Tradespace exploration tools

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***Abstract*—A tradespace is a visual representation of a set of concepts, developed by making a range of design decisions, in a space defined by two or more metrics. This paper discusses the need of a new tool for generating & exploring tradespaces; and describes an online tool developed by the author to do the same.**

Keywords—tradespace, system, system design, architecture.

I. Introduction

The term, Tradespace, is a combination of the words "trade-off" and "play-space", where "trade-off" indicates the method of traversing the Tradespace in search of the optimal boundary space [1]. In simpler words, a tradespace is a visual tool to allow system designers to make design decisions by comparing all feasible concepts at once. This is done by limiting the information being presented to only the relative difference between the concepts that sets them apart. The most common visual encoding used to showcase this relative difference is position (on a 2D cartesian plane).

Figure 1 below shows a sample trade-space where different concepts (represented by "x" marks) are plotted against 2 attributes (cost & benefits/utility). The concepts marked with a red line represent a (set of concepts on a) boundary space – that is optimized at high benefit & low cost (since they are all relatively close to an imaginary point on the y-axis, often called the utopia point, where benefit attribute is infinite and cost attribute is 0 - impossible but ideal concept).

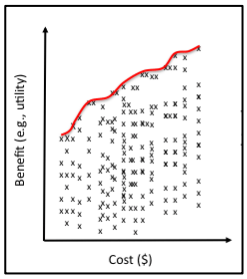

Fig 1. Sample Tradespace

The systems community has been limited to a very small set of software tools for building and analyzing tradespaces. The ones that are available today are both expensive for individuals to leverage, as well as offer a very clunky & complicated user experience that does not match the quality offered by other software tools being used in everyday life. This leads to frustration and therefore reduced efficiency. Often times, users (especially the beginners) choose to fall back on more basic tools like Microsoft Excel, which they are familiar with and offers flexibility. However, they (users) pay for it later in terms of (significant) time - since it's a generic tool, not designed for the specific use of tradespace development & analysis. Hence, there's a gap in the systems world that Tradespace Universe tries to fill in – in form of a browser-based online tool.

The tool is at a very early stage right now (version 1) and misses a lot of features, but the important ones have been prioritized and implemented by the time of writing this paper. Today, a user can build a dual axes tradespace based on a weighted-average value-function (shown in figure 2 below).

$$\text{Weighted Mean/Average} = \frac{\sum_{i=1}^{n} (x_i \times w_i)}{\sum_{i=1}^{n} w_i}$$

Fig 2. Weighted Average Function

This paper is structured such that it starts by discussing different tradespace-exploration software-tools available (& mostly used by beginners) at the time of writing this paper. Then, it discusses some key design elements of the Tradespace Universe tool, followed by its solutions to the problems in currently available tools. Finally, the paper concludes with a discussion on potential impact of tradespaces on humankind and a tentative future roadmap for the tool.

II. EXISTING TOOLS

Systems community, being as old as it is, and as close to technology and engineering as it is, has seen mulitple tradespace analysis tools emerge at different times in the past. This section shall discuss a few of them and try to highlight their pros and cons.

A. Microsoft Excel

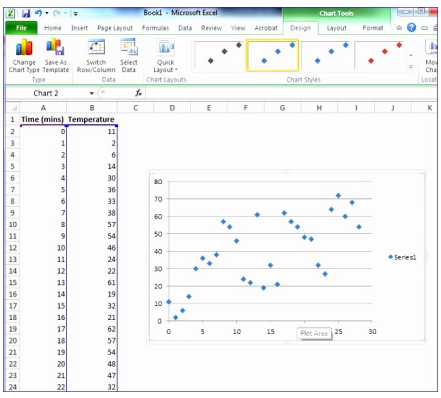

Fig 3. Microsoft Excel

Arguably, the most commonly used tradespace builder & analysis tool by beginners is Microsoft Excel. Being one of the widely used software tools for data analysis, in general – system designers, especially at their early stages, often resort to using this bare-bone tool for their tradespace exploration needs. It offers great flexibility when it comes to analyzing quantitative data, especially the interconnectivity across different columns and sheets containing data. This enables the user to maintain their complete dataset in one place while being able to create logical separation of data entities like design decisions, constraints, weights, concepts, etc. that are required to build a tradespace. Another benefit of using Microsoft Excel is that it's a tool used for multiple purposes, so there's little to no learning curve for getting new users started. In fact, this becomes the primary reason for most beginners to start using Microsoft Excel for their tradespace exploration initially.

On the flipside, Excel has a few disadvantages too. Firstly, although available on multiple operating systems, its most usable form is only available as a desktop application – which calls for a separate set of requirements like a machine with sufficient (storage & computational) resources, security considerations for installation on critical systems, etc. Technically, it is now offered in a web-version as well, however the performance of the web-version is yet to reach the levels of minimum expectations for data analysis such as required by a tradespace exploration.

Secondly, even if it's run as an independent application, (with its own processes & threads on the operating systems), it's a highly generic tool that is not optimized for such reasonably heavy data analysis and hence offers a very slow user-experience, especially as the size of dataset increases. This is a common scenario in tradespace exploration when the number of design decisions and/or their choice options increase.

Thirdly, for the same reason of it being a generic tool, the system designer's user-experience is highly unsatisfactory and requires special tricks to be able to perform the analysis. For example, there's no structure for allowing the user to enter their data, and so requires the user to have a deep understanding of the dataset & the concept of tradespace analysis before being able to use it. This may sound fine, however that's not the case especially for the user base in discussion in this paper (beginners). Also, this leads to unstandardized data formats which result in (data) under-utilization and/or (data) over-processing in longer run.

Finally, it's a paid software tool – which is understandable as it offers value to the user. However, it requires a subscription to a whole suite of software tools (Microsoft Office) that are not even remotely connected to tradespace exploration.

B. Tableau

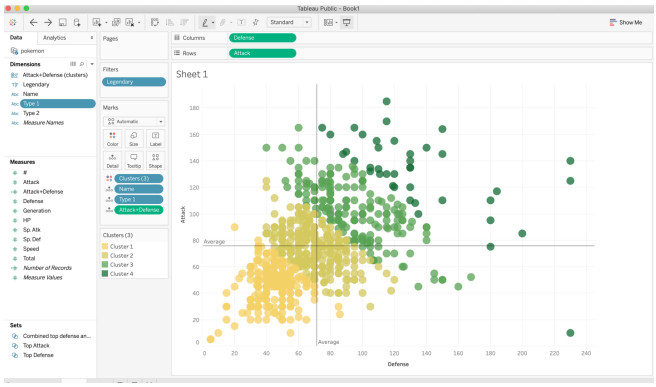

Fig 4. Tableau

Tableau is another great tool that has captured a significant user adoption when it comes to audience without programming background. A beginner tradespace explorer who may have some data analysis experience – might be familiar with this tool and end up using it. Even without a data-analysis background, Tableau's user-interface is highly intuitive (assuming user is familiar with data-visualization nomenclature like measures, dimensions, etc.) and offers low barrier-to-entry for beginners. Tableau offers some great features in order to perform exploratory data analysis as well as intelligence to reduce user effort. Tableau also offers range of features that allow the user to emphasize on visualization itself, rather than the technical nuances of using the tool.

However, Tableau is yet another generic data-analysis tool that requires the user to have deep understanding of the systems approach & clear expectations that drive user interaction with the tool (for the specific scenario of tradespace analysis). It expects a decent amount of data manipulation to be performed outside of itself before even taking any benefit of its rich set of features. Tableau may not do that bad on the performance metric as it has a desktop-version, and also a cloud-version to leverage high-computing capabilities of specialized-remote servers. However, it does come with a significant price tag – which creates the biggest friction point for (especially, beginner) users who may not have access to the same.

Besides the aforementioned tools, a few] other tools like the Osate Guided Trade Space Exploration (GTSE) developed at Carnegie Mellon University's Software Engineering Institute deserve an acknowledgement here too. They aren't discussed in detail, however, since they have mostly overlapping sets of pros & cons. Programming languages like Python and R have recently been attempting to overtake the function of tradespace analysis, much like their impact on the data analysis world, too. However – the friction of learning a new skill (programming language) still keeps them from as widespread adoption as compared to some of these traditional tools being used historically.

III. METHODS

A tradespace exploration tool can have a huge set of features with varied range of value propositions. Some of them include multi-attribute analysis, uncertainty ranges, pareto frontier optimization, utopia point, etc. The author prioritized a set features for the first version of Tradespace Universe which are discussed below, along with the various design decisions that were considered during the development:

A. Multi-attribute Tradespace Exploaration

Although tradespaces are generally represented in form of a scatterplot on a dual axes cartesian co-ordinate system (mostly first quadrant only), they are not always restricted to that form. Other visual encodings like size, color, etc. can be used to encode additional information into the tradespace. One such (analytical) way to encode more than 2 attributes is to create a "value function". Value functions are functions that aggregate the attributes into a single metric that reflect the decision maker's aggregate preferences [2].

The Tradespace Universe tool offers the functionality to include multiple attributes into the analysis. It allows for the user to input all different design decisions (or attributes), as well as their weights & different choice options, that need to be optimized. The tool then calculates a single-metric, called "utility", for each potential concept using its internal weighted-average value-function (figure 2). Finally, it plots the different concepts on a 2-D cartesian coordinate system with computed utility on y-axis & cost on the x-axis. The scatter-plot visualization enables comparison of a large number of concepts by encoding their corresponding tradeoffs (in quantitative form) as relative positions. Few techniques like pareto-frontier based optimization, or criteria-based filtering (for constraints or requirements or targets), or even un/selecting different choice options are all possible in a scatter plot visualization – while maintaining a high0level view of the complete data set. Details of each mark/concept can always be encoded using other ancillary forms like popups/lightboxes, sidebars, alerts, etc.

B. User Interactivity for Tradespace Analysis

Visually, a tradespace is not much beyond just being a scatter plot generated from a specific type of data set. Its actual value proposition comes from its ability to allow for deeper analysis to understand and compare the different concepts - each represented by a dot/mark on the scatterplot, like the "x" marks in figure 1. Each non-overlapping concept/mark highlights a certain set of tradeoffs being made leading to its positioning on the scatterplot, relative to its peers. Sometimes, a concept that is not on the pareto frontier (a set of feasible concepts that are most optimal, in context of the given comparison – represented by the red line in figure 1), rather close to it, is chosen given its fit with the different constraints or certain other subjective or economic criteria that couldn't be incorporated into the value function.

Once the tradespace has been generated by the Tradespace Universe tool, it enables the user with rich features to understand it and supports decision-making process of the user to compare and prioritize among them. A simple but intuitive "hover" functionality allows the user to quickly highlight the marks on the tradespace that correspond to the choice option being hovered upon. A "click" functionality is also available for users to select (or unselect, if already selected) the same, therefore allowing them to further filter the set of concepts/marks based on their selection of multiple choice-options (only 1 per design decision allowed). This click functionality also applies to concepts/marks on the tradespace – to show the set of corresponding design decision choices. A hover on the concept reveals its utility & cost values.

C. User Education

As discussed in previous sections, tradespace exploration tools are used by users with a wide range of expertise levels. The first version of the Tradespace Universe tool focuses on (relative beginners). Hence, the user may not be as familiar with the different jargon used. Therefore, an additional layer of user instructions (in a dedicated panel) has been introduced to guide the user through the process of data input. They can focus on a specific part of the complete dataset, rather than being overwhelmed by a large set of input fields. This also saves the user from anxiety of starting from a blank canvas (like on generic tools, like Excel) towards a highly data-rich visualization that is used to make critical design decisions. The sequence of data input is also a critical element that has been carefully designed to educate the user as they go.

The tradeoff, however, is that the tool lacks quite a few reasonably useful features for tradespace analysis. Still, the author chose to stick with this target audience (& approach) because the early (onboarding) stages of any new tool defines the fate of the complete framework to become a widespread phenomenon. Also, it matches the natural incremental software development roadmap. Therefore, a slight deviation from the actual scope (of developing a tradespace analysis tool) to current scope (at the time of writing this paper) was chosen to start creating value quickly & also receiving early feedback from users.

IV. RESULTS

The Tradespace Universe tool has tried to solve the following problems discussed in the initial sections:

- **Portability**: A browser-based online tool, Tradespace Universe is independent of any operating system as it works on higher-level platforms/applications – web browsers. Although there's a decent diversity in the web

browsers being used today, most (if not all) of them expect their applications to be built using the same technology-stack making the Tradespace Universe a highly portable tool.

- **User Guidance**: Considering the decent range of tradespace exploration tools (generic / specialized) in the market, almost all of them require the user to have a good understanding of how tradespace analysis is performed. None of them actually tries to educate the user, and hence creates friction for retaining the users beyond their current scope of work. The Tradespace Universe attempts to change that through a sample visualization (to set user expectations early on), user instructions (to inform the user about potential actions & their importance), wizard-style format (to avoid overwhelming the user at any given point), and a rich set of interactive features (to finally help the user perform the actual tradespace analysis).
- **Cost**: Developed as an academic project, the Tradespace Universe is a free tool, at least so far. Also, dynamic functionality that requires a remote (application) server has been carefully avoided in the first version to avoid inducing costs.
- **Performance**: Since the Tradespace Universe runs on a web-browser, it is restricted to the amount of resources the web-browser is able to receive and allocate to the tool. This is less ideal as compared to a stand-alone (desktop) application like the currently available options. However, it is a highly-specialized tool serving one function – which allows it to be optimized for the desired use-case. Also, this tradeoff allows for portability, which was a careful design choice as well.

V. DISCUSSION

Tradespaces have been an extremely handy tool to make design choices for highly complex systems that were otherwise beyond human cognitive capabilities. Not only engineering systems, but almost any set of decisions – may it be architectural, financial, or even personal, have been proven to have the potential of being optimized using tradespace analysis. It's worth noting that tradespaces rely heavily on quantitative data, so are unable to handle certain (relatively) subjective attributes like ethics. Even with this caveat, there's plenty of decisions that shape human lives (and the world/context they operate in) on an everyday basis – which can be optimized using tradespaces.

A tool like Tradespace Universe attempts to democratize the use of such analytical approach to everyday decisions, thereby hoping to make the world a little more "perfect" (or efficient).

VI. FUTURE WORK

Tradespace Universe is at its infancy. It's the very first version of a tool that has the potential to make a system-wide impact at both – macro & micro levels. The future roadmap includes many new features like selection of key attributes, allowing constraints-based filtering, enabling multiple visual encodings to visualize more than 2 attributes, defining the value-function, uncertainty ranges, data upload, tradespace download, etc.

Amongst its various potential use-cases, the tool shall go through its early user feedback journey through an education program that has tradespace exploration as a part of its core-curriculum for product refinement. Once ready, there are plenty of different pathways like specialization for a specific industry, academia adoption for educational content, etc. to promote the widespread use of the tool.

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REFERENCES

[1] https://en.wikipedia.org/wiki/Tradespace

[2] https://web.mit.edu/adamross/www/Ross_INCOSE05.pdf