User-centered Taxonomy for Urban Transportation Applications

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Abstract. The widespread use of urban software and information technology infrastructure systems now demand new levels of complexity in data generation and data application across interoperating domains. Given this context, and discoveries in visual analytics research that reveal knowledge is created, verified, refined and shared through the interactive manipulation of the visualization (Pike, Stasko, Chang, O'Connell, 2009), defining a taxonomy of visualizations can assist visualization system designers in understanding key visualization techniques that serve multiple linked user groups (Chengzhi, Chenghu, and Tao, 2013). It could also be meaningful to others working in sectors that are now in the process of interoperating through the pervasive nature of digital economies. Understanding the potential components of a taxonomy for these forms of data visualization demands the identification of inter-relating and diverse user groups utilizing the same data for multiple tasks (Mahyar, Kim, and Kwon, 2015), the complexity of visualization processes, relevant task levels and interactions to supplement human insights. For example, a visualization displaying urban transit data might support the requirements of a wide array of users such as urban-designers, city-planners, data-scientists, engineers, transit-managers, pedestrians and transit users. This paper discusses the taxonomy design and prototype creation process for a user-centered taxonomy for urban transportation applications developed by the Visual Analytics Lab at OCAD University, as part of the VAL's research and design contribution to the iCity research project, a collaboration between academic researchers, industry partners, city transportation planning departments and transit authorities that seeks to develop software support systems for transportation planning.

Keywords. Taxonomy, Visualization, Transportation planning, Urban systems

1 Introduction: The iCity Project and Visual Analytics

Over the last decade, the adoption of smart urban software and information technology infrastructure have had profound economic and societal impacts, while multiplying the complexity of data and the variety of domains of practice called upon to interoperate within the ecosystem of modern cities. To address these challenges, the iCity project brings together the University of Toronto's urban simulation modelling capabilities, IBM's advanced software systems including their Cognitive Visualization lab, the visualization design capabilities of OCAD University, ESRI's GIS and GPS map modeling, city transportation planning departments and transit authorities (Toronto, Waterloo), Waterfront Toronto, and designers and policy analysts from the University of Toronto and the University of Waterloo to develop innovative new solutions for the design and management of urban transportation systems.

The project is based on the premise that the design of any one component of the city, such as transportation, affects not only this system but all the others with which it interacts: housing, the regional economy, etc. These systems, in turn have "feedback" effects on transportation (for example shifts in population affect travel demand and transport performance). A holistic, comprehensive approach to urban system design is therefore essential if major unintended consequences are to be avoided and if implemented policies and technologies are to cost-effectively achieve their intended outcomes with maximum benefit. Within the project cluster, the Visual Analytics Lab (VAL) at OCAD University (OCAD U) is tasked to develop relevant visualization and visual analytics tools that will enable the analysis and use of data outputs in evidence-based planning, predictive models and simulations, real-time decision making and outreach contexts; tools that can provide critical support in understanding and enabling transportation flows and human activities. This paper addresses the process the VAL followed to address the definition of categories that impact the design of such user-centered data visualization tools. The challenge is to ensure that diverse groups of users have appropriate levels of accessibility of data in usable forms. This requires understanding the visualization needs of user groups.

Research in visual analytics shows that knowledge is created, verified, refined and shared through the interactive manipulation of the visualization (Pike, et al., 2009). There exists a relationship between human cognition and interaction with visualizations, whereby visualizations supplement human insights. Thus, the challenge is to ensure diverse groups of users have appropriate levels of accessibility to data in usable forms, which in turn requires understanding the visualization needs of multiple user groups.

As suggested by Simon (1969) we looked to a taxonomy as a first step towards understanding any phenomena, a taxonomy being "A systematic arrangement of objects or concepts showing the relations between them, especially one including a hierarchical arrangement of types" (Webster Online Dictionary, 2006). For work in the diverse and still emerging field of data visualization, a taxonomy provides researchers with a common language with which to categorize and review existing systems, classify new ones and address gaps towards further development (Price, et al., 1993).

A well-developed taxonomy of visualization types can help designers understand which visualization techniques (or combinations of them) best serve the goals and needs of user and stakeholder groups (Chengzhi, 2013). Our work on the taxonomy for urban transportation applications links to the ontological work on urban transportation systems led by the University of Toronto iCity team members which seeks to establish a hierarchy of terms. iCity seeks to serve expert technical users, researchers, urban planners, civic leaders and public users of urban-visualizations. Whether experts or casual users, different user groups can have varied information-seeking motivations and objectives, and desire diverse representations of urban data. Hence, in our proposed taxonomy we recognize the importance of user tasks and data type, and have framed this discussion in the relationship with use domains of the visualizations.

This paper outlines the design process and proposes a 'User-centered taxonomy for urban transportation applications' and outlines how we adapt Sorger et al.'s abstract and spatial data categories, integrating the three major components of *data, visual and navigation* into our visualization taxonomy prototype, along with Mahyar et al.'s levels of user engagement, to build a relationship between user engagement goals and visualization components.

2 Literature Review of Taxonomy

Our survey of a human-centered taxonomy for visualization provided an understanding of various methods through which researchers in the field of visual analytics propose the organization of data, user tasks and visual elements to create meaningful representations. Many taxonomies propose the organization of visualizations based on data type and user tasks, with most focusing on the quality of representation to suit a specific purpose. Shneiderman (1996) played a now canonical role in defining an early formulation of visual analytics, defining a task by data type taxonomy with seven data types and seven tasks. The seven data types include 1D, 2D, 3D, time, multi-dimension, tree, and network data in relation to the seven tasks of overview, zoom, filter, details-on-demand, relate, history, and extract. This taxonomy can be (1) data and view specification (visualize, filter, sort, and derive); (2) view manipulation (select, navigate, coordinate, and organize); and (3) analysis process and provenance (record, annotate, share, and guide), Shneiderman (1996). This approach relates task to data type as components of visualization, whereas Valiati (2006) proposes a taxonomy of tasks in multidimensional visualization. Other user centric taxonomies like (Chignell, 1990) specify the organization of data based on research in cognitive science which suggests that cognitive efficiency results from tying visualization tasks to the needs of defined user groups (Wang and Dunston, 2011).

The most important categorization emerged when we saw that most approaches to establishing a visualization taxonomy essentially fell into three areas: *User Task*, *Level of Interaction or Engagement* and *Data Type* (Mahyar, et al., 2015). We realized we must take into account all three aspects when thinking of visualizations. These three categories served as the foundation for our work towards defining a taxonomy for urban

transportation applications. Subsequent sources gave us deeper insights into these categories as they are used in visual analytics.

User tasks can be defined and classified based on the context and scope of the tasks. Wehrend (1993) defined 'visualization goals' as actions a user may perform on their data and presents nine such goals: identify, locate, distinguish, categorize, cluster, rank, compare, associate, and correlate. Amar, Agan and Stasko (2005) present a list of low-level tasks, such as retrieve value, filter, find extremum and sort. Zhou and Feiner (1998) define "visualization techniques" as low-level operations and "visual tasks" as interfaces between high-level presentation intents such as 'inform' and low-level visual techniques such as 'highlight' without describing 'how' an operation is performed. Brehmer and Munzer (2013) discuss tasks related to abstract visualizations, which focus on three questions: (1) why the task is performed (2) what the data inputs and data outputs are, and, (3) how the task is executed. Bertini et al. (2015) present a task taxonomy for cartograms, categorizing tasks along four dimensions, based on questions, why, how, what and where to address user goals, means, characteristics and cardinality. In the context of visualizations targeted to multiple user groups, the taxonomy of user engagement proposed by (Mahyar et al., 2015) is noteworthy, as it frames ***user tasks*** in relationship to ***user interaction*****,** both 'types of interactions' and 'quality of interactions', also referred to as ***engagements***. Mahyar et al. (2015) argue that there is a spectrum in the degree of engagement (user interaction) with the visualizations varying from a low level engagement, such as simply viewing a data visualization, to a high degree of engagement which requires analysis, synthesis and deriving decisions. The rating of levels of engagement enables the assessment of user engagement for various categories of user groups that we found can prove beneficial while designing visualizations targeted to these multiple user groups.

Tory and Moller (2002) invent a model based taxonomy which classify visualization algorithms based on whether the data being handled is discrete (a fixed and quantitative variable), continuous (a perpetual variable), or spatial. Their taxonomy framework is based on a data model to avoid ambiguity and streamlines conceptual biases of the designers that may influence the quality of data being represented. Although this taxonomy proposes a way of interpreting data based on data models and not data attributes themselves, it does not consider task based categories for complete visualization systems.

Chengzhi et al. (2013), proposed a taxonomy of visualization techniques and systems, enlisting analytical tasks based on data types for users and matching these to representation modes along with the details of interactions for developers. Their taxonomy elucidates a concept and process of visualization, yet limits task and interaction modes and does not elaborate the specifics of the user types nor their related levels of interactions. Sorger et al. (2015), in their paper on integration techniques for visualizations, suggest that almost all types of data can be understood within two categories, *abstract* or *spatial*. Abstract data lacks explicit spatial references (used for example in information visualizations); and spatial data types have inherent mapping coordinates, (used for example in scientific visualization and real-time rendering). Sorger et al.'s (2015) approach to a visualization taxonomy provides various integration techniques for spa-

tial and non-spatial visualizations, to serve a broad spectrum of user needs. They structure visualization into three components: Data (what to visualize), Visual (how to visualize) and Navigation (viewing position and/or direction of the visual), and suggest permutations and combinations of these three components to cover all possible scenarios to build integrated visualizations. This categorization of visualization in our understanding and analysis of taxonomies was useful in its' application to urban data visualization. Pike et al. (2009), discuss the relationship between interaction and cognition and suggest a useful framework to understand the feedback between user goals and interaction components. Their framework embeds visualization into the context of interaction and positions various components of interaction as part of human knowledge creation.

This review of taxonomies led us to the conclusion that there was no single comprehensive framework that could be used to define the urban data visualization needs of diverse groups. Through the taxonomy development process, we have synthesized existing knowledge to propose a taxonomy for urban transportation applications that places user motivations and needs at the center of the design. In the iterative process that led to the creation of the first prototype and the final User-Centered Taxonomy for Urban Transportation Applications, we drew on Sorger et al.'s (2015) adaptation of the visualization pipeline, which helped us to scope the overall structure of the taxonomy at different stages, while Mahyar et al.'s (2015) breakdown of multiple levels of user engagement helped to inform the core categories that breakdown user engagement with applications. To address the complexity that arises from user interaction and cognitive processes, we draw on Pike et al.'s (2009) framework that takes in to account the variance in interaction based on goals of data use and levels of interaction. These components composed part of successive iterations of the visualization prototype and were modified through the steps explained in the following sections; comparing it against the environment scan of applications and toolsets used in the sector, understanding use case examples, and the design charrette with expert users.

Our effort with this research has been to synthesize existing knowledge to propose a taxonomy for urban transportation applications that is user-centered with user motivations and needs at the center of the design. For our taxonomy development process, we have drawn on the importance of the user's role in the visualization process; the significant relationship between interaction and cognition that reflects the feedback loops between user goals and interaction (Pike et al., 2009). This supports the detailed classification of interactive elements based on user tested needs for spatial and non-spatial data types (Sorger et al., 2015), and the need to segment User Task, User Engagement and User Interaction (Mayhar et al., 2015) to ensure that we address the levels of interaction that occur between users and the visualization spaces and processes.

3 Phase One of Taxonomy Development

To understand the data visualization environment within which we would be designing, we surveyed a wide range of software applications and tools being used in urban transportation focusing on tasks being performed by the users in transportation and related

use domains. We did this in tandem with the literature review of taxonomies which helped us to define the evaluation criteria for the software applications we reviewed.

The environment scan provided a broad classification of *software applications and tools* (both of which from this point forward will be referred to as toolsets) serving urban transportation analysis, research, and planning along with the application of systems in related fields. The toolsets were categorized under the following headings: User-Centric Visualization, Transportation, Urban Design, Infrastructure Management, Mapping, Land Use, Big Data Analysis, and Simulation/Interaction/Games. Many of these headings catered to the specific research approach and mandate of the iCity project, resulting in the inclusion of categories such as Urban Design, including Built Environment and Neighborhood Planning; Infrastructure Management including Sustainability and Resilient Cities. This list provided us a baseline for the high-level categories in which to organize both currently listed and future listed toolsets and applications. This also provided us a starting list of *use domains* within urban transportation.

With this list, we created a comparative table/chart as a way of organizing and visualizing our findings, and this remains a core reference for visualization planning and other development with the VAL's iCity mandate. This chart helped us compare and contrast each toolset against similar criteria, thus understanding the nuances and major attributes that each toolset was programmed to serve. The process also helped us gather more information about the users being served by the toolsets, the tasks being performed and the data type, as well as other specifications such as the file formats, data formats, and differentiating features within the toolsets serving similar use cases. This chart (Table 1) became a master document for our reference.

Table 1. Survey of Comparative Software Applications and Toolsets Used in Urban Transportation (partial view of larger table)

Comparative Analysis of Software

Type of Urban System Applica-	Software	Technology /	Description / application	User Type	Tasks (High Level)	Engagement Level	Interaction (Low lev-	Data Visualization	Data Attributes	Open / Private
Selected Toolset / Methods										
Built environment, geodata, multi-player urban planning.	Betaville	HTML / WebGL Three.JS, Postgres and Post GIS	An open-source multiplayer environment for real cities, in which ideas for new works of public art, architecture, urban design, and development can be shared, discussed, tweaked, and brought to maturity in context, and with the kind of broad participation people take for	designer, planners, architects, technicians, transportation engineers, citizens	modelling, navigation, visualization, search /explora- tion, analysis (geometrical), simulation, comment / query, multi-user collaboration (chat, collaborative work	expose (viewing), involve (interacting), analyze (finding trends), synthesis (testing hypothesis) , decide (deriving decisions)	orbit, walk/ fly- through, pan, scroll, zoom, filter, pivot, linking, select, annotate, transform (move, scale, rotate), measure, (anno-	3D Bar charts, 3D Pie chart, 3D scatter plot, geo-data	nominal, ordinal, text, geo-spatial, periodic, dynamic, geometry	open/private
Qualitative and quantitative Data Exploration and analysis and presentation Tool	StoryFacets	HTML, Javascript, D3 framework, Meteor, MongoDB	Explore data through interaction, visual history, presentation, generate consumable overviews, high level-search /browser, visualization dashboard, visualization slide shows,	technicians, transportation engineers, citizens, Business analysts	dataset/media asset navigation, dataset visualization, dataset history and analysis history visualization, decision support	expose (consuming, learning and viewing) involve (interacting) analyze (finding trends) synthesis (testing hypothesis), decide (deriving decisions),	zooming inset, brushing and linking, scrolling, panning, filter, pivot, compare	bar chart, pie chart, gather plot, markup language	categorical, ordinal, interval, provenance, audio, video, text, image	open/private
Transport, land use, demographics	ILUTE (configeration XTMF, ILUTE is a plugin (model)	.NET, XTMF	Agent (person, business)-based micro-simulation multiyears (over the course of year, scenario)	Planners, Researchers	Land use scenario forecasting (yearly currently) (aim is to continuous simulation for multi years)	Planner: Interact , test hypothesis Researcher: model development or submodel development.	drag and drop, node based processing	(binary matrix) binary format (mtx) files, Excel (tabular data), csv data	relationships, all facets, census+transportationetwork+(informa- tion about business characteristics, formological: based on model for e.g. marriage rate, birth rate, etc)	private
Interactive data exploration, mapping and visualization, spatial analytics	ESRI ArcGIS	HTML, WebGL	ArGIS Solutions for Urban & Regional Planning, Spatial analysis, data management and mapping,Integrated collection of GIS software products; provides a standards-based platform for spatial analysis, data management, and mapping, ESRI / ArcGis	cartographers, surveyors, designer, architect, engineer, planners with special- leed training	geodata curation and display, consultation, concept development, visualization	expose (viewing) involve (interact ing) an- alyze (finding trends) synthesis (testing hypothesis) Decide (Deriving decisions)	filter, zooming, orbit,	high level - interactive digital maps with on/off information layer switching, cell-net boxes, KML and GML support	multi - dimensional	open/private

The intention of the environment scan and comparative chart of the available toolsets is to compare the needs of users, identify common toolsets and define a path towards developing a taxonomy that serves the needs of multiple users. This method helped us document the user groups, tasks, existing and required data types, source of the data, and the level of engagement or interaction the various applications currently provided. Although this environment scan will serve further stages of our research and support our work on dashboard design, it's primary role at this stage, is to confirm that users,

user tasks, data types, data source and user engagement are critical attributes to be considered.

3.1 Expert Interviews

We followed the literature review and environment scan with a series of interviews with groups of experts from fields within the urban transportation sector to better understand their visualization needs and challenges. These included iCity transportation researchers, urban planners, and computer scientists. The interviews identified gaps in the existing visual representation of urban data in relation to user needs. The experts also shared visualization challenges they were struggling to address in their day-to-day visual analysis tasks. The interviews helped to map the landscape of visualization possibilities for different types of users, but we needed further clarity to understand the overlaps in requirements listed by various user groups. For example, our discussion with the transit research group indicated that they are currently unable to visualize scenarios such as accidents that may affect the route of a street car and therefore were constrained in their capacity to re-route streetcars and avoid delays. This was a specific use case, which in turn needed a very specific type of representation, yet it may be of limited usefulness for any other use domain. This highlighted the need to research use cases.

3.2 Use Cases

A use case is a series of related interactions between a user and a system that enables the user to achieve a goal; it is an effective method to capture the functional requirements of a system (Shrivathsan M., 2009).

A use case template was circulated to the group of iCity project researchers to identify user profiles that corresponded to specific user scenarios. The researchers had the freedom to include as many profiles as possible to illustrate their visualization challenges. Each Urban Informatics Use Case profile included an outline of a particular user, an application scenario, and a description of tasks to complete this use case. More detailed information around the preconditions for those tasks, required technology and assets required, provided a more comprehensive picture of the task interaction and required visualization functionality. The intention was to filter and aggregate user-types, user tasks and therefore existing and required visualization needs and techniques. This survey template is included in Figure 1 below.

By the end of this process, we compiled a list of requirements, possible user groups and their visualization needs gathered from each research group, which provided enough information to create a tentative structure of classification for urban transit data that would serve all groups.

URBAN INFORMATICS USE CASE PROFILE

Case Number: **C3**

Date: **January 30th, 2017**

User Type

Gender: **Male** Age: **56** **Nationality:** **Canadian** **Occupation:** **Architectural Technician**

Laz is a Senior Architectural Technician working for city planning. His area of expertise is reviewing re-zoning applications and new development projects.

Application Scenario

Laz is reviewing an application for a building re-zoning in the new West Don neighborhood. The applications have not included any parking statistical information, and Laz needs to ascertain whether the existing street and lot spaces will be overburdened by new users if the project proceeds. He must perform Quantitative Data Exploration and Analysis of existing parking resources, land use, and demographics, to evaluate and propose current and proposed parking against policy /regulations as documented in the city's geodata survey and 3D model resources. He needs to provide three documents of his findings:

- **an explanatory presentation for an upcoming community meeting.**
- **a formal record of the application's parking implications, context and applicable regulations**
- **a recommended ruling based on the above**

Description of Tasks

- **Exploration of geodata & 3D model of existing conditions**
- **Record of parking inventory in defined area**
- **Calculation requirements with/without proposed changed**
- **Export of tabular data graphics**
- **Preparation of formal document and slide presentation for ruling recommendation decision**
- **Support/ justification/communication with decision makers and stakeholders**

Preconditions

Knowledge of local study area, accessibility to platform, understanding of interface and functionality, availability of peak parking data on both street level and private areas etc.

Technology

Software **ArcGIS / CityEngine/ Insights**

Environments & Frameworks **HTML5 / WebGL / Javascript**

Assets

Formats **online SHP, CSV, SLS, JSON, dwg, dmg files**

Functions **3D bar chart, geodata, bar chart, interactive digital maps with on/off information layer switching, call-out boxes**

Task Interaction

How are you using this software / tool?

orbit, walk/fly through, pan, scroll, zoom, select, annotate, measure, annotate measurement, zooming inset, scrolling, panning, compare, micro-simulation etc

Data Visualization

What is the visualization functionality of this software / tool?

- **Uses technological interface to visualize street segment, with displayed data of parking per location**
- **Statistical comparison**
- **Capture of generated data in a form that can be presented to others**
- **Access of demographic community data to project potential local patrons of future establishments.**

Interface to select, analyze and prepare a visual summary of queried data on locations parking

Improvements

How could the software / tool be changed to support the required tasks?

Real time 3D infographics, superimposed 3D map, highlighted statistical charts, prep of visual narrative

Fig. 1. Use case template content describing requirements of city planning team member*, the architectural technician.*

3.3 User-centered Taxonomy

Guided by the literature review of data visualization taxonomies, the synthesis of our findings from the comparative applications and toolsets chart, the expert interviews, and use case mapping, we created our first iteration of a taxonomy for urban transportation applications. To test this first prototype we organized a design charrette with our actual user groups, with the objective of refining the categories used in the prototype.

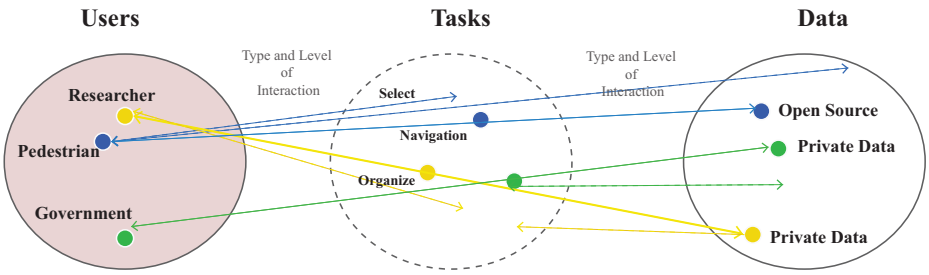

Fig. 2. Comparative Categories of Users, Tasks, and Data Representation - First Iteration of Taxonomy

This Taxonomy Prototype adopts the categories of Users, Tasks, Data representation and Type of Interaction, (Figure 2) based on Sorger et al.'s (2015) and Mahyar et al.'s (2015) levels of user engagement. The visual layout of the prototype was influenced by Sorger et al.'s concept of the general visualization pipeline. Although we had identified Mahyar et al.'s level of engagement to be an essential category, we were unable to place it effectively in our initial taxonomy iteration, since it was still early in our design research.

The design charrette helped us to rework the taxonomy categories based on the suggestions from the iCity research teams. For example, we combined user types with corresponding tasks and included levels of engagements; detailed data representation as a category to enhance understanding around the data type and the techniques of representations. We recognized a need to detail engagements in order to match intended tasks and the representations to the user. Since these users belonged to different domains, it highlighted the possibility to detail use domains further.

4 User - centered Taxonomy for Urban Transportation Applications

Our proposed taxonomy (Figure 3) mainly draws on Pike et al., (2009), Mahyar et al. (2015) and Sorger et al. (2015), to build a relationship between user engagement goals and visualization components.

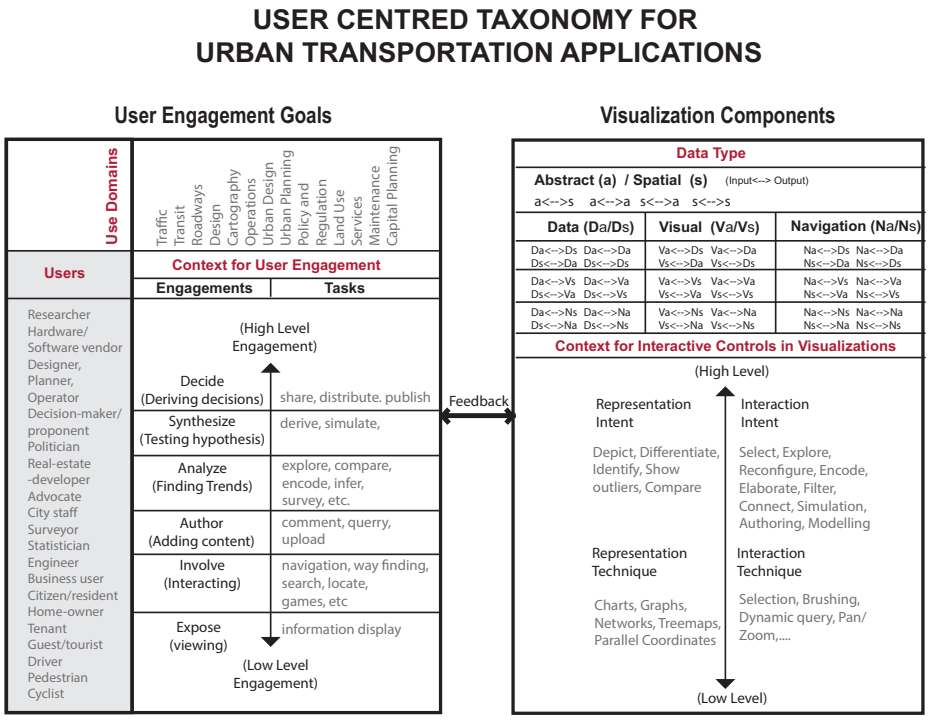

Fig. 3. User Centered Taxonomy for Urban Transportation Applications

4.1 User Engagement Goals

The study of use cases provided an understanding of users and their intended goals. It also helped to clarify various use domains within the urban transportation umbrella, which served as the core of this taxonomy. The users identified in our environment scan of urban transportation application systems included; Researcher, Hardware / Software vendor, Designer, Planner, Operator, Decision-maker / proponent, Politician, Real-estate -Developer, Advocate, City staff, Surveyor, Statistician, Engineer, Business user, Citizen / resident, Home-owner, Tenant, Guest / Tourist, Driver, Pedestrian, and Cyclist, etc. and the domains of Traffic, Transit, Roadways, Design, Cartography, Operations, Urban design, Urban Planning, Policy and regulations, Land Use, Services, Maintenance and Capital Facility Planning.

Interviews showed that different categories of users require varied levels of analytic tools. The design charrette provided us with a more comprehensive list of use domains. This expanded our chart headings from original environment scan to the following: Traffic, Transit, Roadways, Design, Cartography, Operations, Urban Design, Urban Planning, Policy and Regulations, Land Use, Services, Maintenance, and Capital Planning.

User engagement can be defined as the willingness to invest effort to explore and gain information from a visualization (Boy et al. 2015). Mahyar et al. (2015) define a

taxonomy of engagement based on the level of user involvement with the visualizations. Designers can interpret these findings as an imperative to create meaningful and compelling visualizations that are equally useful – providing appropriate tools for non-expert and expert users. Mahyar et al.'s (2015) taxonomy outlines six stages of engagement from high to low level; Decide (deriving decision), Synthesize (testing hypothesis), Analyze (finding trends), Involve (interacting), and Expose (viewing). In our research with experts in the urban transportation applications we found that 'author' or authoring content is another type of user engagement missing in the list suggested by Mahyar et al. (2015). Authoring content may include activities like uploading 3D models on Google Earth etc. and hence we place this activity between 'involve' and 'analyze'. In our taxonomy, we include 'Author', that is authoring content as a crucial step that may indicate user involvement which is more than 'Interacting' but less than 'Analyze'. User tasks are listed next to their corresponding level of engagement for the clarity in understanding user intentions at each stage of engagement. It must be noted that the list of tasks in the proposed taxonomy are descriptive and not prescriptive.

4.2 Visualization Components

Our taxonomy builds on the categories suggested by Sorger et al. (2015) and utilizes their suggested framework of abstract data type and spatial data type to propose a comprehensive structure for representing data in urban transportation applications. They describe Data, Visual and Navigation as components of visualizations, and we use these categories to describe integration techniques between the inputs and outputs in a visualization. For example, if an Excel spread sheet containing statistics on the population of a city is 'Data' input, its representation as a bar chart is a 'Visual' output.

Another way of understanding the relationship between Data, Visual and Navigation proposed by Sorger et al. (2015) is through the concept of interactive controls defined as the control points or elements of interaction in any visualization, for example tool sets, menu options, etc. (Pike et al., 2009). Pike et al. explain the interactive controls of any display device should provide access to a set of low-level representation and interaction techniques that support higher-level intents. User tasks include low-level choices of manipulating interactive components and higher-level goals related to the problems investigated. These then form a feedback loop between the user and the visualization which they should be able to further manipulate based on their intent. For Pike et al., distinction between the techniques and intent helps in the development of analysis support tools, as a technique is never an end but a means to support the user's understanding of the data.

4.3 Example 1: The Architectural Technician

We take the example of an architectural technician above (Figure 1) which is a use case from our research. A user group depicts the technician working on the review of a rezoning proposition for a new building. Two main tasks occupy this technician's work on such a project: (1) the exploration of datasets, and (2) analysis of land use, parking resources, and demographics. Using our aforementioned taxonomy chart, we can first

classify our user engagement goals with the technician as *user* and urban planning as *use domain*. (Figure 4)

Fig. 4. Use Domain of the Architectural Technician tasks

The scenario provided by this specific user group stipulates that the technician is required to perform quantitative data exploration and analysis in order to determine if the building application in question would create any issues with parking lot spaces being overwhelmed by new users. The taxonomy's user engagement context would classify this technicians' activity as *analysis* and the finding of trends, (Figure 5) to unravel the patterns that will help the technician to generate decision support data for synthesis. On the side of the taxonomy regarding the visualization components, the technician's work in this use case involves geospatial data, making use of (a) abstract and (b) spatial data types. The use case also identifies the technician's use of geographical information systems (GIS) software, web, and graphic frameworks. Components of the ArcGIS software gives the technician the ability to explore abstract data in the form of information visualizations and provides the technician with a host of spatial navigation features.

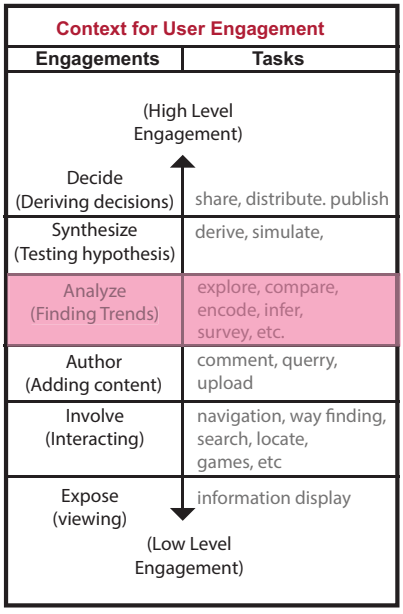

Fig. 5. Architectural Technician's User Engagement

Using Sorger et al.'s (2015) approach, the technicians' situation presents us with all *a<-->s, a<-->a, s<-->a, s<-->s* options for input and output data types. Furthermore, the geospatial applications used by the technician suggest that many of the combinations of input and output of data, visual and navigation components of a visualization can be achieved. For instance, the architectural technician will consider quantitative data sets of a neighborhood population, and is able to display this as a table of data or a 3D geospatial plot of that data, or combinations of both input and output formats. (*Da<-->Ds, Da<-->Da, Da<-->Vs, Da<-->Va, Da<-->Ns, Da<-->Na*).

Data Type		
Abstract (a) / Spatial (s) (Input<--> Output) a<-->s a<-->a s<-->a s<-->s		
Data (Da/Ds)	**Visual (Va/Vs)**	**Navigation (Na/Ns)**
Da<-->Ds Da<-->Da Ds<-->Da Ds<-->Ds	Va<-->Ds Va<-->Da Vs<-->Da Vs<-->Ds	Na<-->Ds Na<-->Da Ns<-->Da Ns<-->Ds
Da<-->Vs Da<-->Va Ds<-->Va Ds<-->Vs	Va<-->Vs Va<-->Va Vs<-->Va Vs<-->Vs	Na<-->Vs Na<-->Va Ns<-->Va Ns<-->Vs
Da<-->Ns Da<-->Na Ds<-->Na Ds<-->Ns	Va<-->Ns Va<-->Na Vs<-->Na Vs<-->Ns	Na<-->Ns Na<-->Na Ns<-->Na Ns<-->Ns

Fig. 6. Source and Target Data Types of Use Case Example

This is essentially accomplished only by the input of abstract data (*Da*, such as a spreadsheet of the neighborhood populations) to produce either spatial data (*Ds*, an example being the plotting of the neighborhoods on a map) or other abstract data, to define spatial or abstract methods of viewing (*Vs* or *Va*), and also defines spatial or abstract positions and/or directions of the visuals (*Ns* or *Na*), (Figure 6).

In Sorger et al.'s (2015) model-based taxonomy, *integration* is triggered through interaction, a *source domain* is what the user interacts with, and in the architectural technician example, these include sheets, tables, maps and charts. The *target domain* is what is affected through the integration. If the source and target domains are the same, they are of *coordination* rather than *integration*, (Figure 7). These tables, maps, and charts are both source and target domains in the case of the technician's GIS software used.

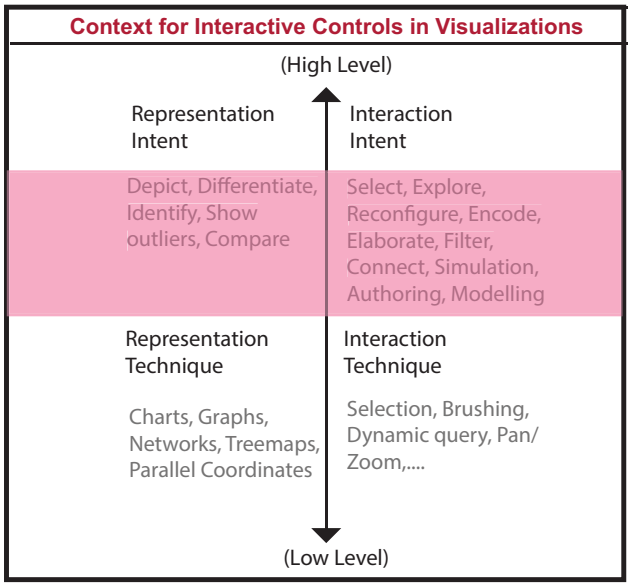

Fig. 7. Use Case Example's Interaction Model

4.4 Example 2: Traffic Operations Technical Support Person

In the example of traffic operations which is another use case from our research, a user group depicts the operations person analyzing the impact of weather events on the performance of a major thoroughfare in the greater Toronto area (GTA) traffic management operations. Three main tasks occupy this operations person's work on such a project: (1) the exploration of datasets to collect weather and traffic information, (2) classification of the weather data impact, and (3) analysis of the impact on road performance and travel times.

Using our taxonomy chart, (Figure 8) we can first classify our user engagement goals with the operations person as *user* and traffic, roadways, and operations as *use domains*. The scenario provided by this specific user group stipulates that the operations person is required to perform quantitative data exploration and analysis in order to determine the severity of weather, and the impact on road performance (speed and flow rates) due to weather conditions. The taxonomy's user engagement context would classify this user's activity as *analysis* (the finding of trends) to unravel the patterns that will help the operation user to generate decision support data for synthesis. On the side of the taxonomy regarding the visualization components, the operations work in this use case involves geospatial data, making use of abstract (a) and spatial (b) data types.

The use case also identifies the operations person's use of historical weather conditions data (e.g. rain conditions, snow conditions, precipitation), historical highway data (e.g. flow-density-speed-relationships), highway characteristics (e.g. free flow speed-capacity) with regression analysis (statistical analysis), and spatiotemporal analysis,

geographical information systems (GIS) software toolsets, web, and graphic frameworks. Components of the ESRI software could give the operations user the ability to explore abstract data in the form of information visualizations and will provide an understanding of the dynamics of the traffic system under differing conditions with a host of spatial navigation features.

This provides a variety of high level engagement contexts, analyze (find trends), synthesize (test hypothesis), and decide (deriving decisions) to publish or for action decision support. The operations user situation presents us with all *a<-->s, a<-->a, s<-->a, s<-->s* options for input and output data types. Furthermore, the geospatial applications used by the operations user suggest that many of the combinations of input and output of data, visual and navigation components of a visualization can be achieved. For instance, the user will consider quantitative data sets of weather and roadways, and is able to display this as a table of data or a 3D geospatial plot of that data, or combinations of both input and output formats. (*Da<-->Ds, Da<-->Da, Da<-->Vs, Da<-->Va, Da<-->Ns, Da<-->Na*). This is accomplished only by the input of abstract data (*Da*, such as a spreadsheet of the weather data, and roadway data) to produce either spatial data (*Ds*, an example being the plotting of the roadways on a map) or other abstract data, to define spatial or abstract methods of viewing (*Vs* or *Va*), and also defines spatial or abstract positions and/or directions, and navigation of the visuals (*Ns* or *Na*).

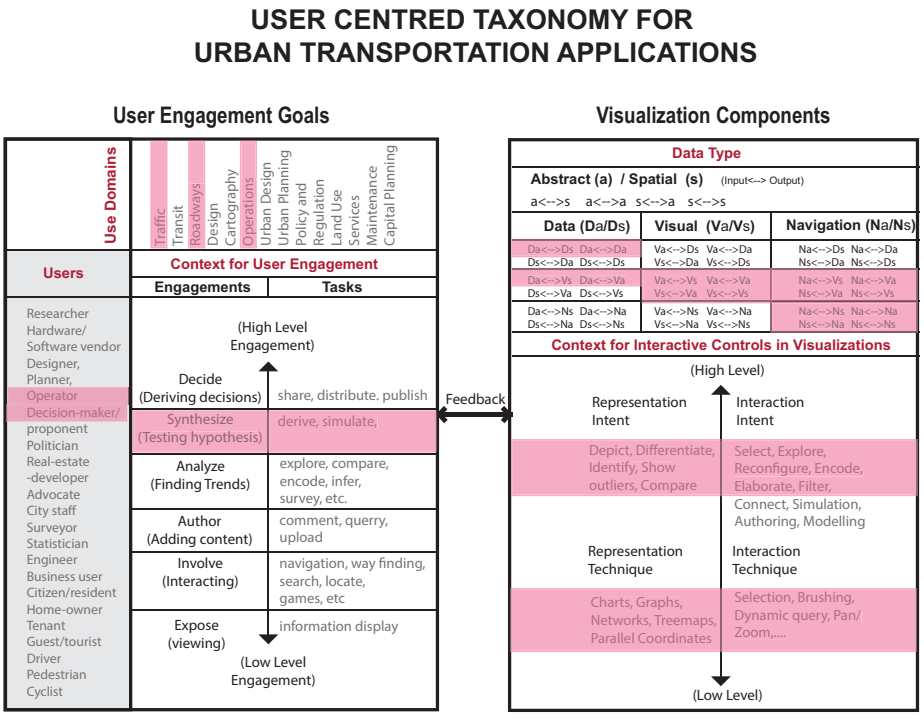

Fig. 8. Use Case Example of Traffic operations task use case

As per Sorger et al.'s (2015) model-based taxonomy, *integration* is triggered through interaction, a *source domain* is what the user interacts with, and in the traffic operations example, these include data sets, spatial data charts and maps. The *target domain* is what is affected through the interaction, a synthesis of various data to be represented and integrated into an integration. In this case of the traffic operations' use of GIS software to depict, differentiate and compare at a high level of visualization control, then the domain is *integration* rather than *coordination*, as shown in the figure 8 above.

The use of the user-centred taxonomy in the two examples preceding serve to illustrate a level of understanding of the levels of task, data type, and user engagement necessary for particular use cases, and provide a guideline for the level of user interaction and visual representation necessary in the design of interactive controls, toolsets and visualization dashboards to serve them. Through a depiction of a variety of use cases in this way, commonalities of interactive controls and toolsets can be identified to serve the variety of users.

5 Conclusions

The literature review provided an understanding of the potential components of a taxonomy for this form of data visualization, and outlined the importance of identifying inter-relating and diverse user groups' needs, utilizing the same data for multiple tasks. Key articles researched also identified a variety of approaches to the complexity of visualization processes, relevant task levels and interactions necessary to consider supplementing human insights through visualization supports. Our survey of a taxonomy for visualization provided an understanding of the various methods through which researchers in the field of visual analytics propose the organization of data, user tasks and visual elements to create meaningful representations.

These findings focused our approach to establishing a visualization taxonomy into three areas: *User Task*, *Level of Interaction or Engagement* and *Data Type,* and the detailed classification of interactive elements based on user tested needs for *spatial and non-spatial data types* within our research groups. We tested this approach through Use Cases, and design consultation and charrettes with the users, identifying the contexts and levels of interactive visualization functionality desired by various users.

The research process led to the creation of a taxonomy that helps us to understand, analyze, and design urban transportation software application systems, while emphasizing the importance the role visualization plays within the understanding and design of these systems. This taxonomy is intended to help designers of urban transportation applications understand essential elements of visualizations and study their relationships. It also serves as a starting point for designers of urban transportation visualizations to address categories of users, their tasks, level of engagements, data types and interaction needs as part of a user centered approach.

5.1 Further Research

As next steps, we plan to conduct more extensive workshops with various user groups identified in the taxonomy to verify and refine the assumptions within the proposed framework. Further research will include surveys of varied user groups, to build, test and refine use cases, and the results of future processes will be shared with providers of software solutions for transportation planning. We will also utilize the results of the research towards our efforts to create visualization dashboards that serve the multiple user groups within the iCity research project.

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