Strategic Decision Support for Brownfield Redevelopment

Ye Chen\textsuperscript{a}, James A. Wittmer\textsuperscript{b} Keith W. Hipel\textsuperscript{a,}, D. Marc Kilgour\textsuperscript{c}

Abstract—A strategic decision support procedure is developed for brownfield redevelopment planning and demonstrated with a practical case study. The procedure contains both higher and lower levels of strategic decisions. The higher-level strategic decision is designed to assess the feasibility of a specific brownfield redevelopment. A well-known business strategic planning tool, SWOT analysis, is adapted to help decision makers (DMs) to identify the strengths, weaknesses, opportunities, and threats involved in implementation of a brownfield redevelopment. The lower-level strategic decision is meant to find the best brownfield redevelopment solution. Several multiple criteria decision analysis tools are employed to assist DMs to evaluate brownfield redevelopment designs using economic, social and environmental criteria. Finally, a practical case study is carried out to demonstrate the proposed procedure.

I. INTRODUCTION

The U.S. Environmental Protection Agency defines brownfield sites as “real property, the expansion, redevelopment, or reuse of which may be compelled by the presence or potential presence of a hazardous substance, pollutant, or contaminant” [16]. The online encyclopedia Wikipedia [19] states that “brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination.” Within Canada, the National Roundtable on the Environment and the Economy [15] noted that “Brownfields are the legacy of a century of industrialization. They are abandoned, idle or under-utilized commercial or industrial properties where past actions have caused known or suspected environmental contamination, but where there is an active potential for redevelopment.”

Brownfields exist in very large numbers and pose serious environmental and health risks in industrialized countries around the globe. For example, the United States is believed to contain between 500,000 and 1,000,000 brownfield sites, and Germany about 362,000 [15]. Canada may have up to 30,000 brownfields, including the sites of almost-forgotten industrial and commercial facilities such as coal gasification plants, locations where toxic substances were used or stored, former gas stations, and abandoned mining operations [7].

The restoration of brownfield sites provides a range of economic, social, and environmental benefits to stakeholders [15]. Economically, brownfield redevelopment has a total output multiplier of 3.8, one of the highest impacts measured in Canada [15]. Other economic benefits include development of exportable restoration technologies, expansion of the tax base for all levels of government, and creation of employment opportunities. From a social perspective, brownfield restoration can improve quality of life, eliminate health threats, and furnish land for housing. Finally, environmental benefits of brownfield redevelopment include restoration of environmental quality, improvement of air and water, and reduction of expansion pressure from urban centers into surrounding greenfields.

Brownfield redevelopments must be considered as complex systems and a multidisciplinary approach in the study of brownfields is mandatory from a scientific point of view [9]. Much research has been conducted in recent years to investigate various issues involving brownfield redevelopments including remediation technologies, environmental assessment, risk assessment and management, financial arrangements as well as community and public involvements. For example, [3] is the proceedings of the third international conference on prevention, assessment, rehabilitation and development of brownfield sites, and contains the latest studies of brownfields redevelopment.

In this paper, a strategic decision support procedure is proposed for brownfield redevelopment planning and demonstrated with a practical case study. Section II summarizes the key elements of brownfields redevelopment and describes the basic steps for implementations. Section III proposes the strategic decision support procedure and a practical case study is explained in Section IV.

II. BROWNFIELD REDEVELOPMENT SYSTEM

Considered as complex systems, brownfield redevelopments feature interactions among multiple decision makers and stakeholders including the property owners, local community, and various levels of government. Moreover, there are multiple objectives, including environmental safety, economic efficiency, and social benefits.

A few approaches have been proposed to overall procedures for brownfield redevelopment. For example, US Environmental Protection Agency (EPA) produced a “road map” to assist a broad audience of brownfields stakeholders to identify and select innovative site characterization and cleanup technologies during the redevelopment process. The road map outlines the steps involved in site investigation and cleanup and introduces a range of technology options and available resources[16]. SMARTe, a web-based decision support system sponsored by EPA, is available to provide

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guidance and analysis tools for all aspects of the revitalization process including planning, environmental, economic, and social concerns [17].

In Canada, the Ontario municipal brownfield redevelopment toolbox was developed as a guide and resource to assist Ontario municipalities with urban renewal, redevelopment and revitalization [1]. The toolbox summarizes the ten key elements of a redevelopment strategy and the five steps to redevelopment, and includes a brownfields decision tree that locates the five steps to redevelopment in a flow chart.

I) **Community readiness** increases awareness of the benefits and issues associated with brownfield redevelopment. This step assists the municipality in understanding why it is important to focus on brownfields, based on the needs of their community and the rationale for taking on the challenge of sustainable community improvement and brownfields redevelopment. This step consists of the following key elements: build the team; create a land and building inventory; raise awareness and identify barriers and benefits; consult with community stakeholders.

II) **Evaluation** provides the tools for determining the viability of a brownfields redevelopment project. This step evaluates market need, property valuation, site characterization, risk assessment, financial risks, governance structure, regulatory compliance, remedial options and public perception. The key elements involved are to conduct research and develop a business case.

III) **Transaction** focuses on: engaging the stakeholders and the public; understanding the planning process; securing financing and investments; creating incentives; preparing implementation tools such as community improvement plans; obtaining approvals; and developing a marketing plan. This step contains the key elements of identification of opportunities and preparation of the implementation tool.

IV) **Implementation** provides guidance regarding how to launch a brownfields marketing plan, identify developers, obtain proposals, engage stakeholders and the public, and start remediation and redevelopment of the brownfield sites into productive uses.

V) **Site Management** emphasizes the importance of monitoring remediation and redevelopment activity as well as showcasing the success of brownfield redevelopment projects achieved by the municipality.

### III. STRATEGIC DECISION SUPPORT PROCEDURE

As mentioned above, different qualitative approaches have been proposed to support strategic decisions for brownfield developments, but there is no systematic investigation of quantitative methods available to assist stakeholders to analyze strategic decisions. Here, a two-level decision support procedure is designed to integrate both qualitative and quantitative analysis methods to assist decision makers (DMs) for strategic decisions in brownfield developments. The framework is shown in Figure 3.

The higher level strategic decision is designed to assess the feasibility of a specific brownfield redevelopment. A well-known business strategic planning tool, SWOT analysis, is adapted to identify the strengths, weaknesses, opportunities, and threats involved in implementation of a brownfield redevelopment. The lower level strategic decision is meant to find the best brownfield redevelopment solution. Multiple criteria decision analysis (MCDA) tools are employed to assist DMs to evaluate brownfield redevelopment designs from various points of view including economic, social and environmental criteria. Connected with the previous discussion of brownfield development systems, the SWOT analysis can be used in the steps of community readiness, evaluation and transaction to identify various qualitative issues such as barriers, benefits and opportunities involved in brownfield redevelopments, while, MCDA tools can be utilized in steps such as evaluation, transaction and implementation to identify the best project design and achieve different objectives.

#### A. SWOT Analysis

SWOT analysis is a strategic planning tool used to evaluate the strengths, weaknesses, opportunities, and threats of an
organization, project, or business venture, to assist an individual or organization in making a decision pursuant of an objective. This involves monitoring both internal and external environment to the organization or individual. The technique is credited to Albert Humphrey, who led a research project at Stanford University in the 1960s and 1970s using data from the Fortune 500 companies [20]. The idea of the SWOT analysis can be nicely displayed in a matrix as follows:

<table>
<thead>
<tr>
<th>SWOT analysis</th>
<th>Advantages to achieving the objective</th>
<th>Disadvantages to achieving the objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal attribute analysis</td>
<td>Strengths</td>
<td>Weaknesses</td>
</tr>
<tr>
<td>External attribute analysis</td>
<td>Opportunities</td>
<td>Threats</td>
</tr>
</tbody>
</table>

Fig. 3. The SWOT analysis matrix

The SWOT analysis is to identify the key internal and external factors that are important to achieving an objective.

- **Internal factors** - The ‘strengths’ and ‘weaknesses’ internal to the organization.
- **External factors** - The ‘opportunities’ and ‘threats’ presented by the external environment

Examples of evaluation criteria of these four key points are listed:

- **Strengths**:
  - What advantages (for example, skills, education or connections) do you have that others don’t have?
  - What do you do better than anyone else?
  - What personal resources do you have access to?
  - What do other people (and your boss in particular) see as your strengths?

- **Weaknesses**:
  - What could you improve?
  - What should you avoid?

- **Opportunities**:
  - Where are the good opportunities that you can enhance?
  - What are the interesting trends you are aware of?

- **Threats**:
  - What obstacles do you face?
  - What are the people around you doing?
  - Is your job (or the demand for the things you do) changing?
  - Is changing technology threatening your position?
  - Could any of your weaknesses seriously threaten you?

B. **Multiple Criteria Decision Analysis**

Multiple criteria decision analysis (MCDA) constitutes an increasingly popular set of techniques used to evaluate and compare different alternative solutions according to diverse environmental, economic, social, and political criteria. For example, in 1998 the Department of the Environment, Transport, and the Regions in the United Kingdom developed an MCDA approach to appraise transport projects instead of using traditional cost-benefit analyses. This approach improved project appraisal by incorporating both monetised and non-monetised impacts of transport projects into the management planning process [6].

An MCDA problem can be summarized using the three steps as shown in Figure 4: (1) Problem construction, which involves defining objectives, arranging them into criteria and identifying all possible alternatives; (2) Data collection, to obtain an information matrix, in which each column represents an alternative and each row provides evaluations of the performance of the alternatives over that criterion; (3) Decision analysis and outcomes, in which decision protocols define how analyses are carried out to obtain ranking, sorting or choice results for the alternatives as an aid to decision making.

During the last thirty years, many methods have been proposed for MCDA. Here three well-known approaches are introduced along with the implementation software to assist decision analysts in brownfield redevelopments. Of course, many other MCDA approaches can also be adapted to any specific brownfield redevelopment problem.

1) **AHP**: The Analytic Hierarchy Process (AHP) is a mathematical decision technique that allows consideration of both qualitative and quantitative aspects of decisions. It reduces complex decisions to a series of one-on-one comparisons, then synthesizes the results. Compared to other techniques like ranking or rating techniques, the AHP uses the human ability to compare single properties of alternatives. It not only helps decision makers choose the best alternative, but also provides a clear rationale for the choice. The process was developed in the 1980s by Thomas Saaty [18]. AHP is based on the following principles:

- The overall objective of the decision problem is decomposed into sub-objective levels in a hierarchy. Elements
of approximately equal importance are arranged at the same level. For example, in a decision problem the overall objective is represented by a few criteria at the criteria level. Then for each criterion, sub-criteria that represent it are located at the sub-criteria level.

- Once a hierarchical structure is established, pairwise comparisons ratio scale of the elements at each level of the hierarchy must be carried out. Local priorities can then be generated by an eigenvalue technique.

- Based on linear additive aggregation, the global priority of each element to the overall objective is determined.

The software which can carry out AHP decision analysis includes Decision Lens [5], Expert Choice [11] and Logical Decisions [14]. Because of its easy understanding and ability of integration of group opinions, AHP can be utilized in brownfield redevelopments in various situations such as carrying out group decision makings.

2) Data envelopment analysis (DEA): DEA is an increasingly popular management decision tool initially proposed by Charnes et al. [4]. The basic idea of DEA is to measure the relative efficiency of different product units or decision making units (DMUs) which have multiple incommensurate inputs and outputs using a weighted linear-additive equation.

\[
\text{Efficiency} = \frac{\text{Weighted sum of outputs}}{\text{Weighted sum of inputs}}
\]

Charnes et al. recognized the difficulty in seeking a common set of weights (relative importance) of inputs and outputs to determine the relative efficiency of DMUs, and that a DMU might value inputs and outputs differently and therefore adopt different weights. Hence, they proposed an optimization model so that each DMU was allowed to adopt a set of weights which shows it in the most favorable light in comparison to the other DMUs. The detailed mathematical model construction is not included here but can be found in the paper by Charnes et al. [4]. Overall, the final results of the relative efficiency of DMUs are normalized and measured by real-value numbers between 0 and 1. Large values indicate high relative efficiency and if a DMU can obtain the value of 1, it is efficient, otherwise it is non-efficient.

The advantages of DEA is that it requires much less subjective information from DMs such as various types of preference information and is easy to implement. DEA can be employed as a screening tool for brownfields redevelopments to carry out initial analysis, and remove inferior project designs and retain good ones for further investigations. There are a few DEA-based software available such as DEAFrontier [8], efficiency measurement system [10] and frontier analyst [2], to name a few.

3) Linear Additive Value Function: Linear additive value function (LAVF) is widely used in many practical applications because it is easily understood and implemented. The basic LAVF can be generalized as follows:

\[
V(A^i) = \sum_{j=1}^{q} w_j v_j(A^i),
\]

where \( V(A^i) \) is the overall evaluation of alternative \( A^i \in A \), \( w_j \) is the weight of criterion \( j \in Q \) and \( v_j(A^i) \) is the value of \( A^i \) over \( j \). Note that usually \( 0 < w_j < 1, \sum_{j=1}^{q} w_j = 1 \) and \( 0 \leq v_j(A^i) \leq 1 \).

The Generic Multi-Attribute Analysis (GMAA) System [13] is a decision support system (DSS) based on LAVF. The GMAA accounts for uncertainty about consequences and admits incomplete information about the DM’s preferences, which leads to groups of value functions and weight intervals. In GMAA, the additive model is used to assess average overall values and base a ranking of alternatives, while minimum and maximum overall evaluations can give further insight into the robustness of this ranking. Another feature of GMAA is that an iteration process is designed to assess the non-dominated and potentially optimal alternatives using Monte Carlo simulation techniques to determine useful information about dominance among the alternatives. The LAVF and associated DSS, GMAA, can be employed in decision analysis of brownfields developments, especially for investigations involving uncertainty.

IV. CASE STUDY: RALGREEN RESTORATION PROJECT

A. Background

The Ralgreen community is located in Kitchener, Ontario. It contained 101 residential lots with semi-detached and town houses and low-rise apartment units. Before the late 1940s the Ralgreen area was part of a family farm with...
a pond. By 1948, the property owners and the City of Kitchener formalized an agreement that allowed the infilling of the pond with organic materials, including cinders and ash from the City’s incinerators. The land was used for agricultural purposes until 1965, when the property was sold to a developer for the construction of the Ralgreen subdivision.

Beginning in 1996, Ralgreen residents notified the City of Kitchener with a number of complaints including geotechnical concerns related to the settlement and structural displacement of housing structures; seepage of liquids into basements and indoor environmental concerns associated with methane and mould. A series of investigative studies conducted by several consultants on behalf of Ralgreen residents in 1996-1997 linked the problems to the infilled pond. In 2000 a mediated settlement was reached by residents, within the City of Kitchener. The Province of Ontario required clean-up of the subdivision in accordance with the Ministry of Ontario Environment (MOE)’s guidelines. The Ralgreen redevelopment was completed in 2005 when soil reports confirmed the success of the project. By the application of the proposed strategic decision support procedure, we carried out the following retrospective decision analysis.

B. SWOT Analysis

The SWOT analysis can assist the City of Kitchener to formalize the key points involving the decision of implementation of the Ralgreen redevelopment which was made in 2000. The details are listed as follows:

- **Strengths:**
  - The City of Kitchener is very proactive to protect the Ralgreen community’s health and environment.
  - The City of Kitchener is a major player in Canada’s Technology Triangle (CTT). The CTT leads the pack in many pioneering technologies, from wireless to internet to production technology and employs more than 18,000 employees at more than 400 high tech companies. The City of Kitchener was strongly motivated to solve the Ralgreen problem.

- **Weakness:**
  - This was the first brownfield redevelopment project for the city of Kitchener. City council had little experience with the issues involving brownfield redevelopment.
  - Site condition information was lacking. The actual remediation expense may be much higher than expected.

- **Opportunities:**
  - A successful brownfield redevelopment project can restore the stability of the community and improve the reputation of the current government.
  - The lessons learned from the Ralgreen project could be valuable for similar projects in the future. Because of extensive industrialization during the 19th and 20th centuries, Kitchener possesses many brownfields, mostly at former or current industrial sites.

- **Threats:**
  - A group of Ralgreen residents undertook legal action against the City of Kitchener in 1999.
  - Different media, including newspapers and television, have reported the Ralgreen problem, and the contamination and the residents’ problem have received wide public attention.

Based on the above major key points, especially the potential legal issues brought by the group of Ralgreen residents, the City of Kitchener had to take action on the Ralgreen project. Hence, a mediated settlement was finally reached by all parties in 2000.

C. Multiple Criteria Decision Analysis

Next, MCDA can be useful to assist decision analysis in the detailed design of brownfield redevelopments such as the selections of restoration options and field work programs. Here, MCDA methods are applied to find the best restoration option. In 2001 Frontline Environmental Management Inc. was requested to develop a work plan with recommendations for remedial options for City Council [12]. Four potential clean up options were outlined as listed below:

- **$A^1$:** Demolition of 20 houses, structural renovation of 9 houses, full-scale waste removal and building/lot resale to neighborhood density.
- **$A^2$:** Demolition of 14 houses, structural renovation of 15 houses, full-scale waste removal and building/lot resale to neighborhood density.
- **$A^3$:** Demolition of 18 houses, partial waste excavation, landfill encapsulation, site-specific risk assessment and parkland construction.
- **$A^4$:** Demolition of 14 houses, structural renovation of 15 houses, stratified removal of waste to 1.5m depth below existing ground, clean soil capacity.

The MCDA methods were carried out to investigate these alternatives as shown below:

1) **Initial Screening:** A screening procedure was used to remove inferior alternatives and retain feasible ones for further comparison. Accordingly, each of the potential options being developed from the approaches in MOE guidelines were evaluated for feasibility and effectiveness considering the following criteria:

- Construction and field implementation (CFI);
- Consistency with the mediated settlement, legal acceptance (CML);
- Compatibility of land reuse in a residential setting (CLR).

As shown in Table I, $A^4$ does not satisfy the criteria of CML and CLR, therefore, $A^4$ is rejected and is not carried forward for further investigation.

2) **Further Investigation:** In 2002 after several discussions and public consultations, the City Council of Kitchener adopted the first option, $A^1$. Based on the authors’ experience involving the project, this decision process is re-analyzed.

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by applying MCDA tools. First, a set of criteria is set up to evaluate the remaining three alternatives, which includes protection of human health and the environment (C₁), acceptance in the community (C₂), operational and maintenance expense (C₃), property tax return (C₄), effect on property values (C₅), length of time for demolition (C₆), excavation of waste in residential neighborhood (C₇). The software, Expert Choice, was employed to carry out the AHP-based analysis. Here, the evaluation data were estimated based on the authors’ experience (A survey may be needed to obtain more representative data for a practical case study). The analysis steps are shown as follows.

- The establishment of criteria and alternatives

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>A¹</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>A²</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>A³</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>A⁴</td>
<td>✓ × ×</td>
</tr>
</tbody>
</table>

- Pair-wise comparisons: pair-wise comparisons were carried out among different alternatives over all criteria.

- Overall evaluation: the software calculated the overall evaluation score of each alternative as shown below. The alternative with the highest score was the best solution, which was A¹ in this project.

Fig. 5. The establishment of criteria and alternatives

Fig. 6. Pair-wise comparisons

Fig. 7. Overall evaluation

REFERENCES