

Information Exchange in the Design, Construction, Operation and Maintenance of Public Transit infrastructure

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Abstract

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Public Transit Infrastructure

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Rapidly growing populations in major metropolitan centres across the world have resulted in unparalleled public transit ridership volumes. Coupled with lagging transportation infrastructure, this has forced public transit agencies to expand their services at a matching pace. The resulting design and construction projects have revealed inefficiencies that can be minimized through the use of standardised information exchange practices. Given the typically slower adoption of technology in the realm of public infrastructure, transit agencies have struggled to regulate newer information exchange practices. This thesis studies existing literature and specifications, internal workflows of the Puget Sound Regional Transit Authority (Sound Transit) and their prevalent contracting practices related to the exchange of asset data from designers and contractors to Sound Transit operations. Staff interviews and close collaboration with members of the Asset Planning and Programming team at

Sound Transit were used to develop a data specification to collect inventory data at early stages of the project and more detailed asset data during and after construction. The benefits of this specification to transit agencies and the field of knowledge are also covered. The research resulted in a data specification that would improve various aspects of Sound Transit's Operations, Maintenance and Asset Management workflows such as condition assessment, lifecycle planning, design review, EAMS system implementation and early inventory documentation from design and construction.

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Chapter 1: Introduction

Context

The United States suffered a crippling economic downturn in the late 2000s with unemployment reaching record highs. In a 2 year period, unemployment figures rose from 5.0% in June 2007 to 9.5% in June 2009 and peaking at 10.0% in October of the same year. (U.S. Bureau of Labor Statistics 2012) Since a majority of public transit trips are associated with people traveling to and from the workplace, there was a significant dip in ridership in this timeframe. However, on a larger scale spanning roughly 20 years (1995-2013), “public transportation ridership grew 37.2 per cent, almost double the amount of the population growth at 20.3 per cent” (APTA 2014). This demonstrates that the American public is slowly but surely moving towards public transit as a lifestyle choice, and with the economy showing a robust recovery, public transit agencies are faced with unprecedented passenger volumes.

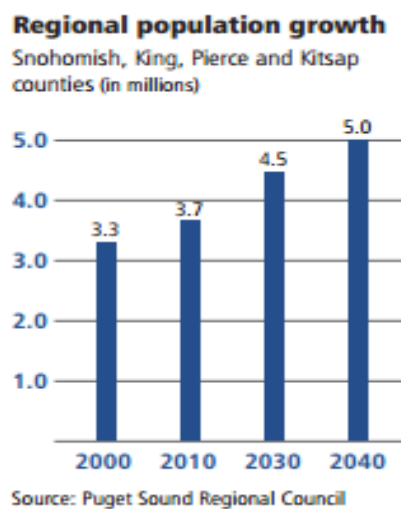


Figure 1: Projected population growth in the Sound Transit region (Sound Transit 2008)

Figure 1 gives us an example of the rate of projected population growth in the Puget Sound region in the Pacific Northwest. Fast-growing metropolitan centres such as Seattle and Philadelphia as well as established cities such as New York and Los Angeles have planned large scale extensions to their transit systems to deal with this pressure. The 8.5 mile long LAX-Crenshaw light rail project will cost roughly \$3.7 billion while Seattle’s Puget Sound Transit Authority has recently authorised their ST2 expansion plan which will cost \$13.2 billion (See Figure 2). ST2 is aimed at improving connectivity in various parts of the Seattle,

Bellevue and Redmond regions. The project is estimated to be carried out over the course of 15 years and involves hundreds of parties in the form of designers, contractors, subcontractors, users and facility managers.

“The large monetary value of (such) construction projects means that it is hard to at once remain nimble enough to adjust to changing markets and at the same time provide a full range of services” (Marsters 2011). To make this adjustment, it has become a growing trend for the construction industry to move away from the rigid world of Design-Bid-Build delivery to more organic, collaborative delivery methods such as Design-Build and GC/CM in order to manage these parties better. A study conducted for the Federal Highway Administration concluded that these methods have a positive impact on project cost, project duration as well as overall project quality. The study used a number of analysis approaches such as a detailed literature review, inputs from the AASHTO’s design-build task force and surveys of program managers and project managers involved at various levels of the program (University of Colorado 2006).

Another reason behind this shift is that Owners now want to take advantage of the Contractor’s experience in order to ensure constructability and economic feasibility. Some go so far as to predict that the construction industry will be transformed from its predatory nature and “Ecosystems will form of companies that have learned to effectively provide integrated solutions, and they will compete together for new work based on demonstrated past successes. This will include design professionals, construction companies, manufacturers, suppliers, fabricators and specialty consultants” (McGraw-Hill Construction 2012). In such a climate, it becomes critical to have a set of standards in place to ensure cohesive delivery of a quality project, which exist for most aspects of the project in the form of standard specifications and detailed contractual obligations. However, there are certain areas where no such standards exist owing to the emergence of new technology which makes it difficult to regulate.

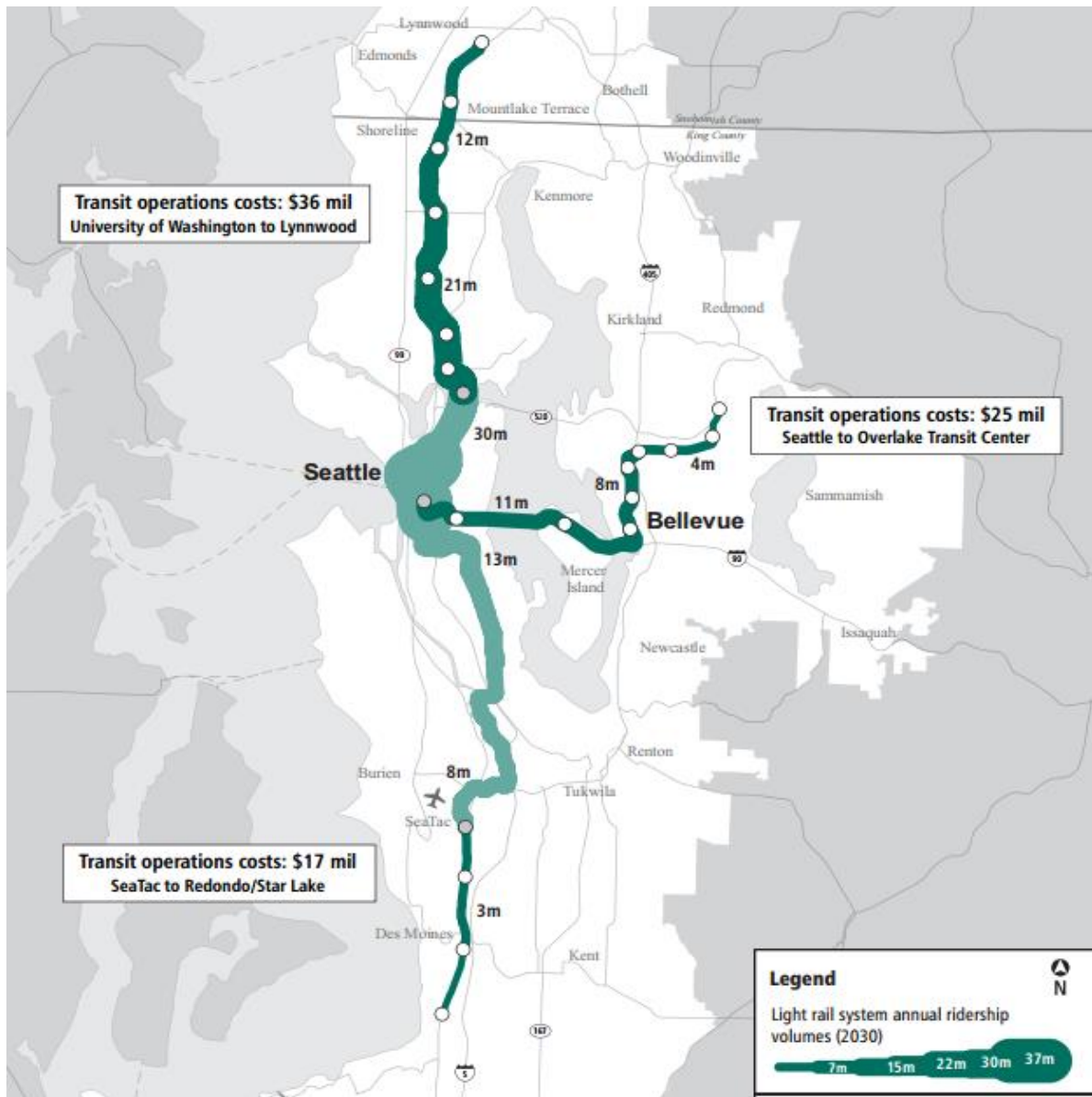


Figure 2: ST2 Planned Light Rail expansion and operation costs (Sound Transit 2008)

Information exchange has been one such area. The design, construction and operation processes throw up numerous challenges in terms of ensuring a speedy and efficient **information exchange process**. In the context of this research project, information exchange can be defined as the timely and error-free transfer of project data among the various stakeholders on a construction project to enable each party to accomplish their goals. These goals will vary according to the nature and length of interaction of the stakeholder with the construction project. From the Owner's point of view, some of the goals would include using the asset data to achieve the successful delivery and operation of a project, better lifecycle planning, maintenance scheduling and facilities management. Identifying successful information exchange is complicated because the criteria used to

measure success will vary throughout the owner agency, i.e. conditions assessment needs are different from those of maintenance. Successful information exchange will vary depending on the department in question and their workflows as they relate to the asset data. While success was not measured in this case, we made some attempts to understand the needs from various departments within Sound Transit.

The design process alone is typically carried out in 3-4 iterations, each of which is exchanged between the Owner, Designer, Contractor and Specialty Subcontractors depending on the delivery method. Such a large volume of information being moved around often creates discrepancies and losses which slow down the project and disrupt the cohesive flow of work. This problem is brought sharply into focus on public transit projects which are typically very large in size. The information and data required for such projects comes from different sources, is created and manipulated several times during the asset life cycle, and is not synchronised between systems, resulting in error-prone processes (Becerik-Gerber et al. 2012). **This thesis aims to address this issue by developing a standard data and compliance specification that can be used on such projects across the nation using Sound Transit's ST2 expansion project as a case study.** The significance of a streamlined information exchange process is greater as the size of facilities, both private and public has increased exponentially. Companies like Microsoft, Amazon, Boeing and public organisations like the University of Washington now dedicate a sizeable amount of their resources towards Facilities Management.

Better life cycle cost planning, conditions assessment, stronger budget forecasting and detailed inventory and maintenance scheduling are just some of the advantages that building information allows planners, owners, designers, contractors and facility managers to enjoy over the operational life of a project. Sound Transit's Asset Management plan involves the transfer of asset data from their design group (DECM) to Construction (Contractor) to Operations and finally into a new EAMS system maintained by the Asset Planning and Programming department (Sound Transit 2014). This transfer is facilitated through the use of a Project Specific Asset List (PSAL) that is developed over the iterative design process and updated throughout the life of the project. Thus, preconstruction and value engineering have become increasingly important processes that are bound to impact the way that the PSAL is developed across various phases of design and construction.

Therefore, there will be provisions in the specification that will accommodate for the delivery method being used such as Design-Bid-Build, Design-Build or GC-CM.

When developing this specification, it will be important to keep in mind the range of experience that most small- to medium-sized subcontractors may have with BIM and information exchange. Characteristically, the construction industry has been one of the slowest adapters of new technology which tends to delay the trickledown effect further (Bigelow and Benham 2015). Therefore, the information that will be collected will need to be vetted down to the most necessary to get the PSAL in its most compact yet effective form. “Accumulation of all disciplinary data in a single integrated data model impedes participation of some of the actors due to inability to work with large-sized complicated models” (Parsanezhad and Tarandi, 2013).

While the thesis attempts to create a general set of specifications that is transferable across agencies, it will use the Sound Transit example specifically to create a set of relatable reference points. Thus, the primary method used will be a detailed case study of information exchange processes on Sound Transit’s ST2 expansion project. The method statement chapter will elaborate upon this and explain the significance of each resource that will be drawn from.

Research Scope

This research project was sponsored by the Asset Planning and Programming (AP&P) department of Sound Transit. Therefore, this thesis aims to study the information exchange process from the point of view of the Owner, specifically Operations and AP&P and draft a specification that will enable them to acquire the correct asset data in the correct format from new project contracts. This asset data will be in the form of an inventory list that is filled into the PSAL template. It is important to note that the scope of this research project was limited to Sound Transit’s shelters and stations. However, the same principles can be extrapolated to include infrastructure beyond this scope. This data will be used to perform Condition Assessment, Lifecycle scope, schedule and cost planning for existing and new assets, Design Review, EAMS System implementation with new and existing project data,

Inventory documentation from design and construction, including tracking and management. Finally, this research will study, compare and contrast our specification with the Construction-Operations Building Information Exchange (COBie) process, which is a “performance-based specification for facility asset information delivery” that is being used at the University of Washington. Applicable concepts and/or data sets may be transferred into the PSAL if it is determined that they bring additional value to the agency.

Research Objectives

The research objectives are closely related to the way that design, construction and operation data is procured, handled and used by the various departments in the organisation. The objectives of this research can be listed as below:

1. Studying the process of procuring asset data from various parties in the design, construction and operation processes at Sound Transit.
2. Review and revise PSAL to identify required asset data and level of detail for upcoming projects.
3. Develop a data specification for the agency to streamline the process of information exchange and assign responsibility to the concerned parties at various stages of the project.

Thus, the result of this thesis will be a data specification that will help to reduce inefficiencies and the resulting costs on public transit projects. The compliance section will help to avoid delays due to rework and/or inaccurate information. This will help the agency to reduce their spending on such projects through improved interoperability and utilize public funds more efficiently.

Research Question

Looking at the aim and scope of this thesis, the research question that will be answered will deal with finding and documenting best practices for information exchange in the public transportation infrastructure construction domain. These best practices will take the form of a data and compliance specification. The requirements of the Owner point to a number of functions that are all connected to the concept of life cycle planning and maintenance of agency assets. Therefore, the following research question will define the central theme of this thesis. **“How can Public Transit agencies implement information exchange practices to support life cycle planning and maintenance management?”**

Chapter 2: Literature Review and Problem Statement

Introduction

Public transit agencies have traditionally been much slower adopters of new technology as compared to private organisations for a number of reasons. The key reason behind this is the budgeting priorities of the Senate and the House. Figure 3 illustrates how the 2015 House and Senate budgets have reduced funding to highway construction and mass transit projects by 28 and 22 per cent over the next 10 years, respectively. Mandatory funding in the transportation sector will be slashed by almost 90% in 2016 according to the House budget, followed by a partial reinvestment in the following years (Reich 2015).

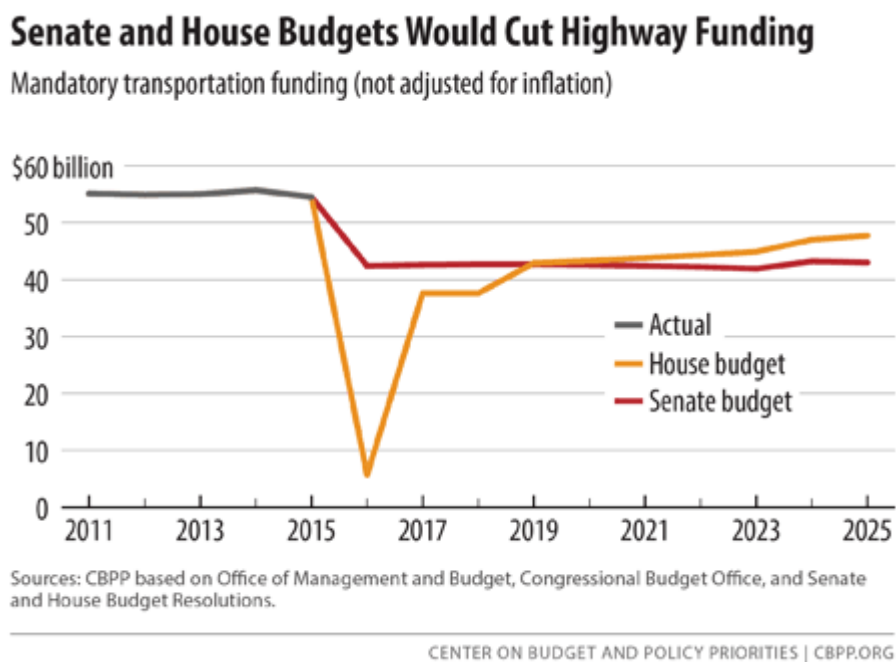


Figure 3: Budget cuts to highway and mass transit projects (Reich 2015)

In such a climate, public transit agencies are forced to address their most immediate needs first. Therefore, new technologies such as the EAMS system or advanced information exchange are not embraced till the agency's basic needs are met. Furthermore, the funds used to finance the adoption of the technology and train agency staff are public tax dollars, which adds a further pressure to avoid a seemingly risky investment. The risk factor in this

case stems mainly from a lack of studies and hard data to back up the tangible benefits of investing in these technologies.

Interoperability and Information Exchange

As construction methods and materials become increasingly efficient, in terms of both cost and function, the focus has shifted to areas that were often marginalised in past times. This includes areas such as value engineering, preconstruction services and facilities management that were considered to have lower returns on investment of time and resources. This can be blamed on a lack of education about their benefits as can still be seen in various developing markets such as Southeast Asia (Cheah and Kiong 2005). The second factor that can be called out is a lack of initiative on the part of government agencies and building authorities. The importance of this factor along with the implementation of new delivery methods such as Design-Bid-Build and GC/CM which allow the parties to participate in these activities was clearly demonstrated in the American construction market (Zimmerman and Hart 1982). These new delivery methods with their characteristic higher collaboration have in turn shifted the focus on to interoperability within these project teams. Effective maintenance and management of agency assets could significantly reduce the annual \$15.8 billion cost associated with inadequate interoperability (Gallaher, et al. 2004). This 11 year old figure highlights the need for a big picture approach that is most easily achievable from a big-picture policy standpoint. It can be broken down into separate life cycle costs according to the following table.

Table 1: Cost of Inadequate Interoperability by Stakeholder group and Life Cycle Phase (in \$ millions) (Chapman 2005)

Stakeholder Group	Life Cycle Phase			
	Planning, Design and Engineering	Construction	Operation and Maintenance	Total
Architects & Engineers	1,007.2	147.0	15.7	1,169.8
General Contractors	485.9	1,265.3	50.4	1,801.6
Specialty Fabricators and Suppliers	442.4	1,762.2	-	2,204.6
Owners and Operators	722.8	898.0	9,027.2	10,648.0
Total	2,658.3	4,072.4	9,093.3	15,824.0

Note: Sums may not add to exact totals due to independent rounding

Thus, we can see that inadequate interoperability affects all the parties on a construction project at various phases. The cost categories used to arrive at this estimate included efficiency losses from activities incurring avoidance, mitigation and delay costs (Chapman 2005). To remedy these losses, efficient information exchange has become the focus of an increasing number of studies. These studies deal with various aspects of the information exchange concept as it interacts with large construction projects.

BIM for FM

One of the aspects that are closely related to this topic is Building Information Modelling (BIM) for the purpose of Facilities Management (FM) or BIM for FM. Based on our staff interviews and discussions with employees of Sound Transit, the end goal with regard to BIM for FM is the creation of models that store asset information which can be modified by the Designer or used by the Owner for life cycle planning, maintenance scheduling, etc. Among the many potential scenarios, one of the workflows that was considered during

these discussions involved the asset data being transferred directly from the model to the asset management database through the phases of the construction project. However, a number of obstacles were identified by different studies on the subject.

Firstly, since the data is currently gathered from a number of different sources, each source requires a different approach to extract the necessary values. In doing so, different types of conflicts were encountered and documented among relevant attribute values extracted from these sources (Gu, Ergan and Akinci 2014). The complex and unique nature of every construction project amplifies the challenge since there is no standard procedure yet that will help avoid these conflicts.

There are a number of other practical challenges that arise in the day to day operation of BIM for FM such as high cost of training and support infrastructure, insurance, liability and communication (Deutsch 2011).

Additionally, “for existing assets, built before the emergence of BIM, the challenge is even greater as their FM legacy systems do not support open BIM standards” (Patacas et al 2015). This presents an additional challenge in that there is no standard to price or extract data efficiently for existing structures. Thus, their maintenance and management becomes a more arduous process. Since lifecycle data is often extrapolated from historic records, the importance of asset data from existing structures is considerable. A recent application of BIM for FM in Manchester Town Hall Complex report (Codinhoto et al. 2013) identified the lack of awareness of the potential of BIM in the FM phase and the *need for clear guidelines* for its implementation in FM as key challenges.” Sound Transit faces many of these problems and it has become imperative to define specifications and best practices at this early stage of development in order to ensure that the process does not become unwieldy and unduly expensive. These best practices should include a management policy statement, conformance with regard to contracts, legal, regulatory and procurement policies, identification and prioritization of information packages and the life cycles in which they are created (Fallon and Palmer 2006).

Potential solutions included in the Deutsch study include changing the working culture of the organisation, clearly demarcating roles and departmental boundaries, etc. While the solutions outlined in the Deutsch study may work for standard building construction, there

is a considerable void when it comes to applying them to the dynamic world of a fast-expanding public mass transit agency. In a study of current BIM industry practices, it was observed that successful adoption of this technology would require a change in the existing work practice. Standard processes and agreed protocols are required to assign responsibilities (Singh, Gu and Wang 2010). Additionally, the workforce will have to be trained or expanded to include internal or external experts such as BIM model manager and BIM server manager.

Other Data Sources

Information exchange in the context of this thesis has been a part of the construction industry for a few decades. Traditionally, the quantum of building information generated for a single building “amounts to several binders or even multiple banker boxes” as seen in Figure 4 (Marsters 2011). This makes the process of sorting through and accessing this data a tedious process. Using it for the purpose of facilities management, maintenance scheduling, or a range of activities that is now taken care of by the EAMS system is unimaginable for the size of projects that are undertaken by transit agencies.



Figure 4: Typical delivery of Handover Documents (B. East 2014)

Public Transit Agencies and Information Exchange

Government agencies are still unconvinced of the benefits of BIM for FM since it is difficult to quantify the returns on investment. However, steps are being taken to make sure BIM has a place in the future of government asset management. This includes the UK Government's Soft Landings approach whose principles ensure "early engagement of FM and the end user during the design and construction process" (BIFM 2012). The need and scope of BIM for FM is clearly identified here. It is also recognized that this will be more effective in the collaborative Design-Build type environment toward which the industry is headed. Another research paper highlights the benefits of using Integrated Project Delivery and Job Order Contracting as delivery methods on BIM for FM, which include greater transparency, increased communication, early cost certainty and more maintainable designs (Cholakis 2011).

There are a number of European agencies that are also trying to leverage the benefits of a standardized information exchange structure. The Virtual Construction for Roads project or V-Con targets the civil infrastructure sector specifically (van Nederveen, et al. 2013). It lists and explains information exchange standards available or currently in use in the European Union. This includes options such as

- ISO STEP or International Organisation for Standardization: Standard for the Exchange of Product Model data. This category includes standard formats such as the Industry Foundation Class (IFC) and other ISO standards.
- IEC 81346-2, or Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations – Classification of objects and codes for classes. This standard is used in Sweden.
- OGC or Open Geospatial Consortium is "an international industry consortium of 481 companies, government agencies and universities."
- INSPIRE, which is a EU-funded platform that coordinates GIS-related standards.
- COINS, a Dutch open standard that lets agencies use BIM in infrastructure and is complementary to standards issued by the buildingSMART alliance such as IFC, IDM,

etc. The inventory of standards includes many such examples that can be applied to various situations and needs.

Asset Data Collection & Challenges

Figure 5 below shows the typical flow of information over the course of a project, with the arrows signifying the direction of communication (Cholakis 2014). As we can see, information flows among different parties in a manner that is difficult to standardise. This is primarily because of the irregularity across project types, delivery methods and project stakeholders which affect the flow patterns for this information.

To add to this exceptional nature of each project, the increased pace and scale of projects require that organizations must be able to process a larger number of changes, exceptions and decisions in shorter time periods in order to leverage the benefits of IT in construction that stem from solutions like virtual design and construction, 4D modelling, concurrent detailed design and operations simulation and training (Fischer and Kunz 2004).

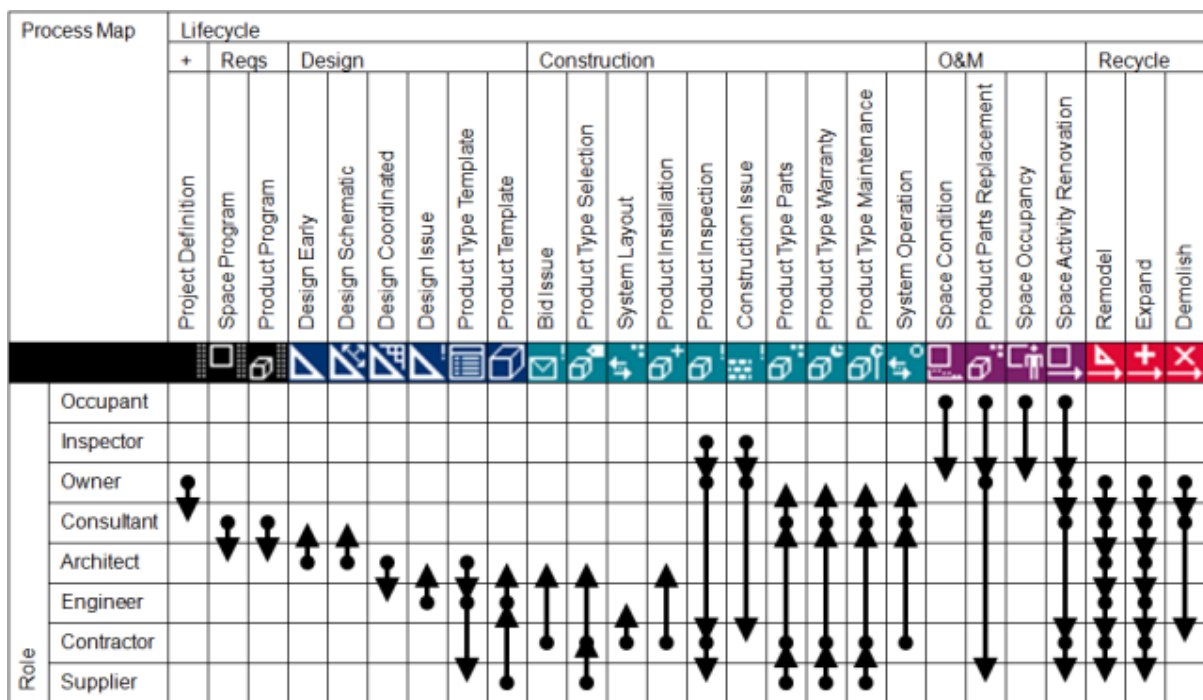


Figure 5: Flow of information during a typical construction project (Cholakis 2014)

The asset data being exchanged through the information exchange process is also crucial since any data over and above the exact Owner requirements is a load on the IE framework

that can be avoided. Recommendations for data capture include manufacturer and vendor information, location information, building, floor, room, and zone where the equipment is located; description: type, asset number, equipment group, criticality and attributes like weight, power, energy consumption, etc. (Becerik-Gerber, et al. 2011). Additional requirements would include documents like warranties, operation and maintenance manuals, manufacturer instructions, certificates and test reports.

Lack of compliance with these Owner requirements was found to be a recurrent theme in the information exchange studies being carried out. This stems from a lack of expertise and time on the Contractor's part which is a result of slow adoption of technology in construction. One paper suggests the installation of a trigger process that will check the incoming asset data template as well as the completed datasets to ensure that no incorrect data is entered and no data sets are incomplete (East, Nisbet and Wix 2010). The batch-import process of data transfer also needs to be monitored for constant updates and modifications from the various parties involved. This was found to further complicate verification of information accuracy, format and version.

BIM Planning and Information Exchange

Collaboration and cohesion are key foundations for an optimal information exchange process. BIM Execution Planning can be one of the tools used to achieve these goals. To create the best value from BIM and information exchange, the focus should not be solely on the technologies being used; the processes used to create information and disseminate it through the organisation are far more important (Love, et al. 2013). Thus, the challenge lies in setting up a framework for this exchange in the form of a BIM execution plan.

A BIM Execution Plan has numerous advantages especially in the field of asset management and information exchange. The Penn State BIM Execution Guide lists several competencies required by Owner, Designer and Contractor staff in order to achieve these advantages (Penn State University 2011). These include:

- An ability to navigate and manipulate a 3D model
- An ability to recognize the value of each asset and if it is worth tracking

- An ability to identify the end needs of the building's operational and FM needs, etc.

A research paper has identified the need for a distinct role in project teams that focuses on special coordination required in BIM contexts (Barison and Santos 2010). Titles for this role may vary from BIM Manager, Modeller or Coordinator depending upon the responsibilities associated with the position and the type of delivery method being used. For the purpose of information exchange on public transit projects, the relevant roles from this paper include:

- BIM Facilitator: The person holding this position can be expected to assist and look after quality control for all BIM related work. He will interact with the people in the field such as the foremen and communicate the engineer's design to them.
- BIM Consultant: There are three potential positions under this title: a strategic consultant to help the agency identify medium to long term goals, a functional consultant to "generate action plans in accordance with these strategies" and an operational consultant who takes care of the day-to-day execution of the plan.
- BIM Manager or BIM Coordinator: This position applies to Designers, Contractors and Owners. The details of each role vary but are centred on managing the BIM team at each of the organisations and ensuring a coordinated approach to solving the information exchange puzzle.

Depending on the size of the project, the Owner can consider appointing a Project Model Manager for various parts of the project to better integrate information from the various stakeholders (Barison and Santos 2010).

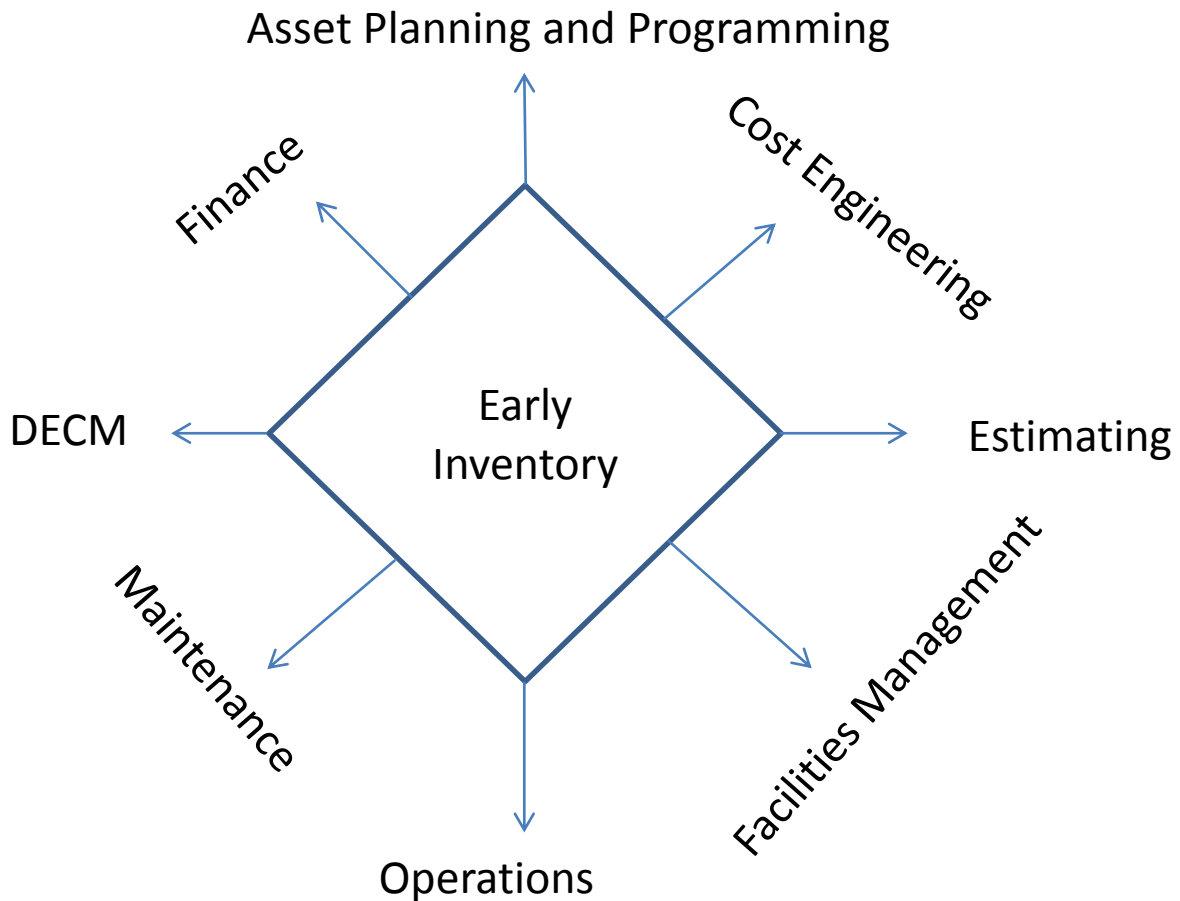


Figure 6: Internal Stakeholders at Sound Transit

A core principle of BIM planning that applies to the information exchange process is to begin with the end in mind (Penn State University 2011). This is detailed in Chapter 2 of the BIM Execution Planning Guide. In this context, it marks a key point of departure for this thesis as it helps to identify the participants who need to adopt this principle as also to whom the principle applies. Figure 6 above provides an overview of these parties. Hence, the needs of all these parties must be taken into account when developing the data specification.

Level of Detail for Information Exchange

A Project Specific Asset List, which is the Sound Transit’s version of an asset data template, can be designed to go down to various levels of detail. However, it is important to identify the needs of an organisation before this level is determined. For a public transit agency, the end goal will be to achieve a balance between obtaining the maximum amount of useful

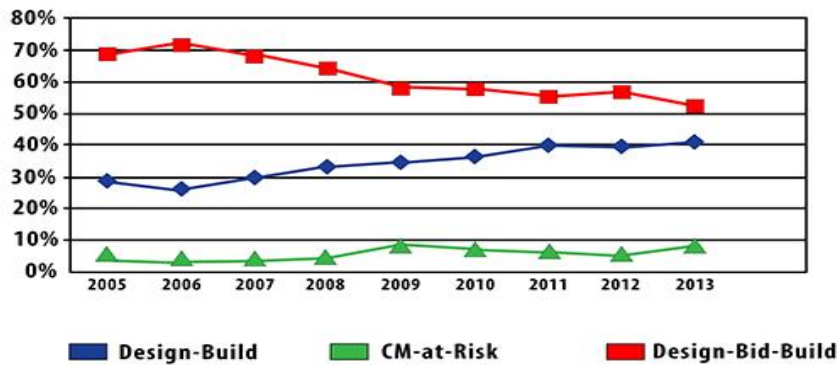
information while ensuring that the Contractor and Designer are able to maintain the quality of their information in an economically feasible manner. This is because “the richer the model, the more useful it may be for future users” (Marsters 2011). This principle applies to the asset data that is being moved around as part of the information exchange process. However, there will be an additional cost component for an additional level of detail since the Designer and Contractor will have to deploy additional resources and manpower to capture the extra information.

One study examined two different projects that were using BIM models and information exchange at two different levels of detail (Akcamete, et al. 2011). The first project was a 5 story commercial building while the second was an academic building comprised of 2 buildings and an underground parking garage. The results varied in that while a higher level of detail in asset data and modelling required more effort, the results were more precise and reduced recall costs specifically on the MEP portions. This is because the MEP systems require a greater level of coordination than other parts of the structure. Therefore, it is crucial to remember the needs of the organisation in order to find an optimal level of detail.

Delivery methods and Information Exchange

Since the impact of the delivery methods being used on the data specification will be substantial, it is important to identify the characteristics of each method that influence the information exchange process. Traditional Design-Bid-Build involves two separate contracts for design and construction between the Owner and the Designer & the Owner and the Contractor. Since the Contractor’s involvement occurs at a stage where the asset list is ready, information exchange workflows will be different from a Design-Build project where the Contractor’s input is considered when making decisions about selection of assets. This is because “Design-Build is a method of project delivery in which one entity – the design-build team – works under a single contract with the project owner to provide design and construction services” (DBIA 2012). Figure 7 below shows the decline of the traditional delivery method and gradual increase of more collaborative methods.

**Project Delivery Method Market Share
for Non-Residential Construction**



Analysis by RSMeans Market Intelligence a div. of Reed Construction Data

Figure 7: Recent trends show a movement away from Design-Bid-Build (Giachino 2016)

It becomes interesting to note how information exchange is transformed as the level of collaboration increases as in Integrated Project Delivery method. Improved channels of exchange will be accompanied with security concerns about the sharing of sensitive or proprietary information. Given the construction industry’s frequent involvement with litigation, various legal considerations such as non-standard contracts and process design will come into the picture (American Institute of Architects 2007). While this is not yet a concern with public transit agencies, it will be an important area of research for the future.

Other Technical Solutions

Technical solutions to the numerous problems impeding efficient information exchange have been proposed. There are various papers that examine options such as Industry Foundation Class (IFC) and COBie (Construction Operations Building information exchange) as a viable solution to BIM for FM (Parsanezhad and Tarandi 2013). They explain each option in some detail but fail to outline means and methods specific to a mass transit agency. The COBie specification proposes a method of modifying current business practices to establish asset management systems that accept data from the upstream (Design) in the form of various IFC data sets to achieve automated extraction of facility inventory and checking of submittal performance against relevant codes, standards and specifications (W. East 2007). While it does outline a superlative information exchange process, it cannot be applied to Sound Transit’s case owing to the much higher level of detail. Industry

Foundation Class is simply a “vendor-independent file format” that can be used to capture building information in relation to the geometry of the building model. This was created by the buildingSMART alliance to facilitate cross discipline coordination, data sharing and re-use for various downstream applications such as life cycle analysis and maintenance (Thein 2011). All these tools also fail to adapt to the much lower level of detail that is typical to the public mass transit realm.

Limitations of Existing Literature

The literature review reveals various gaps in knowledge in the field of information exchange as it relates to the needs of public transit agencies. There are numerous standards for the various platforms available commercially such as Ecodomus or COBie, which are usually the manufacturer’s recommendations. It is critical given the singular state of affairs with regards to the funding and operation of a public transit agency to tailor the standards and specification to the needs of such agencies. Additionally, there is a lack of information on asset data and information exchange and their intrinsic relation with life cycle planning in the construction industry.

Therefore, the thesis research question will seek to address the following major problems:

1. How can Public Transit agencies implement information exchange practices to support life cycle planning and maintenance management?
2. How can information collection and exchange be tailored to meet the needs of different operational uses at Sound Transit?

The data specification that will emerge as a result of this study will explain the role of each party at various stages of the Phasagate process and make the value of the process apparent, thus aiding the existing literature that attempts to do the same.

Chapter 3: Method Statement and Data Collection

Introduction

The Puget Sound Regional Transit Authority or Sound Transit had been expanding their light rail network extensively since 2012, and their Asset Planning & Programming department wanted to use the opportunity to develop and implement a set of information exchange best practices that would benefit several facilities management processes. At the same time, the University of Washington in collaboration with its department of Construction Management and the internal Capital Projects Office was in the process of completing a detailed study on the use of COBie on new construction projects along with a re-baselining effort for a few of the existing structures on campus. This effort was spearheaded by Dr. Carrie Sturts-Dossick and her team. Given her extensive experience in the field of collaboration in construction, BIM and information exchange, Dr. Dossick was approached by AP&P. The entire scope of the research project was broken down into **three major tasks**:

1. Identify internal Sound Transit project data needs for a better handover process from Construction to Commissioning to Operations. This included discovering means to transfer data digitally between the parties and developing a plan for information exchange from DECM to OPS. This was further broken down into the following sub tasks:
 - a. Review existing Project Specific Asset List template format and level of detail for asset data collection.
 - b. Map work processes for Conditions Assessment, Lifecycle scope, schedule and cost planning for new and existing assets, Design review, EAMS implementation, Inventory documentation, tracking and management, and Maintenance Planning. Assess how the PSAL can support each of these processes.
 - c. Review current information exchange policies and practices at Sound Transit.
 - d. Review and revise Design and Construction Data requirements and contract language for new projects in all delivery methods.

2. Review and report on industry best practices related to BIM and integrated project delivery. The AP&P team would coordinate with ST's Design, Engineering and Construction Management (DECM) team to define model uses and responsibility during transition from design, construction, as-built and final delivery to operations. This task would include the following sub-tasks:
 - a. Develop BIM scope language for DECM's Request for Qualifications, scope and project requirements.
 - b. Review best industry practices in the field of BIM planning and develop a BIM execution plan for the agency's new projects.
 - c. Develop a BIM roles and responsibilities matrix based on industry best practices.
 - d. Develop a model validation process map and checklist.
 - i. Coordinate with AP&P and DECM to identify asset data needs for asset planning and facilities maintenance.
3. Rebaselining of existing Sound Transit facilities. In this context, rebaselining can be defined as the process of updating asset databases to match new construction requirements and asset management systems.
 - a. Verify the asset data list to be collected for existing assets.
 - b. Evaluate as-built data sources currently available to support the rebaselining effort. This will be used to develop work processes to collect this data in an efficient manner.
 - c. Develop a work flow for field verification of data collected from as-builts and other data sources.
 - d. Develop a method to import the field verified data into the EAMS system.
 - e. Develop a guide to illustrate process of compiling rebaselined asset data sets for existing facilities.

Of these 3 tasks, this thesis will focus on Task 1, i.e. review and revise the PSAL template, review current ST information exchange practices and write contract language for the collection of asset data on new projects.

Research techniques

The goals of this thesis revolve around the information exchange workflows and processes on Sound Transit's expansion projects. To achieve these goals, a combination of literature review, case study, agency member interviews and close collaboration with Sound Transit's DECM and AP&P teams was used. Figure 8 depicts the research goals, methods and outcomes in the form of a flow chart.

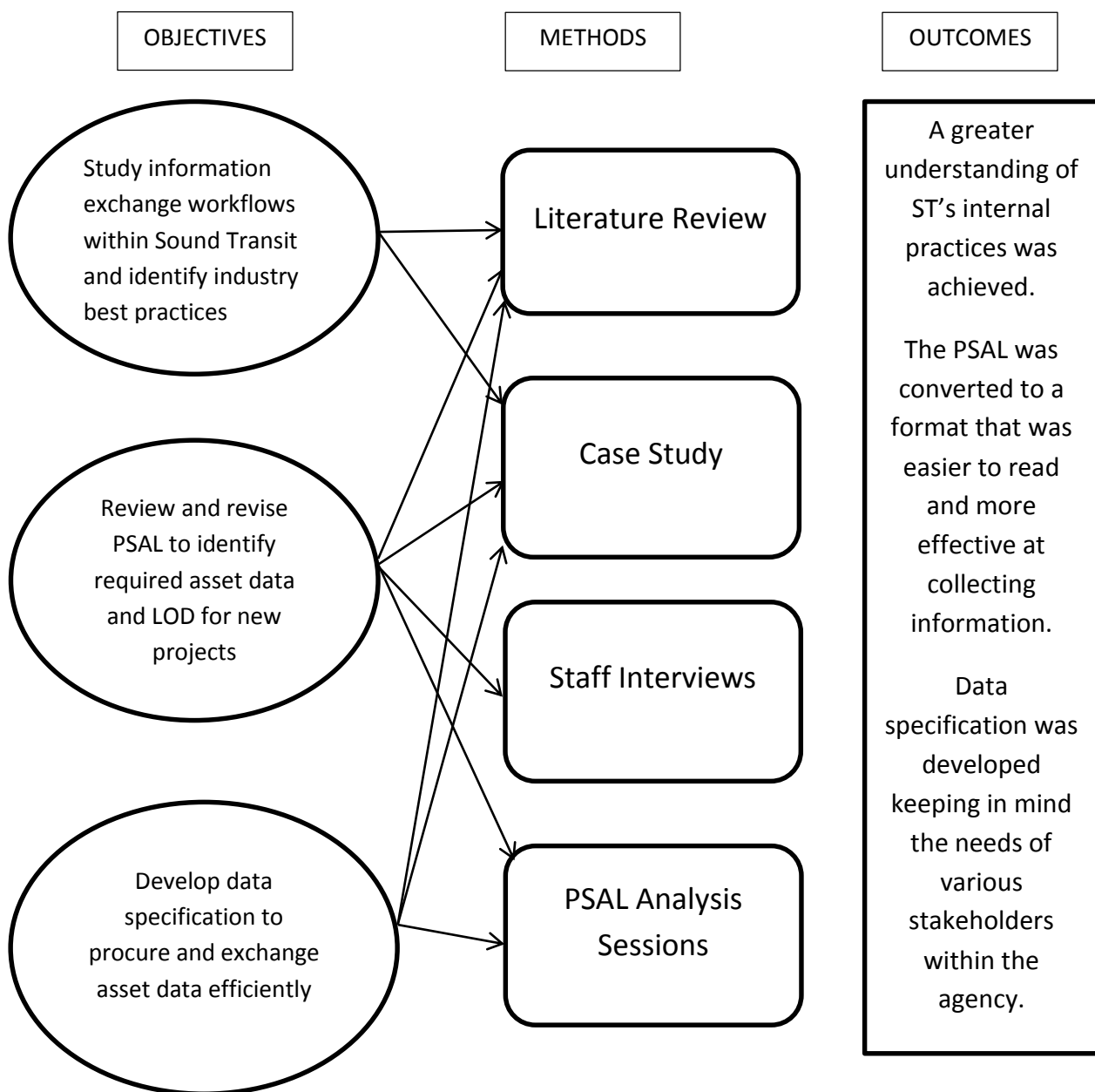


Figure 8: Flow chart detailing research methods and outcomes

The case study method was the major source of data that was collected to achieve the research objectives mentioned above. Traditionally, case study analysis relies on a mix of quantitative and qualitative data to answer 'how' or 'why' questions. In his work, Yin suggests that case study method of research be used when contextual conditions need to be covered as they are relevant to the phenomenon being studied (Yin 2003). Additionally, it can be used to explore a particular project or scenario to generate rich datasets and robust analysis of a complex process. Of the research objectives, the case study method helped to study the following: the information exchange workflows at Sound Transit, identifying the personnel to be interviewed, current state of policies and practices, the need for and importance of various asset data sets and how they interact with the various operational needs at ST. Additionally, it was a starting point to anchor the data specification to the agency's past record since the research provided an idea on how the specifications for such a public transit agency are written. A number of internal ST documents were studied to gain a better understanding of the structure and functioning of such a large organisation. One of the document sets were organizational charts of the various departments such as the Executive branch, Legal, Communications and External Affairs, Information Technology, Procurement & Contracts, DECM and AP&P which were an important tool to identify the hierarchy of the people that would be a part of the information exchange process, directly and indirectly. This helped to identify the personnel that would be interviewed and would contribute most to our knowledge of ST's internal processes. The list of internal documents included but was not limited to the following:

- Existing contract language for BIM and information exchange
- Specifications for ongoing projects that would describe various tasks such as design reviews, budget development, constructability reviews, risk management, etc.
- Meeting minutes for various meetings where key decisions pertaining to AP&P were made
- Strategic overview of ST's Asset Management Plan
- ST's Asset Management Plan

Sound Transit's draft Asset Management Plan was a key internal ST document that gave valuable information about the existing state of practices. Sections 5, 6 and 7 relate specifically to the Asset Inventory, PSAL and the organization & management of asset-

related data (Sound Transit 2014). It is interesting to note that ST policy for Data, Records and Information Systems states that “Data structures and definitions shall be to the greatest extent possible consistent across agency asset types and classes.” However, it does not define a specific level of detail. The results of this thesis will fill in many such gaps in this plan. The Plan also prescribes a step by step process for various activities e.g. Asset Management Documentation and Records, explains the type of documentation required and the parties responsible for each activity.

Literature review was another key research technique to guide this thesis towards the proper outcomes. Since Sound Transit’s overarching goal is to bring their systems up to the industry best practices and standards, this technique was indispensable when reviewing the state of research being done in this field. It was especially relevant to understanding why general solutions that are developed keeping the majority of the construction industry in mind do not apply to public transit agencies. The literature review helped to clearly underline the unique position that these agencies are in. The George Washington University’s FIM Manual (George Washington University 2014) was used as a reference model to structure the specification to Sound Transit’s needs. This is despite the lack of parallels between these two organisations, one of them being a private institution. The comprehensive coverage of information exchange concepts that the manual has achieved is the deciding factor that favours its use.

The staff interviews offered another perspective into the information exchange process at Sound Transit. The interview section details the process of selection of interviewees and a breakdown of the development of the interview tool.

PSAL Review Sessions

The PSAL Review sessions involved a series of weekly meetings for a collaborative assessment of each section of the PSAL template. These sessions were attended by two

members of the AP&P team, two members of the DECM team, a clash detection expert from DECM, Dr. Dossick and our team of Research Assistants. The sessions usually lasted for 2 hours at a time. The value of each part of asset data to be collected was discussed at length from each party's point of view. The difficulties faced by the Design team and the Contractor when collecting the data was also addressed during the session. 4D Revit models from previous projects would be analysed to observe the transfer of asset data from the model into a database. The result of these sessions is discussed further in the Data Analysis chapter.

Research Schedule

After consulting with AP&P, the following research design and schedule was finalised for the research project:

Activity	Jan-Feb 2015	March-April 2015	May-June 2015
1.a. Review known specifications	Mihir lead		
1.b.1 Develop contact list	Team (Luming lead)		
1.b.2 Develop interview tool	Team (Luming lead)		
1.b.3 Conduct interviews		Team (Mihir lead)	
1.b.4 Compile findings from peer institutions		Team (Mihir lead)	
2.a. Review ST current specifications	Mihir lead		
2.b. Compare ST contract language		Mihir lead	
3. Write Report		Team (Mihir lead)	Team (Mihir lead)

Table 2: Schedule of research

Research Design

The research project in its entirety had a very wide ranging scope. The topics to be investigated included developing the data specification for information exchange, BIM Execution planning, a review of best practices among peer transit agencies as well as whittling down the PSAL to its most basic yet valuable form. Since there is a lot of overlap among these topics, it was impossible to limit the scope to Task 1 for the purpose of this thesis. Thus, the research was designed in a way that it used the overlapping topics to add value to the data specification. For example, the BIM execution plan was included in the specification as a mandatory requirement in order to improve communication among the various stakeholders on the project.

Interviews

Sound Transit is a vast organisation that comprises of numerous departments, each of them having their own requirements from the information exchange process. The staff interviews revealed the range of the needs that will need to be addressed by the PSAL and thus, were a significant resource to decide the value of each piece of asset data to the agency.

A total of 4 formal interviews were conducted with members of different departments. The organisation charts detailing the staffing of each department helped to highlight the key participants in the information exchange process. It also revealed the positions in the organization which will be most affected by the implementation of the data specification that will be laid out in this thesis. On reviewing the organization charts, the following people were interviewed as they were found to be in positions important to the research process:

- **Maintenance Manager:** Since one of the research objectives involves the improvement of information exchange practices to support maintenance management and scheduling, it was imperative to understand the needs of this branch. The maintenance manager interviewed worked for Light Rail Facilities Management. His duties included but were not limited to maintaining and improving light rail stations. Since the maintenance is performed by a combination of third

party consultants, King County workers and Sound Transit crews, his duties include overseeing and scheduling the work of these employees.

- Program Manager for Asset Control: The programming manager of AP&P has a background in architecture focused on renovating and remodelling existing structures. Additionally, he has worked with forensic firms to inspect buildings for damage. Therefore, he has considerable experience with inventory management and conditions assessment which made him an ideal candidate to interview for this research project.
- Senior Facilities Specialist: The duties of this interviewee include the supervision of self-performed and subcontracted maintenance work. His duties include collecting field data to build the initial facilities inventory and as such, he has a lot of experience working with facilities maintenance and inventory management.
- Asset Manager: Sound Transit runs a maintenance scheduling system referred to here as 360 which was managed and overseen by this employee. Her duties included generating and distributing work orders for Preventive Maintenance (PM) as and when they were scheduled. She was also responsible for the preparation of these schedules, weekly, monthly, quarterly and yearly, for four years in advance. Thus, any upcoming PM work would result in her creating and distributing a work order to the appropriate vendor and ensure that the work is completed. While she did not have any prior experience working with an asset management system, she had spent 6 years working with the 360 system.
- Facilities Maintenance Manager: With extensive experience in the field of asset management systems such as Maximo, this employee was responsible for reviewing of data output from such systems and organize manpower and agency resources in order to optimize coverage of all preventive maintenance work orders generated by the Asset Manager. His jurisdiction was limited exclusively to facilities and structures.

The interviews were 30 minutes in length and were held at the Sound Transit Headquarters in Seattle, WA. The duration was limited to 30 minutes since it was optimal to the participants' schedules while allowing us to collect a sizeable amount of information. The participants were selected in a way that our research covered the maximum area possible in

an organisation as Sound Transit, where many of the people in one particular department are unaware of developments in other departments. For example, 3 of the interviewees had never seen the PSAL before the interview.

As introduced in the interview tool, the Project Specific Asset List (PSAL) template was developed by ST's Asset Planning and Programming department, specifically the Program Manager for Asset Control. According to him, the PSAL was born of a need to structure Contractor's responses to Sound Transit RFPs which demanded a certain amount of asset data. This document outlines the various data sets that will be collected from the design and construction process. It is important to analyse the value of *each* of these data sets in order to compile best practices for their collection from the Contractor. As we have seen before, it is also important to adjust the process to ensure that inexperienced contractors are able and willing to comply with these best practices.

The interview tool was developed based on the research objectives for the entire project and was loosely structured as below. The full interview tool can be found in the appendices.

The goal of this study was to create a specification that will assist ST with **information exchange** for new and existing facilities. The tool was meant to encourage a discussion about the participants' experience with asset management, information exchange, maintenance scheduling and the interaction and inter-dependence of these operations at Sound Transit. In addition to that, they were asked about their work history and any prior interaction they may have had with respect to asset data. This was followed by identifying each person and in turn, each department's exact data needs and prioritising it in terms of importance. The amount of time spent by each employee on trying to find and access asset data was discussed along with an attempt to estimate the amount of time that would be saved by using the PSAL and the EAMS system.

In the next chapter, the thesis will study this PSAL in detail to identify the type, nature and value of data that the agency intends to collect from the design and construction process in order to achieve its objectives. The responsibilities of each party will be analysed and clearly set out at various phases of design, construction and facility turnover. Since the guidelines will be developed in conjunction with the PSAL, any additions or omissions from the PSAL will be reflected in the guidelines. Additionally, a set of quality control recommendations

and compliance specifications based on a study of other government agencies such as the United States Army Corps of Engineers will be included.

For the analysis of this data, we will use the Phasegate process and the FIM manual (George Washington University 2014) as the backbone of the thesis. We will examine the process and draw from Sound Transit's draft Asset Management Plan to create a specification describing the role of each party at the various Phasegates. Once this is complete, we will consider two delivery method alternatives: Design-Build and GC/CM and examine the entire information exchange process. This will help us understand the detailed impacts of changing the delivery method and how it affects the efficiency of Sound Transit's asset management plan.

Summary & Anticipated Results

The University of Washington's CM department was approached by Sound Transit's AP&P to investigate the value of using better information exchange practices on their projects so that this value could be demonstrated to their executive branch and pertinent policies could be put in place. The data collected through the use of literature review, case study, PSAL review sessions and the staff interviews was anticipated to create a clearer picture of the current state of affairs as well as the industry standard. This would help the UW research team to bridge the gap between the two and thus, achieve the research objectives and answer the central research question.

Chapter 4: Data Requirements and Findings

Introduction

This chapter deals with the information obtained through the PSAL review sessions, interview process and in-depth study of the internal ST Phasegate processes and documents that was explained in the previous chapter. The Project Specific Asset List was a key component of the research since it defines the asset data that will be collected from the Contractor and fed into the EAMS system for the purposes of lifecycle planning, maintenance scheduling, operations management, etc. Since it is important to identify the factors necessitating the use of the PSAL, this chapter will begin with an overview of the inefficiencies in these workflows that were to be resolved. This is followed by a detailed explanation of the process and results of the PSAL review sessions.

Costs of Current Information Practices to Agency

The interviews revealed a number of costs to the agency related to existing information practices that were echoed by the literature review and our interactions with Sound Transit during the PSAL review sessions. These included the indirect cost of inefficient business processes, productivity losses and training costs, redundant efforts for data re-entry for existing structures along with the validation and translation of this data and limitations stemming from limited interoperability within the organisation. A relevant example of these limiting factors was observed when members of the Asset Planning and Programming team would attempt to record asset data for existing facilities. The process would involve going through the as-built information submitted by the contractor and verifying each piece by “getting eyes on it” out in the field. The discrepancies observed in the field would then be brought back to the office and imported into the as-builts. This would have to be done while navigating the numerous updated file format requirements, software and naming conventions. Thus, this process serves as a good example of the costs that the agency was encountering and highlights the need for a standard process.

PSAL Review Sessions

These weekly meetings were held at the Centre for Education and Research in Construction (CERC) at Sandpoint in Seattle, WA. Over the course of 2 months, the PSAL was radically modified from the initial version that was proposed by Asset Planning and Programming.

Figure 9: Initial version of PSAL as proposed by AP&P

As can be seen, the initial version of the PSAL was extremely data-rich but cumbersome. This was one of the reasons behind the Contractor and Consultants' complaints about the PSAL being an additional amount of work for which they were not being compensated appropriately. Since the focus on asset data and information exchange has increased only recently, there has not been an accurate estimate of how the General Contractor or Consultant is to be compensated for these services. Also, there are few players involved in what is still considered a niche market. Given the absence of a unit rate derived from market forces, Owners like Sound Transit and the University of Washington typically have to pay unreasonably high sums through change orders in order to obtain the asset data they need to efficiently operate and manage facilities.

Since this drives up the unit price of collecting the asset data, the PSAL review sessions were used to estimate the value of each portion of the PSAL to Sound Transit. The potential benefits to the organisation in the form of return on investment were estimated and weighed against the cost at which the data was being collected. Since these sessions were attended by DECM, AP&P and Operations personnel, it was a useful exercise to gain an overall perspective of the problem. The problems tackled at these sessions ranged in size and impact, from the use of a master set of abbreviations that will be recognized across departments to eliminating entire data sets from the PSAL. Action items were catalogued and allocated to the responsible party at the end of each meeting to be followed up at the beginning of the next meeting.

In its initial form (see Figure 10 below), the PSAL consisted of a single asset list which would be classified on the basis of various systems such as an internal Sound Transit Finance department FIT number, the AP&P Asset designation number, Uniformat, Term-Lite, CSI 2014, Omniclass and an independently determined Asset Rank. The Designer would be responsible for filling out the Uniformat, Term Lite, CSI and Omniclass columns, which was determined to be extremely tedious and time consuming. It was also decided that AP&P would not need so many different and unrelated classification systems as it would only complicate the process and potentially increase the errors in the asset list.

ASSET NUMBER		ASSET TAXONOMY							FACILITIES ASSET DESCRIPTION		CLASSIFICATIONS SYSTEMS							
Light Rail / Sounder or Facility FIT#	AP&P Asset Designation:	Instance	Existing FIT# (360 Asset List)	Location	Asset Class	Asset Category	Asset Component	Instance	Asset Class	Asset Category	Asset Component	UNIFORMAT		TERM-LITE		CSI (2014)	Omniclass	
												Type	Instance	Buildings	Stations			Type
510	BBBBB	15	07	00			XXX	HVAC	PMP									
512	BBBBB	15	08	00			XXX	HVAC	ACU									
514	BBBBB	15	09	00			XXX	HVAC	ACU:L									
516	BBBBB	15	10	00			XXX	HVAC	SPLT								23 81 26	22-23 81 00
518	BBBBB	15	11	00			XXX	HVAC	CUH								23 55 33	22-23 55 33
520	BBBBB	15	12	00			XXX	HVAC	EHH									
522	BBBBB	15	13	00			XXX	HVAC	ML									
524	BBBBB	15	14	00			XXX	HVAC	LVR									

Figure 10: Classification Systems in the initial PSAL

Therefore, it was necessary to identify a single classification system that could be used to resolve and unite the various departments. For this purpose, a standard list of abbreviations would be required to be drawn up. This was done by combining the two separate lists used by DECM and AP&P since there was significant overlap between the two. This list can be found in the Appendices.

The next problem to be addressed involved the applicability of all the data sets to all the assets or all the columns to all the rows. For example, a piece of equipment such as an Air Handling Unit would not have a length, breadth and height under the Quantity Data Set but a concrete curb would not have a make, model and serial number. In order to resolve this issue, it was decided to split the single asset list into three major sections to accommodate for differing requirements:

- Equipment elements
- Site/Civil elements
- Structural elements

Thus, the data sets that did not apply to certain elements could be eliminated and would save the Designer and Contractor time and resources required to populate these redundant fields. Additionally, it helped to apply different levels of detail to different assets as applicable. For instance, the GIS location data set would be radically different for a piece of equipment vs a part of the structure or site. The level of detail that would be required to locate an air handling unit would be at the room level whereas the location of the concrete curb could be maintained at the facility level.

Project Specific Asset List & EAMS

The Enterprise Asset Management System or EAMS was being tested and implemented at Sound Transit during the course of our research project. This period of transition was a rare and important opportunity for ST to take stock of their asset management policies given the significant number of extension projects that were being flagged off or in various phases of design and construction at the time. EAMS is an advanced facilities management software that is used for “complete asset life-cycle management, including budgeting, acquisition, capital improvement & warranty, purchasing and parts inventory management.” (AssetWorks 2015) Its connection to the PSAL is fundamental in that the information it uses to populate the system will be drawn from the PSAL. Therefore, the Contractor will have to

provide warranty information so that Sound Transit can schedule preventive maintenance or warranty expiry alerts in EAM.

Facilities Asset Description

	A	B	C	D	E	F
1	FACILITIES ASSET DESCRIPTION		APP ASSET ID			Asset Name
2	ITEM 1:		ITEM 2:			ITEM 3:
3	Asset Class		Asset Category			
4	Sound Transit & Designer		Sound Transit			Sound Transit & Designer
5		General	XXX	GENRL	01	GENRL - Assembly (Edit as required):
6	HVAC SYSTEM	HVAC: Air Handling Unit	XXX	AHU	01	Air Handling Unit
7	HVAC SYSTEM	HVAC: Air Handling Unit	XXX	AHU	02	Air Handling Unit
8	HVAC SYSTEM	HVAC: Boilers	XXX	BLR	01	Boiler
9	HVAC SYSTEM	HVAC: Boilers	XXX	BLR	02	Boiler
10	HVAC SYSTEM	HVAC: Chillers	XXX	CHL	01	Chiller
11	HVAC SYSTEM	HVAC: Chillers	XXX	CHL	02	Chiller
12	HVAC SYSTEM	HVAC: Fan - Exhaust	XXX	EFN	01	Exhaust Fan

Table 3: Asset Classification

Column 1 describes the overarching Asset Class that the particular asset falls under. Examples include HVAC system, Lighting, Fire Detection, etc. The primary reason for the inclusion of this dataset in the PSAL is the need for AP&P and the financial wing of Sound Transit (FIT) to classify assets using a similar system. This helps to avoid a clash amongst departments and sets up a proprietary unified system in order to exchange information in a more structured and efficient process.

Asset ID

As seen during the initial PSAL review sessions, there were a number of different classification systems that would create confusion among the Designer, Contractor and various departments of Sound Transit. Therefore, this Asset ID was created using DECM's location codes and the master abbreviations list that was created earlier on in the project. An example of an AP&P Asset ID is XXX-GENRL-01. In this case, XXX signifies the location of the facility per DECM's codes, GENRL signifies the asset identifier abbreviation and 01 is the

instance number for the particular asset. This was agreed upon by all the parties present at the review sessions. All the three sections of the PSAL remain the same up to this point.

Asset Description

Given the diverse nature of assets and their maintenance needs, the PSAL was split into Equipment Elements, Structural Elements and Site/Civil Elements. It was difficult to use the same data sets to describe assets such as a Boiler and an Asphalt Access Roadway. The Asset Description section was hence going to be different for the three sections.

Equipment

For Equipment Elements, the first category would be the Asset Name. Given the long list of abbreviations, the Asset Name dataset would help to avoid errors and reinforce the standard naming of assets across departments. Next, the Equipment type would be listed to classify between say, two different power rated air handling units. This would be followed by the name of the Manufacturer which will serve as a separate classification while satisfying the needs identified during the interview process. Maintenance personnel often need detailed manufacturer information in order to contact them for numerous reasons such as warranty, repair or spare parts material. This dataset is expanded further into the PSAL.

The Model number and Serial number are the next key asset data that is required by the PSAL. Make, model and serial number have been staples of any asset or inventory management system since they are the first identifiers for the particular piece of equipment. This helps to avoid any ambiguity about specific manufacturer's recommendations, warranty information and the maintenance procedures to be carried out on the equipment. The Quantity data set is not applicable to a number of assets since the instance number in the Asset ID addresses the number of equipment in a particular facility. However, if it is an exactly similar kind of equipment being installed in the same location in a plural quantity, it is not necessary to create a new instance each time. This is where the Quantity column can be used in conjunction with the unit of measure.

Structural

Structural elements cannot be described accurately in terms of make, model or serial number. Thus, the element is first broken out in an Asset Assembly data set. This provides information about the exact construction means and methods used to build the element. To quote the Asset Programming Manager’s interview, “We want to know what is inside the element at a high level. We need to know what is in our structures since General Contractors rarely share their estimates with us. This information helps us improve our life cycle cost planning.” They need this information in order to create accurate work orders for upkeep or replacement of worn out elements. An example of an Asset Assembly is as follows: A parking garage foundation can be broken down into concrete for piling, concrete for grade beams, concrete for footings, Protection Mat and Drainage Mat Waterproofing and concrete for foundation walls. In terms of level of detail for location, this section focuses on a high level view of the facility or area that the asset is located in.

	A	B	C	D	E	F	G
1	FACILITIES ASSET DESCRIPTION			APP ASSET ID		ASSET ASSEMBLY	ASSET DESCRIPTION
2	ITEM 1		ITEM 2			ITEM 3	ITEM 4
3	Asset Class		Asset Category				Manufacturer
4	PARKING GARAGE	Parking Garage: Foundation - Concrete	XXX	PRKGRG:FDTN	01	Concrete - Piling Concrete - Grade Beams Concrete - Footings Protection Mat Drainage Mat Waterproofing	
5	PARKING GARAGE	Parking Garage: Foundation - Concrete	XXX	PRKGRG:FDTN	2	Concrete - Piling Concrete - Grade Beams Concrete - Footings Protection Mat Drainage Mat Waterproofing Concrete - Foundation Walls	
6	PARKING GARAGE	Parking Garage: Columns - Concrete	XXX	PRKGRG:COL	01	Concrete Reinforcing Finish	
		Parking Garage: Beams -					

Table 4: Structural elements in the PSAL

Site/Civil

A similar situation arises when the Site/Civil portion of Sound Transit’s assets is examined. In addition to the Asset Assembly broken out in the Structure portion, this section also includes information about the Materials which the asset consists of along with the dimensions, area and volume of the asset. This is particularly applicable when the asset in

question is an asphalt roadway or a chain link fence. Having the data available at a glance will save Maintenance time that would otherwise be spent looking through record drawings and specifications. The Location of these assets is mapped on a facility level of detail.

Asset Value and Warranty Information

This section of the PSAL is important to many of Sound Transit's departments. According to multiple interviewees, this information is indispensable to lifecycle planning. It is valuable to the maintenance management process because the Preventive Maintenance schedule is drawn up based on the manufacturer's recommendations regarding repair and replacement timing. The initial asset value coupled with the life of the asset will aid lifecycle planning so that the depreciating value can be tracked to a point where replacing it becomes more economical than repairing it. This dataset applies to the Equipment, Structure and Site/Civil sections of the PSAL.

Manufacturer Information

This dataset consists of means to contact the manufacturer of the equipment or material vendor and includes:

- Manufacturer/Vendor's website
- Manufacturer/Vendor's representative on the project
- Representative's email and phone contact information

While this dataset was admitted to being rarely used in practice during the interviews, it is essential information to have since "Facilities managers need all the information they can get. Eventually, each piece becomes important to the process." The same principle applies to the Contractor's contact information. GCs can be consulted for repair and rework as long as the asset is covered under the warranty.

Operations and Maintenance Information

O&M Manuals are the backbone of Maintenance Management across the construction industry. Together with As-built drawings and PM schedules, the easy availability of these manuals will save the Sound Transit Maintenance department 5-10% of the time that they usually spend looking for this information. This information is expected to be part of the Contractor's submittal at the end of the project. It can be entered in the PSAL in the form of a file name which can be located in the submittal.

Miscellaneous Information

In addition to this information, there are three more datasets that need to be collected from the Contractor in order to round off maintenance management best practices. The Product Specifications, Product Data, and in the equipment section, the Spare Parts List and the Special Tools list all form small yet important parts of the system. Interview feedback lines up with this and while Sound Transit does not maintain a storage space beyond a warehouse, the EAMS can warn of upcoming PM work orders so that the long lead parts or tools can be ordered well in advance. This will enable crews to close more work order tickets at a much faster rate.

Chapter 5: Data Specification and Analysis

Introduction

The PSAL review sessions were accompanied by a deep dive into the information exchange practices of ST's peer transit agencies. A number of agencies such as Bay Area Rapid Transit in San Francisco, Metropolitan Atlanta Rapid Transit Authority in Atlanta, Metropolitan Transit Authority in New York were contacted to gain a deeper understanding of their information exchange practices.

At the same time, we turned to other public agencies who had taken the lead on making information exchange a priority. This focused mainly on the US Army Corps of Engineers who have consistently been a marker of standard practice in this field. Their Roadmap for Life-Cycle Building Information Modeling was a rich source of information for establishing strategic long-term goals at Sound Transit. During the course of the research project, the AP&P team even met with some of the USACE's information exchange specialists and the UW research team to discuss ways in which the two agencies could collaborate in the future while helping Sound Transit bridge the gap in terms of information exchange standards and practices.

The FIM Manual (George Washington University 2014) was also studied to layout the structure of the data specification. It was decided that the specification would be broken into three major sections that follow the major phases of a construction project, namely design, construction and turnover. The phases would relate to the Phase Gates that are used by Sound Transit to give its internal design reviews, construction and operation cycle a checkpoint system. Thus, the following section will analyse the Phase Gate structure, study the process and establish responsibilities at each checkpoint. This will in turn lead to various topics that the data specification will address. The data specification itself can be found in the Appendices.

Phase Gate Analysis

The analysis of the collected data must begin with examining the stakeholders that are specific to the Sound Transit case and the role of each player in the information exchange process. While a significant portion of ST's design work used to be carried out in-house by the DECM department (Design, Engineering and Construction Management), the trend is changing with the type of delivery methods being used. Thus, DECM in conjunction with the Designer or Design-Builder is one of the key members starting the information exchange process. Together, they will be in charge of developing the initial PSAL based on historic project data and conceptual design requirements. The next major participant is the Contractor that is awarded the job. Depending on the delivery method, the Contractor may be involved in the project and the development of the PSAL at an earlier phase of the project. The final stakeholders in the information exchange process are ST's Operations and Asset Planning and Programming departments.

The Sound Transit Phasegate process consists of 8 different stages of transition in the IE process which is explained in detail in a technical report published by the UW research team (Center for Education and Research in Construction 2015).

Phase Gate 1: Project Identification

Phase Gate 2: Alternatives Identification

Phase Gate 3: Conceptual Engineering (5-10%)

Phase Gate 4: Preliminary Engineering (30%)

Phase Gate 5: Final Design @ 60%

Phase Gate 5: Final Design @ 90%

Phase Gate 5: Final Design @ 100%

Phase Gate 6: Proceed to Construction

Phase Gate 6: APP and Facilities Review

Phase Gate 7: Transition to Operations

Phase Gate 8: Final Completion and Closeout

Phase Gate 1 - Phase Gate 3: Project ID, Alternative ID and Conceptual Engineering: This is the initial phase of the project where the first draft for the Project Specific Asset List is drawn up.

Phase Gate 4: Preliminary Engineering to 30% Design: The iterative design process is begun with the help of various local consultants and their in-house Design, Engineering and Construction Management (DECM) department.

Phase Gate 5 – Phase Gate 8: The Design process is completed in these stages and the PSAL is complete. It is reviewed by all the concerned ST parties, passed on to the Contractor and finally, combined with as-built information and handed over to Operations and FM.

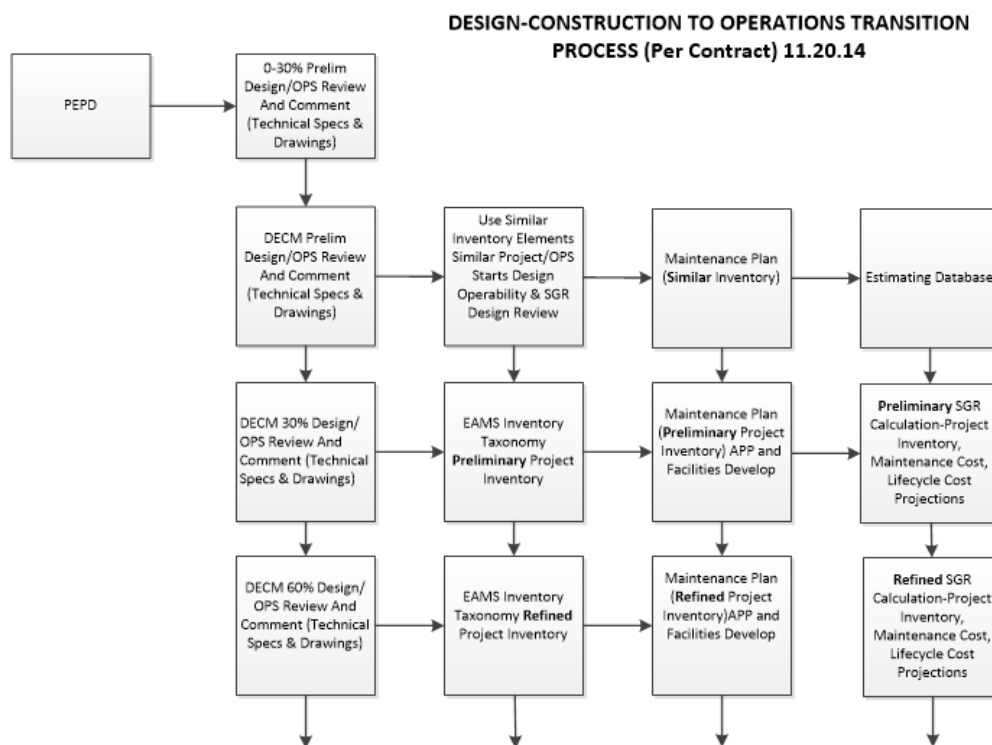


Figure 11: A snapshot of the Sound Transit Phasegate Process (Sound Transit 2014)

Data Specification

Design

This stage covers Phases 1 through 5 and could be considered as the most important stage for the creation of the PSAL. The Design package must include the following documents in order to achieve greater cohesion among the various parties.

- Project-Specific BIM plan: Outline provided for project teams to define how collaboration will support the goals of the various stakeholders on this particular project.
- BIM Procedures Manual: Step-by-step implementation plan for each BIM goal through the use of the BIM Execution Planning Guide and evaluation of stakeholder goals.
- Contract: Definition of terms, rules for ownership and transmitting of information privy to project participants, specifications and overall deliverables on the project must be laid out.
- Definition of terms, ownership of model and information, overall deliverables.
- RFP: General Parameters and eligibility requirements for bidding purposes.

BIM Planning

This leads to the first clause in the specification that talks about the creation of a BIM Execution Plan in order to achieve the higher degree of collaboration that is needed for efficient information exchange. It also speaks to the appointment of a BIM Coordinator from the Owner's side who may oversee BIM requirements on multiple projects and a BIM manager on the Contractor's side specific to each project. The importance of having such a role will only increase as projects, and thus, models grow bigger and more difficult to manage.

The creation of the plan will follow the same process regardless of the type of project or delivery method. The first step is establishing goals for each of the stakeholders on the project. The Designer, Owner and Contractor will then meet and discuss the goals to find areas where BIM will bring greater value and strongly support these goals. These BIM uses can then be used to create implementable strategies that are woven into the project cycle.

The processes must result in certain BIM deliverables which will be defined in the form of information exchanges. Finally, this must be supported and enforced through adequate contract language, communication procedures, access to technology and quality control (Penn State University 2011).

Version Control

Since there are so many different stakeholders on a project at the various project levels such as the prime contractor, subcontractors and even sub-sub-contractors, it is important to define version control guidelines at the outset. This will ensure that there are no losses in interoperability and help smoothen the flow of information without any delays due to incompatible software and file formats.

Level of Detail

A major point of conflict among Sound Transit, the Designer and Contractor has been the level of detail to which the asset data should be defined. A number of UW-ST collaboration meetings focused on this issue and came to the conclusion that there should be a balance between AP&P's requirements and the Contractor's abilities. Without this compromise, the Contractor will continue to struggle to meet the compliance standards expected by Sound Transit and the goals of the information exchange process will not be met.

<i>Model Element Table</i>				
Building System	Level of Development			
	SD	DD	CD	Turnover
Substructure	0	300	300	400
Structure	100	300	300	400
Enclosure				
Exterior Walls	100	300	300	400
Exterior Windows	100	200	300	400
Exterior Doors	100	300	300	400
Roof Coverings	100	200	300	400
Roof Openings	100	300	300	400
Interior				
Interior Partitions	100	300	300	400
Interior Doors	100	300	300	400
Interior Specialties	0	200	300	400
Stair Construction	100	300	300	400
Wall Finishes	0	200	200	300
Ceiling Finishes	0	200	200	300
Windows	100	200	300	400
Floor/Ceiling Construction	100	300	300	400
Conveying Systems	100	200	300	400
Plumbing	100	200	300	400
HVAC	100	200	300	400
Fire Protection	100	200	300	400
Electrical	100	200	300	400
Equipment and Furnishings				
Fixed Equipment	100	200	300	400
Moveable Furnishings	100	100	200	300
Special Equipment	100	200	300	400
Fixed Furnishings	100	200	300	400
Special Construction	100	200	300	400
Sitework	0	100	100	200
Site Improvements				
Roadways	100	200	200	300
Parking	100	200	200	300
Pavement	100	200	200	300
Landscaping	0	100	100	200

Table 5: Model Element Table for Level of Detail (George Washington University 2014)

Naming Conventions

As described in the previous chapter, it was observed that despite the large number of departments in Sound Transit, there was a separate naming convention used by each of these departments. It is important to unify the conventions to avoid the interoperability issues mentioned above. After numerous PSAL review sessions, a conclusion was reached regarding the Asset ID naming convention. However, the debate has not been resolved when it comes to file naming conventions for Operation and Maintenance Manuals, As-Built Drawings, PM Schedules, Specifications, etc. The discussion will be followed among the topics recommended for further research. At the moment, we have a placeholder in the specification that uses the recommendations of the Asset Management Plan draft (Sound Transit 2014).

Construction

The next project phase that the specification will address is the Construction phase. Here, the focus is mainly on the submittals that will be provided by the Contractor to the Owner through the course of the project and the formats for the same. The information exchange process is stipulated and responsibilities are assigned. Finally, the development of accurate as-built drawings and records is specified.

Submittals

The next project phase that the specification will address is the Construction phase. Here, the procedures for the exchange of submittals throughout the project will be outlined. These procedures may already have been designed during the preparation of the BIM execution plan. As we have seen during the literature review, the processes used to create information and disseminate it through the organisation are more important than the tools used. The tools will keep on changing as time progresses but the processes cannot be as volatile given the difficulty of constantly changing procedures in such a large organisation.

Information Exchange

This section will focus on stipulating the mandatory datasets that the Contractor is expected to fill in the PSAL. This may be different for different projects given the nature of the project, the goals of the agency and the asset being tracked. Additionally, the ST BIM Coordinator is also tasked with matching the PSAL assets with the other classification system used by the ST Finance department. Since this is an internal process, the dataset has been removed from the PSAL template so that it does not confuse the Contractor.

Update and Upkeep of as-builts

Since as-built information is extremely important to Maintenance, Operations and AP&P, it is imperative to track this particular set of documents with greater care. Inaccuracies and incomplete information in these as-builts will render the whole IE process obsolete since Facility Managers will have to go back to their record rooms full of hard copies.

Turnover

The last stage of the project before the facility is commissioned and transferred to Operations is the Project Closeout and Turnover stage. All the loose ends must be tied up in terms of pending submittals or other closeout documents.

Closeout Documents

This phase will begin with a closeout meeting which will allow all the stakeholders to check in on the status of the project as well as the documentation required by the Owner. The submittals and as-builts to be transferred to the Owner will have to be in a uniform format to be decided by the BIM Coordinator. This is in addition to prescribing naming conventions for these documents as per the decisions taken in the Design phase. Sound Transit's major role in this stage will be to audit the submitted materials to verify compliance to all required standards. Finally, it falls upon the ST team to collate the data and transfer it from the Project Specific Asset List to the overall EAMS system.

O&M Manuals

As we have already seen through literature review, case study and staff interviews, Operation and Maintenance Manuals are critical to asset management and maintenance. Therefore, this part of the closeout process will have to be closely monitored. The timing for submission of the manuals must be specified so that Sound Transit and/or the Designer has enough time to verify accuracy and compliance. The formats that the manuals will be submitted in are equally important. Per the interview with the Facilities Manager, a lot of time is currently spent trawling through “80 page PDFs” looking for one piece of information. A searchable PDF format will shorten the process. Finally, a consistent naming convention must be maintained throughout Design to Construction and through Turnover.

Chapter 6: Conclusions and Recommendations

The research project aimed to accomplish a number of objectives pertaining to improving information exchange practices at Sound Transit in the Puget Sound Region specifically and public transit agencies in general. The goals outlined in section 1.4 included studying the internal processes of asset data exchange among the various parties at Sound Transit, developing a data specification that would update their practices to the industry standard. A compliance section would be built into this specification to error-proof the collected asset data to avoid rework and project delays and assist in the transition to the new EAMS asset management system. The final goal was to validate the specification developed on the Lynnwood extension of ST's Light Rail Network and receive feedback from the Agency on the effectiveness of the specification. This chapter summarises the research, highlights the contributions to the field and explains some of the obstacles to the process. It also includes recommendations for further research. Since this thesis covers only a section of the work done as part of the larger research project, it is important to view it in this context.

Summary of Findings

Through the numerous research techniques detailed in chapter 1, a number of interesting discoveries were made. The literature review revealed the limited academic research carried out in the field of information exchange at public transit agencies and the tangible benefits of strengthening this infrastructure. This limited the scope and reach of the research team while helping to identify an additional field where further research is urgently required.

The PSAL review sessions and the resulting intimate interaction with AP&P further highlighted the need to identify concrete value addition of asset data to growing public agencies. These sessions also revealed the importance of the various pieces of asset data that are exchanged between the numerous parties. The transformation of the PSAL from a single asset list into a structured 3-part collection of valuable data was a gradual process that was a result of frequent close collaboration between different project participants built around the expertise of Dr. Dossick.

The research also uses the structure of the FIM manual (George Washington University 2014) along with a combination of data sources such as existing literature, peer agency practices and other research techniques to construct a data specification that caters to the very specific needs of a public transit agency. Recommendations for further research in this regard are included in the following sections.

Finally, the case study method used in this thesis reveals the importance of interoperability to gain the maximum value from the design, construction and operation of a facility. Several examples of this phenomenon were observed during the case study phase of the research. The resolution of an inter-departmental location code system into a master list that combined and collated how various departments described a location will serve many different purposes at Sound Transit. This was also observed for asset abbreviations. Seemingly minor items such as file naming conventions which were the subject of long and tedious inter-departmental conversations further highlighted the value of interoperability in the long term.

Contributions

The contributions of this thesis to the general pool of knowledge in the field of information exchange can be seen in relation to the literature that was examined in Chapter 2. With regards to interoperability and information exchange, the data specification developed here provides a number of means to achieve higher interoperability through matching naming conventions and levels of detail across departments. As the literature review mentions, it is far more critical to install procedures that facilitate the flow of information as compared to the technology used for this purpose, and that is what this thesis strives to achieve (Love, et al. 2013).

It also studies the various applications of BIM for FM and adapts them to serve public agencies like Sound Transit. The development of a BIM execution plan serves to bring the project stakeholders closer from the beginning of a project and improves cohesion throughout while setting up clear goals and strategies to achieve them. The research uses the particular characteristics and problems faced by these agencies to come up with tailor made solutions. For example, the problem of differing levels of detail for asset data required

by departments within the same parent organisation was solved by breaking up the PSAL into three separate categories. This solution was achieved through a combination of literature review, staff interviews and conversations with AP&P during the PSAL review sessions, a combination that offers the field new ways to tackle such issues through collaboration. This combination was enabled by the kind of collaboration which is highlighted and necessitated by a BIM execution plan.

The thesis also studies asset data collection and the challenges faced in this unique scenario where different stakeholders have different capabilities. The thesis develops a tool in the form of a PSAL which levels the playing field and offers transit agencies an opportunity to access the required information from parties across the board. This is done by calling for similar asset data requirements from all the different parties, which includes designers, prime contractors, specialty subcontractors and even sub-subcontractors. Having prior experience in this field will no longer serve as a major advantage when bidding for projects that have detailed information exchange requirements.

Benefits to the Agency

Along with contributions to the pool of knowledge, there will also be a number of benefits to Sound Transit and its various departments. For Asset Planning and Programming, a detailed inventory list will enable more accurate Life Cycle Cost planning, improved Conditions Assessment capabilities, the collection of only the most useful and necessary information while minimalising redundancies and waste of Agency resources. This will also aid the improvement of learning cycles within the Agency and provide information in a timely fashion for operations and maintenance planning. The thesis will allow transit agencies to build an asset database that will translate into quick and efficient access to data instead of facility managers having to “scroll through 200 page long PDFs,” according to one interviewee. Lastly, an early and updated inventory offers the ability to predict resource needs for new projects of which there are many given the current expansion boom.

On the maintenance side, startup, shutdown and emergency tasks can be streamlined early since boilerplate PM schedules can be developed at a much earlier stage in the project using the early inventory data. The value of this data is higher to transit agencies since their

projects typically take several years to complete. This will boost efficiency by enabling better maintenance resource levelling and avoiding waste of Agency resources.

Estimators will also benefit from the use of this specification. Having access to early inventory data and detailed lifecycle information such as warranties and asset value will help them build a richer database to prepare accurate estimates. Since the asset list will be updated at various phasegates, estimators will be able to use up to date inventory data for their work. This adds greater value to their work since public agencies in particular are closely scrutinized for the efficiency of their spending.

The Finance department will be able to profit from this data as well. Accurate financial cost forecasting will be a direct result of having access to such data. Increased collaboration with AP&P's Lifecycle plans will help them develop high level forecasts for upcoming projects. Given the improved maintenance scheduling, they will have to deal with reduced costs of equipment failure and repairs through timely response to work orders. Improved budgeting capabilities as per warranty and maintenance schedules will ensure that they do not have to scramble for emergency funding and possible misallocation of government resources.

Beneficiary	Benefit	PSAL contribution	Supporting sources of information
AP&P	Accurate Life Cycle Cost planning	Initial Asset Value, Length of Warranties, Expected Life	Literature review ¹ , interviews, PSAL review sessions
	Improved Conditions Assessment capabilities	Warranty information, In-service Date	Staff interviews, Case study research
	Consolidated access to useful information	Entire PSAL	Staff interviews, literature review ²
	Predict resource needs for new projects	Asset Class and Category	PSAL review sessions, meetings with AP&P
Maintenance	Streamlining of startup, shutdown and emergency tasks early	Length of warranties, Estimated Life	Meetings with Maintenance, PSAL Review sessions
	Early development of Boilerplate PM schedules	PM schedules, O&M Manuals	Meetings with Maintenance, PSAL Review sessions, Case study research

¹ (Fallon and Palmer 2006) (Thein 2011)

² (Love, et al. 2013) (Chapman 2005)

	Better maintenance resource levelling	PM schedules	Meetings with Maintenance, Staff Interviews
Estimating	Access to richer project data will enhance quality of estimates	Asset class, Asset category	Staff Interviews, Meetings with AP&P, DECM
	Early and frequent updates to inventory resulting in improved estimating database	Frequent PSAL submittals during early Phasegates	Case study research, Meetings with AP&P, DECM, PSAL Review sessions
Finance	Accurate financial facility cost forecasting	Initial Asset Value, Level of Detail, Warranties, Expected Life	Literature Review ³ , Meetings with AP&P, Case study research
	Reduced costs of equipment failure and repairs	PM Schedules, O&M Manuals, Product Data	Meetings with Maintenance, Case study research
	Improved budgeting capabilities	Warranty information	PSAL Review Sessions, Meetings with Sound Transit, Case study research

Table 7: Benefits of data specification

Validation & Feedback

The specification developed through this research project is the result of close collaboration with Sound Transit’s AP&P and DECM staff. The process used inputs from the existing literature, staff interviews, case study research and the PSAL review sessions. The PSAL review sessions were particularly critical for validating the utility of the PSAL specification. At these sessions, a new version of the PSAL and thus, the specification was presented to the agency which was modified according to the feedback received in prior meetings. This resulted in a vetting process that occurred at frequent intervals to get the most useful asset data from project stakeholders. This was accompanied by periodic high level review meetings with AP&P to receive feedback regarding the project.

³ (Akcamete, et al. 2011) (Marsters 2011)

The culmination of the research project was a meeting involving various Sound Transit department heads and representatives. The specification was presented to the audience and their notes were recorded. However, the range of people and departments in the room meant that they had differing levels of experience with information exchange, BIM and asset data. This resulted in a less focused discussion that was nevertheless invaluable in terms of feedback (e.g. we learned that it would be challenging to accommodate the needs of multiple departments through one specification. The department heads realized that different units in the organization used different naming conventions and some agency wide standards are needed). Thus, while the specification could not be implemented on a project immediately, it is the result of a detailed internal validation process by the staff that will be using it. This research was the beginning of a large change process within Sound Transit.

Research Limitations

There were a number of limitations to the research process, chief of which was the lack of feedback from the agency regarding the effectiveness of the specification. Due to a number of unforeseeable circumstances, this specification could not be implemented on the Lynnwood extension project as planned in the early phases of the research. Thus, it became difficult to observe its performance in the field and ascertain its effectiveness in the real world.

The number of interviews that could be scheduled in the timeframe of the research project owing to scheduling constraints and availability of participants was another limitation. A greater amount of information could be obtained if more interviewees from different departments were available. Desired participants were from departments such as DECM, Executive, AP&P and FIT-Information Technology.

The final major hurdle was the limited information available on the tangible benefits of improved asset management practices that could be applied to this specific example. As mentioned before, this information could have garnered more support at Sound Transit and provided access to more resources at the organisation.

Further Research

The next steps in the course of this work would include the use of the specification developed on a real project and collection of feedback from the Owner agency, Designer and Contractor. The effectiveness of creating roles such as BIM Coordinator and BIM Manager should also be studied to examine if there are already titles at these agencies that are capable of fulfilling the duties of these positions.

Appendices

Appendix A – Interview Tool

Introduction of the Interview

Purposes: The goal of this study will be to create a set of best practices to assist ST with **information exchange** for new facilities and existing properties. Additionally, the impact of **delivery methods** will need to be understood to apply the necessary modifications to the best practices. The questions will thus be focused around these two areas and your interaction with them.

2. Detailed interview questions

Introduction

1. Please briefly describe your work here at ST.
2. Briefly describe your work history - particularly your experience with asset management systems.

Data and Workflow

3. We are evaluating 6 different operational work processes.
 - a) Condition Assessment,
 - b) Lifecycle scope, schedule and cost planning for existing and new assets,
 - c) Design Review,
 - d) EAMS System implementation with new and existing project data,
 - e) Inventory documentation from design and construction, including tracking and management,
 - f) Maintenance Plan preparation and delivery to MMIS Administration.

For the processes that you are involved with,

- a. What asset data is important for this work?
- b. Where do you find asset data for this work?
- c. How do you manage your data currently?

PSAL Review

We now want to discuss the PSAL specifically and talk about what data is important for your work.

- 4. Are you familiar with the PSAL created by Dan Burton?
 - If no, briefly introduce Taxonomy
 - If yes, does your job involve the creation or any interaction of this list? How?
- 5. Based on the asset activities you identified in your work scope before, which data from the PSAL would help you in your work (a-f)?

FACILITIES ASSET DESCR ITEM 1: Asset Class Asset Category	APP ASSET ID ITEM 2:	ASSET NAME ITEM 3:	EQUIPMENT					LOCATION		VALUE ITEM 12: Initial Asset Value in US Dollars	DATES / WARREN		
			ITEM 4: Equipment Type	ITEM 5: Manufacturer	ITEM 6: Model #	ITEM 7: Serial #	ITEM 8: Quantity	ITEM 9: Unit of Measure	ITEMS 10: Room/Area		ITEMS 11: Area Served	ITEM 13: Date of Manufacture	ITEM 14: Installation Date
Sound Transit & Designer	Sound Transit	Sound Transit & Designer	Contractor					Contractor		Contr.	Contract		
HYAC SYSTEM													
no data this cell	no data this cell	no data this cell											
HYAC: Air Handling Uni	no data this cell	AHU - Schedule (Edit as required):											
XXXX- AHU 01		Air Handling Unit					ndtc	each					ndtc
XXXX- AHU 02		Air Handling Unit					ndtc	each					ndtc
HYAC: Boilers	no data this cell	BLR - Schedule (Edit as required):											
XXXX- BLR 01		Boiler					ndtc	each					ndtc
XXXX- BLR 02		Boiler					ndtc	each					ndtc
HYAC: Chillers	no data this cell	CHLR - Schedule (Edit as required):											
XXXX- CHL 01		Chiller					ndtc	each					ndtc
XXXX- CHL 02		Chiller					ndtc	each					ndtc
HYAC: Fan - Exhaust	no data this cell	EFN - Schedule (Edit as required):											
XXXX- EFN 01		Exhaust Fan					ndtc	each					ndtc
XXXX- EFN 02		Exhaust Fan					ndtc	each					ndtc

Appendix B – Data Specification

To better understand this process, this specification has been divided into four categories that cover the entire project delivery process:

- 1 Project Development
- 2 Design
- 3 Construction
- 4 Turnover

Each stage of this process will be analysed and pertinent instructions will be included in the specification. We will begin with the Design stage.

2.1.1.1 The Designer shall take the lead in preparing a BIM execution plan at the Schematic Development stage in consultation with the BIM coordinator appointed by Sound Transit and the BIM manager from the Contractor's side. The duties and responsibilities of the BIM coordinator are explained below in Appendix a.

2.1.1.2 The BIM execution plan must outline the Project Goals specific to each project. The Designer must also list the BIM uses intended on the project, describe the value addition to the project and develop a model exchange plan per Appendix a. A sample BIM plan can be found in Appendix b. The availability of resources and qualified personnel at Sound Transit must be taken into account when developing the plan.

2.1.1.3 The BIM coordinator must ensure that the Designer must perform regular updates to the BIM plan at the following stages: Design Development, Construction Documents and Hiring of Contractor.

2.1.2.1 The Designer will lead the team in developing the Model Progression Schedule and assign the LOD at each major design deliverable. The Model Element Table (Table 1) will be reviewed and utilized during this process.

2.1.2.2 At the end of each design iteration, the Designer will transmit the model files to the BIM Coordinator to confirm LOD modelling, as well as system compatibility and file naming standards.

2.1.2.3 The LOD shall be developed corresponding to the LOD in the template of the PSAL provided by Sound Transit. Three levels of development will be required: Asset Class will define the overarching asset group, e.g. HVAC System or Lighting. Asset Category will be the next level of detail such as Air Handling Units under HVAC or Exterior Lighting. The third level of detail Asset Name will translate the type of Air Handling Unit or Exterior Lighting device being referred to.

2.1.3.1 The naming convention will be dictated by the location based system [Table 2] and Standard Asset Hierarchy developed by the Operations Department at Sound Transit. [Section 4.1.3 Asset Management Plan, 2014]

2.1.3.2 Asset number is the present-day categorization number used in the agency's current enterprise system 360Facility. Using 577003.1.0 Platform (in Exhibit 10, Asset Management Plan, 2014) as an example, the first three numbers "577" is the location code representing the location Mukilteo Station. The next three numbers "003" represents the Sound Transit Finance or "FIT" parent asset. The next number ".1" illustrates the operational parent asset record. The last number ".0" represents the operational child asset record.

The following asset grouping structure corresponds to the highest level of Sound Transit's asset hierarchy. All operational assets fall into one of these categories.

- Land/Right-of-Way
- Infrastructure
- Transit Centers/Parking Lots
- Stations/Platforms/Pedestrian Bridges/Garages
- Operations and Maintenance Facilities
- Track and Power
- Administration Facilities
- Fare Collection
- Rolling Stock
- Non-Revenue Fleet

- Sound Transit Art Program.

Facility Location IDs

REX & Sounder	
Auburn Station	585
Bellevue Transit Center	572
<i>Bellevue RSB</i>	<i>572</i>
Canyon Park Freeway Station	603
DuPont Station	579
Eastgate Freeway Station	602
Eastmont Park & Ride	571
Edmonds Station	578
Everett Station	570
Federal Way Transit Center	565
Issaquah Transit Center	601
Kent Station	584
King Street Station	581
<i>Weller Street Bridge</i>	<i>581</i>
Kirkland TC	651
Lakewood Station	597
Lynnwood Transit Center	594
Mercer Island Park & Ride	599
Mountlake Terrace Freeway Station	609
Mukilteo Station	577
Overlake Transit Center	573
<i>Overlake Platform</i>	<i>573</i>
Puyallup Station	592
Sammamish Park & Ride	560
South Everett Freeway Station	607
South Hill Park & Ride	574
South Tacoma Station	566
Sumner Station	591
Tacoma Dome Station	593
Totem Lake Freeway Station	606
Totem Lake Transit Center	604
Tukwila Station	583

Table 6: Location IDs used by Sound Transit (Sound Transit 2014)

2.1.3.3 The Designer will establish model using latest version of Autodesk Revit or according to version control directives as listed in Appendix A.

2.1.3.4 The Contractor is in charge of confirming the use of compliant software for preparation of as-builts and coordinated drawings. Naming conventions must be utilized as per ST standards.

2.1.4.1 Sound Transit will transmit to the Designer an electronic set of files containing the ‘skeleton’ or template PSAL. The Designer will be responsible for creation of the Asset List for this specific project subject to review and verification from Sound Transit’s DECM and Operations departments.

2.1.4.2 The Designer will create the PSAL utilizing the Sound Transit template and historic project data.

2.1.4.3 The following item list applies to all three sheets, Site & Civil, Structure, and Equipment & Fixtures, of the PSAL. Some items are not applicable for some categories, and

consequently are not shown in the PSAL Form. For all Equipment & Fixtures, Item 1 through Item 24 are required. For Structure and Site & /Civil sheets, fill in data as applicable or as applicable, as directed herein. For Equipment & & Fixtures, provide data as follows:

a. Item 1 – Facilities Asset Description consists of two sections, Asset Class and Category. This will be included in the PSAL template provided by Sound Transit.

b. Item 2 – Asset ID records and/or establishes the identification code for Class and Asset Category. Asset Class describes the overall group that the asset falls under, e.g. HVAC System. Asset Category is describes a sub-division of the Asset Class, e.g. Air Handling Unit. Required Asset Class and Asset Categories will be defined by Sound Transit. The inventory of the Project Specific Asset List is created jointly by Sound Transit and the Contractor.

The format of XXX-AAA-ZZ translates as:

1. XXX represents the Location.

2. AAA is the abbreviation as listed in the Combined Abbreviation List and Form 01 78 23.10-A. For example, AHU is the established abbreviation for Air Handling Unit. 2. ZZ is the Instance Number (e.g. 01, 02). For example, for Air Handling Unit #1, the Asset ID shall be LXX-AHU-01.

c. Item 3 – Asset Assembly is the description of the Asset. When the asset is a piece of equipment, this is the common name of the equipment or system. For Structures and Site & Civil, these include a description of the assembly components. The Asset Assemblies shown prior to the 30% PSAL are representative examples and shall be edited as required.

d. Item 4–8 - Asset Description, consist of the following items that will help identify the asset tangibly. Item 4 – Manufacturer or Vendor’s Name, enter the name of the equipment manufacturer specific to the equipment listed. This may not be applicable for items built on the construction site.

e. Item 5 – Model Number, for Equipment & Fixtures, enter the model number specific to the assets listed.

Item 5 – Product Name, for Site & Civil and Structures, enter the product name specific to the assets listed.

f. Item 6 – Serial Number, enter the serial number specific to the assets listed. (Equipment and Fixtures only, Item 6 has been omitted for Site/Civil and Structure)

g. Item 7 – Quantity, enter the quantity of “like kind” assets where indicated. For assets such as Air Handling Units and Elevators each instance shall be considered a distinct asset as indicated.

- h. Item 8 - Unit of Measure associated with quantity in Item 7. The Unit of Measure is typically established prior to 100% design.
- i. Item 9 – Facility / Room / Area, enter the facility, room and/or area in which the asset is located.
- j. Item 10 – Area Served, enter the room and/or area the equipment serves. (Equipment and Fixtures only, Item 10 has been omitted for Site/Civil and Structure)
- k. Item 11 – Initial Asset Value, enter the list price from the manufacturer or construction budget for each asset listed.
- l. Item 12-17 details the Warranty information for the Equipment installed.
- m. Item 12 – Date of Manufacture, enter the date the asset was manufactured.
- n. Item 13 - Installation Date, enter the date each asset listed was installed.
- o. Item 14, In Service Date, is the date of substantial completion.
- p. Item 15 – Length of Labor Warranty, enter the duration of the Labor Warranty, in years, for each asset listed.
- q. Item 16 – Length of Material Warranty, enter the duration of Material Warranty, in years, for each asset listed.
- r. Item 17 – Manufacturer’s Website, enter an electronic link to the Manufacturer’s Website for each manufactured asset listed.
- s. Item 18 – Manufacturer’s Representative, enter the name of the Manufacturer’s Representative for each manufactured asset listed.
- t. Item 19 – Representative’s Telephone Number, enter the telephone number of the Manufacturer’s Representative for each manufactured asset listed.
- u. Item 20 – Representative’s E-mail, enter the e-mail address of the Manufacturer’s Representative for each manufactured asset listed.
- v. Item 21 – Installing Contractor, enter an electronic link to the Installing Contractor’s Website for each asset listed.
- w. Item 22 – Installing Contractor’s Representative, enter the name of the Installing Contractor’s Representative for each asset listed.
- x. Item 23 - Representative’s Telephone Number, enter the telephone number of the Installing Contractor’s Representative for each asset listed.

y. Item 24 - Representative's E-mail, enter the e-mail address of the Installing Contractor's Representative for each asset listed.

2.1.4.4 The Contractor is required to maintain and update the live version of the mini-Taxonomy throughout the project and turnover updated version at the end of the project.

2.1.4.5 Sound Transit and the BIM Coordinator is responsible for the review of the PSAL at the end of Construction Documents stage and make any modifications deemed necessary by them.

3.1 Construction

3.1.1 Submittals

3.1.1.1 The BIM Coordinator will work with the BIM Manager (Contractor's side) and the Designer to establish a submittal processing procedure.

3.1.1.2 The Contractor will ensure that all submittal files are prepared with the naming convention stipulated in Section 2.1.3.

3.1.2 Information Exchange

3.1.2.1 This section covers the actual exchange of information during the execution phase of the project. The Designer will ensure that models have been established during design using the required Revit parameters.

3.1.2.2 The Contractor must confirm specific asset requirements to include them in the project-specific mini-Taxonomy. The following list contains attributes that must be included in this information exchange. These are the standard core fields requested by Sound Transit (taken from PSAL). These fields are the same for every type of asset. Sound Transit reserves the right to add or subtract datasets in the future based on their requirements at the time. Information on when the dataset should be populated is provided, as well as direction on how the field should be named. (Pg 55, (George Washington University 2014))

- Location
- Asset Class
- Asset Category
- Field Asset #

- Equipment Type
- Manufacturer
- Year of Delivery
- Model #
- Serial #
- Quantity and Unit of Measure
- Estimated Life
- Warranty period
- Initial Cost in USD and Life Cycle Costs

3.1.2.3 The BIM Coordinator will coordinate with the Sound Transit Accounting department to acquire the EIT F1 numbers corresponding to the asset data in the PSAL. Moreover, it is the BIM Coordinator's duty to monitor receipt of this spread sheet at the three phases indicated.

3.1.3 As-Built Notations

3.1.3.1 The Designer, BIM Coordinator and BIM Manager must collaborate and maintain project as-builts in the BIM model concurrently with the construction process.

3.1.3.2 The Designer and Contractor will discuss the transition of the Design model from the Designer to the Contractor for conversion to the as-built record model during the development of the BIM Execution Plan as discussed in section 2.1.1. Regardless of the timing of the transition, the Designer and Contractor will be jointly responsible to ensure that as-builts are being maintained throughout the construction process.

4.1 Turnover

4.1.1 Closeout Documents

4.1.1.1 The Designer, Contractor and BIM Coordinator must participate in a Closeout Meeting where the following is discussed:

- Preparation of closeout documents by Designer with required formats, version control and naming conventions as specified in the Appendix A.

- Preparation of closeout documents by Contractor with required formats, version control and naming conventions as specified in the Appendix A.
- Transmission of files to Sound Transit by timing indicated and per model requirements as specified in Appendix a.
- Preparation and Audit of final as-built model by Designer and Contractor, followed by submission to Sound Transit.
- Review of closeout documents for compliance with requirements and archiving to systems specified by the BIM Coordinator.

4.1.1.2 Collation of asset data from PSAL and updating of the EAMS to be carried out by the BIM Coordinator and Sound Transit team.

4.1.2 Operation & Maintenance Manuals

4.1.2.2 The Contractor must prepare operating and maintenance manuals in accordance with ST procedures. These must be submitted at 75% construction complete.

4.1.2.3 The Designer will collaborate with the Contractor and review the O & M manuals for compliance with Sound Transit procedures.

4.1.2.4 The O&M manuals will be submitted in the form of a separate PDF comprised of information for one Unifomat or Omniclass number. No paper copies will be submitted.

4.1.2.5 Operating and maintenance manuals will be submitted in a searchable PDF format. For PDF documents, the following guidelines should be followed:

- Use electronic files prepared by manufacturer where available. This helps with resolution of the document, as well as minimizing file sizes.
- Where scanning of paper documents is required, the PDF will be configured to be read horizontally (from left to right) and at a minimum 200dpi resolution
- The PDF will be searchable for text content
- Names shall be in accordance with the conventions established in the Closeout Documents section.

4.1.2.6 It is the responsibility of the BIM coordinator and the Sound Transit team to maintain BIM models for properties once established. This includes the updating of Revit files to the latest available version of software annually.

Appendix C- PSAL Template

Attached as supplemental information

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