that they are the main commuting area of the municipality of Almelo, based on the relative distance to the city. These municipalities are, besides Almelo: Hellendoorn, Rijssen/Holten, Tubbergen, Twenterand and Wierden, (Figure 1). The required data for the model was only available per municipality and so, we decided that the region would be divided into six zones. However, one would assume that the system of interest is closed while employing spatial interaction phenomena, but it is not possible to totally exclude the surrounding regions because there will exist, at some extent, an exchange of people and labor to the surroundings. An external zone is usually suggested to be added to the system of interest in order to minimize the model's error (Wilson, 2010). Therefore, a seventh zone – Outerregion was added, working as a buffer for the model to intercept the irregularities that could arise from non-considered exchanges in the six-zone model.

**Figure 1: Municipality of Almelo and surrounding municipalities.**



All data were collected from statistical websites of The Netherlands such as Centraal Bureau voor de Statistiek (CBS, 2009; 2011; 2012; 2013), which contain demographic and geographic data about each of the considered regions. Data respective to total population, employment and area of each one of the considered municipalities are displayed in Table 1.

It should be reported that the Outerregion data is based on the average of the three biggest cities in the surrounding zone: Hengelo, Hardenberg and Deventer (Figure 1). These cities contain 98.472, 18.330 and 80.896 residents, respectively (CBS, 2011), so the total population of the zone is considered as the sum of these numbers: 197.698. The total employment of the three cities combined is 142.203 jobs.

## 3. MATERIALS AND METHODS

This chapter encompasses the theoretical explanation of the used SIM and its transition into a MATLAB stand-alone application. Important parameters that are necessary as input variables for the model are described and calculated. Finally, we describe the used scenario making methodology: The Shell Method.

**Table 1: Total population, total employment and total area (in hectares) for each of the considered zones**

| | Total Population | Total Employment | Total Area (ha) |
|---|---|---|---|
| Almelo | 72.757 | 50.346 | 6.940 |
| Wierden | 23.812 | 16.018 | 9.435 |
| Twenterand | 33.461 | 20.353 | 10.817 |
| Hellendoorn | 35.796 | 9.524 | 13.900 |
| Rijssen/Holten | 37.573 | 13.413 | 9.437 |
| Tubbergen | 21.145 | 8.685 | 14.740 |
| Outerregion | 197.698 | 142.203 | NA |

### 3.1 SIM Formulation

The formulated SIM is a gravity-based Lowry-type model (Lowry, 1966) which generates urban population and service employments distributions for given patterns of basic employment. This model was transformed to become a non-linear mathematical problem in which dual variables on constraints can be interpreted as rents (Wilson, 2010), and assumes that the spatial interaction $T_{kl}$ between one destination $k$ and one origin $l$ from a set of $m$ zones, is positively related with the attraction $W$ on destination $k$ ($W_k$) and negatively related with the distance between them ($d_{kl}$). The attraction parameter $W$ corresponds to the availability of space and services that exists in a particular area that attract people from other areas. Economically speaking, a higher attraction value on a specified zone represents a higher pressure on the land, which will ultimately be reflected in higher land prices. Subsequently, these high land prices are related to a higher level of amenities and to higher export rates (Diamond, 1980).

The model also presupposes two types of employment: basic employment ($E_b$) and non-basic employment ($E_{nb}$). The "basic employment" is the main economic catalyzer of the model, and refers to employment focused on or supported by external markets and/or institutions. "Non-basic employment" refers to employment focused on the local population. The sum of both $E_b$ and $E_{nb}$ will yield the total employment ($E$).

We can assume the residence-employment spatial interaction $T$ between two zones $k$ and $l$ from a set of $m$ zones such as:

$$(1) \qquad T_{kl} = E_k \frac{r.W_k.e^{-\alpha d_{kl}}}{\sum_{j=1}^{m} r.W_j.\ e^{-\alpha d_{kj}}}$$

For all zones $k$ and $l$, the population for zone $k$ can be expressed as:

$$(2) \qquad P_k = \sum_{j=1}^{m} T_{kj}$$

Where $T_{kl}$ corresponds to the number of commuters that work in zone $l$ and live in zone $k$, $E_k$ is the employment of zone $k$, $r$ is the inverse of the activity ratio (Total Population/Total Employment), $W_k$ is the attraction of zone k, $\alpha$ is the parameter that defines the friction produced by distance for the commuters, $d_{kl}$ is the distance between zone *k* and *l* and $P_k$ is the population in zone *k*.

The activities that serve the population *P* are represented by the population-services spatial interaction *S.* Assuming two zones *k* and *l* from a set of *m* zones:

$$(3) \quad S_{kl} = P_k \frac{s.W_k.e^{-\beta d_{kl}}}{\sum_{j=1}^{m} s.W_j.e^{-\beta d_{kj}}}$$

For all zones *k* and *l*, the employment for zone *k* can be expressed as:

$$(4) \quad E_k = \sum_{j=1}^{m} S_{kj}$$

Where $S_{kl}$ is the activity generated in zone *l* that serves the population in zone *k*, $P_k$ is the total number of residents in zone *k*, *s* is the non-basic activity ratio ($E_{nb}$/Total Population), $W_k$ is the attraction of zone *k*, $\beta$ is the parameter that defines the friction produced by distance for the people that look for activity services, $d_{kl}$ is the distance between zones *k* and *l* and $E_k$ is the employment of zone *k*.

The endogenous variables ($P_k$ and $E_k$) can be obtained from the exogenous variable for $E_b$ through the use of matrices *[A]*, *[B]* and identity matrix $I_M$:

$$(5) \quad E_k = \{I_M - [B][A]\}^{-1}.\ [E_b]$$

$$(6) \quad P_k = \{I_M - [B][A]\}^{-1}.\ [E_b]\ [A]$$

Where:

$$(7) \quad [A] = \frac{r.W_k.e^{-\alpha d_{kl}}}{\sum_l r.W_k.e^{-\alpha d_{kl}}}$$

$$(8) \quad [B] = \frac{s.W_k.e^{-\beta d_{kl}}}{\sum_l s.W_k.e^{-\beta d_{kl}}}$$

To reach a desired equilibrium regarding the residence-employment and population-services interactions in the considered region, the model is iteratively calibrated until the predicted average costs are similar to the real average costs. Both of these real average costs are provided by the demographical database of the Netherlands and are expressed in km's covered per transportation (CBS, 2012). This represents the average distance that an individual is willing to cover for employment and for services in the province of Overijssel. The parameter $\alpha$ is calibrated in order that the average residence-employment cost predicted by the model is similar to the real average commuting cost. Similarly, parameter $\beta$ is calibrated so that the average costs for the population to access to services in zone *k* are similar to real average costs. Finally, $W_k$ values are iteratively calibrated to guarantee the accomplishment of constraints related with job and service supply and available space in each zone.

The $W_k$ calibrated attraction values can also be interpreted as bid-rents (Roy & Thill, 2004). The bid-rent ($\omega_k$) is complementary to the transportation costs and is directly proportional to the attraction values. Therefore, we can assume that:

$$(9) \quad \omega_k = -\left(ln\frac{1}{W_k}\right)$$

Therefore equations (7) and (8) can be mathematically expressed as (10) and (11), respectively:

$$(10) \quad [A] = \frac{r.e^{\omega_k - \alpha d_{kl}}}{\sum_l r.e^{\omega_k - \alpha d_{kl}}}$$

$$(11) \quad [B] = \frac{s.e^{\omega_k - \beta d_{kl}}}{\sum_l s.e^{\omega_k - \beta d_{kl}}}$$

## 3.2 SIM Development in MATLAB

The SIM described in the section above was coded and integrated in MATLAB 2013a (Mathworks, Natick, United States). The developed tool is user – friendly, unlocks the spatial constraints regarding matrix operations with previously used software, speeds up the iterative processes, allows the outputs to be exportable to spreadsheet format and supports model calibration and scenario simulation functions. The spatial interaction model flowchart for both calibration and simulation phases can be found in Annex 1 of the current paper.

### 3.2.1 Model Calibration

Initially, some of the necessary inputs are manually inserted in an Excel standardized workbook which was previously predefined and integrated with MATLAB. For each zone, the user must insert the data for zone name, $E_b$, space for population and space for employment.

The distance matrix and *r* and *s* parameters are also inserted in the Excel template workbook.

Afterwards, the program is initiated and the Excel workbook is loaded from the database into the MATLAB environment. Next, the user is prompted to make optional modifications in some data. Other inputs are inputted manually, which include friction parameters ($\alpha$ and $\beta$), average distance costs for both jobs ($C_e$) and services ($C_s$), maximum number of iterations ($I_{max}$) and required tolerance to stop the iterative cycle ($error_t$).

After all the inputs were inserted, the process starts. On each iteration *I* and through matrix operations, residence-employment and population-services matrices, estimated employment and population values are calculated. For each zone and on each iteration *I*, attractions $W_k$ are calibrated by multiplying the estimated attraction values on each iteration step with a factor that corrects them in relation to the ratio between the real and estimated space values and regarding the spatial constraints of the available space for each zone. If the estimated space values are lower than the available space, $W_k$ and $\omega_k$ on $I + 1$ corresponds to the calibrated attraction. If the estimated values are higher than the available space in a specific zone, $\omega_k$ values are calculated based on the calibrated result but $W_k$ of $I + 1$ is the $W_k$ of the current *I*.

The attrition parameters $\alpha$ and $\beta$ are adjusted by Hyman's calibration method (Hyman, 1969). For a hypothetical parameter $\gamma$ and iteration *I*:

$$(12) \qquad \gamma_{I+1} = \frac{[(C_{real}-C_{estimated}(\gamma_{I-1}))\cdot\gamma_I-(C_{real}-C_{estimated}(\gamma_I))\cdot\gamma_{I-1}]}{[C_{estimated}(\gamma_I)-C_{estimated}(\gamma_{I-1})]}$$

With $C_{real}$ being the real average costs and $C_{estimated}$ being the model estimated average costs.

The optimum stop condition is activated if the absolute value of both the differences of average costs is lower than the $error_t$ parameter previously defined:

$$(13) \qquad |\,EC_e - C_e| \wedge |\,EC_s - C_s| < error_t\ ;\ stop$$

With $EC_e$ and $C_e$ being the estimated and real average commuting cost, respectively. $EC_s$ is the estimated average cost for the population to have access to services, while $C_s$ corresponds to the real average cost for the population to access to services in a specific zone and $error_t$ is the maximum tolerance to end the iterative cycle.

To prevent an infinite cycle regarding non - convergence, a maximum number of iterations is defined at the start. If the loop does start to exhibit chaotic behavior, the iterations are automatically stopped.

When the maximum number of iterations ($I_{max}$) is lower than the current iteration, or when the equation (13) is achieved, the program outputs the calculated data to a spreadsheet compatible format for further numerical and graphical examination of the given results in compatible spreadsheet and statistical packages. Subsequently, we can save the calibrated model to a MATLAB specific format and store it in the database in order to use the saved data to perform scenario simulation.

### 3.2.2 Scenario Simulation

After we obtain the calibrated model, we can load it in the program to perform a scenario simulation methodology in order to assess the impacts of specific scenarios in the calibrated model in terms of population and employment distribution, average costs and ω values.

The process starts with the loading of a previous calibrated model. Afterwards, the user can perform input modifications for scenario simulation in $E_b$, available space and distance matrix variables. $\alpha$ and $\beta$ are considered static as we consider no change in the region global friction, and $C_e$ and $C_s$ are the calibrated model $EC_e$ and $EC_s$, respectively. Next, the user inputs the maximum number of iterations ($I_{max}$) and the tolerance to stop the iterative process ($error_t$), and the iterative process starts until convergence to new average costs is achieved.

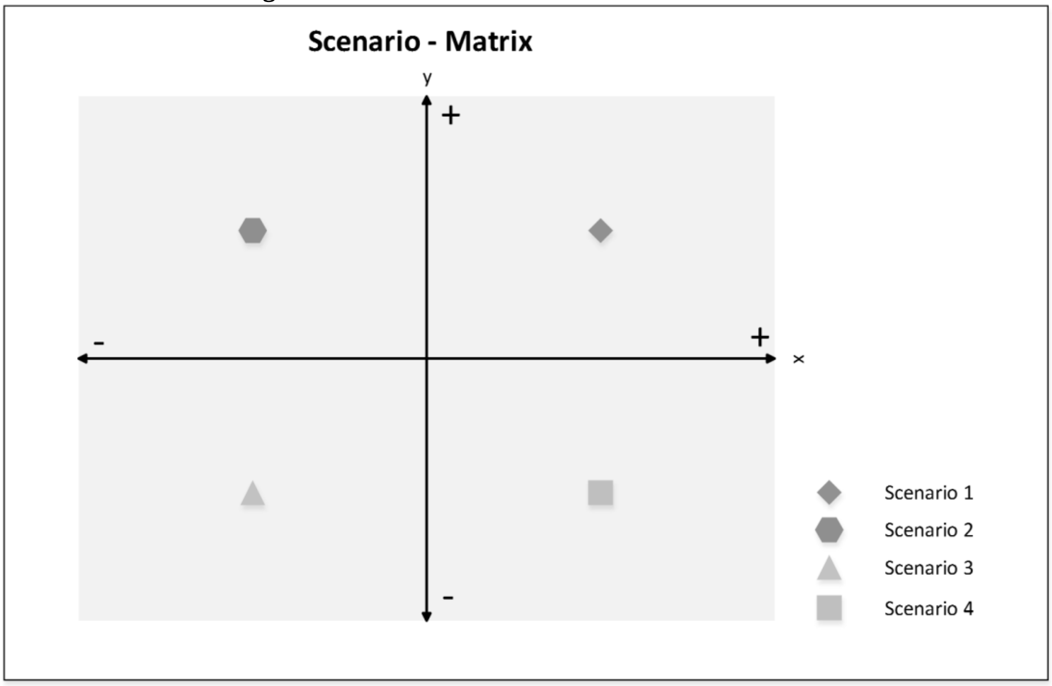
After the simulation, the program outputs a new spreadsheet that directly compares the model calibrated data with the new scenario simulation data, which is useful for intuitively analyzing the possible differences in both calibration and simulation outputs.

### 3.3 Scenario Building – Method of Shell

As Peterson (2003) quotes: *"Scenario planning offers a framework for developing more resilient conservation policies when faced with* *uncontrollable, irreducible uncertainty. A scenario in this context is an account of a plausible future. Scenario planning consists of using a few contrasting scenarios to explore the uncertainty surrounding the future consequences of a decision"*. As a whole, scenarios play an important role in the practice of spatial planning as they help to anticipate to future changes (Couclelis, 2005).

The used scenario building method is a simplification of the method of Shell, created in the 1970's by the oil company Royal Dutch/Shell (Schoemaker, 1992). The Method of Shell begins by defining the topic of interest and the respective trends that have impact on the area in the x and y axis of the scenario-matrix (Figure 2). It is important to define the positive and negative sides of the trend so there will be no mistake about the true meaning of the hypothesized scenarios.

**Figure 2: Scenario – Matrix of the Method of Shell**



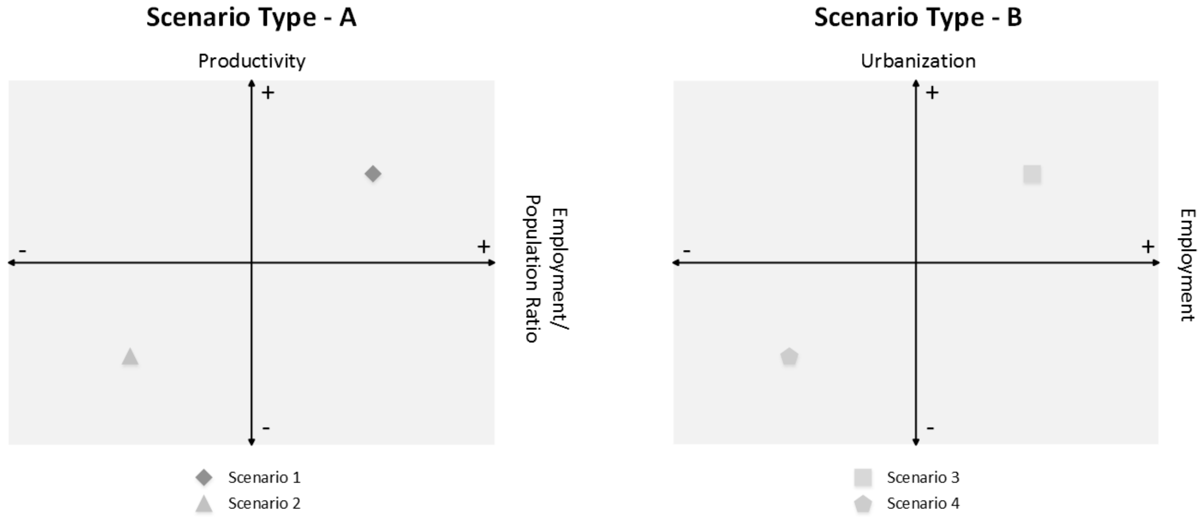

Usually there are four different scenarios projected. However, sometimes we have scenarios that are too similar or unrealistic for this work purposes and, therefore, it is necessary to eliminate them. Therefore, scenarios 2 and 4 from Figure 5 will not be considered in subsequent scenario construction as they would be based in unrealistic spatial and/or economic premises in the context of this work.

We will construct two different types of scenarios for this study. The first type of scenarios (scenario-type A) will have productivity and employment/population ratio as trends, in order to verify the impact of the $E_b$ in the zone of Almelo and in its surroundings. The second type of scenarios (scenario-type B) are driven by trends such as the level of urbanization and employment, for both types of the built scenarios, both trends will be placed alongside the axis of a matrix so both trends will have a negative and a positive axes. Each scenario of each type will be compared with a *status quo* scenario that corresponds to the current situation, which we will call scenario 0.

The type-A scenarios (scenario 1 and 2) assume a simplified theory that the global productivity of a specific zone (y axis) can be positively or negatively modified with a direct change of the $E_b$ in a zone (x axis), which will eventually lead to changes in the economy of the specific zone and surroundings. As $E_b$ is related to the rate of export, an increase of $E_b$ would increase the export per unit of population. This means that the specific zone would produce more money per unit of population, which would express the productivity of the zone. For this type, we considered the affected zone to be Almelo, as it is the main municipality of the region.

The type – B scenarios (scenario 3 and 4) assume that the zones with more population and employment undergo a horizontal or vertical urbanization or de-urbanization process (y axix) with an increase/decrease of allowable space for employment and/or population in one or more zones (x axis). The different types of scenarios are shown on Figure 3. For simplicity purposes, 1 space or employment unit is considered as 1 person.

**Figure 3: Scenario – Matrix for Scenario Type-A and Scenario Type-B**




### 3.2.1 Scenario 1

For scenario 1, it is hypothesized that an increase of 10.000 $E_b$ in Almelo will increase the employment/population ratio to boost the productivity, therefore strengthening the local economy.

### 3.2.2 Scenario 2

For scenario 2, the decrease of 10.000 $E_b$ in Almelo will decrease both employment/population ratio and productivity, which could ultimately weaken the local economy.

### 3.2.3 Scenario 3

In this situation, territorial planning policies in the region opted to reallocate land-use in Almelo due to an increased urbanization of the area of 20.000 space units, therefore increasing the available space in the zone. Excluding the Outerregion, the other five considered zones face a split lowering of the global space of 4.000 space units each. It is assumed that new $E_b$ in Almelo will also increase to 5.000 units after the adjustment.

### 3.2.4 Scenario 4

In scenario 4, a migration from the urban zones to the rural zones is expected due to regional planning policies to reallocate the space in Almelo for the other zones (excluding the Outerregion) as a consequence of a decrease of 5.000 $E_b$ in Almelo. Almelo space also decreases in 20.000 space units, while the other zones have a spatial increase of 4.000 units.

## 3.4 Calculation of $E_b$ and $E_{nb}$

According to Haig (1928), it is possible to calculate $E_b$ by deducting the national or regional percentage of jobs per sector from the local percentage of jobs per sector in the area. For example, when the national norm of employment for agriculture is 5% and the local norm is 8%, then 3% of the employment for agriculture is basic. On the other hand, when the minimal norm of employment per sector for supporting a zone is found, then that value equals the $E_{nb}$. The employment per sector was collected and transformed into percentages by dividing the number of jobs per sector per zone by the total amount of jobs for that zone. The minimum percentage of each sector was multiplied by the total amount of jobs for each zone, which will ultimately lead to the minimum number of jobs needed to support a population. Finally, $E_b$ is calculated by subtracting the $E_{nb}$ from the total employments. Applying this theory to the studied area will lead to the following values in Table 2.

**Table 2: Total of non-basic employment, basic employment and total employment.**

| | $E_{nb}$ | $E_b$ | Total Employment |
|---|---|---|---|
| Almelo | 29.449,80 | 20.896,20 | 50.346,00 |
| Wierden | 5.080,27 | 3.604,73 | 8.685,00 |
| Twenterand | 7.845,91 | 5.567,09 | 13.413,00 |
| Hellendoorn | 9.369,70 | 6.648,30 | 16.018,00 |
| Rijssen-Holten | 11.905,45 | 8.447,55 | 20.353,00 |
| Tubbergen | 5.571,05 | 3.952,95 | 9.524,00 |
| Outerregion | 83.181,37 | 59.021,63 | 142.203,00 |

## 3.5 Calculation of *r* and *s* Parameters

Parameters *r* and *s* represent the inverted activity rate and non-basic activity, respectively. The value of *r* is easily calculated by dividing the total population of the area by the total employment. The value *s* is calculated by dividing the total $E_{nb}$ by the total population. Applying the above mentioned theoretical bases to the area in the Netherlands we obtain, for *r* and *s* parameters, the values equal to 1.62 and 0.36, respectively.

## 3.6 Calculation of Average Distances

Although the average distances can be calculated, it was possible to obtain an estimation of the current average distance for residence-employment and population-services interactions in the defined region, which are 18,08 km and 9,56 km, respectively (CBS, 2012).

## 3.7 Used Data

The inserted workbook data respectful to available space and $E_b$ that were used in the model calibration and scenario simulation functions are illustrated on Table 3. The available space is the sum of the existent space for population and employment. Distance matrix data in km's are illustrated in Table 4. The Outerregion distances were weighted by 2 in order to isolate the area even further by increasing the friction inside the region for people to move outside in search for their jobs and services.

**Table 3: Inserted workbook data used in the model calibration and scenario simulation functions.**

| | Available Space | Basic Employment |
|---|---|---|
| Almelo | 123103 | 20896 |
| Wierden | 32497 | 6648 |
| Twenterand | 46874 | 8447 |
| Hellendoorn | 51814 | 3952 |
| Rijssen-Holten | 57926 | 5567 |
| Tubbergen | 30669 | 3604 |
| Outerregion | 339901 | 59021 |

**Table 4: Distance matrix in km's**

| | Almelo | Wierden | Twenterand | Hellendoorn | Rijssen-Holten | Tubbergen | Outerregion |
|---|---|---|---|---|---|---|---|
| Almelo | 3,1 | 11 | 20 | 20 | 21 | 18 | 82 |
| Wierden | 11 | 3,7 | 14 | 16 | 15 | 24 | 74,2 |
| Twenterand | 20 | 14 | 3,9 | 14 | 27 | 27 | 92,6 |
| Hellendoorn | 20 | 16 | 14 | 4,4 | 21 | 35 | 74,8 |
| Rijssen-Holten | 21 | 15 | 27 | 21 | 3,7 | 34 | 69,8 |
| Tubbergen | 18 | 24 | 27 | 35 | 34 | 4,6 | 101,4 |
| Outerregion | 32,2 | 34,6 | 32,9 | 32,4 | 33,9 | 35,6 | 4,7 |

## 4. RESULTS AND DISCUSSION

### 4.1 Scenario 0

This scenario represents the original calibrated situation of the model for the average distance costs for jobs and services, which are 18.08 and 9.56 km respectively. The outcomes of the calibrated model consist of the $\omega$ and the estimated $E$ and $P$ in the available space previously inserted in the Excel workbook (Table 5 and Figure 4). Table 5 also has data on the estimated space/available space ratio, which is very important in defining $\omega$ values in overpopulated spaces. Residence-employment and population-services matrices are shown in Annex 2. The final $EC_e$ and $EC_s$ are 18.077 km and 9.566 km, respectively.

**Table 5: Outcomes of the calibrated model, including data on initial available space and calibrated estimated space, estimated population, estimated employment and estimated bid-rents. Estimated space/available space ratio was later calculated**

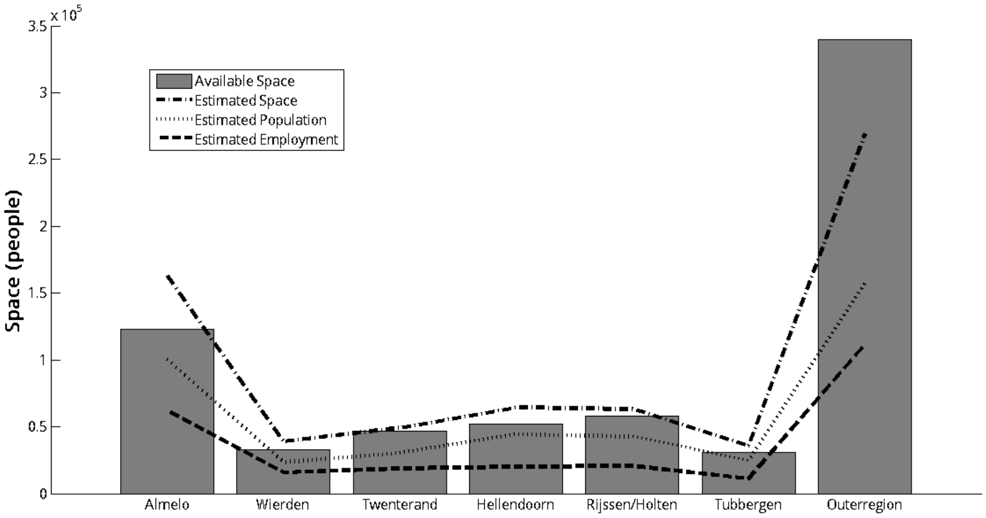
| | Available Space | Estimated Space | Estimated Space/Available Space Ratio | Estimated Population (P) | Estimated Employment (E) | Bid – Rents ($\omega$) |
|---|---|---|---|---|---|---|
| Almelo | 123103 | 162638 | 1.321 | 100153 | 62485 | 12.081 |
| Wierden | 32497 | 38954 | 1.199 | 23373 | 15581 | 10.630 |
| Twenterand | 46874 | 49080 | 1.047 | 30273 | 18808 | 10.927 |
| Hellendoorn | 51814 | 64323 | 1.241 | 44282 | 20040 | 11.383 |
| Rijseen-Holten | 57926 | 63166 | 1.091 | 42507 | 20659 | 11.335 |
| Tubbergen | 30669 | 35657 | 1.163 | 24557 | 11100 | 10.897 |
| Outerregion | 339901 | 268815 | 0.791 | 157001 | 111814 | 12.858 |

The $\alpha$ and $\beta$ calibrated parameters are 0.0313 and 0.0883, respectively. These parameters are related to the inputted real average distance costs and indirectly determine the maximum range area of residence – employment ($\alpha$) and population – services ($\beta$) interactions. When one of these parameters tends to infinity, consumers will tend to go to their nearest appropriate centers (Wilson, 1977; Wilson & Senior, 1974). Higher average residence-employment costs will yield lower $\alpha$ and lower average population – services costs will be represented by higher $\beta$. There is a big confinement of the population in each zone as people are searching for services in their own municipality, with the exception of Wierden. However, when people are searching for their jobs, they are willing to travel further for them, preferably in the municipalities with higher attraction. This ultimately means that people are more willing to get their jobs further away than their search for services. Comparing the available space with the estimated space, we can visualize that there is a higher migration of people to Almelo, and the available space in the zone is surpassed by roughly a third of the available space. Eventually, people will have to pay more to obtain space in Almelo than in the other considered zones.

The residence-employment interactions (Annex 2, Table 1) confirm that Almelo is the economic center of the considered region, as people from the region are willing to get their jobs in Almelo due to a bigger and better offer in terms of jobs. As Hellendoorn and Wierden are close to Almelo and have low $E_b$, this makes them mainly residential areas, while Twenterand and Rijssen/Holten can be considered as secondary economic centers. Some inhabitants from Hellendoorn, Rijssen/Holten and Wierden are also willing to travel to the Outerregion for their jobs. This could be due the fact that Deventer, which is one of the municipalities considered in the Outerregion, is quite closer to these zones. Usually, the Outerregion inhabitants are not willing to travel to their jobs for the considered zones.

Regarding the population – services interactions (Annex 2 – Table 2), the majority of the population in the other zones search for services inside the zone. The exception is Wierden, where inhabitants travel to Almelo for their services due to its proximity and possible lack of services in the zone. The Almelo and Outerregion populations rarely travel to other zones for services (66% and 93%, respectively). However, and discarding the Outteregion, all other zones still have the need to travel to Almelo to complement or strengthen the offer they have in terms of nearby services.

**Figure 4: Plotted data of available space and calibrated estimated space, population and employment per considered zone.**




Finally, regarding the estimated $\omega$ values, and discarding the Outerregion $\omega$ value as the zone is mainly employed as a buffer, Almelo has the highest value of ground than the other considered zones as it has a high estimated space/available space ratio and is the main economic center of the region. Twenterand and Rijssen/Holten are considered as being secondary economic centers, but Twenterand $\omega$ value is lower than Rijssen/Holten. This is due to the estimated space/available space ratio in Twenterand, being lower than in Rijssen/Holten. Hellendoorn has a high $\omega$ value even though it is a residential area, as the estimated space/available space ratio is much higher than other zones excluding Almelo.

## 4.2 Tested Scenarios

In this section, simulation results for each of the four scenarios are illustrated in terms of estimated space and $\omega$ differences for each zone. Differences are measured in relation to scenario 0 and are shown in Figure 5 and 6 for estimated space differences and $\omega$ differences, respectively.

### 4.2.1 Scenario 1

The graphical illustration of the differences in terms of estimated space and estimated $\omega$ values for scenario 1 is illustrated in Figure 5 (a) and Figure 6 (a), respectively. The final $EC_e$ and $EC_s$ are ≈ 18.25 km and 9.55 km, respectively.

The global growth of the region in terms of $E$ and $P$ is 24.000 and 41.000, respectively. There is a big growth in terms of employment in Almelo, with approximately 4.000 new $E_{nb}$ added to the 10.000 new $E_b$. Other zones will also increase their $E_{nb}$ due to the major boost in the economy of the region. The main reason for the increase in the $EC_e$ (18.08 to 18.24) is due to the new employments created in Almelo, as people will be more willing to travel to Almelo to search for their jobs.

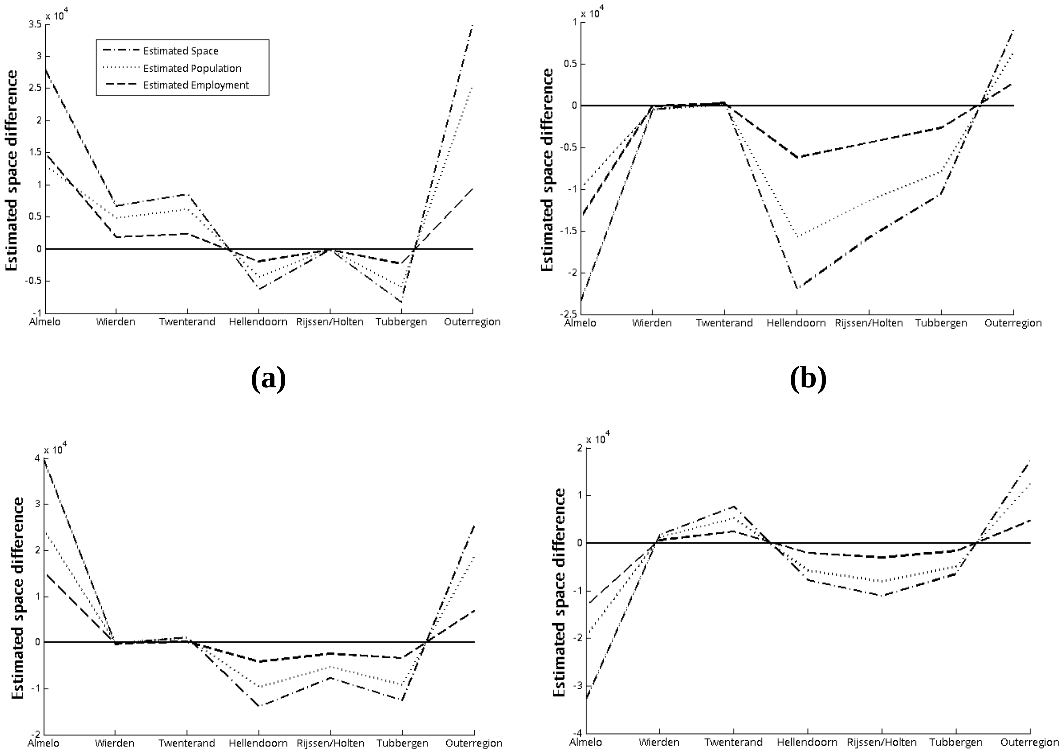
The creation of new $E_b$ in Almelo will have a positive economic impact on the region, with an increase of the $\omega$ in every considered zone. The demand will increase and people from other regions will come to Almelo and nearby zones to settle down due to the newly created jobs, which will boost the value of the land in each of the considered zones.

### 4.2.2 Scenario 2

The graphical illustration of the differences in terms of estimated space and estimated $\omega$ values for scenario 2 is illustrated in Figure 5 (b) and Figure 6 (b), respectively. The final $EC_e$ and $EC_s$ are ≈ 17.70 km and 9.27 km, respectively.

The drawdown of 10.000 $E_b$ from Almelo creates a multiplier effect that originates the loss of roughly 24.000 $E$ and 39.000 $P$ in the considered region. The people that stay in the region will be less willing to travel to Almelo in search for their jobs and services, as reflected in the decrease of $EC_e$ and $EC_s$ after the simulation (17.70 and 9.25, respectively). The zones of Twenterand and Rijssen/Holten face serious drawdowns in terms of $E$ and $P$, which originates available space and suggests that they

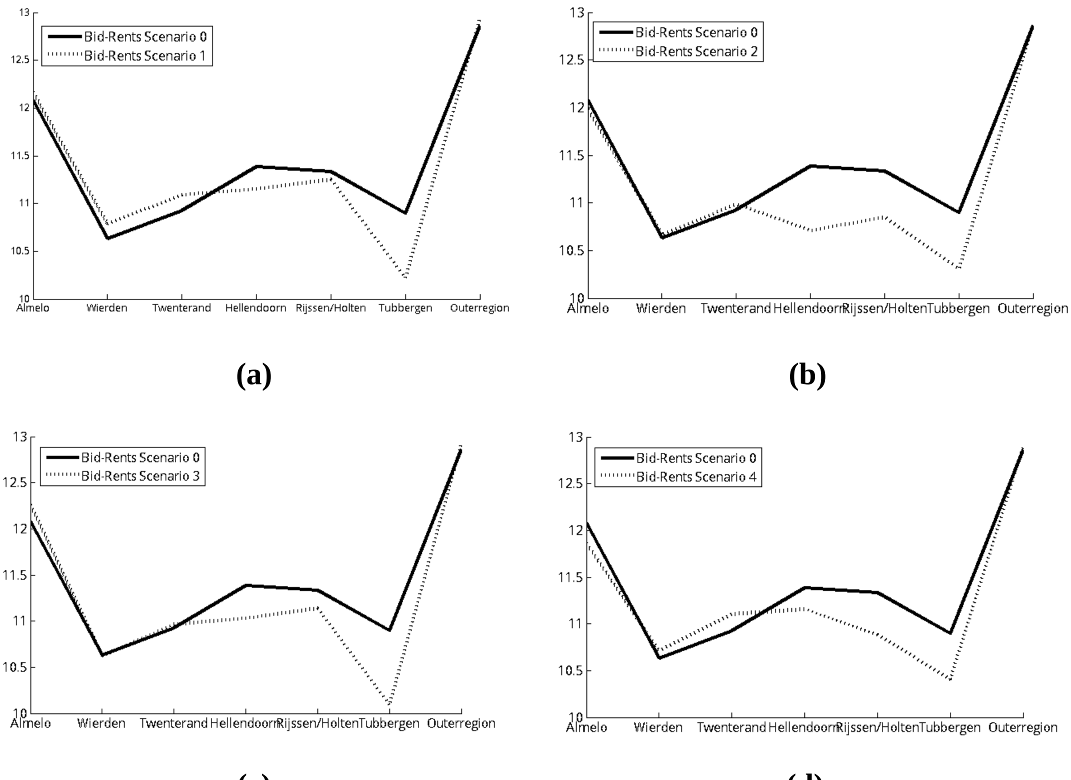
**Figure 5: Difference comparison in terms of estimated space, employment and population for each of simulated scenarios. Differences were assessed in comparison with scenario 0. (a) – Scenario 1; (b) – Scenario 2; (c) – Scenario 3; (d) – Scenario 4.**




**(a)** **(b)**

**(c)** **(d)**

**Figure 6: Difference comparison in terms of bid-rents. Differences were assessed in comparison with scenario 0. (a) – Scenario 1; (b) – Scenario 2; (c) – Scenario 3; (d) – Scenario 4**




**(a)** **(b)**

**(c)** **(d)**

were more dependent of Almelo than the other zones.

The drawdown of 10.000 $E_b$ from Almelo will have an expected negative economic impact on the region, with a decrease of the $\omega$ values in every zone. Due to the available space that is created in the zones of Twenterand and Rijssen/Holten after the drawdown, the $\omega$ value of both zones drastically decreases in comparison with the other zones.

### 4.2.3 Scenario 3

The graphical illustration of the differences in terms of estimated space and estimated $\omega$ values for scenario 3 is illustrated in Figure 5 (c) and Figure 6 (c), respectively. The final $EC_e$ and $EC_s$ are ≈ 18.16 and 9.54, respectively.

The outcome of scenario 3 is very identical to the final scenario 1 estimate, with some small but important differences. Scenario 3 compensates the increase in the residence – employment average cost due to the space reallocation and there are slight differences in the $\omega$ values. Moreover, only 5.000 $E_b$ were created instead of the 10.000 of scenario 1.

Although the other zones have some of their space reallocated to Almelo, their $\omega$ actually increases. This means that the peripheral areas of Almelo actually face a vertical urbanization phenomenon due to the lack of space and suggest that people will offer resistance in moving their residences to Almelo. On the other hand, Almelo $\omega$ value decreases a bit due to new extended available space and resistance from the population from other zones into moving their residences to Almelo. Moreover, and even though the estimated space still surpasses the available space after the simulation, the estimated space/available space ratio is now lower than the *status quo* situation. This might suggest that efficient territory reallocation might balance a region in terms of rents, promoting a sustainable development.

### 4.2.4 Scenario 4

The graphical illustration of the differences in terms of estimated space and estimated $\omega$ for scenario 4 is illustrated in Figure 5 (d) and Figure 6 (d), respectively. The final $EC_e$ and $EC_s$ are ≈ 17.72 and 9.22, respectively.

Some interesting phenomena happen in scenario 4. The $EC_e$ and $EC_s$ are lower than the *status quo* and there is a drawdown of 12.000 total $E$ and 18.000 total $P$. People will be willing to travel less to reach their jobs and services and similarly to scenario 2, the drawdown of 5.000 $E_b$ in Almelo will affect the secondary economic centers (Twenterand and Rijseen/Holten) in terms of total $E$.

As the newly reallocated space to the smaller order regions is not occupied as there is no new allocation of employment and population, the $\omega$ from all zones except Almelo will decrease. Almelo faces an increase because the estimated/available space ratio increases, and stakeholders will have to pay more for the land in Almelo. We may conclude that this creates a big unbalanced economic centralization in the region. This scenario gives a clear indication that a simple reallocation might not be enough for the economy of a region when facing an external cause such as $E_b$ drawdown. It also indicates that $E_b$ should also be reallocated or people need to be stimulated to travel to an economic center by giving them other opportunities (for example, cheaper transport or a new and faster highway).

## 5. CONCLUSION

In this paper, we successfully applied an economic spatial interaction model to the region of Almelo in The Netherlands. By simulating different scenarios that were constructed with the Shell Method, we could ultimately estimate changes in the economy of the region.

Some considerations about the model should be discussed. First of all, there is a clear need of the model in having an external zone. For a geographical region like the Netherlands, there are no geographical or political barriers that lead to isolation of the region in terms of import or export of employment. Therefore, the model should always assume that there is interaction with an external region in case of geographical proximity to avoid system closure, which could ultimately bias the results due to the assumption of a non-realistic current situation. However, and even though the addition of the external region had led to good results, the reliability of the values that were used for this specific area can still be questioned. The values of the Outerregion were only based on the averages of three major surrounding cities and the population and employment of the smaller surrounding towns are not considered. Also, some of the considered regions are geographical closer than others to the major surrounding cities considered in the

Outerregion, which might create some unrealistic patterns that have to be detected and refactored. Finally, as a result of merging three boundary zones, the Outerregion results are overvalued in comparison with other zones. In this case, one should consider the variations between scenarios when assessing the impact on the study considered outer region.

Each of the four hypothetical scenarios have shown very interesting phenomena not only in terms of changes in residence – employment and population – services interactions, but also in terms of territory valuation due to rent and costs variations. Two different types of scenarios were constructed with the aid of The Shell Method. Scenario Type - A concentrated on the economy of a region by adding or subtracting $E_b$ as a result of a massive increase or drawdown of companies, and Scenario Type – B focused in the processes of urbanization or de-urbanization in terms of territory reallocation due to drawdowns in terms of $E_b$ or due to the increase of job opportunities in a specific area.

In both of the negative scenarios (scenarios 2 and 4), the regions of Twenterand and Rijssen/Holten, which could be considered as secondary economic centers, will have a big decrease in the $\omega$ values, which might suggest the urgency of planning countermeasures to attenuate this possibly catastrophic event. Although, it was interesting to observe that efficient boundary reallocation policies might help in counterbalancing the rents of a whole region.

As for future work, there is a clear possibility of integrating the spatial interaction model with the land use aspect, by specifying different types of soil for land use as a sub-zone in each zone, where each soil class will have a predefined suitability for considered economic activities. The calibrated final result and subsequent simulation could be projected with the aid of specialized geographical information system tools. This proposal has already been done in former applications of the model to different areas (Gonçalves & Dentinho, 2007; Silveira & Dentinho, 2009). However, it is still not implemented in MATLAB language, which could ultimately lead to the application of the disaggregated model to national and continental regions due to the unlocking of big spatial constraints regarding matrix operations with previous software. Future studies could also consider transportation or method of transportation with associated costs which might be important in the impact assessment of external factors, public policies or spatial separation structures in the dynamics of disaggregated transportation as well.

In conclusion, it can be affirmed that the developed spatial interaction model has proven its ability and usefulness in predicting the outcome of future scenarios that threaten the regular flows and economy of a specific region. In the future, the rent variations between scenarios can be a useful parameter for the monetary assessment of an impact. Furthermore, this validation enables the possibility of subsequently developing more robust impact measuring methodologies such as integration with land use methodologies and cost benefit analysis based in hedonic models.

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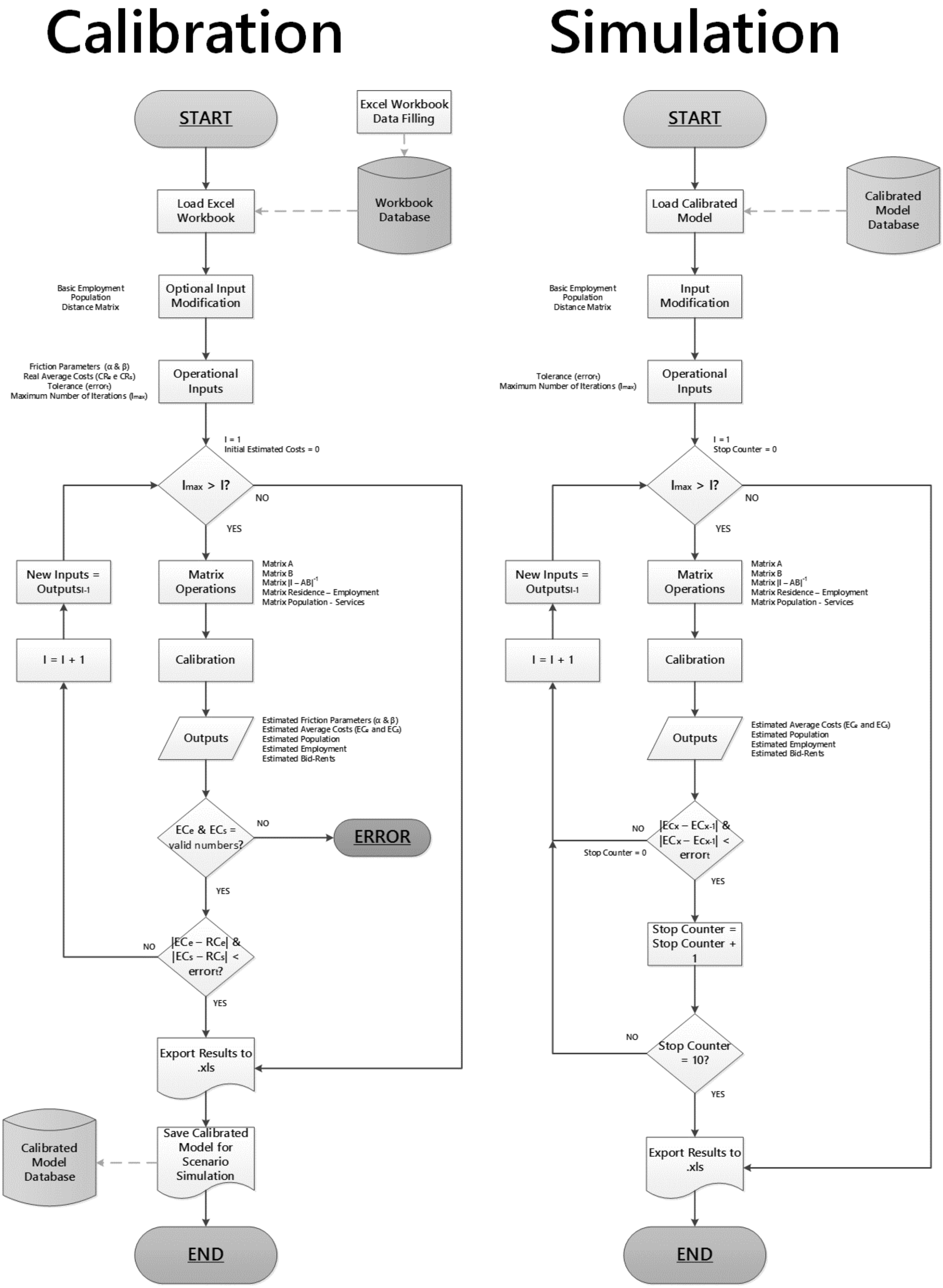
## ANNEX 1 – SPATIAL INTERACTION MODEL FLOWCHART



## ANNEX 2 – SCENARIO 0: RESIDENCE – EMPLOYMENT AND POPULATION-SERVICES INTERACTIONS

**Table 1: Calibrated residence – employment probabilities (in %).**

| | Almelo | Wierden | Twenterand | Hellendoorn | Rijssen-Holten | Tubbergen | Outerregion |
|---|---|---|---|---|---|---|---|
| Almelo | 40.8 | 7.8 | 8.4 | 12.3 | 12.0 | 8.3 | 10.3 |
| Wierden | 31.8 | 9.8 | 10.1 | 13.9 | 14.5 | 6.9 | 13.1 |
| Twenterand | 28.8 | 8.5 | 16.7 | 17.8 | 11.9 | 7.5 | 8.8 |
| Hellendoorn | 26.5 | 7.4 | 11.2 | 22.1 | 13.3 | 5.3 | 14.2 |
| Rijssen-Holten | 26.0 | 7.7 | 7.5 | 13.3 | 23.1 | 5.6 | 16.8 |
| Tubbergen | 35.8 | 7.3 | 9.5 | 10.8 | 11.2 | 17.7 | 7.8 |
| Outerregion | 10.1 | 2.3 | 3.5 | 5.1 | 4.9 | 2.9 | 71.1 |

**Table 2: Calibrated population – services probabilities (in %).**

| | Almelo | Wierden | Twenterand | Hellendoorn | Rijssen-Holten | Tubbergen | Outerregion |
|---|---|---|---|---|---|---|---|
| Almelo | 66.2 | 8.1 | 5.2 | 7.6 | 7.0 | 5.8 | 0.2 |
| Wierden | 39.4 | 18.4 | 10.6 | 13.0 | 14.3 | 4.0 | 0.4 |
| Twenterand | 23.8 | 9.9 | 34.6 | 20.7 | 6.6 | 4.2 | 0.1 |
| Hellendoorn | 21.9 | 7.6 | 13.0 | 44.6 | 10.4 | 1.9 | 0.5 |
| Rijssen-Holten | 21.5 | 8.9 | 4.4 | 11.0 | 51.1 | 2.2 | 0.9 |
| Tubbergen | 38.4 | 5.5 | 6.1 | 4.4 | 4.8 | 40.7 | 0.1 |
| Outerregion | 2.7 | 0.5 | 0.9 | 1.4 | 1.2 | 0.7 | 92.6 |