Available online at www.sciencedirect.com
ScienceDirect
Transportation Research Procedia 3 (2014) 631 – 640
Transportation Research Procedia
www.elsevier.com/locate/procedia

17th Meeting of the EURO Working Group on Transportation, EWGT2014, 2-4 July 2014, Sevilla, Spain

Incorporating Systems Engineering Methodologies to Increase the Transferability of Journey Planners

Sharon Shoshany-Tavory[a], Ayelet Gal-Tzur[b*], Niv Eden[b]

[a]*Gordon Center for Systems Engineering, Technion - Israel Institute of Technology - Technion City - Haifa 32000, Israel*
[b]*Transportation Research Institute, Technion - Israel Institute of Technology - Technion City - Haifa 32000, Israel*

Abstract

One characteristic that is highly desired in transportation-related applications, and particularly journey planners, is transferability – i.e., the capacity to be used with minimal modification in different locations. To achieve transferability, the initial design must take into account all factors that may diverge between locations, including existing modes of transport, the availability of required data, the technological habits of users, etc. In consequence, a highly transferable system is difficult and expensive to develop and maintain. A very flexible initial design, one ensuring low-cost adaptability of the system for different cities, regions, or countries, might not be cost-effective. On the other hand, a rigid design, tailored for a specific location, might act as a barrier to implementing the system elsewhere. This dilemma has motivated researchers to seek a structured process for selecting the most promising design, one that will realize the benefits of transferability while minimizing development costs.
One of the fundamental building blocks of structured design in SE is requirements-design exploration. This paper evaluates the use of Multi-Attribute Tradespace Exploration (MATE), a leading design exploration process, for the effective design of journey planners.
We examine the process of changeability assessment (e.g., transferability) in light of the goals of journey planning from the point of view of different stakeholders: travelers, private developers, and transport authorities. The analysis demonstrates how tradespace exploration can also be used to identify specific designs that bridge the gap between the public and private sectors and provide value over time to all parties. Moreover, when specific concerns of public authorities are not met, tradespace exploration can reveal measures the public sector can take (financial or others) for making their preferred design attractive to the private sector as well.

Selection and peer-review under responsibility of the Scientific Committee of EWGT2014

* Corresponding author. Tel.: +972-4-8292956; fax: +972-4-8225716.
E-mail address: galtzur@cv.technion.ac.il

Selection and peer-review under responsibility of the Scientific Committee of EWGT2014
doi:10.1016/j.trpro.2014.10.042

Keywords: Journey planner;Travel information systems;Transferability;Changeability;Tradespace exploration

1. Introduction

Journey Planners (JPs) have become a part of mobility services that almost every traveler expects to have. A multimodal journey planner is an IT system able to propose a set of one or more transport services answering at least the question "How can I go from location A to location B at a given departure/arrival date and time and under which conditions, using various modals" (ITS Action Plan 2011). Modern JPs support multiple user objectives while accounting for his/her constraints and available resources (Bie et. al, 2012). Future JPs are expected to actively influence user behavior by introducing incentives as well as travel information.

JPs are often sponsored, fully or partially, by transportation authorities, which understand their potential to promote the use of sustainable modes of transport, such as public transportation (PT), cycling, walking, or ridesharing. Moreover, JPs can support economic and tourism development in a region by increasing mobility and social inclusion and opening opportunities for private services and revenue-generating activity.

From the perspective of public authorities, such initiatives raise three interrelated questions:

- What features of a JP will enable it to be transferable to different locations (e.g., cities or regions)?
- What features of a JP will ensure a business model able to minimize public funding over time?
- What investment of public funding will be needed to achieve the benefits of a JP as an ongoing promoter of sustainable transport in a variety of locations?

Clearly, design of a JP must take into account the needs of the travelers who are its potential users, as well as the concerns of its developer. The goal of this paper is to propose a systematic approach for analyzing various possible designs and selecting the most promising ones, based on methodologies adapted from the domain of SE. Our purpose is to demonstrate how these methodologies can be applied to the design of a JP, while aiming to ensure that the needs of all stakeholders are addressed.

2. The problem of transferability

Most JPs are initially developed in a narrow context, Yet both private developers and public authorities have an interest in ensuring that the JP can be used in different contexts, whether in a different geographical context, or by a different group of people – a trait known as transferability. However, achieving transferability is not simple, as different locations and users groups have their own demands and constraints. For example, a JP developed for a region where raw data (maps, transit routes etc.) is available online as data feeds will need alteration for a region where such data must be manually updated.

These issues present a design problem for all parties engaged in the development process. Specifically, should transferability be considered in the initial design, and if so, to what extent and under what conditions, especially when private developers and public authorities seek to combine their efforts. Transferability can be treated a trait that define the way a system reacts to change. Within the domain of SE, transferability is regarded as part of the broader trait of system changeability – a system property supporting lifetime value delivery across changes. Changeability is the ability to alter either the physical design parameters or operations of the system, and can be leveraged in any of the lifecycle phases of common engineering systems: design, build, integration, testing, and operation. Ross et al. (2008) explored the different attributes that makeup the changeability feature of a system (Robustness, Flexibility, Adaptability) and defined "a change" as a state transition, where a system moves from one state to another based on some forces, and as result produces an impact.

Every changeability feature of a system has its own price to be paid in order to enable the transition from one state to another. Given these definitions, transferability can be regarded as part of changeability, thus following the suggested SE approach, can give better insight to the research questions.

Addressing changeability and its implications in the context of JP transferability requires us to explore high-level system design. This, in turn, requires elicitation of the system's design variables (DVs) – i.e., key design features that can take various values. For example, the most typical design variable for JPs is "supported transport modes". This DV may take a range of values, from private vehicles as a single transport mode to a multimodal option including rail, buses, walking, and car-sharing.

Table 1 provides examples of some DVs and their values for existing JPs. Each column represents a DV.

Table 1 – DVs of existing journey planners

Case study	Supported transport modes	Support preference	RT based	Supported interface	Selection criteria
Google	1 car, N transit, walk	No	Only for car	Web->mobile	time
Moovit. co.il	N transit +walk	Walking distance	Yes	mobile	Time, # of changes
Transport Direct	1 car, N transit & walk	Many	General info	multiple	Time, Cost, CO2, changes
Waze	1	No	Yes	mobile	time

Changeability is a fundamental design feature that should be explored as part of the consideration of different design alternatives. Multi-Attribute Tradespace Exploration (MATE), used and extended by Fitzgerald and Ross (2012), can be used for this purpose, as it allows for the systematic creation and evaluation of design alternatives and their changeability features.

3. Using MATE as a methodology for exploring the design space

MATE provides a methodology for the selection of an appropriate design based on the identification of stakeholders, their goals and attributes, the system's DVs, and on exploration and evaluation of the tradespace. MATE uses the following definitions:

1. **Attributes** are features of a product or system that the decision maker takes into consideration when deciding between any two design options. The attributes chosen will reflect the goals of the stakeholders involved in developing the system. In the case of a JP, for example, equity is an attribute likely to be valued by a public authority, reflecting its goal of providing a good level of service to all sectors of the population. Other stakeholders, such as private developers, may give preference to other attributes, in keeping with their goals.
2. **Utility (U)** is a dimensionless metric representing the satisfaction derived from having a certain level of attributes, following Keeney and Raiffa's (1993) multi-attribute utility theory (MAUT). A utility function is associated with the preferences of each stakeholder. MAUT has been used in several transportation case studies, e.g. Zietsman, Rilett, and Kim (2006).
3. **Design Variables (DVs)** are key design features of a system that can take various values, such as those described in the columns of Table 1.
4. **Design Vector** is a vector describing an alternative design by a set of specific values, one for each DV, such as those described in each row of Table 1.
5. **Cost (C)** is the price associated with the development, operation, or maintenance of a given design.

MATE evaluates the utility of a given design as perceived by the stakeholders and uses it as a decision metric. The relationships between the design's attributes and DVs are defined, and serve as the basis for obtaining the level of each attribute for a given design vector. The stakeholder's utility is then calculated based on the attribute levels associated with each alternative design, along with the cost associated with the same design. The resultant tradespace, made up of (U, C) pairs, is explored for Pareto front designs – designs that are not dominated in both cost and utility by any other design. Use of the MATE methodology for a JP is illustrated in Section 5.

4. Assessing design solutions in MATE using changeability criteria

Ross and Rhodes (2008) extended MATE to support dynamic life cycle development by incorporating Epoch Era Analysis (EEA). EEA was designed to clearly show the effects of time and context on the value of a system in a structured way. The base unit of time is the epoch, which is a period of time defined by a fixed set of variables describing the context in which the system operates. In the context of JPs, an epoch can describe a specific region in which the JP is implemented. The original region for which the JP was developed is the first epoch. Transition to the next epoch occurs when the JP is implemented in a new region. Fitzgerald and Ross (2012) further extended MATE and EEA by introducing the concept of a fuzzy Pareto front, which is a set of (U, C) points that are sufficiently close to the Pareto front designs to merit consideration.

5. Analysis of journey planner changeability

In this section, we shall systematically explore and evaluate the design space of a JP according to the methods described earlier. While the analysis is systematic, it is merely a demonstration and thus by no mean complete.

5.1. Stakeholders' concerns

The first stage in any SE process is to identify stakeholders and analyze their concerns regarding the system. JPs have a large number of stakeholders, including travelers, national authorities, regional authorities, private developers, transport service operators, etc. We describe the concerns of three of these stakeholders:

- **Public Transport Authority (PTA).** The role of the PTA is to regulate PT in its jurisdiction and to plan future improvements. Its main concerns therefore include promoting PT use by all population sectors; spatial extension of PT services; and improving the quality of PT services based on an understanding travelers' needs.
- **Private Developer (PD).** A PD developing a JP, is mainly concerned with achieving a high return on investment (ROI). While initial funding is mandatory, the main goal thus becomes attracting a large number of users. Key to success is innovation while maintaining low development and operating expenses, especially in the early phases.
- **JP Users.** Users are interested in: access to information (e.g., alternatives, cost, time); alternative suggestions based on preferences, abilities, resources; free information; data availability and quality; ease of use; and privacy.

For the sake of simplicity, only the concerns of the PTA and the PD will be hereby modeled. Concerns of travelers are reflected in the concerns of both of these stakeholders; however, these are driven by additional concerns (Nickel 2010). Based on understanding of the stakeholders' concerns, detailed and quantifiable attributes are derived, as a transformation of the concerns listed above. Table 2 provides the attributes associated with a PTA.

Table 2 – Attributes associated with PTA

Attribute	Interpretation
Modes of transport coverage	The journey alternatives offered to the JP user should reflect the breadth and flexibility of the transportation system.
Equity	The information provided should take into account the mobility needs of various population sectors, and should be accessible to travelers via communication means available to them.
Policy support	Journey plans and the manner in which they are presented should encourage the use of public transport.
Transferability	The JP should be easily adaptable to other locations of concern, including interconnection to existing systems.
Reliability	Information provided, regarding the journey plans, should be complete, precise, and timely.
Decision support info	Information obtained through the use patterns of the JP should support decision making associated with transportation planning.

Once the attributes are defined, each attribute X is associated with weight W, i.e., its importance to the decision maker. Each attribute is also associated with a utility function, which is delineated by the thresholds X_{min} and X_{max}.

X_{min} specifies where the utility function drops to 0 (the minimally acceptable attribute level for the stakeholder), and X_{max} defines where utility rises to 1 (above which there is no additional contribution to utility). A linear function was used for the utility function – though in some cases, an increasing or diminishing general function more accurately defines user preferences. Attributes, their relative weights, and the utility functions associated with them are stakeholder-dependent. In MATE, these parameters would have been elicited from structured customer interviews. We use alternative logic. To obtain the weights of the various attributes, we assume that the contents of a call for proposals issued by a public authority to develop travel information systems reflect the aspects of the system valued by the authority. Our approach links the number of occurrences of specific words to the relevance of the topic at hand (Manning & Schütze, 1999). We used topics MG.7.1-2014 and MG.7.2-2014 of the Horizon 2020 Work Programme 2014-2015 in the area of Transport[1]. We counted the terms associated with each attribute, and computed the weight of the attribute based on the frequency of these terms appearances. To derive the values of X_{min} and X_{max} for the PTA, we used the following demonstrative scheme:

1. The X space was split into five levels, from zero to one.
2. The attribute level characterizing the currently available JP serves as a reference, and reflects a value of 50% (medium satisfaction) for the PTA.
3. One level above the existing one, for a specific attribute, can be regarded as a satisfying improvement and is therefore assigned the maximum value (100% satisfaction). Any higher levels also score the maximum value.
4. Since no authority wants to decrease performance, lower levels of the attribute generate a value of 0.

The suggested method accounts for the fact that the weights and utility functions of stakeholders in different locations are expected to differ as a result of human tendency to judge each service in comparison to those currently available. This approach also accounts for changes over time. With the passage of time, the introduction of new and better systems elsewhere and new emerging stakeholder needs, will reduce the level of satisfaction with the existing systems. Table 3 summarizes the value attributes associated with the preferences of our hypothetical PTA. For each attribute the weight (W) is given, and attribute utility value margins are defined by X_{min}, X_{max}.

Table 3 – Weights and utility threshold values associated with each attribute for PTA

Attribute	W	X_{min}	X_{max}
Modes of transport coverage	17%	0.2	0.6
Equity	14%	0.4	0.8
Policy support	14%	0	0.2
Transferability	28%	0	0.4
Reliability	15%	0.4	0.8
Decision support info	12%	0	0.4

The computed weights specified in Table 3, based on the results of the term count method described above, show that the importance of transferability is about twice that of any other attribute. The values assigned to X_{min} and X_{max} are based on the assumption made for the sake of the example regarding the specific attribute level of the locally available JP. For example, it was assumed that for the attribute equity, the current level available (on a 5-level scale from 0 to 1) is 0.6. Hence, any JP whose features reflect a 0.4 level or less with regard to equity makes no contribution to the overall utility value. Similarly, a JP whose features reflect a level of 0.8 with regard to equity already contributes the maximum level of utility, as does a JP providing a level of 1 for this attribute. The attributes of the PD are derived from its concerns in the same manner as those of the PTA, and are given in Table 4.

The different epochs considered for our example relate to the realization of transferability through implementing the JP in additional regions, and the value change of the PD once it completes its first development stage.

[1] http://ec.europa.eu/research/horizon2020/pdf/work-programmes/smart_green_and_integrated_transport_draft_work_programme.pdf

Table 4 – Attributes associated with a PD

Attribute	interpretation	W	X_{min}	X_{max}
Innovation for customer	Offering innovation is the best way for a PD to enter the market, in terms of both funding and the goal of quickly increasing the first body of users (the "first comers"). Innovation in JPs is location-sensitive and dependent on currently available transportation services and other available JPs in this area, as explained above.	0.7	0.7	1
Focus on user Pareto	The PD's focus is on reaching a reasonably large subset of travelers (e.g., holders of Android based smartphones; urban commuters).	0.1	0.33	0.66
Minimize features	Since development investment is proportional to features, only minimal features are supported.	0.1	0.1	0.25
Innovation for public investor	This attribute relates to concerns of public investors who value advanced policy support services (such as incentive-based travel).	0.1	0.5	0.7

5.2. Design variables

The following design variables capture the design space and drive stakeholder satisfaction. Some are feature-based, and some are physical design parameters. For each parameter the range of change is ordered by complexity:

1. **Supported Modes.** These are the modes supported by the JP.
   a. **Single**. The basic value is single-mode.
   b. **Basic Multimodal.** Multimodal journey plans, including various means of PT in conjunction with walking.
   c. **Fixed-Hub Sharing.** Inclusion of modes of transport that involve sharing, such as car-sharing and bike-sharing, using fixed hubs.
   d. **Dynamic Sharing.** Flexible modes such as shared rides or DRT, characterized by flexible routing.
2. **Real-Time information (RT info).** Real-time information support can have the value of:
   a. **None.** No support of real-time information.
   b. **External Sources.** Use of available information from external sources, such as PT operators.
   c. **Self-generated.** Self-generated real-time information based on monitoring travelers using the JP.
3. **Personalization.** A JP can have different levels of personalization.
   a. **Basic.** At the basic level, only the origin (O) and destination (D) are user-specific.
   b. **User-defined.** User-defined preferences, such as a walking range or exclusion of specific transport modes.
   c. **Search History.** The user's search history is saved and used for new searches (e.g. O-D, walking distance).
   d. **Inferred.** The system can analyze multiple historic searches and selected alternatives to learn user preferences, and can assimilate the results into the current journey planning.
   e. **Incentives.** Profile-based travel and incentives, e.g., incorporating incentives into alternative journey plans.
4. **Access Means.** Different travelers have different access means, from telephonic (accessing call centers), through cellular (text messages), to computers, smartphones, and car navigation systems. This design variable can have the value [1-5], representing the number of access means supported by the JP.
5. **Import Automation.** JPs need data to run their services, and can adopt various approaches to getting it.
   a. **Manual data feed** requires a design interface and manual labor to input and check data (sanity test).
   b. **Harvesting.** When data exist in websites but has no standard way of acquiring it, data harvesting is needed (e.g., by transforming data in text form into a database).
   c. **Importing** refers to data feeds from standard and authorized sources.
6. **Standard Interface protocols (Std ICD).** This design parameter can be either True (support) or False.
7. **Rank Method.** This defines the complexity of the search algorithm employed.
   a. **Single.** A predefined single criterion (such as overall travel time).
   b. **Predefined multi-criteria.** This can take the form of setting one criterion for ranking and the others as constraints, for example, ranking by travel time while setting a limit on the number of transfers.
   c. **User-defined multi-criteria.** The user can choose the relevant criteria from a predefined list, selecting thresholds for some criteria and weights for others.
   d. **Dynamic weight search & branch.** This level allows the inclusion of flexible arcs.
8. **Data Warehouse.** This DV can be either True (supports the saving of historic user's choices), or False.

Table 5 explores the most important relationships between the design variables and the attributes defined in the previous paragraph. For lack of space, these are given only for the PTA. Strong relationships are marked by X.

Table 5 - Main relationships between the DVs and the attributes for a PTA Authority

Attribute/ Parameter	Supported Modes	RT Info	Personal-ization	Access Means	Import Automation	Std ICD	Rank Method	Data Warehouse
Modes of transport coverage	X							
Equity			X	X				
Policy support	X		X				X	
Transferability	X				X	X		
Reliability		X			X			
Decision support info			X					X

5.3. Calculation of cost and utility

The total cost of a design includes the costs of development, testing, operation, and migration to additional locations. The development cost is associated directly with the design variables analyzed. For the sake of this paper, we shall assume that costs of testing, operation, and migration are mostly independent of the values assigned to the DVs, and shall treat them as constant per released version. In Eq. 1, the initial cost of a JP is calculated as:

$$C = \sum_i CD\left(DV_i^j\right) + CT + CO \tag{1}$$

where:

C is the total cost of the JP;
$CD\left(\mathrm{DV}_i^j\right)$ is the development cost for obtaining the j^{th} value for the i^{th} DV of the JP;
CT is the cost of testing the JP; and
CO is the cost of operating the JP.

When the JP is transferred to a different location, the additional cost is calculated according to Eq. 2:

$$\Delta C = \sum_i \Delta CD(DV_i^r) + CT + CM + CO \tag{2}$$

where:

ΔC is the additional cost for implementation of the JP in another location;
$\Delta\mathrm{CD}(\mathrm{DV}_i^r)$ is the development cost associated with the r^{th} value for the i^{th} DV, where the r^{th} value is the one required for the new location;
CT is the cost of testing the JP, as required for the new design;
CM is the cost of migrating the JP; and
CO is the cost of operating the JP in an additional location.

The total utility of a specific stakeholder, such as the PTA, is calculated in a stepwise manner. First, the level achieved for each DV is calculated based on a normalized [0-1] scale. The level achieved for each of the attributes reflecting the stakeholder's concerns is derived from the levels of the related DVs, calculated based on Eq. 3:

$$X_a = 1 - \prod_i \left(1 - L\left(DV_i^j\right)\right) \tag{3}$$

where:

X_a is the level achieved for attribute a based on the values of the influencing DVs; and
$\mathrm{L}\left(\mathrm{DV}_i^j\right)$ is the level for the i^{th} DV, given its j^{th} value.

Once the level achieved for a specific attribute is obtained, its utility is calculated based on Eq. 4:

$$U_a = \begin{cases} 0 & If \quad X \le Xmin_a \\ 1 & If \quad X \ge Xmax_a \\ \frac{X_a - Xmin_a}{Xmax_a - Xmin_a} & Otherwise \end{cases} \tag{4}$$

where for each stakeholder:

U_a is the utility achieved for attribute a based on its achieved level;

$Xmin_a$ is the lower threshold of attribute *a,* where its utility drops to 0; and

$Xmin_a$ is the upper threshold of attribute *a,* where its utility reaches the maximum value of 1.

At this stage, the total utility associated with the proposed design is calculated according to Eq. 5:

$$TU = \sum_a W_a * U_a \quad (5)$$

where:

TU is the total utility obtained by the stakeholder; and

W_a is the weight assigned to attribute *a.*

5.4. An example for the calculation of utility and cost

The following example demonstrates calculation of cost and utility for design D2. The values of the various DVs characterizing D2 are given in Table 6. The assigned values are normalized in a [0-1] scale for each DV.

Table 6 - The values of the various DVs for a specific design denoted as D2

Design Variable	Supported Modes	RT Info	Personal-ization	Access Means	Import Automation	Std ICD	Rank Method	Data Warehouse
Value for D2	Basic Multi-modal	External Sources	Search History	1	Import	False	Single	False

The utility associated with D2 for a PTA is the sum of the utilities computed for each attribute, driven by the influencing DVs as captured in Table 5. For each attribute, the weight (W) and attribute utility value margins Xmin and Xmax are defined in Table 3. The attribute equity will serve for the purpose of demonstrating calculation of the utility of a single attribute. Equity is associated with two of the DVs: personalization and access means. D2 is characterized by the third of five possible levels with regard to personalization, and is transformed into a level of 0.4 for this DV (the lowest level is graded 0, as the basic personalization level of specifying origin and destination is not associated with any significant value). As for access means, D2 is characterized by only one access means supported, the lowest level out of five, and therefore 0.2 is the appropriate level for this DV. In order to obtain the attribute level achieved for equity, Eq. 3 is applied to the levels of the influencing DVs, namely personalization (0.4) and access means (0.2), resulting in $X_{Equity} = 0.52$. The utility of equity is calculated according to Eq. 4. Given that X_{min}=0.4 and X_{max}=0.8 for equity (Table 3), the third condition of Eq. 4 is fulfilled, and the resulting utility for equity is 0.3. The contribution of equity to the total utility (TU) is therefore 0.042, based on its relative weight (0.14) and using Eq. 5. The total PTA-related utility for D2, based on all six attributes, is 0.817.

As for the cost calculation, we defined cost rates for each possible value of DV, with the aim of reflecting the relative amount of effort required for obtaining each DV level (all costs are defined relative to the same baseline). For example, for the five possible values of the DV personalization, the following cost rates were assigned: When the value=Basic, the associated cost is 1. The cost rates of the values User-Defined, Search History, Inferred, and Incentives are 1.1, 1.3, 2, and 3 respectively.

5.5. Results

After performing all the steps of the MATE analysis, for each of the stakeholders, the different tradespaces need to be explored and analyzed. Each tradespace was constructed using all possible values of DVs (1440 options) and is shown in the following diagrams as a "cloud" of (U, C), with the Pareto front marked. Diagrams 1(a) and 1(b) show the tradespace in the first epoch for the PTA and the PD, respectively. Diagrams 2(a) and 2(b) show the tradespace for the PD and the PTA in the second epoch – i.e., once transferability to an additional location is implemented. Diagram 3 shows the tradespace of the PD in the second development phase, once the JP is a viable market product.

Analyzing the tradespaces reveals the following phenomena:

1. Design D1 is on the Pareto front for the private developer (Diagram 1[a]); however, it is located low on the U-C scale of the PTA, as shown in Diagram 1(b). The reverse is true for design D2 (whose features were shown above). These results show that the Pareto front designs for each stakeholder may differ.
2. In Diagram 2(a), the design alternative D3' is an evolution of D3. The value change for the PD is achieved by switching the value of the DV supported modes from “Basic Multimodal” to “Fixed- Hub Sharing” at a rather low cost change. It demonstrates how exercising changeability can increase the value for the stakeholder represented by the utility function.

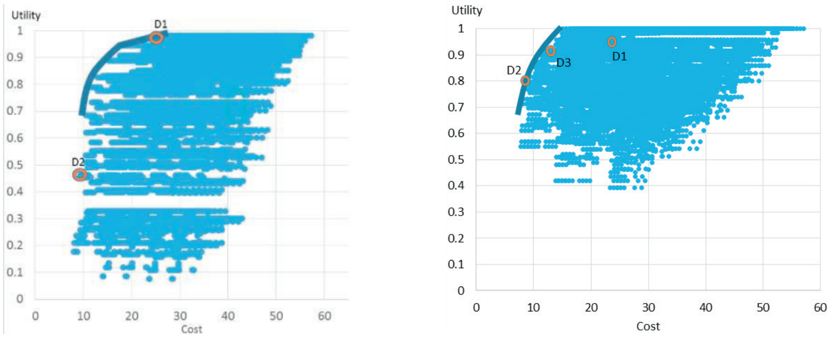

Diagram 1 – (a) U-C associated with PD for first epoch tradespace; (b) U-C associated with PTA for first epoch tradespace

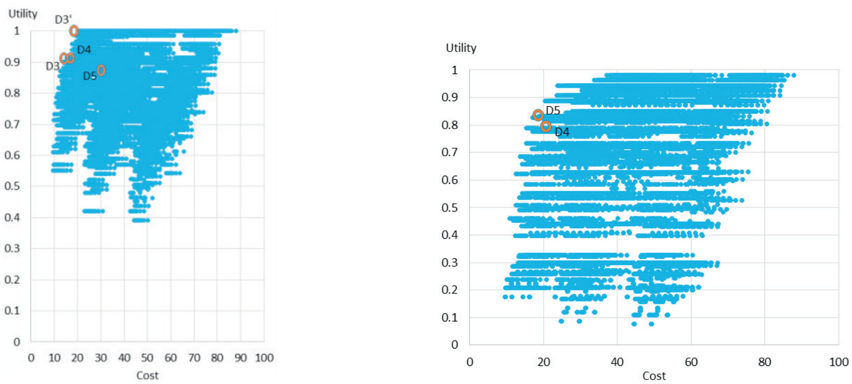

Diagram 2 – (a) U-C associated with PD for second epoch tradespace; (b) U-C associated with PTA for second epoch tradespace

3. D4 is included in the fuzzy Pareto front of diagrams 2(a) and 2(b), exposing the potential of the epoch-centric tradespaces to generate designs that are "Pareto-near" for both stakeholders. D4 was a non-optimal design in the first epoch, as the cost of developing a data warehouse is high. However, once this feature is implemented, it can be leveraged at another location without additional cost, and so the design enters the optimal region for both stakeholders. When such a design exists, it is worthwhile for the PD to consider it and for the PTA to sponsor it.
4. Diagram 3 shows the U-C tradespace for the PD once the initial development stage is over, and its concerns reflect the ongoing development phase. Originally, D5 was nowhere near the Pareto front for the PD, as shown in Diagram 2(a), but was an attractive design for the PTA (Diagram 2[b]). Its implementation in an additional region with no design changes brings D5 to the PD’s Pareto front. However, suppose this region requires data harvesting (a change of DV "Import Automation" level), as might occur in a small city, where transit data is not available electronically. With this design change, the new design – an evolution of D5, denoted by D5' in Diagram 3 – drifts away from the PD’s Pareto front due to the increased development costs, which would reduce the PD’s return on investment. If implementing the JP in this new location is of importance to the PTA, they should consider either providing the needed data online or sponsoring the additional costs. The gap on the cost axis between D5' and D5 shows the actual price the PTA should consider paying.

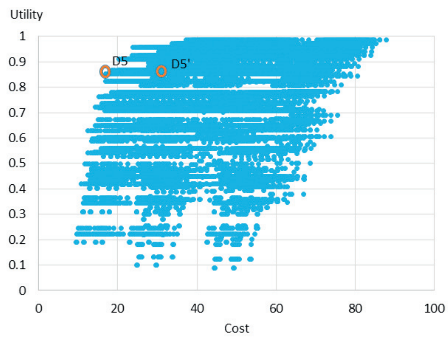

Diagram 3 – U-C associated with PD for the second phase of JP development

6. Conclusions

This paper demonstrates the use of MATE, a methodology for tradespace exploration, as a structured and rational way to compare different designs for a JP, bearing in mind the many possible features of such a system and the varying goals of different stakeholders. Through an example, we illustrate how this methodology can be used to gain insight into different stakeholder preferences, and the benefits (in terms of utility) of alternative designs. The most effective designs, identified by a fuzzy Pareto front of the utility-cost tradespace, can be analyzed over a range of DVs and over a range of future implementations in additional locations (epochs). Thus, we show how the exploration can be leveraged to support transferability. Moreover, the proposed methodology facilitates bridging gaps between different stakeholders' concerns to pinpoint a solution that has a better chance of providing value over time to all parties. The use of the proposed methodology is not limited to the selection of efficient JP designs, but can also be used for other transportation-related systems. Future research should address the impact of various utility functions on the final decisions as well as methodologies and algorithms for selecting the most appropriate design out of those included in the fuzzy Pareto front.

Acknowledgments

This research was kindly sponsored by the Gordon Center for Systems Engineering, Technion—Israel Institute of Technology.

References

Bie J., Bijlsma M., Broll G., Cao H., Hjalmarsson A., Hodgson F., Holleis P., Van Houten Y., Jacobs K., Koolwaaij J., Kusumastuti D., Luther M., (2012). Move Better with tripzoom. International Journal on Advances in Life Sciences, Vol. 4, pp.125-135.

Fitzgerald E.F, Ross A.M. (2012). Mitigating Contextual Uncertainties with Valuable Changeability Analysis in the Multi-Epoch Domain. *6th Annual IEEE Systems Conference*, Vancouver, Canada, March 2012

ITS ACTION PLAN (2011). Study regarding a European Multi-Modal Journey Planner D4 – STAKEHOLDER'S VIEWS. *FRAMEWORK SERVICE CONTRACT TREN/G4/FV-2008/475/01*. Lyon, 21 July 2011

Keeney, R. L. and Raiffa, H. (1993). *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. Wiley,New York(1976). Reprinted, Cambridge Univ. Press, New York (1993).

Manning C., Schütze H., (1999). *Foundations of Statistical Natural Language Processing*. MIT Press. Cambridge*, MA*.

Nickel J (2010). Trading political feasibility and technical optimality:Multi-Attribute radespace Exploration as communication tool in transportation planning. *Industry Studies Conference 2010*, Chicago, IL, May 2010.

Ross, A.M., Rhodes, D.H., Hastings, D.E. (2008). Defining Changeability: Reconciling Flexibility, Adaptability, Scalability, Modifiability, and Robustness for Maintaining System Lifecycle Value. *Systems Engineering*, Vol. 11, No. 3.

Ross, A.M., Rhodes, D.H. (2008). Using Natural Value-Centric Time Scales for Conceptualizing System Timelines through Epoch-Era Analysis. *INCOSE_IS*.

Zietsman, J., Rilett, L. R., Kim, S. (2006). Transportation corridor decision-making with multi-attribute utility theory. *Int. J. Management and Decision Making, Vol. 7, Nos. 2/3,* 254-266.