Pacific Northwest
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PNNL-32248

Visual Modeling for Complex System Valuation

Implementation Guidance

October 2021

Sadie R Bender
Danielle C Preziuso
Trevor D Hardy

U.S. DEPARTMENT OF ENERGY | Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

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Abstract

The need to incorporate a valuation analysis design early in the research process of transactive energy systems led to development of a valuation methodology under the Transactive Systems Program (TSP) at Pacific Northwest National Laboratory (PNNL). This methodology allows for economic exchanges within a complex system to be modeled and supports the evaluation of individual stakeholder economic outcomes, in addition to systemwide costs and benefits. The use of visual modeling practices enables the research team to reach common understanding and agreement on the analysis design within the complex system. While this methodology was developed for transactive energy systems, it can be applied to any complex system where a granular economic analysis is desired. It allows for the inclusion of equity analyses and ties individual activities and microeconomic outcomes with the systemwide macroeconomic impacts. This document serves as implementation guidance for analysts planning to deploy the methodology within a research study. The appendixes provide specific examples on how this methodology is deployed within the TSP at PNNL for analysts seeking guidance for deployment within that context.

Acknowledgments

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Acronyms and Abbreviations

DER	distributed energy resource
DSO+T	distribution system operator and transactive
PI	principal investigator
PNNL	Pacific Northwest National Laboratory
TES	transactive energy system
TSP	Transactive Systems Program
UML	unified modeling language

Glossary

Activity – in unified modeling language (UML) an activity is a task that must take place within a system or process. Within this methodology an activity is modeled within the value activity diagram as a task that results in a value exchange.

Actor – An actor in UML specifies a role played by a system or user that interacts with the subject. Within this methodology actors are commonly used to model stakeholders and their interactions with the system being developed and studied.

Value activity diagram – A visual model that depicts the value exchanges of interest to the research study between actors and activities. A UML activity diagram is the graphical representation of activities performed by a system; within this methodology this is used to model value exchanges.

Value model – within the context of this methodology, the value model is the collection of valuation artifacts that are completed throughout the methodology. This includes use case diagrams, value activity diagrams, and accounting tables.

UML – The unified modeling language is a general-purpose modeling language and intended to provide a standardized way of visually modeling systems.

Use case diagram – A UML diagram that is used to describe a set of actions or functions of a system (use cases) and their interactions with actors.

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1.0 Introduction

As society adopts more distributed energy resources (DERs) and automated demand-side management practices, there will be a need for electricity markets to evolve to better value those device interactions with the electric grid. This increased participation of DERs drives the need to simultaneously understand the technical and economic implications of introducing these technologies into the system at scale as well as the underlying economic theories enabling their success. This is particularly true for transactive energy systems (TES), which exist at the intersection of market-based constructs and control theory. The GridWise Architecture Council defines transactive energy as “a system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter” (GridWise 2015).

Due to the integral role value has in a TES, Pacific Northwest National Laboratory (PNNL) developed a valuation methodology under the Transactive Systems Program (TSP) that aids in analysis design and models value exchanges within a TES. While the methodology was developed and originally applied in TES research, its structure lends itself to applications in other domains that span both engineering and economic fields within complex systems. Bender (2021) provides an overview of the methodology and this document serves as a guide for an analyst applying the methodology.

Many research studies prioritize the engineering-based technical evaluation and performance of systems, leaving economic assessment and feasibility to later stages of the study where they are limited by decisions that have already been made and data that have already been collected. While this approach is appropriate at times, it can restrict the types of economic assessments that can be completed and often leaves them lacking in granularity, specificity, and practicality. In order to support the adoption of TES and other DER coordination methods, both the engineering and economic aspects of the system must be well understood and modeled. Thus, a primary objective of this valuation methodology is to integrate the economic analysis into the core of research studies, thereby promoting transparency into the value exchanges that occur and driving the economic feasibility of a system for a given stakeholder. This allows system economics to be considered from an early stage, both informing the research study and ensuring access to data that support a range of valuation activities, particularly helping stakeholders understand their individual economic outcome within the system of interest. The Distribution System Operator and Transactive (DSO+T) study leveraged this methodology and demonstrates the ability of valuation to provide granular economic results within the study of a complex system (Pratt 2015).

Figure 1 shows a valuation-centric research process that includes both simulation and deployment of the system, commonly used within the TSP. A valuation analyst is typically significantly involved in the steps highlighted in red. The nature of the valuation methodology necessitates that valuation is considered while a research study is being designed to ensure the system being modeled and the data being collected are aligned with the desired analyses.

Figure 1. Transactive energy research process.

Once a research study's objectives are identified and the scope of the system being studied is defined, the valuation activities outlined in this document should begin. Within the "Valuation/Analysis Design" phase, valuation analysis requirements are defined in parallel with the design of the engineering analysis to ensure cohesiveness and consistency between the two to guarantee that the data needed to complete the economic analysis are considered before any engineering modeling, simulation, or field deployment occurs. The valuation analyst is also involved in later parts of a research study, often post simulation when preliminary analysis of the system is conducted to ensure research goals are being met, and again when the final analysis is completed. While a research process may differ from what is shown in Figure 1, the key takeaway should be that the primary integration point for valuation exists alongside analysis design and before the engineering-based system modeling, simulation, and demonstration occurs.

This guide focuses on the role of valuation in the "Valuation/Analysis Design" phase in Figure 1. It provides analysts with the information needed to structure a valuation analysis, with a focus on what should be understood throughout the valuation process. The output, or artifacts, from this methodology includes visual models depicted in the unified modeling language (UML) and accounting tables that provide the structure for the economic analysis that will take place. UML has many uses among many domains. Common uses that make it applicable to this methodology include its ability to capture details about a system for requirements or analysis and provide documentation of a complex system or process (Pilone 2005). The collection of these outputs is generally referred to as the value model. While the details for creating the valuation artifacts are provided in Section 2.7, a summary of the information they convey is provided below in Table 1.

Table 1. Summary of value model.

Artifact	Key Uses and Information Conveyed
Use case diagram	Use case diagrams provide a dynamic view of the system, showing where actors interact with functional behaviors of the system (i.e., use cases). Use case diagrams are valuable for building a foundational understanding of system behaviors relevant to valuation and the actors that are involved. Multiple diagrams can be used to depict different operational scenarios to compare value behaviors. Use case models can show system behaviors at a high level as well as more intricate interactions.
Value activity diagram	Value activity diagrams, an adaption of both UML activity diagrams (Sparx Systems 2021) and e3 business value models (Gordijn 2001) show the exchanges of value between the actors within a given operational scenario (e.g., use case). Activities completed by the actors being modeled are associated with value exchanges and define where values are created or accrued within the system.
Accounting table	Accounting tables are the economic analysis structure that is directly derived from the value activity diagrams. These tables incorporate double-entry accounting practices to show each activity's or actor's net value. That is to say, each value exchange modeled in the value activity diagrams appears twice within the accounting table structure, typically as a negative value from the source of the value exchange and a positive value on the accounting table of the target. Once the accounting table structure is developed, analysts are tasked with determining how to best quantify the value exchanges. This informs the data requirements needed to complete the economic analysis that is designed within the valuation methodology.

Many terms used within this methodology are specific to UML and have been defined in the glossary of this report. Alternate terms may be used when discussed outside of the UML context, for example when stakeholders are discussed within UML context the term actor is used. This is because a stakeholder is modeled within UML as an actor.

This document breaks down the fundamental tasks in the valuation methodology, detailing how an analyst can work through the application of the methodology to a research study, ending with a detailed description of the valuation artifacts identified in Table 1.

2.0 Applying the Methodology

While valuation efforts are embedded within a larger research project's structure as shown in Figure 1, the methodology has its own unique process shown in Figure 2. To employ the valuation methodology in this guide, analysts are tasked with understanding the system, identifying where and between whom the relevant value exchanges take place, defining metrics required for study analyses, ensuring the data necessary to compute selected metrics are collected, informing, helping refine study objectives, and modeling those values within system operations. This process is shown linearly in Figure 2, although the process is iterative and will require cycles of work, revisiting previous steps as needed.

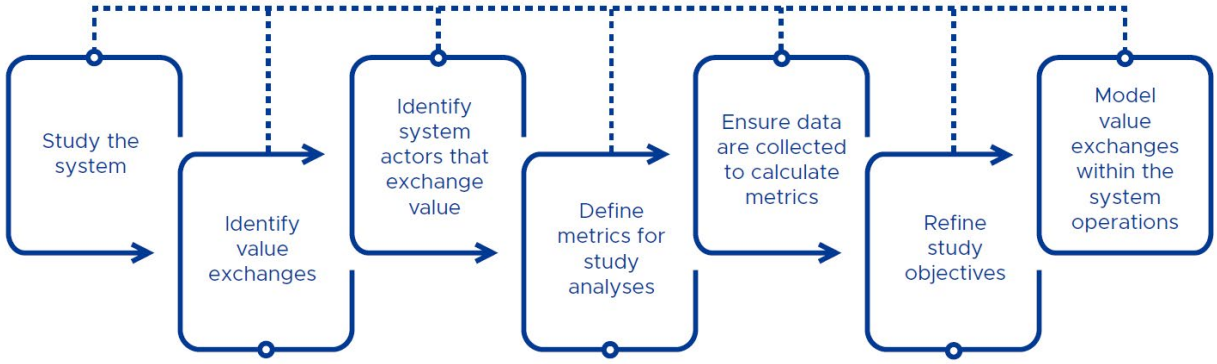

Figure 2. Valuation process.

The value model described in Table 1 is developed throughout the process and is shown as the final step since it is the output of applying the valuation methodology to a research study. PNNL builds these models within Enterprise Architect, although many visual modeling platforms would support the development of UML diagrams. Appendix A provides detailed instructions regarding how PNNL currently builds these models within Enterprise Architect, which enables collaboration with the simulation portion of a research study.

An unfamiliarity with visual modeling, and UML specifically, should not deter an analyst from applying the valuation methodology. Visual modeling serves as a way to organize the discoveries uncovered during the valuation process. In this context, it should be viewed as a communication tool. While UML is recommended, other ways of communicating the same concepts could be considered as alternatives, and analysts are encouraged to use any visual language with which they are comfortable. In the following sections different UML diagrams are mentioned frequently. Analysts who do not intend to implement UML while applying the valuation methodology should take note of what each diagram intends to communicate about a system and ensure that information is well understood and communicated among the research team. Table 1 and Appendix B briefly discuss what relevant information is modeled in the UML diagrams mentioned. There are also many sources available for detailed information and tutorials (Sparx Systems 2021).

It is important to note what has taken place before valuation begins, shown in Figure 1. The principal investigator (PI) should be able to identify the research objectives and the scope of the system that is being studied. The remainder of this section will walk through the valuation process shown in Figure 2, concluding with a detailed description of the artifacts of the valuation methodology.

2.1 Study the System

The valuation analyst's first task is to study the system and understand the project's research goals at large. To create an accurate and effective value model, the model must align with both the system being designed and the objectives of the research. The recommended approach to obtaining this understanding is a meeting, or alternative communication, with the larger research team, primarily the PI. A review of any project proposal, scoping documents, work done previous to this point, or literature review of studies done within the applicable domain could also provide insight.

Understanding the fundamental components of the system and research study allows the valuation analyst to understand the general function of the system and desired outcomes. As such, it lets the analyst begin building a model of the system and supports discussions between the analyst and system designers.

The valuation analyst will ultimately continue to learn about the system through the duration of the project life and iterate through new levels of understanding, but at this initial stage in the valuation methodology, analysts should have:

- General understanding of the system
- General understanding of the desired analysis and research goals
- A strong working relationship with the PI and system designers that includes established forms of communication for regular knowledge exchanges.

Below are some guiding questions that the analyst can ask to help gather the information needed to achieve the objectives of this step in the methodology.

- What are the key behaviors or defining characteristics of the system?
- What stakeholders interact with the system being studied and in what ways?
- What is the primary research goal? What questions are we trying to answer?

In achieving these objectives and answering these questions the valuation analyst likely has enough information to make a draft of the use case diagram, which is discussed in more detail in Section 2.7.1.

If the research team is using UML, class diagrams and sequence diagrams are helpful in sharing complex aspects of the system between the research team. A system designer could use these UML diagrams to concisely share information with the valuation analyst. It is not recommended that valuation analysts develop class and sequence diagrams unless they were directly involved in designing the system. Class and sequence diagrams are discussed in Appendix B and Pilone (2005) provides an overview of UML.

In addition to using any existing documentation and conceptual models, regular communication between valuation analyst, system designer, and the PI is critical in this stage as updates to the study design must eventually be reflected in both the value model and system, or simulation, design.

Because of valuation's placement being relatively early in the project lifecycle it is likely to raise questions that do not yet have answers. Frequent communication with the research team provides clear benefits to valuation analysts, and it also supports system designers as they are

being asked to articulate the general specifications of the system through this task, guiding them in solidifying system design details and creating a fully functioning system that supports the research objectives.

2.2 Identify Value Exchanges

Once the valuation analyst has a general understanding of the system, how it is intended to operate, and the research objectives, the specific value exchanges that need to be accounted for in the study must be identified. Where the previous step was general to the research study, this step is the start of the valuation analysis design specifically.

A key objective of deploying this valuation methodology is to achieve a granular economic analysis that can support the calculation of economic impacts to individual stakeholders in addition to the system as a whole. In this step the analyst should further their understanding from the previous step to begin identifying what stakeholder perspectives should be considered. As mentioned previously, the stakeholders that are identified are modeled as actors within the framework and will be referred to as actors when discussing the development of the visual models to maintain consistency with UML notations.

During this step the analyst identifies which value exchanges must be captured in the analysis in order to support the study objectives. To do this, the analyst needs to oscillate between a holistic, system-level perspective and individual stakeholder perspectives.

To identify the value exchanges, the analyst needs to understand the following:

- What economic assessments need to be performed?
- Which stakeholder perspectives should be considered?
- What values are exchanged within the system and relevant to the research objectives?

A collection of questions can assist the analyst during this phase.

- What economic questions need to be answered about the system as a whole? What value exchanges need to be accounted for to answer those questions?
- Which stakeholders need to see themselves represented in the model to understand their respective economic outcome?
- How do value exchanges vary in different operational scenarios that are being studied?
- How is value exchanged and what mechanisms enable those exchanges?

It is worth noting that some systems will have value exchanges that are not necessary to include within a specific study. These would subsequently be excluded from the value model. The value exchanges that are necessary to model impact the ability to answer the research objectives.

Furthermore, not every detail of the value exchanges needs to be understood at this phase; rather it is the valuation analyst's first concerted effort to learn more granular information about the system and begin translating those details into the knowledge necessary to produce the value activity model. The information gathered will be a first step in the development of value activity diagrams. A draft diagram will require this information and the information gathered in Section 2.3. More details on the development of the value activity diagram can be found in Section 2.7.2.

2.3 Identify System Actors that Exchange Values

After the valuation analyst broadly understands the values exchanged and how they support the economic assessments that need to be conducted, it is necessary to understand who or what actually exchanges those values and interacts with the system in a way that generates or accrues values. Where the previous step was a beginning to identify what types of values are relevant, this step is essentially defining what is the source and the target of the value exchanges.

This step supports transparency into the system and is essential for creating a meaningful value model. It advances the valuation analyst's knowledge to the level needed to generate the value activity model discussed in Section 2.7.2. During this step, the valuation analyst should:

- Begin mapping the value exchanges identified in the previous stage to the stakeholders and operational scenarios they are associated with
- Develop an understanding of the mechanisms needed to enable value exchanges in the system.

Thought should be given to the collection of guiding questions from Section 2.2 again. Specifically, in this stage it may be beneficial to ask further questions such as:

- Which stakeholder perspectives were identified and how might those be represented through actors in the value model?
- What values are necessary to answer the research objectives that are not well understood in terms of who or what within the system generates and exchanges the value?
- Are there classes of stakeholders (for example, customer type such as residential and commercial) that need to be captured in the analysis to answer certain valuation questions?

While this step seems similar to the previous steps, many studies of complex systems benefit from thinking about these value exchanges from both a general perspective, like what is described in Section 2.2, and then separately in a very specific way where the details are defined. For example, knowing that a customer pays a utility for electricity is a general understanding of a value exchange. Determining that a customer sends a monetary payment to a utility, for not only consumption of electricity but also connection charges and other aspects of a bill, and understanding the values the customer receives in return from the utility is specifically defining the exchanges between the two actors.

It is worth noting that activities or actors can both be the source or target of value exchanges when building the value model. Depending on the study it may be known what activity produces or receives a value, but not determined at this point which stakeholder, or actor, is responsible for that activity. This outstanding detail should not halt the process at this stage, the focus should be on defining what or who is responsible for either side of the value exchange.

Mapping the value streams can take place in any format that works for the valuation analyst at this time so long as it is well documented and can be used as a communication tool with other team members, as shown in Table 1. Versions of a UML activity model and e3 value model are used within the TSP at PNNL. This step inherently results in an early draft of the value activity diagram, an example can be seen in Figure 4.

At this stage, the iterative nature of the valuation methodology begins to materialize. Once stakeholders are identified and initial mapping of value exchanges between them begins, the valuation analyst will likely identify new value streams that had not been identified in the previous step of the methodology. Additional knowledge of the system may become necessary when confirming value exchanges, requiring a return to the first step in the process.

The first three steps in the methodology can be thought of as fact finding missions that uncover the details of the system to enable and inform the economic assessments that the valuation methodology supports. This mission often identifies gaps in the system and study design when questions arise that do not have immediate answers. One benefit is that these gaps are addressed before models are built, making the research process more efficient.

2.4 Define Metrics for Study Analyses

With knowledge of the research objectives, who exchanges values in the system, how those value exchanges are enabled by the system, and under what circumstances they take place, the valuation analyst needs to define the metrics necessary for the economic analyses that need to be conducted. The objective of understanding what should be measured and calculated to gauge the success of the system is critical to the valuation methodology to ensure the necessary data are modeled and captured.

Selecting metrics for the desired assessments requires the analyst to articulate which units of measure are required given the research objectives. During this phase, the valuation analyst should assess the value exchanges in conjunction with the desired economic assessments to determine appropriate metrics to answer the economic questions of the research study.

These guiding questions can be useful to the analyst while working through this step:

- Do the currently modeled value exchanges provide enough information to sufficiently answer the relevant research questions?
- What is the most appropriate way to measure success and failure for the actors in the system?

The communication within the research team is again critical at this point. If the value exchanges modeled do not confirm the calculation of key metrics that support the research objectives then additional stakeholders, system scenarios, or values may need to be included, or objectives reevaluated which is a later step.

Analysts should keep in mind that most metrics will require information from outside of the value exchanges to calculate. A metric requiring information that exists outside the valuation model is not what this step is targeting. An example of this is needing information like temperature from a simulation in order to calculate the metric of building occupant comfort. This step aims to identify if a value exchange and subsequent calculation of comfort is missing from the draft value activity diagram and a research objective was to analyze the financial compensation for the customer at varying levels of comfort. There also may be metrics within a research study that are not relevant to valuation and are not identified by the valuation analyst. These are often system performance-based metrics that are solely focused on the technical success of the system under different operational scenarios.

2.5 Ensure Data are Collected to Calculate Metrics

Once the valuation analyst has identified and defined metrics that are relevant, they should coordinate with both the system designer and those who will execute the model and simulation to ensure that the appropriate data are collected. If the system is going to be deployed, consultation with the deployment team is also recommended. This coordination is key for enabling the economic assessments as some value exchanges can be conceptually exchanged within a system but not explicitly modeled or captured through simulation or deployment. Most metrics also have inputs to calculations that come from these other areas of the research team and need to be well understood. This can shed light on any shortcomings that the proposed model and simulation have for achieving the understood research objectives.

Ultimately, during this phase, the valuation analyst should:

- Hold discussions to reconcile any discrepancies between the data needed to complete the desired assessments and the limitations that the model, simulation, or deployment may create for capturing that data
- Develop a plan for ensuring the model, simulation, or deployment captures the agreed-upon data and determine how those data will be shared with the valuation analysts

The key question here is whether there are any data requirements that cannot be fulfilled. The answer can be driven by model, time, or budget limitations and would require potentially refining the objectives or reiterating the previous steps of the methodology.

At this stage the value model draft should be mature enough that it can be used to develop a clear list of data requirements. Additionally, the analysis activity diagram discussed in Appendix B can be useful in completing this step. The value model, particularly the accounting table discussed in Section 2.7.3, can give the analyst a set of data requirements for the desired economic analysis that can be shared with the larger research team.

2.6 Refine Study Objectives

Execution of the previous steps will provide insight that will allow the team to reevaluate the research objectives that were originally laid out for the study. Namely, during this phase, valuation analysts should coordinate with the larger research team to determine if the valuation methodology has shed light on new questions that the project can or should answer or identified any discrepancies between the research objectives as they have been written and the model and simulation that have been designed.

Some guiding questions for this coordination are:

- Can the original research questions be answered based on what has been developed? Were there any data discrepancies highlighted in the previous step that need to be resolved?
- Have additional or supporting research questions come to light during this process that should be included in the objectives?

Given the iterative nature of the valuation methodology, and since the steps leading to this phase should take place before the model and simulation are finalized, there is real opportunity to allow the valuation methodology to enhance and improve the research project as a whole.

Changes made to the research objectives lead to the valuation analyst reiterating through the previous steps of the methodology to ensure they are consistent with the revised objectives.

2.7 Value Model Example

If the previous step of the valuation methodology did not lead to revisions in study objectives the valuation analyst can complete modeling the value exchanges through a series of UML diagrams and accounting tables. These artifacts should ideally be developed throughout the entire process, being revised frequently. They are considered the final step of the methodology since, once the research team has consensus on them, the research process should move forward from valuation to the next stages of the research project. Within the TSP this is often building the simulation model.

Utilizing the development of visual models within valuation has dual purposes. One is to help the research team concisely communicate and validate potential system designs. Another is to provide documentation of the complex systems being studied to the desired audience. For this purpose, the value model should be updated with any relevant system changes that are implemented later in the research process.

The diagrams provide a visual depiction of the value exchanges and the critical system behaviors that enable them; they can be seen as the blueprint of the analysis. The structures of the accounting tables are generated from the visual models, where the valuation analyst then defines the required calculations. In many ways once this is done so is the analysis design phase of the research study. To populate the tables with values, the execution of the analysis must take place as part of the later steps of the research process that the valuation analyst is likely involved in (see Figure 1).

The number of diagrams and content for each are subject to the research goals and objectives as well as the economic analyses that are desired. Examples of each artifact and the generic process to develop them are included in the following sections. The use case and value activity model examples are shown from PNNL TSP studies that were done within Enterprise Architect. For specific guidance on developing these models within this software please see Appendix A.

2.7.1 Use Case Diagram

Use case diagrams provide a dynamic view of the system, showing where actors interact with the functional behaviors of the system (i.e., use cases). Beginning the valuation process by creating use case diagrams often provides a foundational understanding of system behaviors. Through these diagrams, multiple operational scenarios that potentially generate different value exchanges can be modeled. Use case diagrams can show the system behaviors at a high level as well as more intricate interactions. Careful consideration of the types of use case diagrams is recommended when determining the views of the system most useful for analysis. An example of a use case diagram developed within the TSP is shown in Figure 3. Actors are indicated by the stick figure icon, and use cases are indicated by ovals. The lines connecting the actors to the individual use cases indicate the interaction between the use cases and the actors.

In order to create the use case diagram shown, the valuation analyst had to be aware of who the relevant stakeholders, shown as actors in UML notation, were within this study, and the system and conditions that would be modeled and analyzed. This information is all gathered in the first step of the valuation methodology (see Section 2.1). This visual model can be seen as a point of consensus between the research team on the scope of the research study. Using

Figure 3 as an example, one can conclude that the transactive system is going to be compared to a conventional system where there is strained grid capacity due to heat. A use case diagram also clearly shows what is not included within a study. For example, there is no conventional system demand response use case shown here. While it could be analyzed and compared to a TES for managing the grid under these conditions, it is not shown, so it can be concluded it is not included.

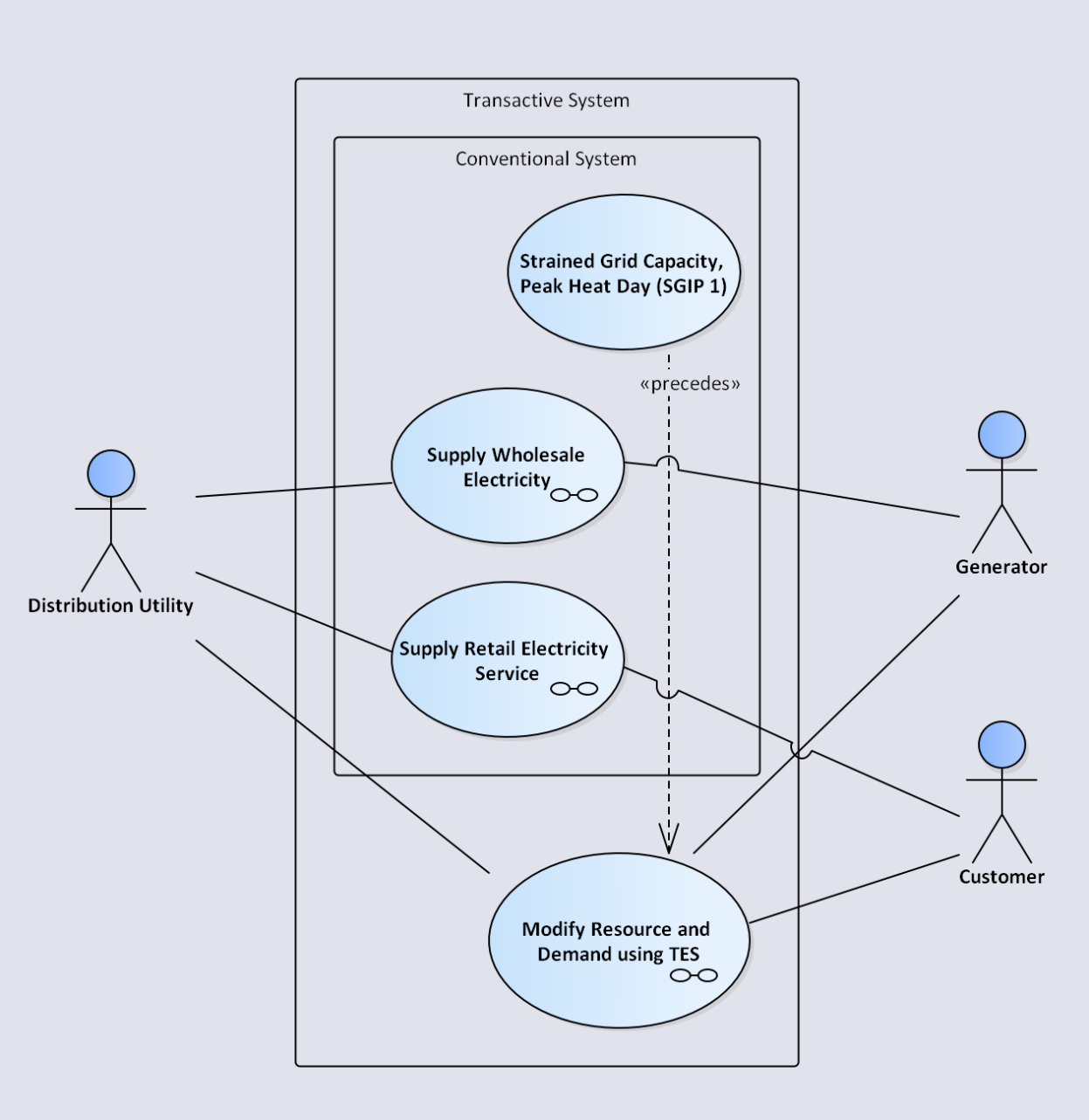

Figure 3. UML use case diagram

Actors are shown interacting with the use cases. These actors are the UML representation of stakeholders that have been identified in steps one and two of the methodology (Sections 2.1 and 2.2). These are the stakeholders whose economic perspective will be considered as a part

of the study. The use case diagram also shows which use cases within the system actors are associated with. Figure 3 shows that the customer does not directly interact with the conventional supply of wholesale electricity. Because of this, when that use case is analyzed, no direct value exchanges with the customer actor will be modeled and the customer actor will not be present in the value activity diagram for that use case or have an accounting table associated with that use case.

The use case diagram is helpful to gain consensus among the larger research team about what is and is not going to be studied, so different levels of detail may be necessary depending on the situation. A use case diagram can also be used to model a specific complex aspect of a system, as explained in Table 1. Using the study in Figure 3 as an example, a use case diagram could be developed that further details of Modify Resource and Demand using TES. That use case could be explained in a more granular sense with a use case diagram that is more specific about the functional behaviors included. The analyst and research team can determine how many use case diagrams should be created.

UML use case diagrams represent the behavior of the system, describing the functions and scope. Defining the system in this way is likely the PI's responsibility rather than the valuation analyst, but the analyst will need this information to move forward effectively. If the PI is not familiar with visual modeling, developing a use case diagram is a way for the analyst to confirm that their understanding of the system at this level is consistent with the PI's understanding.

2.7.2 Value Activity Diagram

The value activity diagrams used within the valuation methodology draw upon fundamentals used in e3 value models (Gordijn 2001) and UML activity diagrams. The concept of applying a UML notation to the e3 value modeling principles has been done (Huemer 2008), and the specifics of how this is applied in this context is detailed in Appendix A.

While activity diagrams are broadly used to show system behaviors, in the valuation methodology these diagrams anchor the model by specifically mapping value exchanges of interest between different objects in the system. They subsequently serve as the basis for the accounting tables. These value activity diagrams show which actors or activities exchange economic value as a result of system behaviors. One actor can be modeled with multiple activities that result in value exchanges. Within valuation these are created for the use cases being studied. Figure 4 shows the value activity diagram for the Modify Resource and Demand using TES use case shown in Figure 3. Note that the three actors associated with the use case in Figure 3 are actors that are represented in the value activity diagram below. Also note that in these diagrams, it is often valuable to indicate actors with their rectangular notation, implementing these specifics will be discussed further in Appendix A.

Within the actors shown there is an activity, the lighter blue rectangle. These are useful for showing the value exchanges specific to a certain value creating or receiving activity. Figure 4 shows a value exchange within the customer of local generation that will be specifically accounted for within the analysis. The value exchanges are the connections between the action pins, shown as a yellow square, on the activities.

The valuation analyst begins gathering information necessary for the value activity diagram in steps 2 and 3 (sections 2.2 and 2.3), which is consistent with having at least a high-level use case diagram in place prior to beginning the value activity modeling. These diagrams will likely be updated and modified as system and study understanding progresses, using the diagram to

highlight this point, during the metric definition stage of the valuation process it was discovered that losses in the distribution utility were critical to calculate a desired metric, this value exchange was added to the value activity diagram shown in Figure 4 at that point.

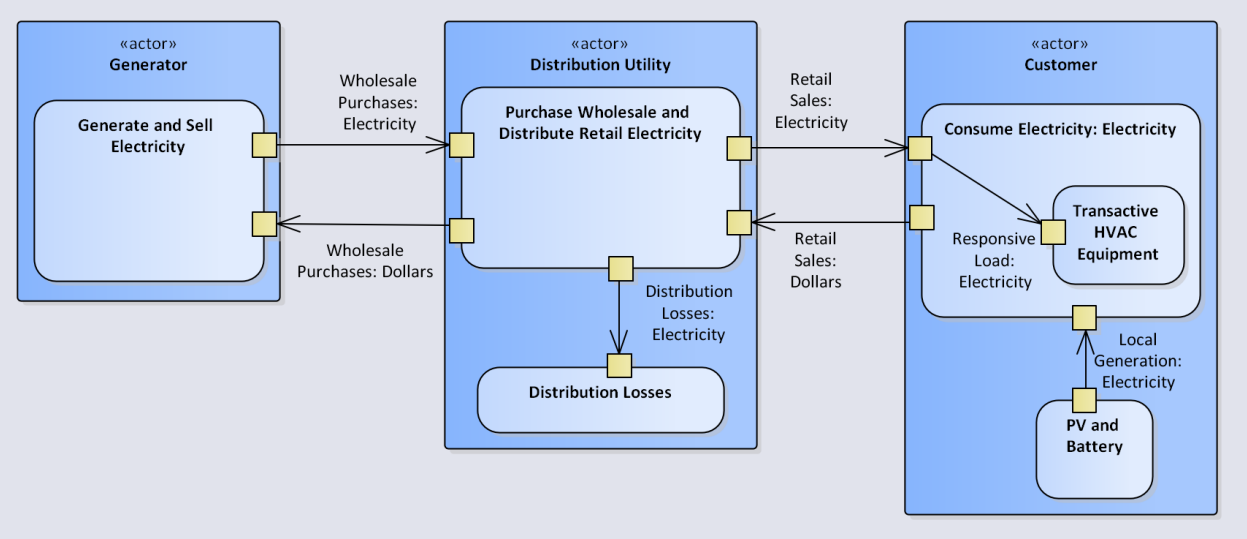

Figure 4. Value activity diagram.

2.7.3 Accounting Tables

The value activity diagram is used to generate the accounting table structure shown in Table 2. Each actor, activity, and value exchange from Figure 4 is present in the accounting table with the hierarchy preserved.

Table 2. Accounting table.

Customer		
Consume Electricity		
Incoming values (+)		
	Local Consumption	---
Outgoing values (-)		
	Electricity Payment	---
PV and Battery		
Incoming values (+)		
Outgoing values (-)		
	Local Generation	---
Transactive HVAC Equipment		
Incoming values (+)		
	Responsive Load	---
Outgoing values (-)		
Distribution Utility		
Distribution Losses		
Incoming values (+)		
	Distribution Losses	---
Outgoing values (-)		
Purchase Wholesale and Distribute Retail Electricity		
Incoming values (+)		
	Retail Sales	---
	Wholesale Purchases	---
Outgoing values (-)		
	Wholesale Purchases	---
	Distribution Losses	---
	Retail Sales	---
Generator		
Generate and Sell Electricity		
Incoming values (+)		
	Wholesale Sales	---
Outgoing values (-)		
	Wholesale Sales	---

When this table is populated the net value outcome for each actor and activity can be easily identified, as well as the comparison across the different use cases to see if one system configuration was more economically feasible than another. A main goal of the valuation methodology is to be able to determine individual microeconomic outcomes within a large and complex system and trace those outcomes to the macroeconomic outcome of the system as a whole. This objective allows equity to be considered within a study as well, since the individual outcomes of each behavior can be identified. Once the accounting table structures are in place it is important that they are updated along with any changes to the value activity diagrams.

The valuation analyst, along with the larger research team, uses the table structure to then define how each item will be calculated and the source of the information for that calculation. It is important to note that each value exchange is typically present twice on the accounting tables, as an incoming and an outgoing value. Using Table 2 as an example the outgoing value of electricity payment to the customer should be the same value as the incoming value of retail sales to the distribution utility. The analyst would then likely define the calculation of this value as the quantity consumed from the distribution utility multiplied by the price. The quantity consumed would be impacted by the local generation the customer experienced and would be

considered in this calculation as well. This point of the valuation process becomes very project specific and requires coordination with the larger research team as the data requirements to calculate the values within this table are identified (see Section 2.5).

Once the data requirements are identified and the sources of data are confirmed, the valuation portion of the analysis design can be considered completed. After simulation or modeling takes place and the data are generated the analysis or preliminary analysis can be conducted as shown in Figure 1. It is likely there will be separate analyses from the simulation that are necessary to provide inputs to the accounting table calculations. This is up to the project team and analyst to determine who should be responsible for these analyses and when they need to take place. When appropriate, PNNL uses the Enterprise Architect software to model the analyses components that make up a research study and integrate this with the valuation modeling, as discussed in more detail in Appendix B.

3.0 Conclusion

Many times, economic analyses of complex systems generate results in aggregate, but in reality, it is necessary to quantify the economic outcome of each stakeholder to implement these systems in practice. In the absence of such an understanding, implementation can be hindered and progress delayed. Adopting and managing complex technical systems will involve stakeholders that were not involved with the in-depth research and analyses that went into designing the system.

The guidance presented provides researchers with a methodology to create transparency into the system details that influence the economic outcomes and bridges that divide between stakeholders. The methodology directly maps the systemwide macroeconomic outcomes of implementation to the individual microeconomic outcomes alongside the system behaviors that generated them. In doing so, the application of the methodology allows inequities to be identified and an opportunity to address them directly in the design of the system. The resulting visual models allow for the analyses to be shared efficiently with a broad audience and increase the impact of research. Including a valuation-centric perspective in the system design allows for economic analysis to parallel the technical system in robustness and supports the widespread adoption and investment in the systems that are researched.

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Appendix A – TSP Use of Enterprise Architect

When creating visual models within the TSP, the Enterprise Architect software developed by Sparx Systems is utilized. Information on the general use and applicability of Enterprise Architect can be found on the Sparx Systems website, along with support, tutorials, and training resources.[1] Figures 3 and 4 in Section 2.7 were developed within Enterprise Architect. This appendix will provide instructions on how they were created in a way that is consistent with the current scripts that support the visual modeling, specifically a script that supports the research process. The script has two related functions that both come from parsing an XML-exported version of the value and analysis models that are defined in Enterprise Architect:

1. Evaluate the data flows between activities in the analysis activity diagram looking for missing data connections or inconsistencies in the connected data flows.
2. Create an outline of the accounting table based on the value activity diagrams; this script is only effective if the value activity diagram is built with the specifics from this appendix.

The first diagram created in the process is the use case diagram, which is a fairly straightforward process in the software. In a new project within Enterprise Architect, select Add Model from the project browser. Within the model patterns, select the Basic Use Case Model option, then select Create Pattern(s). There should now be a use case model within the browser that can be renamed and edited. Figure 5 shows what the project browser looks like at this point.

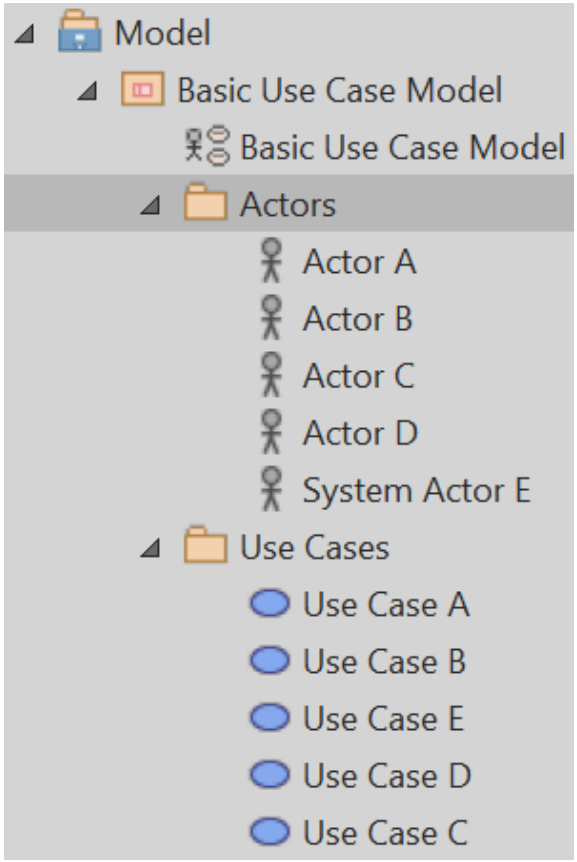

Figure 5 Project browser

From here the analyst can use the actors and use cases that were generated with the model by renaming them and deleting unnecessary actors and use cases from the project browser. The default use case model includes some associations between actors and use cases that should be edited to be appropriate to the system being studied. Additional system boundaries, actors, use cases, and associations can be added to the model by searching for the desired addition within the toolbox.

Creating a value activity diagram begins similar to a use case diagram. Right click the Basic Use Case Model Package in the project browser and select Add Diagram. Select UML: Activity from the UML Behavioral model options. For this example, this is the value activity diagram for Use Case A. The project browser should now look like the figure below, with a blank activity diagram in place shown with the activity icon in yellow to the left of it. In the example below the names of the use case and activity diagrams have not been updated, the analyst can name these accordingly, the default name of the diagram is that of the model which is shown as Basic Use Case Model.

[1] https://sparxsystems.com/

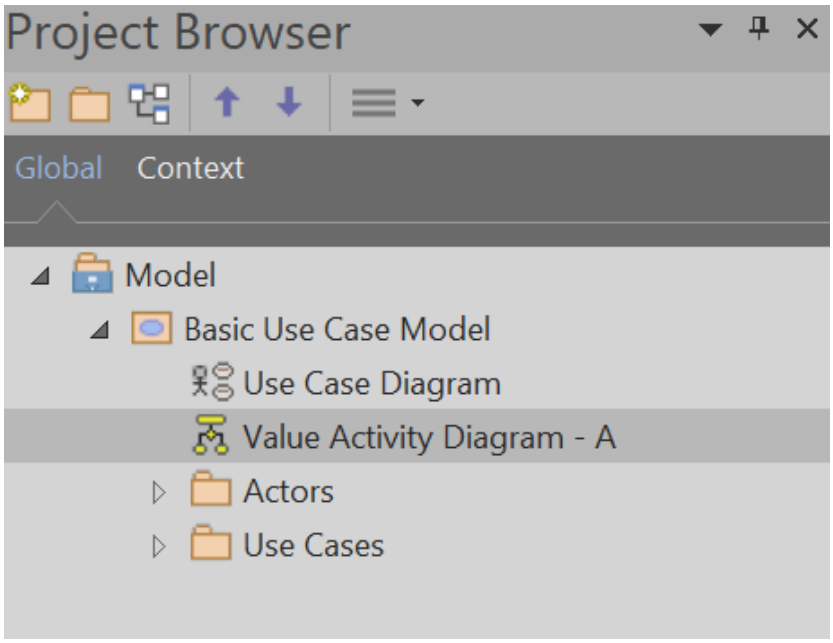

Figure 6 Project browser with activity diagram

Within the valuation methodology the value activity models are connected to the use cases, the analyst should now connect this new value activity diagram to the appropriate use case within the model. The figure below shows an example use case diagram. To associate a value activity diagram with Use Case A, right click Use Case A, then select New Child Diagram and Select Composite Diagram. From there the analyst should select the value activity diagram that was created that will detail the value exchanges for Use Case A. When this is done the use case will have an eyeglass graphic in it. Double clicking that use case will now take the analyst directly to the relevant value activity diagram. This feature can also be used if developing a more detailed use case diagram and linking that to the more general use case diagram.

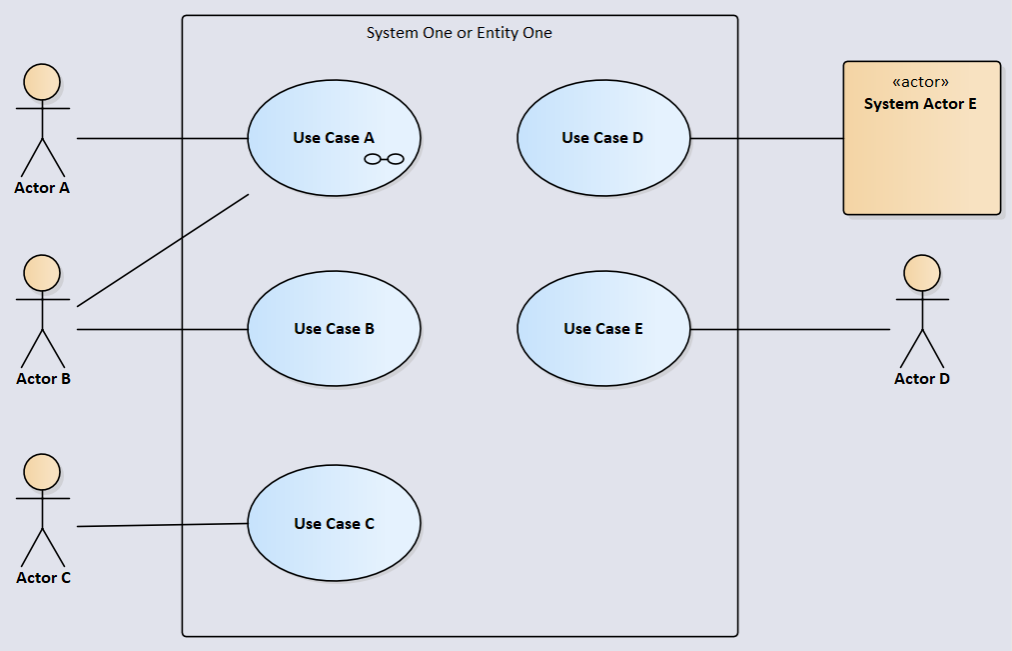

Figure 7 Default use case diagram

Within the value activity diagram, using the proper modeling techniques becomes important to ensure the relevant scripts will be effective.

The first step in the value activity diagram is to add the relevant actors. Actors A and B interact with Use Case A, so those actors can be added to the activity diagram by dragging them from the project browser. Actors should be shown in rectangle notation in this diagram, right click, select Advanced, then select to use rectangle notation.

Within the actors an activity should be added from the toolbox. One actor can have multiple activities, and the activities should be seen as the value creating or receiving action that the actor is responsible for. The activity should be placed entirely within the actor. The actor will highlight when the activity is placed within it to indicate this hierarchy.

Attached to the activity is an action pin object, which can also be found in the toolbox. It is important to note that in some versions of the software, this is not available in certain diagram types. For example, in version 14 of Enterprise Architect, if the analyst selects the UML: Simple Activity diagram rather than the one identified previously, the action pin object is not available. Each action pin should only have one connection associated with it.

To add the value flow between action pins, the analyst can left click the pin that is the source of the value exchange and select the arrow that shows up when the action pin is selected. Click and hold the arrow, dragging to the action pin that is the source of the value exchange. The analyst will then be prompted to select the association type, this is an information flow. The analyst can then choose information items to be conveyed. These information items can be added to the information flow later as well by right clicking the line, selecting Advanced, and then information items conveyed. The end result should be similar to the figure below.

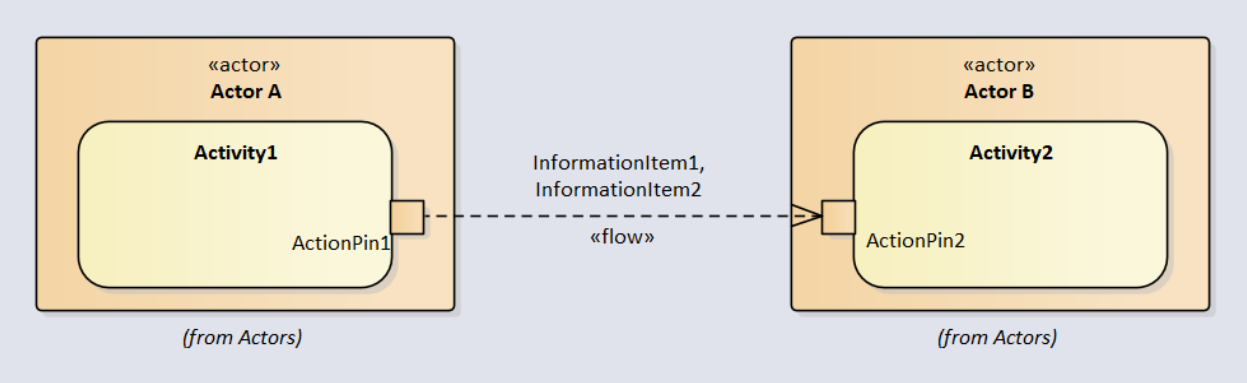

Figure 8 Value activity diagram

The next modeling step is to add an object diagram, which is done in the same way an activity diagram was added. This diagram is not included within the valuation artifacts. It is used as a place to add information item objects to the model but is not typically needed for communicating system aspects as a visual model. Information items can be added to the object diagram from the toolbox and represent the values being exchanged. Multiple information items can be conveyed on one information flow to keep the diagram organized. In the example above it shows both Information Items 1 and 2 being sent from Activity 1 to Activity 2 using action pins as the point of interaction.

The following accounting table shown in Figure 9 would be generated based on the value activity diagram above.

	A	B	C	D	E
1	Actor A				
2		Activity1			
3			Outgoing Values		
4				InformationItem1	
5				InformationItem2	
6			Incoming Values		
7	Actor B				
8		Activity2			
9			Outgoing Values		
10			Incoming Values		
11				InformationItem1	
12				InformationItem2	

Figure 9 Accounting table

At this point in the process the valuation analysis moves out of Enterprise Architect and the calculation definitions. The data requirements are defined in whatever platform is most appropriate for the research team.

Appendix B – Additional Visual Models for Valuation Input

Table 3 Additional Diagrams

Diagram	Key Uses and Information Conveyed	Diagram Generator
UML Class Diagram	Class diagrams communicate the structure of a system by displaying the objects within the system, their relationship to each other, and the attributes and operations of each class.	Principal Investigator, Simulation Team
UML Sequence Diagram	Sequence diagrams show the object interactions within a system with a time sequence. Allowing the modeling of exchanges between objects in orders that are necessary for the system to function.	Simulation Team
Analysis Activity	Activity diagrams outline the planned analysis process and defines both the flow of data between analysis activities. Metadata on outputs and inputs of activities can be compared to ensure consistency.	Principal Investigator

Class and sequence diagrams, both of which are in standard UML, are recommended tools for system designers to use when sharing the conceptual models of the system with valuation analysts. Class diagrams provide a static view of the system, depicting a series of classes and the connections between them. Classes are structures representing an object or objects that share attributes and operations. In UML, classes are notated as rectangles with the name of the class at the top followed by attributes and operations. These diagrams can help guide valuation analysts in determining how the system model might generate needed data and understanding the types of behaviors that different objects in the system display. In comparison, sequence diagrams show a dynamic view of the system, most often displaying the core order of operations of objects (i.e., instances of a class) in the system. At their core, these diagrams rely on a series of connector lines to indicate the relationship of interactions between objects and actors (external stimuli to the system). These diagrams are particularly useful for valuation analysts as they provide high-level information about how the system functions, offering insight into where value exchanges can occur and between whom.

The analysis activity diagram is a standard UML activity model that has been customized with input and output pins associated with activity blocks. These blocks represent analysis activities that must be undertaken to complete the intended analysis. The input and output pins (modeled as UML action pins) define the input data requirements and output data required by the analysis activity. Metadata associated with these pins create a more comprehensive view of the data and show information such as units and dimensionality of the data. Thus, a pin labeled “Annual Energy Consumption” could be defined as a single value with units of kWh or as a set of vectors of hourly values for eight locations in a region with units of MWh. Particularly for analysis plans that include multiple parties, this documentation of the data and metadata moving between the various parties of analysis can be helpful in ensuring a common understanding of the data exchange taking place and bring necessary consistency to the analysis

To that end, when the metadata is properly defined, a script PNNL created can be run to evaluate the data flows between activities in the model and look for errors and/or inconsistencies such as input pins with no data flowing in, output pins that are not mapped to any inputs, or a mismatch in units between two connected activity data flows. This script operates directly on the XML-exported version of the model produced by Enterprise Architect and serves as a validator for any analysis design model that includes this level of detail. Use of this data validation script is included within Appendix A, where the specific process is detailed.

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