Performing a Power Consumption budget analysis in an Extended Enterprise context with TeePee

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ABSTRACT

The Power Consumption budget is a major topic of interest in the preliminary mission design phases as performed by ESA. As the design progresses, ESA relies more and more on data provided by the prime Large System Integrator and its suppliers. Each member of the supply chain have its own modelling methodology and tools, its own information system, and shall keep under control the exported data. Therefore, the problem of how to aggregate adequately this heterogenous data in order to keep the power consumption budget under control rises. In the frame of TeePee4Space project, a solution to this problem is proposed, using the methodology for Information Sharing in Extended Enterprise and its implementation into the TeePee platform. A viewpoint dedicated to the Power Consumption budget analysis, relying on the concept of power consumption modes and their mapping all over the Product Breakdown structure, has been designed and succesfully implemented. The capability to bring back aggregated data into the native authoring tool has also been explored.

ESA MBSE2022 objectives: O-5, T-2, T-3, S-3, S-4

1 PROBLEM STATEMENT

When assessing the feasibility of a mission, the Power Consumption budget is a key driver that has impact on the system design and operations. It must be kept under control all along the design process, with an increasing level of confidence when the system design becomes more mature. Whereas phase 0 is mainly performed by ESA only without involving Large System Integrators (LSI), the analyses performed in phase A/B1 are based on LSI's designs proposal, which are evaluated with regards to the ESA high-level requirements. Therefore, there is a need for sharing data in this Extended Enterprise context, in which ESA retrieves information from the supply chain (LSIs and their suppliers) and compares the resulting power consumption budget with its requirements.

In [2], the challenges that emerge have been summed up and a methodology has been described, along with an application to the mass budget analysis. This paper describes how the previous work has been enriched with a viewpoint dedicated to Power Consumption analysis. In section 3, the proposed methodology for this analysis is described, which relies on the formalization of power consumption modes at various system levels and the *mapping* of those modes between the different system levels. Section 4 describes how this viewpoint has been experimented on the TeePee platform, with a representative case study.

2 TEEPEE CONCEPTS AND IMPLEMENTATION

Here, the main concepts behind TeePee that have been developed in [2], and some details about the technical implementation of TeePee, are reminded.

2.1 Challenges for data sharing in Extended Enterprise

TeePee aims at providing a distributed solution for System Engineering data sharing in Extended Enterprise. As explained in [2], several challenges have been identified:

- **C1 Build a shared vocabulary:** the identification of common concepts shared between the EE stakeholders. A strong attention shall be given to the meaning of those concepts projected onto the data.
- **C2 Specify the collaboration in the extended enterprise:** This challenge refers to the specification of EE's exchanges. It shall contain requirements about the expected collaboration method between each collaborating company, and about the orchestration of flows that are produced and consumed by each collaborating companies.
- **C3 Controlled data exposure:** For instance, a company shall expose the minimal set of data needed to answer a specific demand expressed by another one in the EE.
- **C4 Consistency of the exposed data:** the constraints that shall be respected by collaborating companies to ensure the federation of SE data over the EE will be consistent. It relates to different validation activities performed under version control to detect and manage inconsistencies between SE data coming from different stakeholders.

2.2 Building a Shared Vocabulary

Since authoring tools (such as Cameo, Capella, or COMET in the ESA CDF context) relies on heterogeneous methods and languages, the TeePee decision cockpit shall implement a shared vocabulary. Hence, it is proposed to rely on a common vocabulary formalized as a pivot meta-model to ensure the federation of heterogeneous data. Instead of trying to provide an exhaustive mapping with the concepts of the various modeling languages, it is proposed to define viewpoints dedicated to a given analysis, for which only the modeling artifacts required and agreed between the stakeholders are considered.

This meta-model, called SEIM (Systems Engineering Information Model), specifies, for each System Engineering (SE) analysis viewpoint, the concepts that shall be retrieved from the distributed models to address analysis needs, e.g. mass parameters, interfaces, functions, products, etc.

Then, each company contributing to it can map the meta-model of its authoring tools with the SEIM.

To complete the mutual understanding, stakeholders shall also discuss and agree the graphical representation via glyph, colors, layout, etc. to share a common mind-set on SE analysis results.

2.3 Specifying the Collaboration in Extending Enterprise

The Extended Enterprise emerges when a customer delegate parts of its work to several suppliers according to its "make or buy" strategy. This decision is taken on leaves of a given breakdown structure (e.g. Product, Functional). When a "buy" commitment is taken on a particular leaf, suppliers refine customer data for this leaf. Fig. 1 illustrates an example of a system designed by different companies collaborating through an EE network.

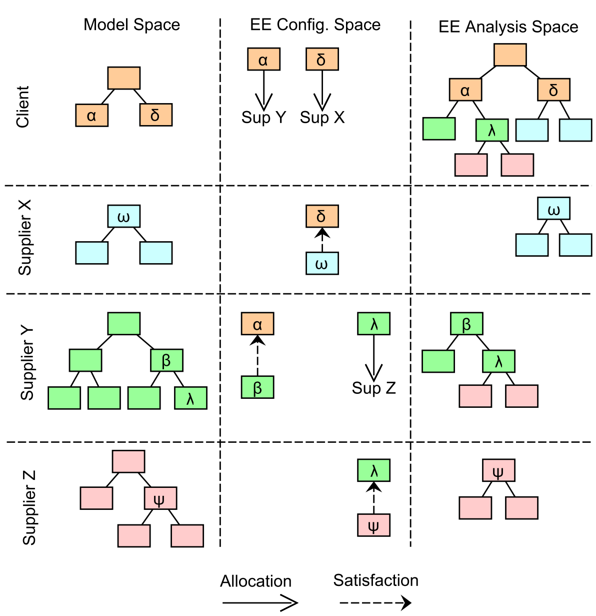

Figure 1: Collaboration mechanism in EE.

Our proposal to manage this refinement of SE data is to mimic what is done for requirements with allocation and satisfaction links. For instance, the customer allocates leaf model elements (functions, sub-system, component, etc.) to its suppliers (X and Y). The suppliers can then satisfy the customer request by providing their model elements. With this kind of EE, the distribution constraint allows the client to get SE data from a Tier2 supplier (Supplier Z) without having a direct contract with it. It assumes however that the contract between Supplier Y and Supplier Z allows Supplier Y to transmit data to the customer.

2.4 Controlling Data Exposure

When dealing with information sharing, many concerns exist (levels of confidentiality, management of IP, export control ruling country trades...) and they are crucial for any company. Thus, each data shall clearly identify their owner and have attributes to cope with these concerns.

In the Fig. 1, supplier Z has a white-box strategy meaning that it exposes everything to its customer, the supplier Y. But in the case where supplier Z wants to protect IP on Ψ model artefact, it shall be able to hide (black-box strategy) or filter (grey-box strategy) elements related to it. Access control management shall also be considered to give the right privileges to specific users. In this way, only authorized people shall be able to perform analyses. As an example where all members are strictly isolated from each other, a team from Supplier X shall not be authorized to access data about β model artefact.

2.5 Consistency of Exposed Data

The consistency of exposed data is necessary to perform consistent federation of data, even if not sufficient.

Several principles are implemented:

- A mapping between customer's and supplier's project and version allows achieving consistency regarding the version control aspect at a viewpoint level.
- For completeness, the *allocation* and *satisfaction* links illustrated in Fig. 1 allow the coverage checking of customer's model artifacts by supplier's ones.
- For correctness, even if some checks may be performed through the shared SEIM datamodel explained in section 2.2, systems engineers should rely on the analysis results to detect inconsistencies.

2.6 Technical implementation in TeePee

An instance of TeePee consists in several services and user interfaces (see Figure 2). These services communicate between each other and with the other TeePee instances thanks to their REST-like API. The architecture is the same for each company of the Extended Enterprise.

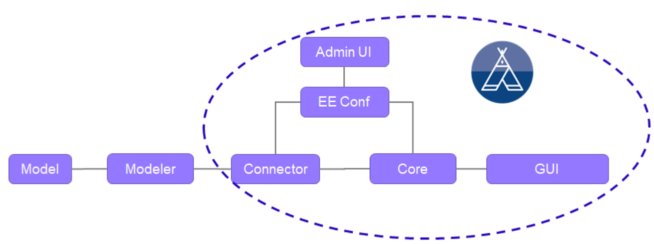

Figure 2: TeePee architecture.

The Connector service is responsible for the extraction of data from the modeling tool, and conversion into the pivot meta-model format. The Core service is responsible for the data aggregation. The EE Conf service is responsible for the Extended Enterprise configuration (management of allocation and satisfaction links).

3 METHODOLOGY FOR THE POWER CONSUMPTION VIEWPOINT

We describe here our methodology, inspired from the current practices in CDF tools, for the representation of power consumption all along the product breakdown structure, and for the computation of the global power consumption.

3.1 Modes for power consumption analysis

A common way to represent the power consumption of a system or a component is to introduce the concept of modes. Indeed, the power consumption is related to the way the system or component is used, and therefore which mode is active at a given time. Ex: a star tracker can be in mode “On”, for which the power consumption is 10W, or “Standby”, for which the power consumption is 1W.

In order to study the power consumption at various levels of the product breakdown, several levels of modes corresponding the the various system levels can be defined. Here are some examples of high level modes for a satellite: Umbilical to sun acquisition, Slow slew, Manoeuver, Observation high declination, Observation low declination, Safe,etc

Then, a power consumption value can be associated to each mode of each component. Of course, this only makes sense for components that actually consume electrical power: purely structural or mechanical components do not consume power, and the notion of modes is not relevant for them. The proposed methodology naturally excludes these components from the analysis.

3.2 Mapping of modes between system layers

Similarly to the mass analysis, the idea of the power consumption analysis is that the global power consumption of a system is the sum of the power consumptions of its constituents. Because the concept of modes is introduced, there is a need to represent the mapping between high level system modes at which the analysis is made, and the component modes at which the power consumption is available. In other terms, it is required to know for each system modes what are the active modes of each constituent of the system. This is the so-called “mapping of modes between system layers”.

3.3 Mapping of modes between customers and suppliers

As for the mass analysis, the power consumption viewpoint analysis is performed all along the Product Breakdown Structure. Therefore, the concept of allocation and aliases between components of the PBS is re-used. Because it is needed to have a mapping between the modes as viewed by the customer and those viewed by the supplier for a given element of the PBS, the same allocation and alias concepts for the modes are used. This is illustrated on Figure 3.

3.4 Power Consumption computation

Once the two types of mapping are completely defined, the relations between the modes of different system layers of the PBS can be represented under the form of a graph, that is called the “Modes Breakdown Structure”. An example is given in figure 4.

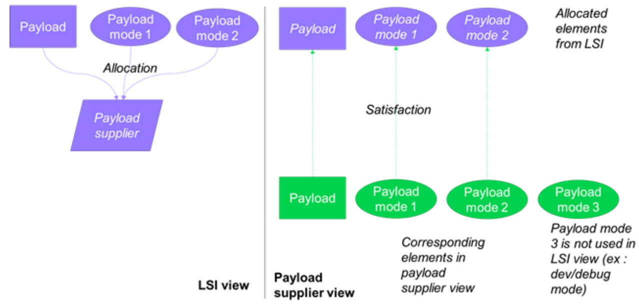

Figure 3: Modes mapping between customer and supplier.

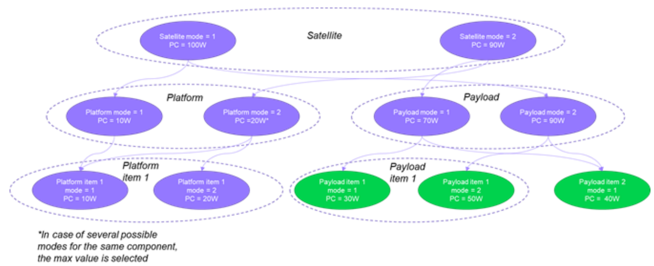

Figure 4: Modes Breakdown Structure and power consumption roll-up.

In order to compute the power consumption for a given system mode, an algorithm goes along this Modes Breakdown Structure and performs a roll-up computation of the power consumption.

4 EXPERIMENT

The proposed methodology has been validated on a case study that is similar to the one used in [2]. This case study involves an agence (ESA), a Large System Integrator (LSI) and its suppliers (see Figure 5).

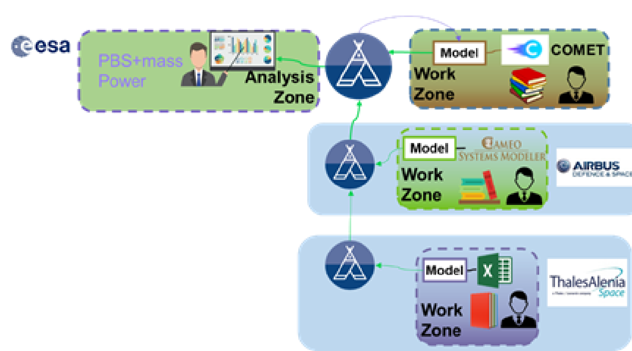

Figure 5: Simulated Extended Enterprise.

The proposed *Power Consumption modes* viewpoint has been added to TeePee, which has required the definition of a dedicated pivot meta-model, the extension of the existing connectors to the various modelling tools, along with the adaptation of aggregation principles to take into account the modes mapping rules.

New visualisations dedicated to this power consumption analysis, and the capability to bring back the resulting top-level power consumption values to the ESA model, have also been implemented.

4.1 Case Study

The considered system-of-interest for this experiment is a generic satellite system, composed of a Service Module and a Payload Module. Each module is then composed of several components. In order to be representative of an Extended Enterprise context, the satellite representation is split into three different models that correspond to the stakeholders: ESA, LSI, Payload supplier. This is illustrated in fig 6.

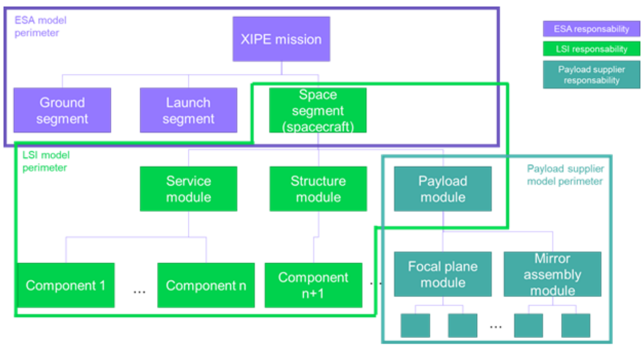

Figure 6: Split of satellite representation in different models.

Here are some metrics about the complexity of the case study:

- 6 system levels
- 6 high-level power consumption modes
- about 80 low-level items

4.2 Simulated Extended Enterprise Network

To assess the relevance of our proposed solution, the Extended Enterprise network of figure 5 has been simulated.

It shows that the Extended Enterprise network is composed of three companies with two levels of suppliers. The *ESA*'s *Decision Cockpit* provides analyses based on the SE data federated by the various instances of the TeePee tool installed on each supplier's premises. Additionally, each supplier may also implement its own decision cockpit.

It is assumed that each company of the network creates its models using different modeling tools, languages, and methods from each other:

- ESA model is implemented within the COMET tool, and shows the whole mission level (including ground segment, launcher and space segment)
- LSI model is implemented within Cameo Systems Modeler, following the modeling methodology used by Airbus Defence and Space. This model represent the whole satellite (corresponding to the space segment of the ESA model), assuming the Service Module design is under the LSI responsibility. The Payload module appears as a black box in the LSI model.
- The Payload Supplier model is implemented within the IDM-CIC tool as done by Thales Alenia Space. The corresponding data is exported in Exago (see [3]), then to an Excel file. It represents the detailed design of the Payload Module.

4.3 Results

The Power Consumption viewpoint provides two possible views: one synthetic view that just gives the targeted and estimated power consumption for the top-level modes in the form of a bar chart (Figure 7), and one detailed view that gives all the modes and power consumption information in a table (Figure 8).

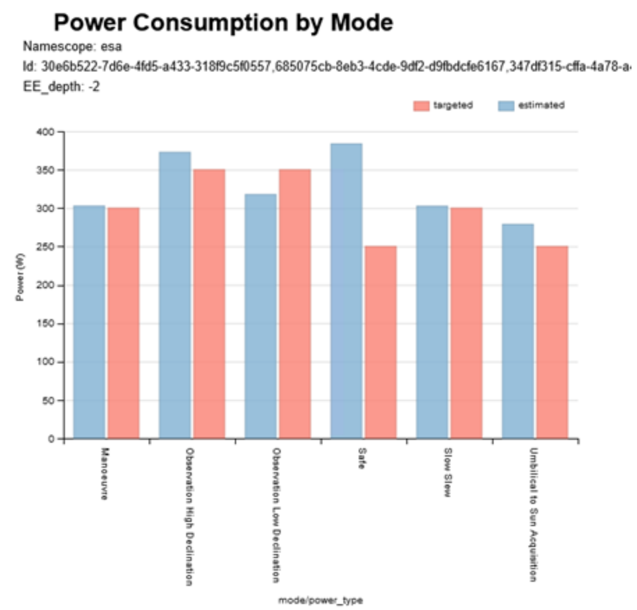

Figure 7: Bar chart visualisation.

In this bar chart view, the targeted values in red are the Reference values from the ESA model. And the estimated values in blue are computed by TeePee, from the content of the Airbus Defence and Space and Thales Alenia Space models.

Product Breakdown Structure	Observation High Declination (Target: 350.0W)	Manoeuvre (Target: 300.0W)
- Spacecraft	372.566W (Observation High Declination)	302.766W (Manoeuvre)
- Service Module	*302.57W (roll-up)*	*302.77W (roll-up)*
- AOGNC	*154.52W (roll-up)*	*154.52W (roll-up)*
STR Sodern Hydra Electronics Unit 1	1.12W (On)	1.12W (On)
MTQ Zarm MT110-2	2.9W (On)	2.9W (On)
GYRO Selex Galileo Sireus 1	0.0W (Standby)	0.0W (Standby)
GYRO Selex Galileo Sireus 2	0.0W (Standby)	0.0W (Standby)
RW Rockwell Collins RSI 12	90.0W (On)	90.0W (On)
STR Sodern Hydra Electronics Unit 2	11.0W (On)	11.0W (On)

Figure 8: Table visualisation.

In this table view, the first column corresponds to the PBS, and the other columns represents the high level modes (corresponding here to the spacecraft modes). Then, each line gives the power consumption value in this high level mode, and the active mode considered for computation. When the mention “roll-up” appears, it means that no modes were defined for the corresponding component. In this case, the power consumption value is the sum of the consumptions of the child components.

In addition to the results presented in [2], a capability to bring back information resulting from the analyses described earlier back to the COMET tool has been implemented. In the proposed implementation, the COMET capability to give several values for each parameter (see Figure 9) is leveraged: the “Reference” value is used as the target value for the TeePee analysis, and using the “close the loop” functionality updates the “Computed” value.

Name	Computed	Manual	Reference
peak consumed power			
Umbilical to Sun Acquisition	278.716	-	250
Observation Low Declination	**317.566**	-	**350**
Manoeuvre	302.766	-	300
Slow Slew	302.566	-	300
Safe	383.546	-	250
Observation High Declination	372.566	-	350

Figure 9: Computed power consumption values updated in COMET.

5 CONCLUSION

This paper sums up the activities realised in the second part of the TeePee4Space project. The purpose is to apply the Information Sharing in Extended Enterprise methodology to the Power Consumption budget analysis. To do so, a methodology for this analysis has been defined, based on the Power Consumption modes, and the associated viewpoint has been implemented in TeePee . Adequate visualisations are proposed, and a capability to bring back the computed top-level power consumption values to the ESA tool has been added. A case study, representative of the space industry context, has been used for the validation of this implementation.

This work represents the second and last part of the TeePee4Space project. This achievement opens some perspectives for future research activities around the topic of Information Sharing in Extended Enterprise. One perspective would be to take advantage of the OSMOSE initiative which aims at defining a Space System Ontology (see [1]). Indeed, as TeePee relies on the concept of viewpoints for which a simple data model is defined and agreed between stakeholders, such an ontology would be very relevant to be implemented as a more complete data model in Teepee.

Other axes for the development of TeePee could be:

- The integration of the model aggregation principles of Teepee with the model review concepts defined in the EasyMOD OSIP project, in order to enable the review of unified aggregated models,
- Taking advantages of the capacities of TeePee to aggregate data from heterogeneous models to allow the comparison and the consistency management of different views on a system (ex: safety, simulation,. . .) or from different suppliers during a Request for Quotation phase.

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