Innovative Applications of O.R.

Decision support for centralizing cargo at a Moroccan airport hub using stochastic multicriteria acceptability analysis

Abdellah Menou, Abdelhanine Benallou, Risto Lahdelma, Pekka Salminen

1. Introduction

The geographical position of Morocco places it at the heart of important sea, air, rail and motorway transport routes between four different continents. Literature works in the USA have shown the strong link between the economic power of urban areas and the air traffic volume (Ivy et al., 1995; Brueckner, 2002). Many authors have highlighted the structure of the local economy in different works. According to these studies a concentration of certain types of economic activities stimulate more air traffic because of their need for contacts and the high tertiary sector; for example, they generate a large volume of air traffic via business travel. Ivy et al. (1995) demonstrated the close relationship between the number of administrative and ancillary jobs and the level of air traffic.

Tangier Med Port has become the largest port on the Mediterranean Sea. The motorway network and rail connections between this port and Casablanca, as well as connections to the airports in Tangiers, Casablanca and Benslimane provide opportunities for the multimodal shipments of goods that enhance this position. In addition, the various free trade agreements available to Morocco (Europe, USA, the Arab Countries) create a platform for the receiving, packaging and shipping of cargo for airlines and major distributors of goods between Asia, America, Africa and Europe.

The main objective of this study is to provide support for the decision on the location of a centralized air cargo hub. The hub will be located at one of the existing airports in Morocco and will serve the multimodal transport of goods between different continents. The decision process is undertaken by the National Airports Authority of Morocco (ONDA) in cooperation with the Civil Aeronautical Department (DAC) and the Air Bases Department (DBA). The actual decision maker (DM) is the CEO of ONDA. ONDA will provide the airport infrastructure for the hub. External investors will manage the commercial development part of the hub. The decision is based on all the elements and results produced by this study. In this process, the decision depends mainly on the marketing strategy of ONDA and its relationship to the potential developers of hub logistics. ONDA needs to justify the validity of the decision process and its conclusions towards the investors. On the basis of this study, ONDA should be in the position to present crucial factors to attract potential investors.

In this study we perform detailed analysis on nine alternative locations. The choice between them depends on different socio-economic criteria, the geographical location, and the environmental impacts, which are measured in terms of six criteria. Since different alternatives have different advantages and disadvantages with respect to different criteria, and different stakeholders may have different opinions on the relative importance of different
criteria, this problem is a typical multiple criteria decision aiding (MCDA) problem.

We applied Stochastic Multicriteria Acceptability Analysis (SMAA) in this study. For recent real-life MCDA location problems applying different methodologies, see e.g., Feng et al. (2010) and Mateus et al. (2008). The DM considered SMAA suitable, because it can handle flexibly different kinds of incomplete information present in the problem. Some of the criteria were measured quantitatively, while for others only qualitative (ordinal) assessment was feasible. Significant uncertainty or impreciseness was present in the criteria measurements. Furthermore, reliable and up-to-date preference information was not available for all criteria and from all stakeholders. SMAA allows the representation of such a mixture of different kinds of uncertain, imprecise and partially missing information in a consistent way using probability distributions. The analysis is based on a stochastic simulation of the uncertain information and the collecting of statistics on the performance of different alternatives, on the basis of an assumed decision model. Missing preference information can be treated in SMAA with what is called inverse weight space analysis in order to identify the preferences that favor each alternative. In general, the results of the analysis describe the conditions that make each alternative the most preferred one, or give it a particular rank.

The idea of weight space analysis was introduced by Charnetski (1973) and Charnetski and Soland (1978). Their method could handle preference information in the form of linear constraints for the weights, but was restricted to deterministic criteria measurements and an additive utility function. A more versatile approach to handling incomplete preference information is to represent the preferences by suitable distributions. Examples of such methods include the overall compromise criterion method by Bana e Costa (1986), and the stochastic multicriteria acceptability analysis (SMAA) methods. The SMAA methods handle imprecise, partly missing, or conflicting weight information by exploring the weight space in order to describe what weights, if any, make an alternative most preferred. During the analysis, both criteria measurements and weights are constrained by their distributions. Related simulation approaches for analyzing multicriteria problems with different kinds of incomplete information include, for example, those by Stewart (1993, 1995, 1996), Butler et al. (1997), Durbach and Stewart (2008), García et al. (2009) and Jiménez et al. (2009).

Different variants of SMAA exist. In the original SMAA method by Lahdelma et al. (1998) the analysis was performed on the basis of an additive utility or value function and stochastic criteria data to identify for each alternative the weights that made it most preferred. SMAA-2 by Lahdelma and Salminen (2001) generalized the analysis to apply a general utility or value function, to include various kinds of preference information and to consider holistically all ranks. SMAA-3 (Lahdelma and Salminen, 2002) is based on pseudocriteria in the way of the ELECTRE III decision-aid (see, e.g., Roy, 1978, 1996; Vincke, 1992). Instead of a value function, SMAA-D (Lahdelma and Salminen, 2006) applies the efficiency score of Data Envelopment Analysis (DEA). The SMAA-O method (Lahdelma et al., 2003) extended SMAA-2 for treating mixed ordinal (qualitative) and cardinal criteria in a comparable manner. The Ref-SMAA and SMAA-A methods (Lahdelma et al., 2005; Durbach, 2006, 2009a) compare the alternatives by applying Wierzbicki’s achievement scalarizing functions. Different ways to represent dependent uncertain criteria are presented in Lahdelma et al. (2006, 2009). Recent developments include SMAA-P (Lahdelma and Salminen, 2009) based on the piecewise linear prospect theory, SMAA-TRI (Tervonen et al., 2009) for sorting problems, based on ELECTRE-TRI (Yu, 1992), and an application of SMAA for descriptive decision analysis (Durbach, 2009b). The efficient implementation and computational efficiency of the SMAA methods have been described in Tervonen and Lahdelma (2007). For a survey on the different SMAA methods and applications, see Tervonen and Figueira (2008). Because the problem at hand contains a mixture of qualitative and quantitative information, we decided to apply the SMAA-O method.

2. Problem description

Centralizing multimodal cargo is very actual issue for Morocco. Although domestic cargo traffic has declined recently, international cargo tonnage has increased (see Appendices A and B). The decline in domestic cargo traffic is caused by several factors, including the annual agricultural crop levels and the level of air cargo tariffs. The average annual growth of international cargo tonnage has increased (see Appendices A and B). Although domestic cargo traffic has declined recently, international cargo tonnage has increased (see Appendices A and B). The average annual growth of international cargo tonnage was only 1.8% during the period 1995–2005; however, over the last five years it increased in volume at the average annual rate of 3.8%.

2.1. Selecting the alternatives

To determine the potential alternative sites for analysis, we first performed a rough analysis of all 16 national and international Moroccan airports listed in Table 1. Both large and small cities can be favorable locations for the air cargo hub. The high competence level and versatile economic structure around larger cities is boosted by the hub. But also small cities can benefit from the strong growth potential of air cargo and from the competition it causes. Other important factors for locating the hub are the con-

<table>
<thead>
<tr>
<th>Airport</th>
<th>Current traffic</th>
<th>Connectivity by road</th>
<th>Connectivity by rail</th>
<th>Freight potential</th>
</tr>
</thead>
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<tr>
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<td>xx</td>
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<td>xxx</td>
</tr>
<tr>
<td>Al Hoceima</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benslimane</td>
<td>x</td>
<td>xx</td>
<td>xxx</td>
<td>xxx</td>
</tr>
<tr>
<td>Casablanca</td>
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<td>xxx</td>
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<td>xxx</td>
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<td>Dakha</td>
<td>x</td>
<td></td>
<td>xxx</td>
<td>xxx</td>
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<tr>
<td>Errachidia</td>
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<td></td>
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<td></td>
<td>xxx</td>
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<tr>
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<td></td>
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<td>Marrakesh</td>
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<td>Ourzazate</td>
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<td></td>
<td></td>
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<tr>
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<td></td>
<td>xx</td>
<td>xxx</td>
</tr>
<tr>
<td>Rabat</td>
<td>xx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
</tr>
<tr>
<td>Tangier</td>
<td>xx</td>
<td>xxx</td>
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<td>xxx</td>
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<tr>
<td>Tetouan</td>
<td>xx</td>
<td></td>
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</tr>
</tbody>
</table>
nections with other transportation networks and logistic services. In the initial selection of most promising alternatives we therefore consider the following factors:

- Current passenger and freight traffic volume.
- Connectivity to existing road transport networks.
- Connectivity to existing rail transport networks.
- Freight traffic potential.

These factors are evaluated in Table 1 by assigning to the alternatives from 0 to 3 x-marks, where “xxx” is the highest (best) level. The initial selection of alternatives included the principal city airports of Agadir, Casablanca, Fez, Marrakesh, Oujda, Rabat, and Tangier. These locations have received eight or more x-marks. In addition, Benslimane was included due to its high freight potential. Dakhla was included in the list of alternatives because it is a major airport in southern Morocco. The location of these sites is given in Fig. 1. Almost all of the air cargo in Morocco (nearly 98%) is carried through these airports. The majority of these cities are already connected to the highway network (Casablanca, Rabat, Benslimane, Tangier and Fez). Some of them will be linked to it shortly (Agadir, Marrakesh, Oujda). This factor is particularly important because the cargo airport must be served well by the road network.

2.2. Criteria

The decision of locating an infrastructure as important as a freight airport must take into account several parameters and must answer many questions, such as:

1. Which traffic operators serve the potential sites, how frequently do they operate and what is their reliability?
2. What transport infrastructure is available?
3. What is the quality and reliability of the multimodal chain?
4. How versatile are the transport options?
5. Can the operators deliver urgent orders quickly and at a low cost?
6. Are there logistic service companies that can manage the whole or part of the distribution chain?
7. What is the availability of land for warehouses?

The location decision is influenced by both qualitative and quantitative factors. Among the important factors, we consider

1. the cost and availability of utilities;
2. the air, rail, highway and waterway systems;
3. the proximity to suppliers and to markets for rapid access (time-based competition), perishable products, transport costs;
4. the size of the markets;
5. the cost of land (construction or rental) and operations;
6. the distances (or costs) between sites and
7. the volumes of goods to be shipped.

When formalizing the above questions and factors into criteria, it is important to construct a model that takes into consideration different interests, such as those of the airlines, manufacturers, ONDA and the environment. The resulting set of criteria used in this study is listed as follows:

<table>
<thead>
<tr>
<th>INVEST</th>
<th>Investment cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROXIMITY</td>
<td>Proximity to producers</td>
</tr>
<tr>
<td>POTENTIAL</td>
<td>Potential of the site</td>
</tr>
<tr>
<td>TRANSPORT</td>
<td>Transport cost</td>
</tr>
<tr>
<td>SERVICE</td>
<td>Service level</td>
</tr>
<tr>
<td>ENVIRON</td>
<td>Environment</td>
</tr>
</tbody>
</table>

The criteria measurements are based on the statistics available from ONDA (ONDA, 2007), the Ministry of Transport (cost of transport between cities), and reports of studies by the World Bank (environmental impacts, in a study conducted for the Ministry of Water and Environment (BMME, 2006), and CETMO (Cisse, 2007)).

The INVEST (Investment cost) criterion is based on the costs estimated by ONDA for the terminal with a 30,000 m² station area.

![Fig. 1. Alternatives proposed as potential location sites.](image-url)
planned for the Mohamed V airport. The total cost of that facility is estimated to be 132 million DH. These costs were converted for the other locations by using the local construction costs per square meter in the region of Casablanca (Menou et al., 2007), and the other regions. The investment costs were then mapped to a linear scale.

The PROXIMITY (Proximity to producers) criterion was assessed qualitatively by the DM because it is difficult to quantify. The Casablanca region accounts for 50% of domestic industry, but high-tech industries such as electronics, aerospace, automotive, are all based in this region. The subregion covers the majority of agricultural production; 50% of all exports of fruit, flowers and fish come from this region. Casablanca is best on this criterion, followed by Agadir on rank level 2, Benslimane and Tangier sharing rank level 3, and then Rabat, Marrakesh, Fez, Oujda and Dakhla on levels 4–8.

The POTENTIAL (Potential of the site) criterion is quantified by using the results of the method of center of gravity. The potential of each site is determined on the basis of how close it is to the optimal (most central) point. The center of gravity method is used for locating a single facility that considers existing facilities, the distances (or costs) and the volumes of goods to be shipped between them. This methodology involves formulas used to compute the coordinates of the two-dimensional point that meets the distance and volume criteria stated above.

The center of gravity location is the weighted average of the X and Y coordinates. This method approximately minimizes the transportation cost.

\[ C_x = \frac{\sum d_i x_i}{\sum Q_i}, \quad C_y = \frac{\sum d_i y_i}{\sum Q_i}, \]  

where \( C_x \) and \( C_y \) are the X and Y coordinates of the facility one wants to locate, \( d_i \) is the coordinate of location \( i \), and \( Q_i \) is the volume of goods moved to or from location \( i \).

The TRANSPORT (Transport cost) criterion is based on the distances from each site to the other sites as shown in Table 2. The bottom row shows the sum of the distances to different sites. The total distances are then multiplied by the transport cost of 1.5 DH per ton-km per ton, determined by the Ministry of Transport (REG-MED, 2004).

To compute the TRANSPORT criterion, we apply the Hub Location Problem (HLP) (see Alumur and Kara, 2008). Cargo must be transported from different origin nodes \( i \) to destination nodes \( j \). The direct link between each origin–destination pair is impossible to establish or too expensive. Hubs will act as consolidation, switching and distribution centers for traffic. They enable economies of scale resulting in lower transportation costs. The hubs are fully interconnected and non-hub nodes can be linked directly to one hub. The demand is expressed in terms of flow between the nodes and the transportation cost between hubs is supposed to be lower than between two ordinary nodes. The general HLP model for locating \( P \) hubs is a mixed integer linear programming (MILP) model where the objective is to minimize total shipping costs:

\[ C_{total} = \sum_{ij} \sum_{kj} w_{jk} \left( \sum_{i \in I} c_{ij} y_{ij} + \sum_{m \in M} c_{im} y_{im} + 2 \sum_{i \in I} c_{ij} y_{ij} \right), \]  

subject to

\[ \sum_{kj} z_{k} = P, \]
\[ \sum_{ij} y_{jk} = 1, \quad \forall j \in J, \]
\[ y_{jk} \leq z_{k}, \quad \forall j, k \in J. \]

where \( J \) is the set of nodes, \( P \) is the number of hubs to be located, \( w_{jk} \) is the flow between nodes \( j \) and \( k \), \( c_{jk} \) is the unit cost of transport between nodes \( j \) and \( k \), and \( z \) is a transfer cost coefficient between hubs \((0 < z < 1)\). The binary decision variable \( y_{jk} \) equals 1 if the flow of node \( j \) is shipped to hub located at \( k \) and 0 otherwise. The binary decision variable \( z_{k} \) equals 1 if a hub is located at node \( k \) and 0 otherwise. In our case we are locating a single hub \((P = 1)\), and to compute the TRANSPORT criterion we assign \( z_{k} = 1 \) in the model for each airport in turn.

The SERVICE (Service level) criterion is calculated on the basis of infrastructure data provided by the Ministry of Transport. Here we considered the service level of the site, railroad connections, and highway connections between the airport and the city center. Next, we evaluated the service level of each alternative on a linear scale from excellent down to very low.

The ENVIRON (Environment) criterion is assessed qualitatively by the DM on the basis of environmental reports on the different sites. The alternatives Benslimane, Dakhla and Marrakesh are considered best on this criterion, and they share the first rank. They are followed by Agadir on level 2, Rabat and Tangier sharing level 3, Fez on level 4, and Casablanca on the lowest level.

Table 3 summarizes the criteria measurements for all alternatives. A ±10% uncertainty is assumed for the cardinality measured criteria INVEST, POTENTIAL, TRANSPORT and SERVICE.

### 3. Analysis methodology

We analyze the problem using Stochastic Multicriteria Acceptability Analysis (SMMA). SMMA is based on simulating uncertain criteria and preferences and collecting statistics on the performance of each alternative. The results obtained from the analysis are descriptive. The DMs are given rank acceptability indices for each alternative, describing the variety of different preferences that support an alternative for the best rank or any particular rank. This information can be used to classify the alternatives into more or less acceptable ones and those that are not acceptable at all. SMMA also computes central weights describing typical preferences.
that make an alternative the most preferred one. It is also possible to measure with confidence factors whether the problem data is accurate enough for decision-making.

Consider an MCDM problem with m alternatives measured in terms of n different criteria. SMAA-O is based on an assumed additive utility function

\[ u(x_i, w) = \sum_{j=1}^{n} w_j u_j(x_{ij}), \quad w \in W, \]  

(3)

where the vector of weights w represents the preferences of the DM, \( x_i \) is the ith alternative, and \( x_{ij} \) is the criteria measurement of the ith alternative with respect to the jth criterion. For cardinal criteria, the criteria measurements are assumed to be stochastic values following some assumed or estimated distribution, such as a uniform or normal distribution. For ordinal criteria, the criteria measurements are assumed to be stochastic values following some assumed or estimated distribution, such as a uniform or normal distribution. For ordinal criteria, the criteria measurements are assumed to be stochastic values following some assumed or estimated distribution, such as a uniform or normal distribution.

The rank acceptability index is a measure of the variety of different valuations granting alternative \( x_i \) rank \( r \), and is computed as a multidimensional integral over the criteria distributions and the favorable rank weights using

\[ b'_i = \int_{x} f(\xi) \int_{W'_i(\xi)} f(w) dw \, d\xi. \]

(7)

The rank acceptability indices can be examined graphically in order to compare how different varieties of weights support each rank for each alternative. The candidates for the most acceptable alternatives should be those with high (clearly non-zero) acceptabilities for the first rank. When seeking compromises, alternatives with high acceptability for the worst ranks should be avoided. However, the acceptability indices should not be used for ranking acceptable alternatives, because the magnitude and mutual order of the acceptability indices depend on the chosen (assumed) distributions and scaling of criteria.

The central weight vector \( \mathbf{w}^* \) is the expected center of gravity of \( W'_i(\xi) \) (favorable first rank weights). The central weight vector is computed as an integral of the weight vector over the criteria and weight distributions by

\[ \mathbf{w}^* = \int_{x} f(\xi) \int_{W'_i(\xi)} f(w) \, dw \, d\xi / b'_i. \]

(8)

With the assumed weight distribution, the central weight vector represents the preferences of a typical DM supporting alternative \( i \). The central weights can be presented to the DMs in order to help them understand what preferences correspond to the different choices. Furthermore, the central weights are used to compute the confidence factor. The confidence factor \( p'_i \) is the probability of alternative \( i \) obtaining the best rank when the central weight vector is chosen. The confidence factor determines whether the criteria data are accurate enough to discern the alternatives. The confidence factor is computed as an integral over the criteria distributions \( \xi \) by

\[ p'_i = \int_{\xi} f(\xi) \int_{W'_i(\xi)} f(w) \, dw \, d\xi. \]

(9)

In practice the multi-dimensional integrals are computed numerically through Monte-Carlo simulation. In the simulation, the stochastic criteria measurements and weights are drawn from their corresponding distributions, the decision model is applied to rank the alternatives, and statistics on the performance of the different alternatives is collected.

### Table 3

Criteria measurements for alternatives.

<table>
<thead>
<tr>
<th>Alt</th>
<th>INVEST(max)</th>
<th>PROXIMITY(min)</th>
<th>POTENTIAL(max)</th>
<th>TRANSPORT(max)</th>
<th>SERVICE(max)</th>
<th>ENVIRON(min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agadir</td>
<td>70</td>
<td>2</td>
<td>165</td>
<td>644</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>Benslimane</td>
<td>80</td>
<td>3</td>
<td>560</td>
<td>3718</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>Casa</td>
<td>65</td>
<td>1</td>
<td>585</td>
<td>3621</td>
<td>80</td>
<td>5</td>
</tr>
<tr>
<td>Dakhla</td>
<td>80</td>
<td>8</td>
<td>82</td>
<td>600</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Fez</td>
<td>70</td>
<td>6</td>
<td>385</td>
<td>2872</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>Marrakech</td>
<td>65</td>
<td>5</td>
<td>379</td>
<td>2589</td>
<td>45</td>
<td>3</td>
</tr>
<tr>
<td>Oujda</td>
<td>75</td>
<td>7</td>
<td>82</td>
<td>663</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Rabat</td>
<td>65</td>
<td>4</td>
<td>542</td>
<td>3718</td>
<td>45</td>
<td>3</td>
</tr>
<tr>
<td>Tangier</td>
<td>70</td>
<td>3</td>
<td>357</td>
<td>1915</td>
<td>60</td>
<td>3</td>
</tr>
</tbody>
</table>

Uncertainty ±10% Ordinal ±10% ±10% ±10% Ordinal ±10% ±10% ±10% Ordinal

\[ W'_i(\xi) = \{ w \in W : rank(\xi_i, w) = r \}. \]

(6)

The favorable rank weights are simply the (stochastic) set of weights that result in rank \( r \) for an alternative. All descriptive measures are then computed as properties of \( W'_i(\xi) \).

The rank acceptability index \( b'_i \) is the expected volume of \( W'_i(\xi) \). The rank acceptability index is a measure of the variety of different valuations granting alternative \( x_i \) rank \( r \), and is computed as a multidimensional integral over the criteria distributions and the favorable rank weights using

\[ b'_i = \int_{x} f(\xi) \int_{W'_i(\xi)} f(w) \, dw \, d\xi. \]

(7)
4. Results

In the following section we analyze the problem assuming an additive utility/value function and without preference information. The cardinal criteria measurements given in Table 3 are scaled in the utility function so that the worst value is 0 and best value is 1. Uniform distributions with ±10% uncertainty around the original values in Table 3 are used in the computation. Ordinal criteria are treated as described in the previous section.

Table 4 and Fig. 2 show the rank acceptability indices for the alternatives. The rank acceptability indices show how large a share of the different preferences (weights) support an alternative for a particular rank. To make the results more readable, the alternatives are sorted lexicographically according to their rank acceptability indices. The results show that Benslimane and Casablanca are the most promising alternatives for the first rank, because they are supported for the first rank by 70% and 29% of the different preferences (weights). These alternatives also obtain the highest acceptability indices for the second rank (24% and 33%, correspondingly). Dakhla receives third rank with 1% of the preferences, and the other alternatives obtain less than 0.5% acceptability for the first rank. These results indicate that none of them is very likely to be the most preferred alternative, on the basis of the assumed decision model. However, without preference information, we cannot eliminate them, as it is possible (though unlikely) that the DM’s preferences actually favor these. For this reason we analyze the problem further.

Fig. 3 and Table 5 present the central weights for the alternatives. The central weights are the typical (average) weights that can make an alternative most preferred. From the central weights we can see that the Benslimane and Casablanca alternatives are favored by weights that are fairly uniformly distributed among the different criteria. Benslimane would be the choice if a little more emphasis is placed on INVEST and ENVIRON criteria, while Casablanca would be the choice if PROXIMITY and SERVICE are considered more important. For the other alternatives we can point out that the alternatives Oujda, Fez and Dakhla are favored by an extremely high (over 50%) weight on the INVEST criterion, Rabat is favored by much weight on TRANSPORT, and Marrakesh is favored by much weight on ENVIRON.

In Table 5 we can also see the confidence factors. The confidence factors represent the probability for an alternative to be most preferred if the DM’s preferences coincide with the central weights. The confidence factors indicate that with suitable preferences, Benslimane can be chosen with 100% confidence and Casablanca with 96% confidence. This means that the criteria measurements are already accurate enough for choosing between these two alternatives, if sufficiently accurate preference information can be obtained.

The confidence factors for the other alternatives are quite low. For example, Dakhla has the confidence factor of 18%, which means that even with perfect (and non-conflicting) preference information coinciding with the central weights, Dakhla would still be very unlikely as the most preferred alternative. For the remaining alternatives, the confidence factors are even lower. One of these alternatives could potentially be chosen only if more accurate criteria and weight information is collected and all that information hap-

Table 4

<table>
<thead>
<tr>
<th>Alt</th>
<th>b1</th>
<th>b2</th>
<th>b3</th>
<th>b4</th>
<th>b5</th>
<th>b6</th>
<th>b7</th>
<th>b8</th>
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<td>Benslimane</td>
<td>72</td>
<td>23</td>
<td>4</td>
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<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
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<td>Casablanca</td>
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<td>8</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Dakhla</td>
<td>1</td>
<td>7</td>
<td>6</td>
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<td>5</td>
<td>7</td>
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<td>15</td>
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<tr>
<td>Tangier</td>
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<td>17</td>
<td>27</td>
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<td>16</td>
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<td>1</td>
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<tr>
<td>Fez</td>
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<td>19</td>
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Fig. 2. Rank acceptability indices for alternatives in lexical order.
pens to favor the alternative. The very low confidence factors (<5\%) together with very low (first rank) acceptability indices (<0.5\%) suggest that it is safe to eliminate the alternatives Tangier, Rabat, Oujda and Fez from any further analyses.

5. Discussion

SMAA has earlier been applied in different public and private decision problems. In past applications there has been great variability in the organizations responsible for the decision process, the legislation regulating the process, the number of decision makers, stakeholder groups, and public participation in the process. The current application requires heavy investments, and the choice is difficult politically and strategically. The CEO of ONDA has full authority to make the decision. However, he must still consider different stakeholders’ points of view and find a widely acceptable location for the hub. The choice should also be robust with respect to different uncertainties.

The problem had been studied earlier with different sets of alternatives and criteria (Cisse, 2007). These analyses identified Casablanca as the ‘optimal’ location for the air cargo hub followed by Tangier and Rabat. However, no decision was made based on these analyses, because it was considered necessary to broaden the analysis with additional alternatives and criteria. For example, the Environment criterion was omitted in the earlier analyses, because it could not be measured quantitatively. Also the smaller airports at Benslimane and Dakhla were not included. The idea to apply SMAA for this problem was proposed by the CEO of ONDA at the 66th meeting of the EWG-MCDA meeting that was organized in October 2007 at Marrakech. With SMAA it was possible to include criteria that could only be measured ordinally. Also, in the lack of quantitative preference information from different stakeholder groups, SMAA allowed performing an impartial and balanced analysis without preference information. This was needed to convince the different stakeholders about the validity and transparency of the choice process.

The SMAA method was found suitable and easy to use for the current problem. Overall, the results of the analysis were clear and helpful for the DM. After discussion with stakeholders, they were convinced that Benslimane is a good and robust location for the hub.

6. Conclusions

A real-life application of MCDA in selecting the location for centralizing cargo at a Moroccan airport hub was described. Nine different alternative locations were evaluated in terms of six criteria. Significant uncertainty or imprecision was present in the criteria measurements, and quantitative weight information was not available at this phase. The problem was analyzed using SMAA.

The results indicated that two of the alternatives, Benslimane and Casablanca, were superior to the others on the basis of the applied decision model. The choice between these two alternatives depends on how the different criteria are weighted. Casablanca Airport CMN is currently the largest air logistic platform in Morocco, but it is expected to reach its capacity limit in year 2015. Therefore, Benslimane airport was chosen as the first choice for centralizing the Moroccan air cargo and developing a good logistic platform. On the basis of this study, ONDA has developed a marketing plan and started negotiations with an investor from the United Arab Emirates.
Appendix A. Annual domestic and international air cargo (Metric Tons)

Source: ONDA and ICAO.

Appendix B. Directional Air Cargo Flows for Morocco (Metric Tons), 2000–2005

Source: ONDA and ICAO.

References

Cisse, Kh., 2007. Air cargo centralization in a major Moroccan airport with efficient connections to the road transport network. ETHP, Universitat Politècnica de Catalunya (UPC), Mémoire d’Ingénieur d’Etat, p. 118.
Cissé, Kh., 2007. Air cargo centralization in a major Moroccan airport with efficient

représentation floue des préférences en présence de critères multiples.
Publishers, Dordrecht.
Stewart, T., 1993. Use of piecewise linear value functions in interactive multicriteria
decision support. Management Science 39 (11), 1369–1381.
Stewart, T., 1995. Simplified approaches for multicriteria decision making under
Stewart, T., 1996. Robustness of additive value function methods in MCDM. Journal
of Multi-Criteria Decision Analysis 5 (4), 301–309.
Tervonen, T., Figueira, J.R., Lahdelma, R., Almeida-Dias, J., Salminen, P., 2009. SMAA-
TRI: A stochastic method for robustness analysis in sorting problems. European
Tervonen, T., Lahdelma, R., 2007. Implementing stochastic multicriteria
acceptability analysis. European Journal of Operational Research 178 (2), 500–
513.
Yu, W., 1992. Aide multicritère à la décision dans le cadre de la problématique du tri: