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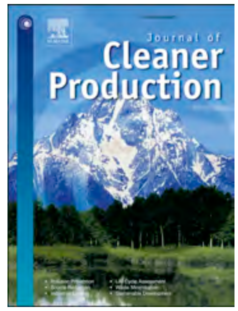

Incorporating carbon footprint with activity-based costing constraints into sustainable public transport infrastructure project decisions

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Abstract

An optimal sustainable public transport infrastructure project portfolio selection requires an environment management strategy for both the social and economic development. This study considers the application of a multi-criteria decision-making (MCDM) methodology that can be applied to assess the sustainable development of transport infrastructure projects, taking into account a range of transport, social, financial and environmental criteria. Furthermore, in order to resolve the strategic decision-making under resource constraints and the carbon footprint factor, a zero-one goal programming (ZOGP) model is developed to facilitate an optimal portfolio of sustainable public transport infrastructure projects in Taiwan.

The resulting data shows that the perspective of sustainable transport and the criterion of decreasing traffic energy consumption are the most significant evaluation factors, and that the Tamhai Light Rail (TLR) Project and Tambai Expressway (TE) Project comprise by far the optimal portfolio of sustainable transport infrastructure projects which strengthen the connection between activity-based costing (ABC) evaluation and carbon footprint in a life cycle assessment. The integrated approach is a practical and useful tool for providing solution-related information for sustainable public transport infrastructure projects, and to help managers incorporate environment costs into decision-making processes.

Keywords: Environmental Management Initiatives; Sustainable public transport infrastructure project; MCDM (Multiple criteria decision-making); Activity-Based Costing (ABC); Carbon Footprint; Zero-one Goal Programming (ZOGP).

1. Introduction

In recent decades, global warming and climate change in general have gained increasing public attention. The industrial activities relevant to social economic development, including irrigated and rain fed agriculture, population growth, limited water resources (Valipour, 2012a; Valipour, 2012b; Valipour, 2015a; Valipour, 2015b) etc., have negatively influenced the quality of human life and impacted the environment. According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), CO_2 in greenhouse gases (GHGs) has increased as a result of human activities, such as the use of fossil fuels in transportation, manufacturing industries, and the way we heat and cool our buildings. In particular, the transport sector accounts for 27% of the total energy use of 6.7 $GtCO_2$ direct emissions in 2010, with baseline CO_2 emissions projected to almost double by 2050 (IPCC, 2014).

Sustainable development provides a basis for evaluating climate change mitigation policies, and emphasizes the need for adaption in order to avoid climate disaster. The World Commission on Environment and Development (WCED) defines sustainable development (SD) as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Consequently, the core focus of a public sustainable transport infrastructure is on construction and seeking equilibrium among environment care, economic development and social justice. Applied in the transport sector, development of a public sustainable transport infrastructure has recently become a more important consideration in Taiwan as a result of government policies on energy saving and reduction of CO_2 emissions. The government has proactively supported sustainable transport policies while simultaneously providing co-benefits, such as improving local transport services and enhancing the quality of the environment and urban living. Public transportation infrastructure is part of an important policy for adapting to climate change, especially in environmentally-friendly and economic development. The more efforts expended on climate protection and adaption, the greater the increase in transport infrastructure costs and the more pronounced the effect on the selection of infrastructure projects for investment (Hamin & Gurran, 2009). Thus, the demands for protecting the environment as well as for economic benefits are embedded in sustainable transport infrastructure selection, which in turn will increase the sustainable transport infrastructure quality and value.

More accurate estimations within simulation models can enhance the decision-making quality, such as in regard to surface and border irrigation water management (Valipour et al., 2015; Mahdizadeh Khasraghi et al., 2015). The selection of the most appropriate sustainable public transport infrastructure project is usually based on an uncertain and complex procedure since many evaluation criteria are involved in the decision-making process. To deal with this challenge, multiple criteria decision-making (MCDM) techniques can assist stakeholders and decision makers in solving the uncertainties in sustainable-related problems, especially regarding transport systems (Mardani et al., 2015). It is important to select an optimal transport infrastructure project in order to simultaneously obtain the maximum benefit of social development and environmental protection. Hence, this study proposes four critical perspectives and twelve criteria upon which to focus: (1) sustainable transport, (2) social development, (3) financial feasibility and (4) environmental impact. In regard to the benefits and environmental impacts caused by the sustainable public transport infrastructure life cycle, Taiwan's government has implemented a sustainable transport policy to reduce emissions via transport infrastructure planning. Most importantly, effective control of the information related to infrastructure cost and carbon emission is extremely helpful in achieving the sustainable transport goals. The measurement of public transport infrastructure costs and economic benefits is used to enhance social development profits within the government; sustainable-based transport infrastructure is often perceived as entailing high construction costs. However, as opposed to traditional cost systems, Activity-Based Costing (ABC) could improve the accuracy of cost data and further control project costs because of its activity characteristics (Kamal Abd Rahman et al., 2003; Tsai and Hung, 2009). Furthermore, the management technology of ABC can guide decision making and establish alternative priorities. From the sustainable development perspective, carbon footprint emissions from transport infrastructure require full accounting of the life cycle assessment (LCA), including the design, construction, construction waste and post-construction phase. To achieve the desired benefits, carbon footprint consideration must include monitoring carbon emissions within the project life cycle and providing carbon information related to the traffic infrastructure supply chain. Conversely, because limiting the carbon footprint may constrain the development of sustainable transport, it might influence the decisions related to transport infrastructure. Many studies have applied the MCDM and Mathematical programming (MP) models to provide solutions for achieving sustainable development and mitigating environmental problems, e.g. carbon tax planning, manure management, energy policy, economy-energy-environment interactions, wind power projects, green building projects, etc. (Kunsch and Springael, 2008; Gebrezgabher et al., 2014; Haris Doukas, 2013; Oliveira and Antunes, 2004; Tian et al., 2013; Tsai et al., 2014). However, little research to date has combined the MCDM and MP decision-making models for measuring sustainable transport infrastructure related to activity-based costs and carbon footprint. The purpose of this study is to develop an integrated decision model to use in selecting sustainable transport infrastructures without sacrificing profit margins and sustainable environment.

The paper proceeds as follows. Section 2 provides a comprehensive review of the literature on sustainable transport infrastructure selection problems, with a brief description of the MCDM presented. The decision network model, with criteria derived from case-based research, is then created and subsequently applied for a government facing sustainable transport infrastructure selection decisions. Section 3 is an introduction to the research methodology adopted, while section 4 contains a short description of a case study and a discussion of the results. Finally, conclusions related to the integrated approach for problem solving and suggestions for further research are presented.

2. Literature review

This section discusses recent relevant literature on public sustainable transport infrastructure selection problems and presents an integrated decision model that incorporates sustainable criteria, carbon footprint evaluation and activity-based costing concepts.

2.1 Sustainable public transport infrastructure

Public transport infrastructure plays a significant role in providing services to promote economic development. Forkenbrock and Foster (1990) indicate that improvement in transport infrastructure services is expected to reduce transport costs, with lower congestion, shorter distances and higher speeds to reach the goal of reducing fuel consumption and capital costs. While congestion decreases operational efficiency of the transportation system and increases air pollution, the feasibility study of technical engineering for transport infrastructure does not consider this problem when evaluating the economics and simultaneously promoting awareness of environmental sustainability and natural resource protection.

Sustainable public transport infrastructure has to balance urban-rural development in terms of services, such as residential, business, education and medicine. Shen et al. (2012) identify, through the relevant literature, the level of benefits and fairness for evaluating the contribution of infrastructure projects to coordinated urban-rural development. Zhang et al. (2015) define the indicators, both efficiency and equitable investment, for evaluating infrastructure projects on urban-rural balance, by using a mathematical model. Actually, the transport infrastructure has crucial influences on the environment, ecology and carbon emission. It is important to select an optimal transport infrastructure project for simultaneously realizing the maximum benefit of social development and environmental protection. Therefore, public transport infrastructure projects should aim to embed sustainability considerations by not only assessing transport performances of potential designs, but also by taking into consideration the environmental, social and economic factors of that particular design during the life cycle of the public transport infrastructure projects.

2.2 The evaluation criteria of public transport infrastructure

2.2.1 Sustainable Transport (ST)

Sustainable transport, arising from the concept of sustainable development, focuses on providing accessibility for all to meet the daily mobility needs consistent with human and ecosystem health under the constraints of GHG emissions (IPCC, 2014). Indicators can be used to evaluate sustainable transportation, to guide the decision-making process, and to assist planners and administrators by evaluating policy effectiveness in progressing towards sustainable development (Litman, 2008; Adelle and Pallemaerts, 2009). Santos and Ribeiro (2013) summarize a set of 20 sustainable transportation indicators, including environmental, economic and social categories. The transport infrastructure’s life cycle in the construction, operation, maintenance and disposal stages, all result in CO_2 emissions. A sustainable public transport infrastructure’s life cycle, including the design, construction, maintenance and operational phases, has to pay attention to the environmental impacts by decreasing energy consumption and setting the CO_2 reduction target to improve traffic service quality (Haghshenas and Vaziri, 2012; Velazquez et al., 2015; Lu, 2015).

2.2.2 Social Development (SD)

The transportation infrastructure planning process needs to consider and forecast how future travel demands are affected by land use (La Greca et al., 2011). Appropriately used, the transport infrastructure can promote land use and economic development through population immigration and local tourism. Sim et al. (2001) examined a process in which traffic congestion can be alleviated through the integration of transportation planning and land use.

Geerlings and Stead (2003) claim that by considering policy integration and implementation, various types of policy integration can be distinguished, particularly in relation to transport, land use planning and environmental policies. Therefore, transport infrastructure should incorporate the related dimensions into its evaluations, such as land use, planning and design, infrastructure definition, management and maintenance, travel demands, financial analysis, proposals and promotion, as well as the creation of career opportunities (Wey and Wu, 2007).

2.2.3 Financial Feasibility (FF)

Daraio et al. (2016) reviewed the literature on public transport infrastructures focusing on evaluation indicators and economic efficiency, such as productivity, economic performance, cost structures, cost functions, subsidies, deregulation and privatization, scale and scope. Regarding financial feasibility, in addition to transport infrastructure cost reduction, the tracking of environmental costs is used to coordinate important environmental management and integrate environmental issues into organizational operational activities (Aschaiek, 2012; Henri et al., 2015) Tracking may also help to eliminate waste and reduce production costs for both operation and production. Actually, a sustainable public transport infrastructure is currently facing unprecedented and growing pressures from global climate change problems, increasing natural disasters, dwindling material resources, and other political and environmental issues. Kubba (2010) indicates that a construction project must consider the operational and maintenance cost over its life cycle, such as operating staff, labor, materials for maintenance and repairs, etc. Therefore, a sustainable public transport infrastructure must pay attention to the measurement of infrastructure project costs and economic benefits to enhance operating profits while satisfying the needs of environmental protection.

2.2.4 Environmental Impacts (EI)

Within certain branches of the administration, notably the transport sector, environmental impact assessments have received considerable attention; the transport sector has explored and developed environmental assessments as an element in its planning. Sustainable public transport infrastructure projects must analyze and assess their environmental impacts, including noise (compliance with abatement levels, sleep impact, noise footprints) and air pollution (gaseous and particulate pollutants, acid rain, greenhouse effect, ozone) (ECMT, 2004).

Natural resources, including animals, water and plants all support life. Javid et al. (2014) propose the MCDM method to estimate the potential carbon dioxide mitigation for a given strategy allocation; it incorporates environmental criteria to assess public transportation planning. Strategies to reduce the environmental impact of public transport infrastructures encompass construction technology maturity. Newer construction methods, such as the prefabrication method, would lead to minimizing waste, improving energy efficiency and reducing the impact on the environment (Chen et al., 2010; Tsai et al., 2013). Conversely, construction technology immaturity may lead to ecological risks threatening the natural environment. To sum up, the concept model has four levels. The higher level is the goal of selecting optimal public transport infrastructure project portfolios in order to attain sustainable development; the second level includes the four perspectives of sustainability; and the third level deals with evaluation dimensions, which consist of 12 key criteria to demonstrate sustainable public transport infrastructure projects. The bottom level presents the three alternative transport infrastructure projects. Based on a detailed review of the relevant literature, an analytic framework was established, as shown in Fig. 1.

<*Insert Figure 1 here *** >**

2.3 Public transport infrastructure cost assessment: Activity-Based Costing (ABC)

Traditional cost systems mainly focus on material and labor to allocate overhead costs. Especially in the construction industry, the traditional cost system using only direct labor costs as a primary apportioning source can cause significant cost distortions and lead to poor strategic decisions. As public transport infrastructure projects differ in the complex process of construction, they include activities in different proportions. The main advantage of ABC, developed by Cooper and Kaplan in 1988, is the improved accuracy of product cost information, adopted from the traditional cost system, using activity-based assessment as the intermediary of cost assignment. ABC has been widely used in various environmental and energy issues, such as product ecological footprint calculations, green building project decisions, product-mix decision models, green airline fleet planning, etc. (Limnios et al., 2009; Tsai et al., 2014; Tsai et al., 2013; Tsai et al., 2012).

The ABC technique uses a two-stage procedure to assign resource costs to cost objects, as shown in Fig. 2. This study regards sustainable public transport infrastructure projects as cost objects, and selects suitable cost drivers that rely on measurement goals, the cost of measurement and the degree of correlation (e.g. energy consumption-related). In the first stage, resource costs are assigned to various activities; using resource drivers, the factors are chosen to approximate the consumption of resources used in construction activities. Each type of resource traced to a building activity becomes one cost element within an activity cost pool. Thus, an activity cost pool provides the total costs associated with a particular activity. An activity center is composed of related activities, usually clustered according to function or process.

In the second stage, the costs in each activity cost pool are assigned to cost objects by an adequate activity driver used to measure the consumption activities by the cost objects. From the view of sustainable public transport infrastructure projects, building construction costs are divided into direct and indirect cost categories. Direct costs are divided into direct material costs, direct labor costs and direct machine costs. Indirect costs are divided into four activity levels (Tsai et al., 2014):

(1) Project level activities performed as needed for the sustainable public transport infrastructure project's construction (e.g. green and energy saving design planning);

(2) Unit level activities performed for each unit of the sustainable public transport infrastructure project (e.g. construction method, maintenance, and repair warranty);

(3) Environmental protect-level activities related to the environmental energy of the sustainable public transport infrastructure project (e.g. eco-energy and water conservation activity,

construction waste recycling activity);

(4) Batch level activities are performed each time for a batch of the sustainable public transport infrastructure project (e.g. building material purchasing activity).

<*Insert Figure 2 here *** >**

2.4 Carbon footprint evaluation for transport infrastructure

The carbon footprint concept emerged to measure the impact (measured in CO_2-equivalent) that a product, service or organization has on climate change (Boguski, 2010; Musanighe, 2010). Public transport infrastructures are designed for sustainable energy development, constructed with low-carbon technology and use available natural resources, such as energy, water and recycled materials (Conefrey et al., 2013). It is the same with green building projects; the primary objective of the sustainable public transport infrastructure is therefore to reduce the emission of carbon dioxide in construction materials, manufacturing machines and labor (Chen and Jim, 2011; Roe and Mell, 2013) and to provide a cleaner, zero-waste pollution environment quality for inhabitants. Carbon footprint of sustainable public transport infrastructures, being an emission quantitative expression of CO_2 from building construction to end-life activity, helps in energy consumption management and evaluation of environmental pollution. It is important to identify the sources of emissions, including all direct activity and indirect CO_2 emissions resulting from construction.

The transport sector and construction companies have the responsibility to calculate and disclose the carbon footprint of public transport infrastructure projects for the benefit of the general population, in reaching the objective of reduced CO_2 emissions. Many previous studies have evaluated the carbon footprint of public transport infrastructures in terms of energy management and environmental impact issues (Chang and Kendall, 2011; Lu et al., 2013; Chao, 2014; Li, 2015). This study aims to incorporate the carbon footprint concept into the energy consumption measurement for sustainable public transport infrastructure projects; it includes four main stages in its life cycle. Fig. 3 illustrates the energy consumption and system boundaries for carbon footprints of sustainable public transport infrastructure projects. The design and pre-construction phases involve energy consumption during green building material production and transportation, as well as sustainable design planning activities. Second, the construction phase is a main carbon emission source which includes low-carbon construction technology management, with energy saving and water conservation activities. Third, the construction waste phase includes building waste material recycling and the energy consumed during waste landfill activities. Finally, the post-construction phase includes the maintenance and repair warranty, taking into account the calculation of the energy consumption.

<*Insert Figure 3 here *** >**

3. Methodology of the integrated approach

This section illustrates an evaluation model procedure that not only constructs a network structure for sustainable transport development, but also finds an optimal portfolio for sustainable public transport infrastructure projects, while still allowing for limited internal resources. The procedures of this hybrid MCDM model, a combination of DEMATEL and ANP with ZOGP, are explained in the following subsections.

3.1 Decision-Making Trial and Evaluation Laboratory (DEMATEL)

Between 1972 and 1976, the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva developed an approach, the DEMATEL (Gabus and Fontela, 1972; 1973; 1976). The DEMATEL technique has been applied to many decision-making issues, including: sustainable development (Tsai et al., 2009), recycled material vendor selection (Hsu et al., 2012), improving metro–airport connection service (Liu et al., 2013) and transportation service quality (Liou et al., 2014), CO_2 capture and storage criteria evaluation (Quader et al., 2015), and so on. The DEMATEL approach illustrates inter-relationships of criteria concerns and constructs network relationships. The steps of the DEMATEL method are summarized as follows:

1. Calculation of the direction-relationship matrix

The first step is to design the five levels that measure the relationships among problematic factors. Here, the scores 0, 1, 2, 3 and 4 represent levels of influence ranging from no influence at all to a high influence. Then, pairwise comparisons are determined in order to model a mathematical matrix. Assuming that the factors considered contain several criteria A= {A_1, A_2… A_N}, respondents propose the level of direct influence of each criterion and derive an average matrix X, where e_{ij} denotes the level criterion A_i exerts on criterion A_j. The average matrix X is shown as follows:

2. Normalization and analysis of the direct-relation matrix and total-relationship matrix

According to matrix X, a normalized direct-relationship matrix Z can be acquired through Eqs. (1) and (2), in which all major diagonal criteria are equal to zero:

$$Z = r \cdot X \tag{1}$$

$$r = Min\left(1 \big/ \max_{1\le i\le n} \sum_{j=1}^{n}\left|a_{ij}\right|, 1 \big/ \max_{1\le j\le n} \sum_{i=1}^{n}\left|a_{ij}\right|\right), ij \in \{1,2,3,\cdots,n\} \tag{2}$$

Then, a total-relationship matrix **W** can be derived through Eq. (3), in which **I** denotes the identity matrix (Tsai and Chou, 2009):

$$W = Z + Z^2 + Z^3 + \cdots = \sum_{i=1}^{\infty} Z^i = Z\left(I - Z\right)^{-1} \tag{3}$$

3. Find the dispatcher and receiver groups and set the threshold values to obtain the impact-digraph-map

The values of D-R and D+R are derived from Matrix W, where D is the sum of the rows, and presents the influences dispatched from criterion *i* to other criteria. R is the sum of columns presenting the influences that criterion *i* receives from the other criteria; as shown in Eqs. (4)-(6) (Tsai and Chou, 2009). Some criteria have a positive value of D-R, indicating that criterion *i* is affecting the other criteria; this is called the cause group. Conversely, if the value of D-R is negative, criterion *i* is being influenced by the other criteria; this is called the effect group. Moreover, the value of D+R indicates an index of the intensity of the influences delivered and received, and presents the relationships for each criterion:

$$W = \left[W_{ij}\right]_{n\times n} \quad i, j \in \{1,2,3, \quad \cdots\cdots \quad ,n\} \tag{4}$$

$$D = \sum_{j=1}^{n} W_{ij} \tag{5}$$

$$R = \sum_{i=1}^{n} W_{ij} \tag{6}$$

Finally, it is necessary to set a threshold value *q* to clarify the influence level and to filter out the smaller effects. The threshold value is determined through discussions with the decision makers and expert group. When the threshold value has been decided, an impact-digraph-map can be drawn accordingly. The map is obtained by drawing the values of (D+R, D-R), where the horizontal axis is D+R, and D-R is set as the vertical axis.

3.2 The Procedure of Analytic Network Process (ANP)

Mardani et al. (2015) provide a systematic review in proposing that the MCDM techniques are adequate to assist in the decisions related to transportation system problems. The sustainable public transport infrastructure project-related decisions contain multi-criteria with interdependent relationships among the criteria. The ANP method can be applied; the ANP technique is derived from the AHP (Analytic Hierarchy Process). The AHP approach is presented through a hierarchical structure for solving multi-objective decisions. However, the elements of decisions are often both interdependent and complex within the hierarchical structure model. Saaty (2001) proposes the ANP for decision-ranking priorities because it frees the restrictions among decision levels of the hierarchical structure. The ANP method has been widely applied in several academic fields, including green supplier development evaluation (Dou et al., 2014), CO_2 reduction management (Theiben and Spinler, 2014), green supplier selection (Hashemi et al., 2015), sustainable building energy efficiency retrofit (Xu et al., 2015), automotive parts remanufacturing (Govindan et al., 2015), carbon reduction management (Liou, 2015), green partner selection (Wu, and Barnes, 2016), and more. The following steps describe the ANP method:

1. Establish the network structure and calculate the priorities of the criteria

First, the problem must be clearly defined. All of the interrelationships among the criteria should be considered. Decision makers using professional opinions should form the network structure through interviews and brainstorming.

2. Analyze the pairwise comparisons with criteria for a priority weight matrix and conduct a consistency test

These interrelationships are measured using pairwise comparisons. The level of importance can be decided by using a scale of 1 to 9 to represent a range from equal importance to extreme importance. The general form of matrix P is as follows:

$$P = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_N \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_N \end{array} \\ \begin{bmatrix} 1 & k_{12} & \cdots & k_{1n} \\ 1/k_{12} & 1 & \cdots & k_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/k_{1n} & 1/k_{2n} & \cdots & 1 \end{bmatrix} \end{array} \tag{7}$$

In matrix P, the problem becomes one of assigning A_1, A_2… A_n to the n criteria. A set of numerical weights k_1, k_2… k_n represents the expert judgments. Saaty (2001) suggests that the largest eigenvalue would be seen in Eq. (8):

$$\lambda_{\max} = \sum_{j=1}^{n} k_{ij} w_j \Big/ w_i \tag{8}$$

Saaty (2001) proposed to certify the consistency of judgments by decision makers CI and CR through the value of a consistency index, as shown in Eqs. (9) and (10):

$$CI = (\lambda_{\max} - n)/(n-1) \tag{9}$$

$$CR = CI/RI \tag{10}$$

Random index (RI) indicates the average consistency index of numerous random entries of the reciprocal matrices. If CR is less than 0.1, the outcome of the pairwise comparison is acceptable; if CR is greater than 0.1, the result presents the pairwise criteria for comparison again. Finally, the results of the comparisons are used to generate a supermatrix. According to their relationships with the supermatrix, it is possible to derive the interdependence of each evaluation criterion and the weighting priorities of the alternatives. The results of higher priority weighting alternatives indicate that the alternative with the greatest priority will be selected.

3.3 Zero-one Goal Programming (ZOGP)

The ZOGP method was first recommended by Charnes and Cooper in 1955. The ZOGP method has been applied to many real-world multi-objective problems because it considers the limitations of resources. While this characteristic of the goal programming model does not provide an optimal objective, it does try to contribute suggestions to decision makers for resource allocation. The ZOGP method minimizes deviations between achievement goals and realized results. Accordingly, the ZOGP model priority weightings set by the ANP are useful when the transport sector makes a public infrastructure project selection under constrained resources (such as activity-based project budget costing, carbon footprint calculations, etc.). The ZOGP model is described as follows:

Minimize $V = P_k \left(w_j d_i^+, w_j d_i^- \right)$

Subject to:

$$\sum_{j=1}^{n} r_{ij} x_j + d_i^- - d_i^+ = f_i \quad \text{for } i = 1, 2, \cdots, m \quad j = 1, 2, \cdots, n$$

$$x_j + d_i^- = 1 \quad \text{for } i = m+1, m+2, \cdots, m+n \;;\; j = 1, 2, \cdots, n$$

$d_i^+ \geq 0, d_i^- \geq 0$ for $\forall_i$

$x_j =$ 0 or 1 for $\forall_j$

where V denotes the sum of the derivation variables from m goals considered; i indicates m restricted resources; j indicates n selected alternatives; P_k presents a preemptive priority (P_1>P_2>P_3>>>P_k) for goal V; x_j indicates the binary variable of the jth alternative; w_j represents the weight value by ANP results on the jth alternative; r_{ij} is the alternative parameter j of the selection resource *I; and* f_i denotes the available resources or limitation factors that must be considered in the process of decision making and evaluation. This study used LINGO 13.0 software to calculate and obtain the final optimal portfolio for sustainable public transport infrastructure projects when resources are limited.

4. An empirical example for sustainable public transportation project selection application

This study presents an empirical study on the portfolio selection of sustainable public transport infrastructure projects located in Northern Taiwan to illustrate the feasibility of the proposed method, with details described as follows:

4.1 Sustainable public transport infrastructure projects: alternatives

Tamsui, a cultural district with 400 years of history, is located north of Taipei. Tamsui is surrounded by mountains and rivers, and the scenery is well-known. The riverside view, fascinating relics and culture, as well as gorgeous sunsets all make Tamsui a popular destination on weekends. Therefore, alleviating traffic congestion and increasing convenience are important issues for tourism development. This study includes the following public transport infrastructure project alternatives, and is an ongoing program.

Alternative 1: Tamhai Light Rail (TLR)

- The Tamhai Light Rail Project would provide a link for the residents and travelers in the New Taipei districts of Tamsui and Tamhai New Town.
- From Point A to Point B, and Point C to Point D (length of route: 13.99 kilometers).
- The TLR project is planned to divide into two routes, 20 stations and one depot, with the “Green Mountain Route” and “Blue Sea Route” providing the traffic improvement services.

Alternative 2: Tamjiang Bridge (TB)

- The Tamjiang Bridge project would connect the New Taipei districts of Tamsui and Bali, reducing the notorious traffic congestion in those areas.
- From Point E to Point F (length of route: 12.08 kilometers).
- The Tamjiang Bridge project would cross the Tamsui River and be combined with a light rail system, simultaneously taking into consideration the requirements of Tamsui sunset landscape maintenance, environmental protection and the promotion of tourism.

Alternative 3: Tambai Expressway (TE)

- The Tambai Expressway project would connect Tamhai New Town with Beitou in north Taipei, serving both residents and tourists.
- From Point G to Point H (length of route: 4.7 kilometers).
- The Tambai Expressway project would be constructed north of the Tamsui River and pass through Mangrove nature reserves. In addition to promoting urban development, it would mainly ease the congestion of the current streets.

<*Insert Figure 4 here *** >**

4.2 Application of the Integrated Method: five-step analysis

4.2.1 Step 1: Evaluating Relationships among the Perspectives and Criteria with DEMATEL

Prior to analyzing the sustainable public transport infrastructure project selection of the ANP decision model, the potential relationships of the complicated criteria should be measured, and the influence directions among the affected criteria groups determined. Based on the DEMATEL, the criteria scale and pairwise comparisons from the expert panel will determine the intensity of the influence direction for each criterion, in order to acquire the total-relationship matrix.

The assessment results of the group decisions are provided in Tables 1 and 2. If the value is greater than the threshold value of 1.518 for perspective and 0.385 for criteria, then the column criterion strongly affects the row criterion. According to Table 1, the perspectives are arranged in terms of the degree of their importance, based on their respective (D+R) scores. The Sustainable Transport (ST) with (D+R) score of 12.791 has the highest degree of importance, followed by Social Development (SD) $\succ$ Financial Feasibility (FF) $\succ$ Environmental Impacts (EI). In addition, considering the value of their respective (R-C) scores, the evaluation perspective (Sustainable Transport (ST), Social Development (SD) and Financial Feasibility (FF)) is divided into cause group factors, while the Environmental Impacts (EI) come under effect groups.

As shown in Table 2, the evaluation criteria are also divided into the cause groups, including: Decreasing traffic energy consumption (DTC), Attaching the goal of CO_2 emissions (ACE), Promotion of land use (PLU), Minimize Maintenance & Operational Costs (MPC) and Construction technological immaturity (CTI). The effect group was composed of criteria including: Improving traffic services' quality (ISP), Promotion of local tourism (PLT), Promotion of economic and career opportunities (PEC), Minimize Environmental Costs (MEC), Minimize Infrastructure Costs (MIC), Construction noise and air pollution (CAN), and Ecological damage (ED).

Finally, the impact-digraph-map of these four perspectives for selecting the optimal sustainable public transport infrastructure projects model was developed; the final influence results are shown in Figure 5.

<*Insert Table 1, Table 2 and Figure 5 here *** >**

4.2.2 Step 2: The Priority Weight of Evaluation Projects Created by ANP

Using the formulated criteria for the alternative decision hierarchy, the ANP procedure is adopted to produce the weight of each potentially sustainable public transport infrastructure project. In order to measure the levels of influence among the criteria, the expert panel makes professional judgments through pairwise comparisons on the basis of Saaty's nine-point scale. The scale uses 1 to 9 to represent influence levels, from equal importance to extreme importance, respectively, in determining the relative values. After inserting data from each questionnaire, the Consistency Index (CI), the Consistency Ratio (CR) and the arithmetic mean method are applied in succession to integrate the data in this study. Based on the expert panel measurements, the entire computing process was completed using Super Decision software. The corresponding priorities of the perspectives and criteria have built the unweighted and weighted supermatrix, and limiting powers until the weights converge to stabilize the limited supermatrix. This study presents only the limited supermatrix for the sustainable public transport infrastructure project as shown in Table 3. As can be seen in the table, the priority results are as follows:

$$ANP_{SPT} = \begin{bmatrix} TLR = 0.5132 \\ TB = 0.2895 \\ TE = 0.1973 \end{bmatrix}$$

<*Insert Table 3 here *** >**

4.2.3 *Step 3:* The Direct Costs and Allocation of Indirect Costs according to ABC for Sustainable Public Transport Infrastructure

The main advantage of ABC is that it provides an accurate and integrated cost computation, especially under conditions in which activities vary and in which the indirect costs represent a substantial proportion of the total costs. In this study, the total costs of sustainable public transport infrastructure projects are divided into direct and indirect costs. The direct costs refer to direct material costs, direct labor costs and direct machine costs that can be directly traced to sustainable public transport infrastructure projects. As shown in Table 4, each sustainable public transport infrastructure project requires the following main activities when considering indirect assignment of costs by activity-based costing methods:

- Project-level activity refers to sustainable construction design activity costs allocated to infrastructure projects by the activity driver of design drawings.
- Unit-level activity refers to low-carbon construction activity, maintenance, and repair warranty activities costs allocated to the infrastructure projects by the activity driver of machine hours and labor hours, respectively.
- Environmental protection-level activity refers to eco-energy and water conservation activities, and construction waste recycle activity costs allocated to infrastructure projects by the activity driver of energy control hours and recycle tons, respectively.
- Batch-level activity refers to building material purchasing activity and construction waste landfill activities costs allocated to infrastructure projects by the activity driver of transport distance and disposal tons, respectively.

The direct costs and indirect costs assigned by activity-based results are shown in Table 4. The example data reveal that the total costs of Tamhai Light Rail (TLR) Project, Tamjiang Bridge (TB)

Project and Tambai Expressway (TE) Project are: $15,141 (million), $17,285 (million) and $11,144 (million), respectively. In particular, information on the indirect cost data, which are usually considered as general overhead costs by traditional cost systems, may help managers' decision making in regard to project cost evaluation and achieving sustainable transport developing strategies. More importantly, the decision maker can employ the improvement plan to identify non-essential activities or poor-performing activities related to the sustainable public transport infrastructure project, while simultaneously contributing to managing the capacity of human resources, construction equipment and reengineering the supply chain to achieve value creation.

<*Insert Table 4 here *** >**

4.2.4 *Step 4*: Carbon Footprint Computations for Sustainable Transportation Project

Based on the assumption that the transport sector has the responsibility to disclose the carbon footprint of public transport infrastructure projects to the public, this step applies the LCA method to calculate the carbon footprint of sustainable transport infrastructure projects. The amount of the carbon footprint emission that results from energy consumption, according to the LCA method, is calculated as listed in Table 5; it shows the carbon footprint emission quantities resulting from the three alternatives. Furthermore, the CO_2 emission quantities were used to evaluate the CO_2 emission factors according to IPCC (2014). These values are 2,213,110 tons for the Tamhai Light Rail (TLR) Project, 2,377,019 tons for the Tamjiang Bridge (TB) Project and 2,424,874 tons for the Tambai Expressway (TE) Project. Thus, based on the responsibility of carbon disclosure, this study adopts CO2e emission quantities measured as part of the resource requirements and essential limitations of the sustainable public transport infrastructure project.

<*Insert Table 5 here *** >**

4.2.5 *Step 5:* An Optimal Portfolio for Public Sustainable Transport Infrastructure Project using the Zero-One Goal Programming Model

Advanced optimization using mathematical programming for the simulation of the decision making problem is suited to explore solutions among the conflicting criteria and reduce costs and time effectively, such as its application in irrigation system management (Valipour & Montazar, 2012;

Valipour, 2012b; Mahdizadeh Khasraghi et al., 2105; Valipour, 2016). In order to handle the real situations of sustainable public infrastructure, this study employed the goal programming method to deal with problems involving multiple conflicting objectives. Miller & Szimba (2015) present information on the risks and challenges pertaining to transport infrastructure projects being associated with investment costs, socio-economic benefits and the construction period of the project. As transport infrastructure projects may have an impact on construction resource allocations, it is crucial to incorporate the resource constraints within the decision-making processes for a sustainable public transport infrastructure, especially in environmental perspectives. In this application, the transport sector, responsible for the sustainable public transport infrastructure project selection, seeks the optimal portfolio projects with the most suitable construction costs, carbon footprint quantities, construction time, percentage of green material and low-carbon construction machine hours, as the data show in Table 6.

There are five resource constraints as obligatory goals: (1) total maximum budgeted construction costs of $450,000 (million) are available to complete all of the projects selected; (2) a total maximum of 7,000,000 KgCO2e of carbon footprint quantities is slated to complete all of the projects selected; (3) a total maximum of 130% of green material percentage is available to complete all of the projects selected; (4) the maximized low-carbon construction machine hours are 2,000; and (5) the maximized construction time for all of the projects is 160 months. The other flexible goal is an initial allocation of carbon footprint quantities set at 7,000,000 KgCO2e, which can vary up to, but not beyond, the total maximum quantities of 4,800,000 KgCO2e; deviation from this allocation is permitted.

The mathematical optimization model developed considers the limited resources and uses the weights obtained from the ANP model. The final ZOGP model formulation is shown in Table 7, presenting the priority of ANP weights and d_1^+ and d_1^-, respectively. Meanwhile, the binary variables were $x_1(TLR)$,$x_2(TB)$ and $x_3(TE)$. x_1,x_2 or x_3=1 shows that the j_{th} sustainable public transport infrastructure project is selected, and x_1,x_2 or x_3=0 shows that the j_{th} sustainable public transport infrastructure project was not selected.

<*Insert Tables 6 and 7 here *** >**

The constructed ZOGP model with relevant constraints and parameters is as follows:

X_1=1, X_2=0, X_3=1,$d_1^- = 18715, d_1^+ = 0, d_2^- = 237, d_2^+ = 0, d_3^- = 5, d_3^+ = 0, d_4^- = 198, d_4^+ = 0,$ $d_5^- = 0, d_5^+ = 64, d_6^- = 0,\ d_7^- = 1,, d_8^- = 0, d_9^- = 17, d_9^+ = 0$

5. Discussion

According to the empirical results in Section 4, this study's proposed integrated MCDM approach could provide more relevant results. Specifically, the interdependent relationships of perspectives and criteria can be used as the evaluation standard of sustainable public transport development. Also the carbon footprint with activity-based costing, combined with Mathematical Programming can be used to obtain the optimal portfolio of sustainable public transport infrastructure projects.

According to the (D-R) values by the DEMATEL method, this study's findings indicate that the major influencing perspectives include: Sustainable Transport (ST), Social Development (SD) and Financial Feasibility (FF) for selecting sustainable public transport infrastructure projects (shown in Table 1); the criteria of the cause group include: Decreasing traffic energy consumption (DTC), Attaching the goal of CO_2 emissions (ACE), Promotion of land use (PLU), Minimize Maintenance & Operational Costs (MPC) and Construction technological immaturity (CTI) (shown in Table 2). Of the five evaluation criteria for sustainable public transport, 'decreasing traffic energy consumption' (DTC) (1.252) ranks first under the case group. It is pointed out that government and industry decision makers have regarded the 'reduce traffic energy consumption' concept as a sustainable transport developing trend. Also there are less carbon emissions from the transport infrastructure project life cycle by decreasing traffic energy consumption. Similarly, seven evaluation criteria appeared in the effect group: Improving traffic services' quality (ISP), Promotion of local tourism (PLT), Promotion of economic and career opportunities (PEC), Minimize Environmental Costs (MEC), Minimize Infrastructure Costs (MIC), Construction noise and air pollution (CAN) and Ecological damage (ED). However, when multiple criteria and network structure relations are included in the alternatives evaluation, the priority weights become: Tamhai

Light Rail (TLR) Project (0.5132) ≻ Tamjiang Bridge (TB) Project (0.2895) ≻ Tambai Expressway (TE) Project (0.1973).

Moreover, the total costs of sustainable public transport infrastructure projects are divided into direct costs and indirect costs. In order to trace costs for the sustainable public transport infrastructure project, the ABC technique's related activities include: Project-, Unit-, Environmental protection- and Batch-level activity. The total cost of the sustainable public transport infrastructure projects is shown in Table 4. In addition, the amount of carbon footprint emissions that result from energy consumption, according to the LCA method, is listed in Table 5, which shows the carbon footprint emission quantities resulting from the three alternatives. The cost evaluation of ABC and the amount of carbon footprint are viewed as resource constraints within the decision-making process.

Finally, the optimal portfolio of sustainable public transport infrastructure under resource constraints (the budgeted construction costs, carbon footprint quantities, green material percentage, low-carbon construction machine hours and construction time) uses the ZOGP model, by which the ANP priority weights can be combined with the objective functions. The results indicate that Tamhai Light Rail (TLR) Project and Tambai Expressway (TE) Project would be selected by the integrated decision model. After using this integrated MCDM approach, we conclude that we can solve problems having multiple criteria, interdependence and resource constraints. The outcome of this study should be useful to promote the implementation of sustainability transport development strategies, particularly in Taiwan.

6. Conclusions

Public transportation infrastructure policy is important for adaption to climate change, especially in environmentally friendly and economic development. This study presents an integrated model to evaluate sustainable public transport infrastructure projects. The model includes five steps: evaluating relationships among the perspectives and criteria with DEMATEL, finding the priority weight derived by the ANP, calculating the direct cost and allocating indirect cost according to ABC, computing the carbon footprint and using the ZOGP to obtain an optimal portfolio for sustainable public transport infrastructure projects in Taiwan. The main contribution of the paper is benefitting academia, industry and policy makers by providing a new way to integrate activity-based costing and the carbon footprint into transport infrastructure project selection.

(1) For the academic field, this study is concerned with the incorporation of the carbon footprint and cost measurement into resource constraints content, utilizing an MCDM with a mathematical planning-decision model for transport infrastructure projects.

(2) For the industrial field, the integrated model can help transport infrastructure project managers accurately understand how to allocate resources and funding for energy-saving activities to each project, through appropriate cost drivers.

(3) For the policy field, this study has developed an optimal transport infrastructure project cost assessment solution and carbon footprint computations regarding sustainable development.

The conceptual model can be extended to sustainable urban transport planning decision problems such as Bus Rapid Transit (BRT) system, Rapid transit system and High-speed rail system in order to apply the concepts systematically. Sustainable assessment models are particularly suitable for the urban transport system that contains mixed transport infrastructure located in different regions. Moreover, different transport system may have different evaluation criteria and available resources. It is worth mentioning that as the environment impact of transport infrastructure intensifies in the search for sustainable urban development, it is imperative for government and industry to develop sustainable assessment models, as well as carbon footprint and construction activities improvement to reduce environment damages.

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Table 1: The total-relationships matrix of perspectives for sustainable transportation project selection (p≥1.518)

	ST	***SD***	***FF***	***EI***	D	D + R	D - R
ST	1.493	***1.801***	1.517	***1.992***	6.802	12.791	0.813
SD	***1.676***	1.456	1.438	***1.910***	6.481	12.618	0.343
FF	***1.696***	***1.732***	1.264	***1.951***	6.643	11.841	1.445
EI	1.124	1.148	0.979	1.115	4.367	11.335	(2.602)
R	5.989	6.138	5.198	6.968			

Table 2: The total-relation matrix of criteria for sustainable transportation project selection (p≥0.385)

	DTC	**ISP**	**ACE**	**PLU**	**PLT**	**PEC**	**MEC**	**MIC**	**MPC**	**CAN**	**CTI**	**ED**	**D**	**D+R**	**D-R**
DTC	0.372	***0.445***	***0.483***	***0.470***	***0.497***	***0.490***	***0.529***	***0.478***	***0.456***	***0.498***	***0.461***	***0.520***	5.699	10.147	1.252
ISP	0.328	0.280	0.341	0.370	0.378	0.375	***0.385***	0.352	0.349	0.375	0.339	***0.389***	4.262	8.745	(0.221)
ACE	***0.408***	***0.404***	0.333	***0.401***	***0.424***	***0.419***	***0.473***	***0.422***	***0.402***	***0.428***	***0.401***	***0.465***	4.981	9.535	0.428
PLU	***0.398***	***0.388***	***0.406***	0.361	***0.469***	***0.450***	***0.485***	***0.433***	***0.411***	***0.445***	***0.410***	***0.476***	5.132	9.926	0.338
PLT	*0.371*	***0.393***	*0.378*	***0.402***	0.348	***0.420***	***0.439***	***0.404***	0.358	***0.408***	0.356	***0.437***	4.714	9.748	(0.320)
PEC	*0.339*	*0.336*	*0.339*	*0.361*	***0.403***	0.303	0.383	0.358	0.346	0.347	0.330	***0.387***	4.232	9.114	(0.650)
MEC	***0.395***	***0.390***	***0.415***	***0.440***	***0.451***	***0.420***	***0.391***	***0.435***	***0.394***	***0.448***	***0.407***	***0.485***	5.069	10.323	(0.185)
MIC	*0.321*	*0.330*	*0.328*	*0.363*	*0.371*	*0.354*	***0.397***	*0.288*	*0.322*	*0.356*	*0.339*	***0.389***	4.157	8.889	(0.574)
MPC	*0.355*	*0.364*	*0.362*	***0.385***	***0.401***	***0.397***	***0.414***	*0.368*	*0.293*	*0.378*	*0.360*	***0.400***	4.476	8.936	0.015
CAN	***0.399***	*0.382*	***0.394***	***0.417***	***0.428***	***0.417***	***0.450***	*0.387*	*0.381*	*0.348*	***0.398***	***0.442***	4.844	9.738	(0.051)
CTI	*0.360*	*0.362*	*0.380*	*0.377*	***0.400***	***0.402***	***0.434***	***0.392***	*0.367*	***0.417***	*0.308*	***0.445***	4.644	9.165	0.124
ED	***0.400***	***0.409***	***0.395***	***0.446***	***0.464***	***0.433***	***0.473***	***0.415***	*0.382*	***0.447***	***0.412***	***0.388***	5.067	10.290	(0.156)
R	4.448	4.483	4.554	4.794	5.034	4.882	5.254	4.732	4.460	4.894	4.520	5.223			

Table 3: The limited supermatrix of the sustainable transportation project

	Goal	*Perspectives*				*Criteria*											
	STP	***ST***	***SD***	***FF***	***EI***	***DTC***	***ISP***	***ACE***	***PLU***	***PLT***	***PEC***	***MEC***	***MIC***	***MPC***	***CAN***	***CTI***	***ED***
Alternatives																	
TLR	0.5132	0.5257	0.4934	0.4976	0.5069	0.4245	0.4714	0.5299	0.4400	0.4979	0.5888	0.4245	0.4714	0.5299	0.4400	0.4979	0.5888
TB	0.2895	0.2762	0.3029	0.3108	0.2985	0.3460	0.3299	0.2617	0.3697	0.3408	0.2301	0.3460	0.3299	0.2617	0.3697	0.3408	0.2301
TE	0.1973	0.1981	0.2037	0.1917	0.1946	0.2295	0.1987	0.2085	0.1904	0.1613	0.1812	0.2295	0.1987	0.2085	0.1904	0.1613	0.1812

Table 4: Direct costs and allocation of indirect costs according to ABC for sustainable public transport infrastructure

	Sustainable public transport infrastructure		**Tamhai Light Rail**	**Tamjiang Bridge**	**Tambai Expressway**
Direct construction costs	***Direct Material costs***	(million)	5,120	6,200	3,400
	Direct Labor costs	(million)	3,400	2,300	1,800
	Direct Machine costs	(million)	4,100	5,600	3,000

Indirect Activity costs

Required resources (million) / Activity level	Labor costs	Materials	Equipment	Total Activity costs	Activity drivers	Costs per activity driver	**Tamhai Light Rail**		**Tamjiang Bridge**		**Tambai Expressway**	
							Activity driver quantities	Activity cost	Activity driver quantities	Activity cost	Activity driver quantities	Activity cost
Project-level activities												
Sustainable construction design activity	20	10	5	35	Design drawings	26,882	500	13,440,860	425	11,424,731	377	10,134,409
Unit-level activities												
Low-carbon construction activity	141	200	100	441	Machine hours	304,138	340	103,406,897	600	182,482,759	510	155,110,345
Maintenance and repair warranty activity	54	6	3	63	Labour hours	35,493	800	28,394,366	520	18,456,338	455	16,149,296
Environment -level activities												
Eco-energy and water conservation activity	130	15	13	158	Energy control (h)	144,954	360	52,183,486	350	50,733,945	380	55,082,569
Construction waste recycle activity	24	15	11	50	Recycle (tons)	73,529	200	14,705,882	250	18,382,353	230	16,911,765
Batch-level activities												
Building material transport activity	30	24	40	94	Transport distance (km)	54,398	568	30,898,148	550	29,918,981	610	33,182,870
Construction waste landfill activity	15	2	7	24	Disposal (tons)	33,946	267	9,063,649	210	7,128,713	230	7,807,638
Total Indirect Activity costs (million)							2,520.93		3,185.28		2,943.79	
Total costs=Total Direct costs + Total Indirect Activity costs (million)							**15,140.93**		**17,285.28**		**11,143.79**	

Table 5: The Carbon footprint computations for sustainable transportation project - Example Data

Sustainable transportation project construction activity	Tamhai Light Rail		Tamjiang Bridge		Tambai Expressway	
	Activity data	KgCO2e	Activity data	KgCO2e e	Activity data	KgCO2e
(Ⅰ) Design & pre-construction						
*Sustainable construction design activity (*Electric Power *)*	30,000	**15,960**	43,000	**22,876**	24,000	**12,768**
Green building material production activity (Diesel Oil)	11,000	**28,666**	12,500	**32,575**	12,000	**31,272**
*Building material transport activity (*Motor Gasoline)	22,000	**49,788**	32,000	**72,419**	18,000	**40,736**
(Ⅱ) Construction						
*Low-carbon construction activity (*Diesel Oil)	240,000	**625,440**	280,000	**729,680**	310,000	**807,860**
*Eco-energy and water conservation activity (*Electric power)	22,600	**12,023**	31,100	**16,545**	19,900	**10,587**
(Ⅲ) Construction waste						
*Construction waste recycle activity (*Diesel Oil)	114,000	**393,300**	119,000	**410,550**	124,000	**427,800**
*Construction waste landfill activity (*ton)	120,000	**848,400**	114,000	**805,980**	113,000	**798,910**
(Ⅳ) Post-construction						
*Maintenance and repair warranty activity (*Electric Power*)*	1,400	**745**	1,500	**798**	1,700	**904**
Total CO2e mission quantities		**2,213,110**		**2,377,019**		**2,424,874**

Note :CO2e emission factor (EPA,2012): (1) Electric Power: 0.69 Kg CO2e/degree ; (2) Diesel Oil: 3.45Kg CO2e/L ; (3) Motor Gasoline: 3.1 Kg CO2e/L; (4) Waste landfill: 7.07 Kg CO2e/ton.

Table6: The resource requirements and essential limitations of the sustainable public transport infrastructure project

Resource requirements	*Sustainable transportation project*			**Goal (bi)**
	Tamhai Light Rail	Tamjiang Bridge	Tambai Expressway	
Budgeted construction cost ($)(x1,000,000) (from Table 4)	15,141	17,285	11,144	45,000
Carbon footprint quantities (KgCO2e) (x10,000) (from Table 5)	221	238	242	700
Green material (Percentage) (%)	65	70	60	130
Low-carbon construction machine hours (H)	1,002	890	800	2000
Construction time (months)	60	48	36	160

Table 7: The ZOGP model formulation

ZOGP model formulation	***Goal***
Minimize V=	
$P_1(d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+)$	Satisfying five mandated resource constraints for the sustainable transport infrastructure project.
$P_2(0.5132d_6^- + 0.2895d_7^- + 0.1973d_8^-)$	Selecting the highest weights for the sustainable transport infrastructure project from ANP.
$P_3(d_9^+ + d_9^-)$	Using 480 (1000Kg CO2e) carbon footprint quantities for all sustainable t transport infrastructure projects selected.
Subject to	
$15141X_1+172851X_2 + 11144X_3 - d_1^+ + d_1^- = 45000$	Avoiding over-utilizing maximum budgeted construction costs.
$221X_1+238X_2 + 242X_3 - d_2^+ + d_2^- = 700$	Avoiding over-utilizing maximum carbon footprint quantities.
$65X_1 + 70X_2 + 60X_3 - d_3^+ + d_3^- = 130$	Avoiding over-utilizing maximum percentage for green material.
$1002X_1 + 890X_2 + 800X_3 - d_4^+ + d_4^- = 2000$	Avoiding over-utilizing maximum low-carbon construction machine hours.
$60X_1 + 48X_2 + 36X_3 - d_5^+ + d_5^- = 160$	Avoiding over-utilizing maximum construction time.
$X_1+d_6^- = 1$	Selecting sustainable transportation project for Tamhai Light Rail.
$X_2+d_7^- = 1$	Selecting sustainable transportation project for Tamjiang Bridge.
$X_3+d_8^- = 1$	Selecting sustainable transportation project for Tambai Expressway.
$221X_1+238X_2 + 242X_3 - d_9^+ + d_9^- = 480$	Avoiding over- or under-expected total carbon footprint quantities.
$X_j = 0 \; or \; 1 \; for \; j = 1,2,3$	

Formulation Results

X$_1$*=1*,*X*$_2$*=0*, *X*$_3$*=1*,

$d_1^- = 18715, d_1^+ = 0, d_2^- = 237, d_2^+ = 0, d_3^- = 5, d_3^+ = 0, d_4^- = 198, d_4^+ = 0, d_5^- = 0, d_5^+ = 64, d_6^- = 0,\ d_7^- = 1,, d_8^- = 0, d_9^- = 17, d_9^+ = 0$

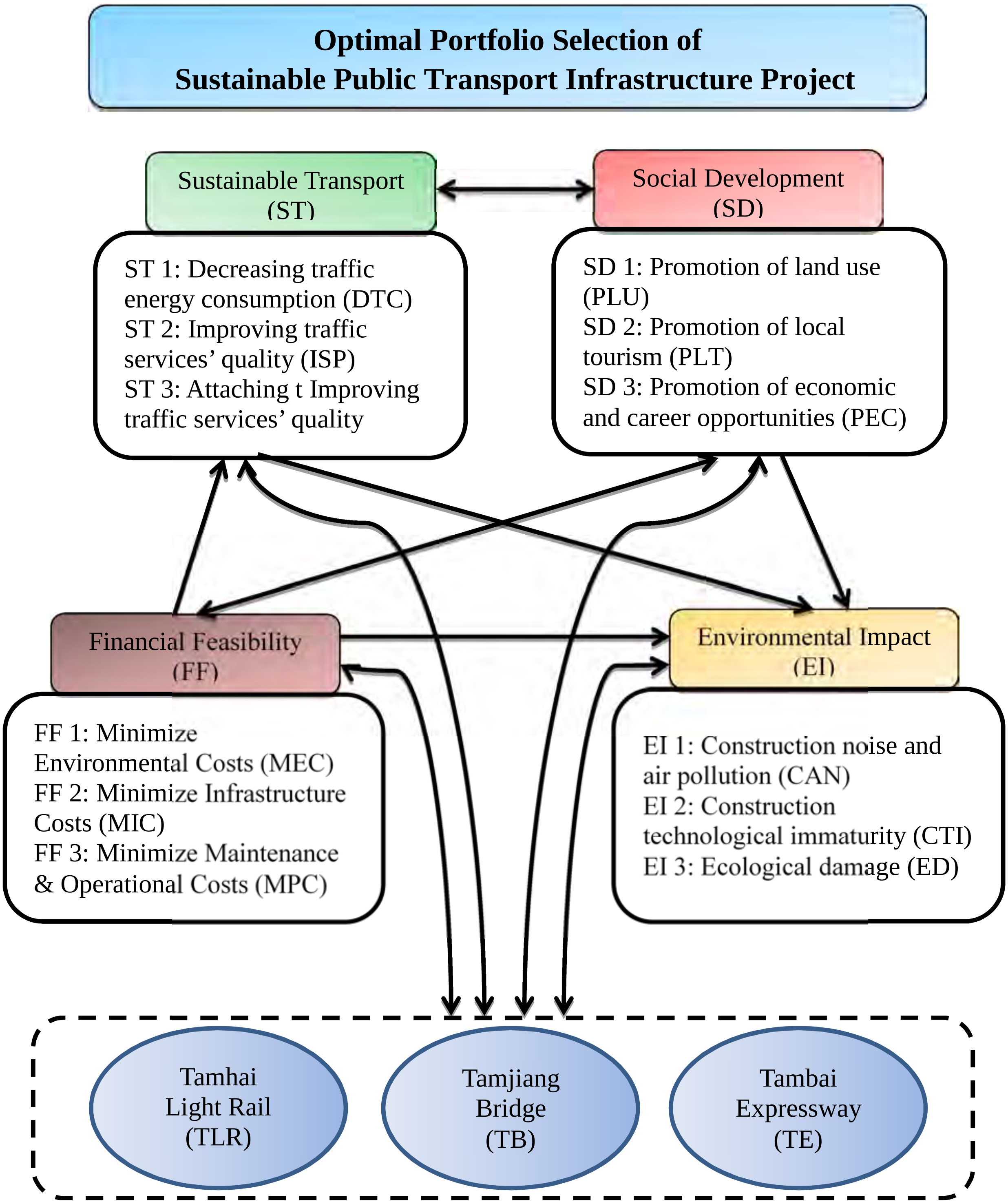

Figure 1: An overview of the proposed ANP-based model for sustainable public transport infrastructure project selection

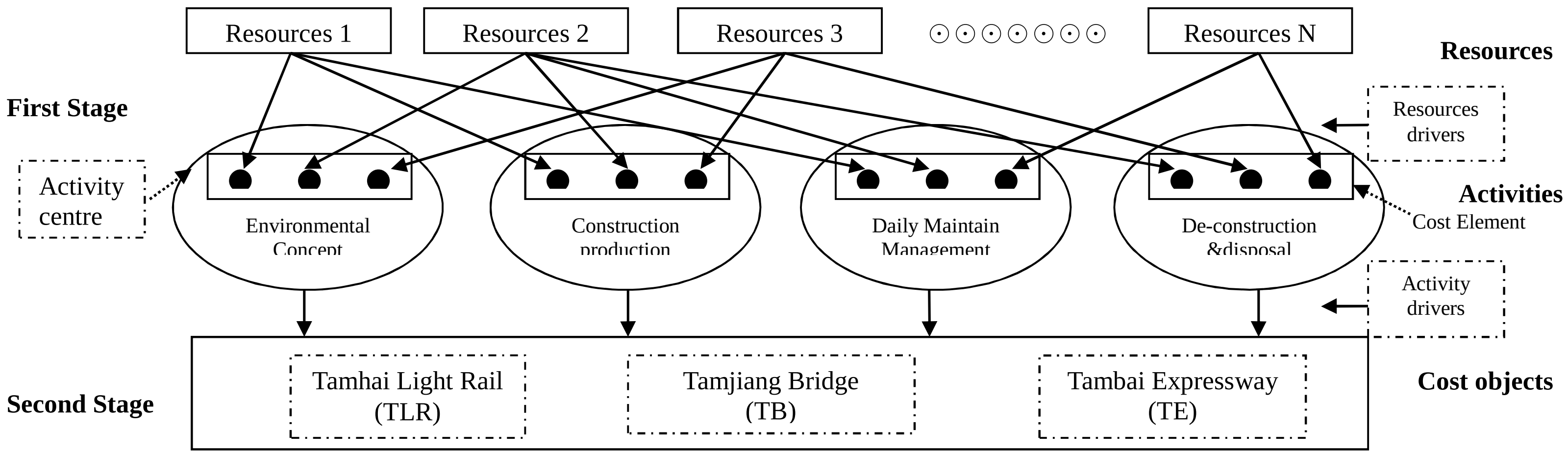

Figure 2: The cost assignment view of ABC for sustainable public transport infrastructure projects (Tsai et .al., 2014).

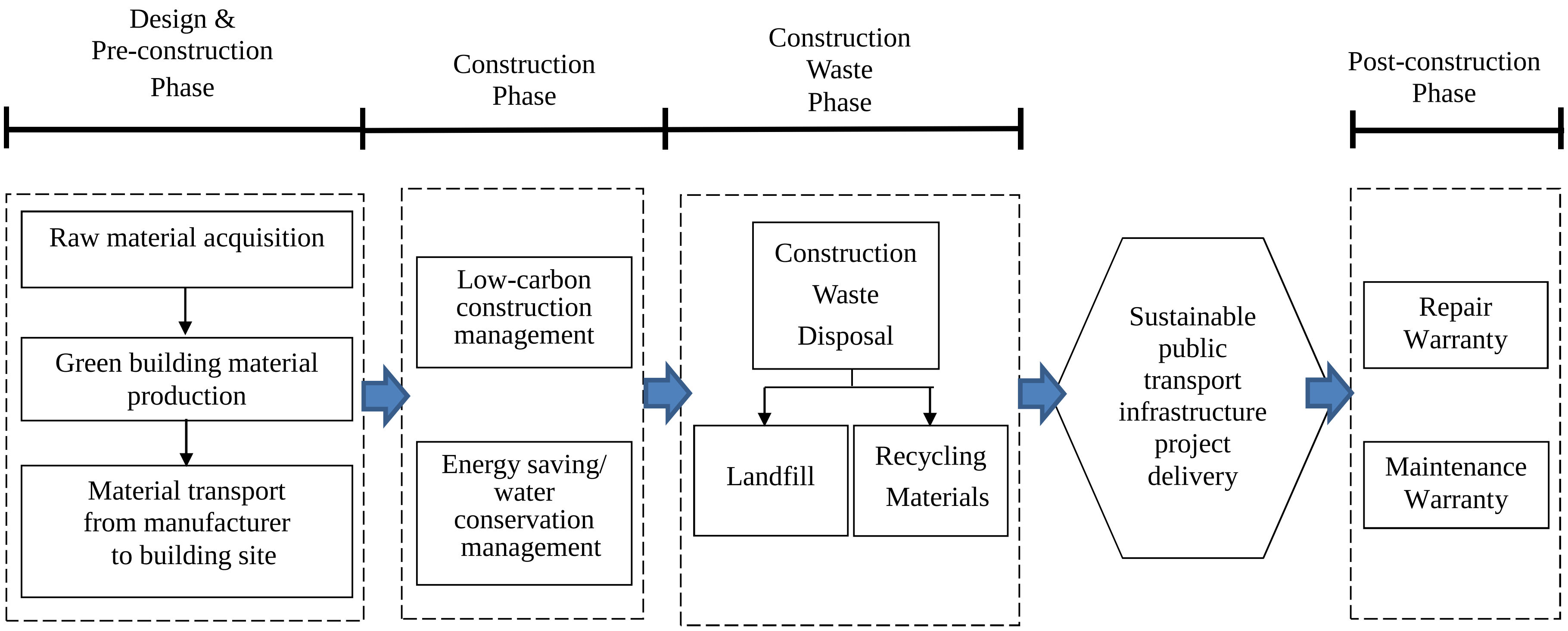

Figure 3: The system boundaries for sustainable public transport infrastructure project's carbon footprint

Figure 4: Taiwan's Public transport infrastructure project alternatives

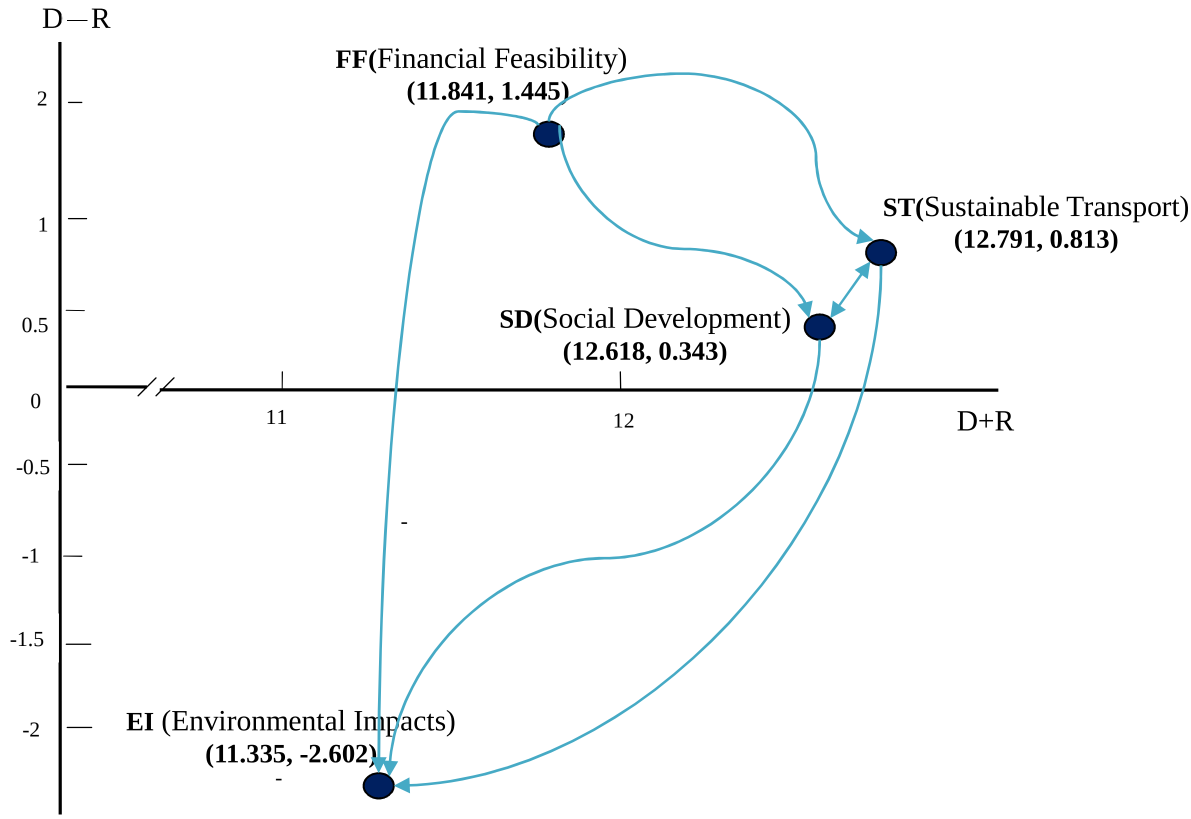

Figure 5: The impact-digraph map of all relationships for perspectives for the sustainable transportation project (p≥1.518)

Incorporating Carbon Footprint with Activity-Based Costing Constraints into Sustainable Public Transport Infrastructure Projects Decisions

Research Highlights

- A sustainable concept framework is presented to evaluate transport infrastructure.
- Developing an optimal transport infrastructure project cost assessment solution.
- Integrating MCDM and Goal Programming in selecting transport infrastructures.
- Government must incorporate Carbon Footprint into overall transport infrastructure.