

COMBINING SYSTEM AND PROCESS MODELING TO ACHIEVE BETTER EFFICIENCY IN CATERING

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Abstract

In aviation, improving onboard efficiency, particularly reducing mass, volume, and power consumption, is crucial for reducing environmentally harmful emissions and lowering operating costs. System modeling forms an engineering basis to describe the technical characteristics of individual systems and their architecture, e.g. the aircraft galley, including their components, interfaces, dependencies and functional relationships. However, while this structural view is vital, it does not reflect how a system is actually used in operational processes. As a result, important opportunities for more efficient operation and use, e.g., in the catering process value chain, often remain undiscovered. Therefore, this work combines system structural modeling with process behavioral modeling using the example of an aircraft galley. The galley system and the flight catering process are both described using the Systems Modeling Language (SysML), a modeling language standardized by the Object Management Group (OMG). The catering process is represented as a sequence of process steps involving the use of catering supplies, galley inserts (GAINs) for meal and beverage preparation, serving trolleys, working environment, energy requirements and human actors such as cabin crew. The process model enables formalization, analysis and comparison of different operating variants for business goal achievements and revenues increase. Each input and output of a process step can be parameterized with assumptions or expected values, allowing simulation and evaluation of process changes across multiple variants. By interaction between the process model with the system model, the approach demonstrates how operational behavior influences resource utilization and overall efficiency. This combined system and process perspective reveals opportunities for improvement that remain hidden in a pure structural description, which describes only the systems architecture, but not its behavior and use. Thus, combining system and process modeling supports more improved galley design and more efficient catering processes.

Keywords

System modeling, process modeling, operational and business processes, system requirements, structural and behavioral design

1. INTRODUCTION

The aviation industry is increasingly aiming to reduce environmentally harmful emissions and improve economic performance by lowering operating costs and increasing revenue, while maintaining a high level of safety and customer satisfaction. Within the aircraft cabin, the galley represents the largest electrical consumer. With a possible maximum rated power of up to 75 kW, the galley accounts for the highest electrical demand among all cabin systems [1]. In addition to energy demand, catering items add to the aircraft payload. On a Boeing 747, for example, the catering load can be around six tons [2]. This heavily contributes to fuel burn and CO₂ emissions, making the galley and the catering process relevant targets for efficiency improvements.

The aircraft galley represents a complex system composed of multiple interacting subsystems. To manage this complexity, system modeling is used to describe the galley's structure, functions, dependencies, and interfaces. However, the usage of resources by the galley as well as other cabin systems within the catering process, which aims

to deliver customer service, cannot be captured within system models. As a result, potential improvements within the catering process, such as better resource utilization, remain insufficiently revealed and cannot be reflected within the system design. This limitation hinders identification of optimization opportunities that could support the achievement of overall business goals. E.g., processes for solid municipal waste (MSW) management in civil aviation are modelled and analyzed at the organizational level [3], while SysML-based toolbox approaches enable simulation-based analysis of business processes to study behavior and the effects of changing resource allocations [4]. Authors in [3] and [4] focus primarily on the analysis and simulation of business processes, however, they do not consider the interaction between business processes and the system.

This paper combines system modeling with business process modeling by interfacing an aircraft galley system with a flight catering business process using the Systems Modeling Language (SysML) [5]. The added value obtained from the analysis of the business process model is incorporated into the system design at the system model

level, and consequently, the resulting system design supports the business process.

In commercial aviation, a distinction should be made between operational processes and business processes. An operational process can be defined as a set of interrelated activities required to operate an aircraft in a way that ensures safe take-off, flight and landing, in full compliance with authorities regulations and aircraft certification. In Europe, these regulations are specified by the European Union Aviation Safety Agency (EASA) under Air Operations (EASA-OPS) [6], which evolved from the earlier EU-OPS framework. This framework defined minimum safety and operational procedures for commercial passenger and cargo fixed-wing aircraft and was largely based on JAR-OPS 1, developed in cooperation with the preceding Joint Aviation Authorities (JAA) [7].

An Original Equipment Manufacturer (OEM) designs the operational processes in full compliance with these regulations. After the operational processes are defined, they are approved by EASA, granting the authorization to operate the aircraft. The airline wants to achieve its business goals with safe aircraft operations serving as the foundation. Achieving business objectives can be viewed as a business process, which is defined as a set of interrelated activities executed by one organization or collaboratively by multiple organizations in order to fulfill business goals and to generate revenue [4]. These business processes may be organized flexibly by the airline, as long as the prescribed operational processes are not negatively affected.

In this work, the business goals of the airline and the identified value of catering are formalized as a SysML-based business process model that describes the catering process. The catering process is represented as a sequence of process steps. The model is then analyzed by parameterizing the inputs and outputs of the process steps with expected values, enabling simulation and evaluation of process changes across multiple variants. The added value or decisive variants resulting from the analysis and comparison of different alternatives are economically assessed and accepted, and subsequently drive the definition of use cases in the system model to provide a technical response. This interaction between the system architecture model and the process supports a more elaborated design and a more efficient and effective catering process.

2. PROCESS MODELING

A process is defined as a set of interrelated or interacting activities that transform inputs into outputs. These activities are performed by stakeholders who contribute to achieving a specific outcome [8]. In aviation, it is important to balance revenue, customer satisfaction, CO₂ emissions, and complying with safety regulations. To achieve that, it is useful to model business processes performed by the involved stakeholders in order to visualize, analyze, and improve the workflow and support the achievement of business goals. In addition, compliance with safety regulations is essential in aviation. These regulations are translated into operational processes that must be followed. Therefore, business processes have to be adapted by implementing the required operational steps within the

operational process to ensure compliance with these regulations.

2.1. Operational process in aviation

To operate a commercial aircraft, an airline must hold an Air Operator Certificate (AOC). This AOC is the license, *i.e.*, the formal authorization issued by a national aviation authority such as the EASA in Europe that allows an organization to perform commercial air transport operations [9]. To receive an AOC, the airline must demonstrate that it has the necessary personnel, systems, procedures, and aircraft in place to ensure safe and reliable operations [10]. Moreover a "MRO capability or contract according to EASA Part 145 [11] is required". Once the AOC is granted, the airline is legally allowed to operate flights. However, holding an AOC does not remove the airline's responsibility to follow operational rules. In Europe, these rules are defined by the previously mentioned EASA-OPS requirements. The airline translates these operational requirements into operational processes that must be followed. For example, during a flight, specific safety procedure must be applied when turbulences occur [6]. Turbulences may occur while the catering service is happening. In such situations, the service must be paused, heavy catering items have to be stored, and further appropriate actions must be taken depending on the intensity of the turbulence [12].

2.2. Business process

Scheer and Jost [13] understand a business process as the model-based description of the functions to be carried out by several organizations or organizational units, using information and communication technologies, in terms of content and time. Functions are understood to mean individual tasks and activities that are linked to each other via triggering or generated events. It serves to create services in accordance with the predetermined, process-oriented goals derived from the corporate strategy. A business process can be formally described at different levels of detail and from different perspectives.

The business process is initiated by a starting event and is executed within the constraints of operational and safety regulations. Output of the process is the delivered customer service, while the process execution supports the achievement of business goals, as depicted in Figure 1. In the context of the catering process, one business goal is to ensure efficient catering operations for a flight, thereby reducing operating cost, increasing revenue and reducing CO₂ emissions. Another business goal is to increase customer satisfaction through the delivery of high-quality service. Based on these goals, the catering process is formalized and represented in the form of a business process model.

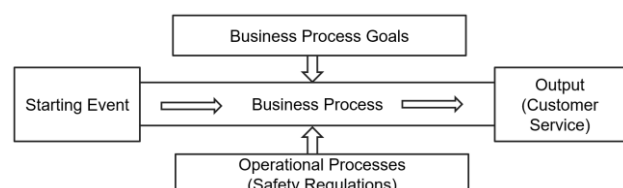


FIG 1. Business process schematics with influencing factors.

2.3. Modeling the catering process using the SysML

The catering process in aviation is considered a highly complex process, because it requires the coordination of multiple direct and indirect stakeholders, compliance with operational and safety regulations, and the efficient management of resources and information. In addition, the complexity is increased by the high number of passengers that must be individually served under strict time and quality constraints. For long-haul flights, the situation becomes even more demanding, as multiple meal services are required during a single flight, which further increases planning and management effort as well as storage requirements and disposal.

The described complexity highlights the need for a model-based representation of the catering process. Therefore, the catering process is formalized as a process model using the SysML. It is widely used in system modeling because it can represent structure, behavior, interfaces, and interactions of a system. In addition, this work also involves the structural modeling of aircraft systems, which is expected to lead to improvements in the overall system design.

An activity diagram is the primary representation for modeling flow-based behavior in SysML [14]. The activity diagram defines the actions in and activities along with the flow of input/output and control between them. Actions can include input and output pins, which serve as buffers for elements exchanged between actions as the execution of an activity either consumes or generates them. These elements may represent physical materials, energy, power, data, information, or any other type of entity that can be produced, transferred, or consumed, depending on the system and the modeled activity. Within the catering process context, such elements can refer to quantities of meals, volumes of beverages, passenger numbers, or required electrical power during process execution. In SysML activity diagrams, the flow of data and control between actions is represented by tokens. Tokens carry the values of inputs, outputs, and control signals from one action to another. An action processes the tokens available on its input pins. Input pins temporarily store incoming tokens until the action starts or during its execution. Once processed, the tokens are produced on the output pins, where they can be taken by subsequent actions.

In this work, the type of action mainly used is the Call Behavior Action. This type of action invokes a behavior during its execution. The invoked behavior is typically another activity. A Call Behavior Action contains pins whose names, multiplicities, and types must correspond to the parameters of the invoked behavior. Figure 2 illustrates a Call Behavior Action that invokes the behavior process step and contains input and output pins. The action also includes

one incoming and one outgoing control flow, represented by dashed arrows.

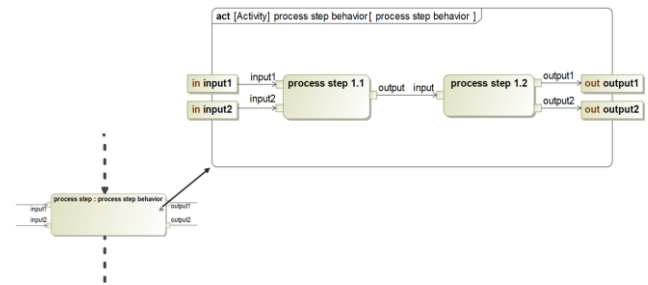


FIG 2. A call behavior action with its invoked behavior.

In Activity Diagrams, activities can be grouped by so called swim lanes to indicate responsibility (cf. Figure 5 and description there). Each swim lane represents a specific role, stakeholder, or organizational entity responsible for performing the associated activities. By partitioning the workflow, swim lanes provide a structured view of the behavior within the process and can be arranged either horizontally or vertically.

Another SysML diagram used during stakeholder modeling is the Block Definition Diagram (BDD). It provides a structural view of the system by defining blocks and the relationships among them. The BDD helps represent system hierarchies, stakeholder-related entities, and their interactions through compositions, generalizations, and dependencies, thereby supporting a clear understanding of the architecture [15].

The catering process comprises three main Phases: *pre-flight*, *in-flight*, and *post-flight*. Each phase involves operations that ensures catering is produced, delivered, stored, prepared, served, and disposed after the flight, as shown in Figure 3. To ensure that passengers are catered during the flight, several stakeholders contribute and collaborate within the catering process. The caterer supplies the airline with meals, beverages, and, if required, additional items such as paper goods, magazines, or headsets. The caterer essentially fulfils two main roles: first, preparing items that are not directly sourced from external suppliers into a flight-ready condition; and second, assembling trays and catering trolleys for onboard service. The caterer works directly for the airline and operates in accordance with its requirements and specifications. In this relationship, the end customer is not the paying passenger but the airline itself, which defines the requirements and expectations for the catering service. In addition, the caterer maintains relationships with various suppliers. If the airline decides to procure certain items from these suppliers, caterer manages the sourcing and also handles the storage of these goods [16].



FIG 3. Overview of the catering process across the phases pre-flight, in-flight, and post-flight.

The actual preparation and production of catering items typically takes place at a local catering production site, which is operated by the caterer, at the departure airport. This facility is responsible for producing, assembling, and preparing all onboard catering elements. After production, the caterer is also responsible for transporting the catering items, which are loaded onto trolleys, to the aircraft.

Another key stakeholder in the catering process is the cabin crew, who are employed by the airline. The cabin crew manages the catering trolleys on board and are responsible for overseeing the in-flight catering process and serving the passengers.

The catering process also depends on supporting external resources such as potable water, which is used for onboard food and beverage preparation. Most airports receive or purchase water from a public water supply system. The water is delivered to the airport and made available to aircraft through the water/waste service provider [17].

Stakeholders are modeled as blocks in the Block Definition Diagram (BDD) and are connected through “directed composition” relationships, as illustrated in Figure 4.

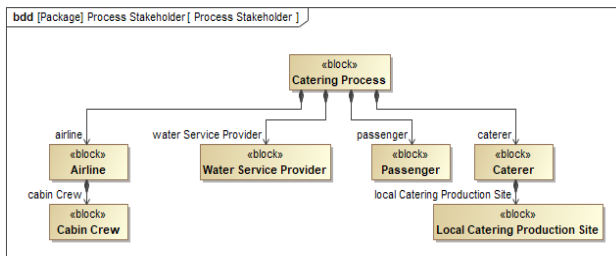


FIG 4. Catering process stakeholders represented in a block definition diagram.

The modeled catering process, which is structured into the three phases pre-flight, in-flight, and post-flight starts with the stakeholder airline and the activity “*plan a flight*” as a trigger event. This activity generates the outputs “*Flight Time*” and “*Location*”. Based on this information, the airline requests a menu offer from the caterer, which is modeled in the activity “*ask for menu offer for certain time and location*”, derived from the output “*Menu Offer Request*” flowing into the caterer. The caterer then prepares the menu offer for the airline, which is subsequently used by the airline to select the menu, as shown in Figure 5. While the complete process model includes all stakeholders identified in Figure 4, Figure 5 presents only an excerpt of the process and focuses on activities performed by three stakeholders airline, caterer, and passenger.

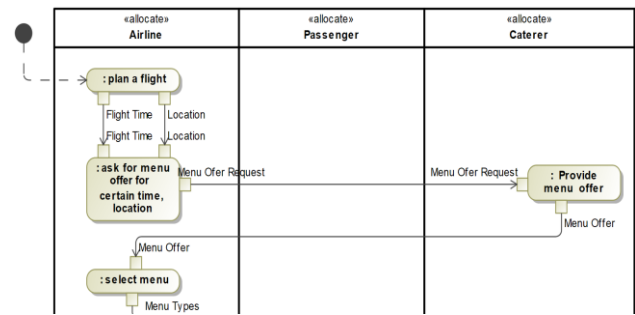


FIG 5. Excerpt of the beginning of the catering process.

After the airline selects the menu, different menu types are generated, which passengers can choose during the flight booking. Based on these selections, the airline can determine and order a specific number of meals as well as the required amount of potable water. For this purpose, an activity “*book a flight*” is modeled in the “*Passenger*” swim lane. This activity includes an internal behavior describing how passengers book the flight, including the selection of meals. This activity generates outputs such as the number of meals categorized by meal type (chicken, beef, and vegetarian), the amount of potable water, and the number of passengers who have booked the flight. These parameters are then passed to the activity “*order menu and potable water*”, which is allocated to the “*Airline*” stakeholder. In this activity, a behavior is modeled to calculate the estimated number of meals and potable water demand, which is then forwarded to the caterer, as shown in Figure 6

Figure 7 illustrates the behavior of the activity “*book a flight*”, modeled in an activity diagram. The diagram contains a decision node that determines whether meal pre-ordering is available.

If pre-ordering is enabled, the activity “*select meals*” is executed. The behavior associated with this activity generates the required number of meals categorized by meal type, as well as the estimated amount of potable water. These values are then transferred to the corresponding output nodes of the activity diagram. If meal pre-ordering is not offered, the required number of meals and the amount of hot beverages are estimated within the behavior of the activity “*order menu and potable water*”. This estimation is based on the parameter “*Passenger Number*”, which is defined in the behavior of the activity “*book a flight*”.

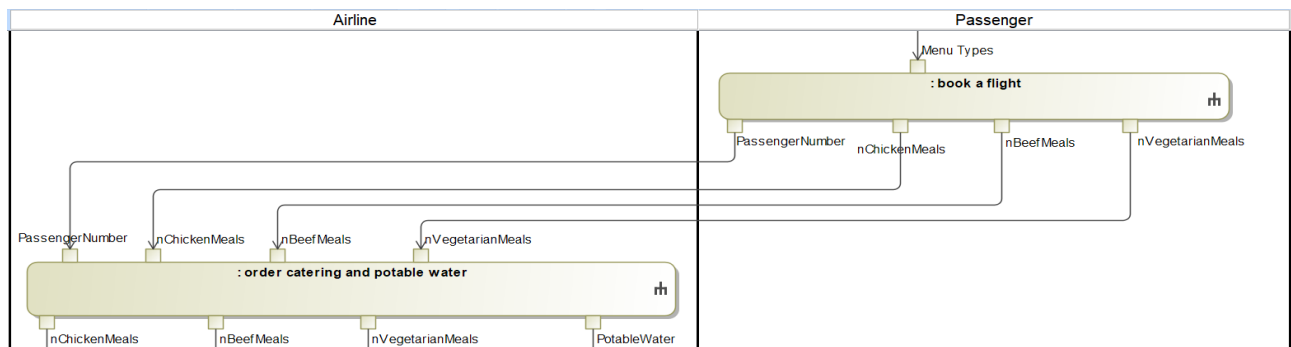


FIG 6. Passenger activity “*book a flight*” and airline activity “*order menu and potable water*”.

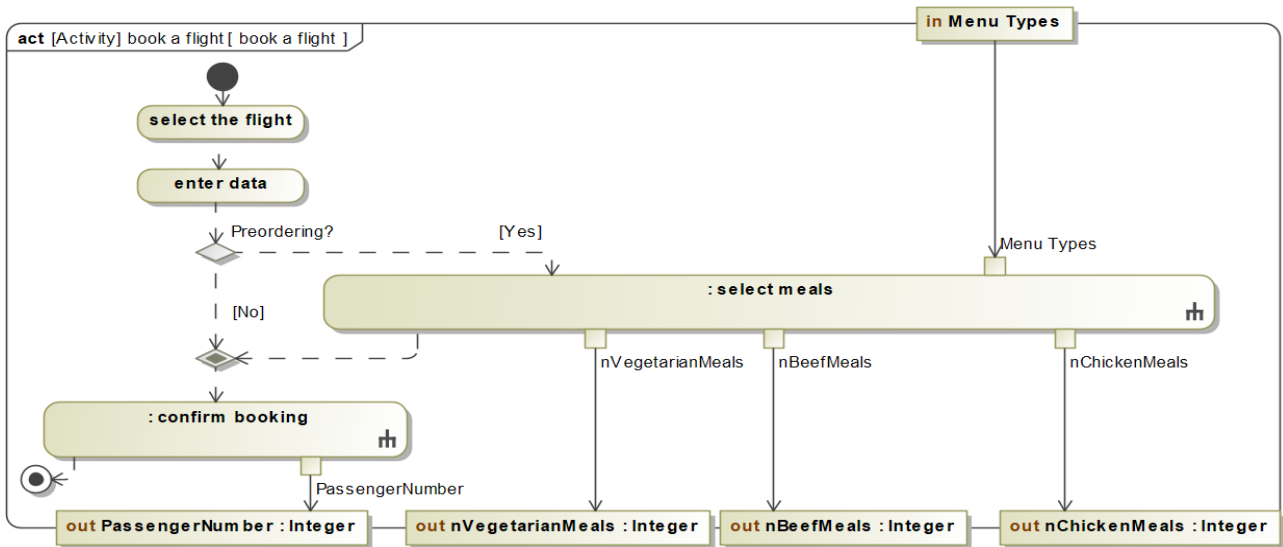


FIG 7. The behavior of the activity "book a flight".

In the behavior of the activity "order catering and potable water", the estimation of meals and hot beverages is performed based on three different variants. In the first variant, all passengers have pre-ordered their meals, allowing the estimation to be determined directly from the available pre-order information. In the second variant, passengers have not pre-ordered their meals; however, a passenger identification (ID) is available to the airline. The passenger ID is a unique identifier assigned to each passenger and is used to access passenger-specific information, such as the passenger's name and dietary attributes (e.g., vegetarian or other nutritional requirements). Although the passenger's specific meal is not known, the available passenger information allows the range of possible options to be restricted, thereby enabling a more informed estimation. In the third variant, no passenger ID is available to the airline. Consequently, the passenger cannot be linked to passenger-specific information, and neither dietary attributes nor individual preferences can be considered in the estimation. As shown in Figure 8, the decision element "all Preordered?"

determines whether the estimation is performed according to the first variant, in which only the beverages are estimated, or according to the other two variants, in which both meals and beverages are estimated. If no pre-ordering is available, the decision element "ID Known?" is used to determine whether the estimation of meals and hot beverages is carried out according to the second or the third variant.

The estimation of the required number of meals and the amount of potable water is performed by an activity using equations implemented within an Opaque Action in Python. An Opaque Action enables the integration of external implementation logic for functions that cannot be directly expressed using SysML modeling elements. An example is the activity behavior "estimate number of meals and amount of beverages without ID", which is illustrated in Figure 9. Within this activity, predefined parameters such as "OverloadFactorWithoutID", "ShareBeef", "PassengerWater Share", and "FlightDuration" are called.

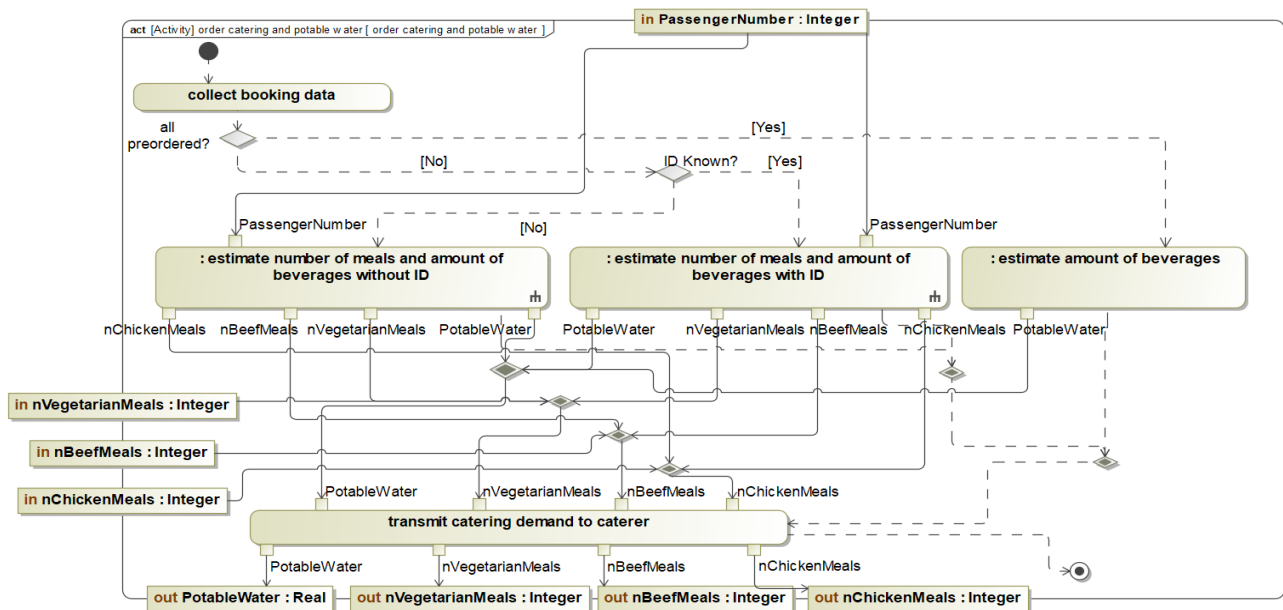


FIG 8. The behavior of the activity "order catering and potable water".

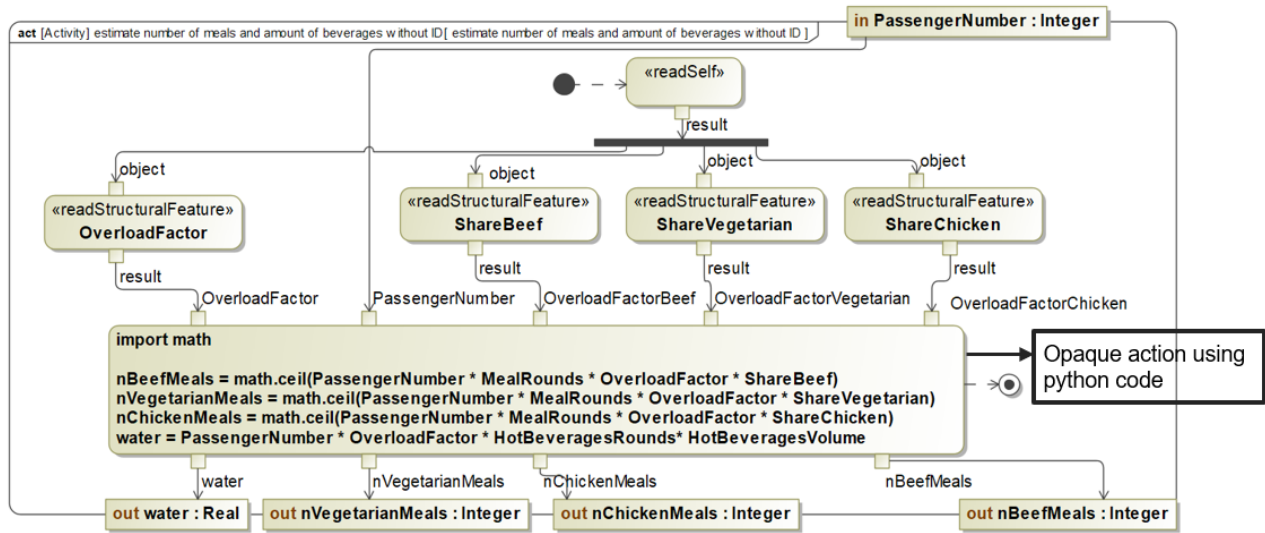


FIG 9. Calculation of required meals and potable water for the third process variant with an opaque action using python code.

Based on these parameters, the required quantities of meals for the different meal types and the amount of potable water are calculated. The resulting values are subsequently propagated through the process and serve as an input for downstream activities.

2.4. Analysis of the catering process

The parameter definitions were based on a Boeing 777-300ER operated by Turkish Airlines, assuming a passenger load of 300 economy class passengers and 49 business class passengers. The analysis focuses exclusively on the economy class service, considering two meal service rounds and three rounds of hot beverage service during the flight. The number of economy class seats was assumed to be equal to the number of passengers, cf. “*Passenger Number*”. During the simulation of the modeled process, the activity “*order catering and potable water*” generates the required number of meals for each meal type and the amount of potable water required for the preparation of hot beverages, depending on the selected variant, as an output.

In the first variant, the selected meal option is uniquely assigned to a specific seat and passenger, resulting in a fixed allocation. Consequently, the catering process is based on a clearly defined actual state. A one-to-one relationship exists between each seat and the corresponding meal order. Therefore, no estimation is required, and both over- and undersupply are significantly reduced. As meals are preordered, the actual demand for meals can be determined precisely. This enables a reduction in excess meal loading. In this variant, the catering load exactly matches passenger demand, resulting in a demand fulfillment rate of 100%. Regardless of whether additional passenger information or passenger ID is available, this variant provides the highest added value with respect to mass, volume, power, and fuel savings.

In the second variant, no fixed assignment exists between a passenger and a specific meal; however, the range of possible options can be narrowed based on available

passenger information. For instance, if a passenger is known to be vegetarian, a beef meal does not need to be considered for that passenger. Similarly, known preferences or passenger attributes can support an estimation of the passenger's meal. As a result, the required catering quantities can be reduced and planning reliability can be improved, allowing for a partial optimization of the meals loaded on board. Since uncertainties regarding the final passenger choices still remain, a catering buffer is required. Therefore, the catering load is assumed to correspond to a demand coverage rate of 110%. Overall, this variant provides a medium level of process benefit, as no fixed selection exists, but relevant passenger information is available to support the planning process.

In the third variant, the catering process must rely entirely on estimations and therefore has to be planned with high safety margins. This requires larger quantities of meals to be loaded on board. Since no passenger-specific information is available, personalization is not possible and the level of uncertainty is maximal. To ensure sufficient catering supply under these conditions, a demand coverage rate of 120% is assumed. Consequently, this variant provides the lowest process benefit and represents the least efficient catering strategy.

For all three variants, the required amount of potable water is determined based on the estimated beverages consumption. The analysis is limited to hot beverages.

The meals and potable water ordered by the airline are represented by the activity “*order catering and potable water*” and are modeled as input parameters to the process section illustrated in Figure 10. Based on these parameters, the activity “*provide electrical energy*” models the electrical energy required for meal heating and hot beverage preparation through the output parameters “*eEnergyMeals*” and “*eEnergyBeverages*”, respectively. The activities “*prepare meals*” and “*prepare hot beverages*” are allocated to the “*Cabin Crew*” stakeholder.

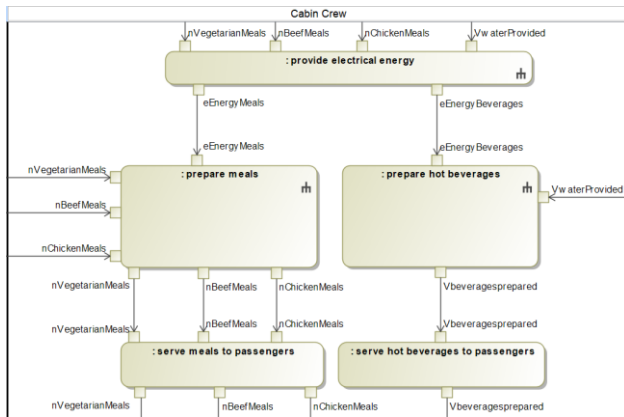


FIG 10. Excerpt of the meal and hot beverage preparation during the flight.

Based on these parameters, the activity *"provide electrical energy"* models the electrical energy required for meal heating and hot beverage preparation through the output parameters *"eEnergyMeals"* and *"eEnergyBeverages"*, respectively. The activities *"prepare meals"* and *"prepare hot beverages"* are allocated to the "Cabin Crew" stakeholder.

According to the process simulation, the corresponding parameters were determined for each variant, as presented in Table 1. These parameters include the total number of meals and the amount of potable water required, based on two meal services (i.e., 2×300 meals) and three hot-beverage rounds, assuming a volume of 150 ml per hot beverage. These quantities are generated by the "order meals and potable water" activity illustrated in Figure 6. In addition, the quantity of remaining unconsumed items is generated by the "consume meals and hot beverages" activity. The electrical energy required for meal heating and hot beverage preparation is generated by the "provide electrical energy" activity illustrated in Figure 10, and is calculated using the sensible heat equation.

TAB 1. Determined parameters from the process analysis.

	Demand Coverage Rate	Total Number of Required Meals	Non-Consumed Meals	Electrical Energy for Heating Meals [kWh]	Electrical Energy for Preparing Hot Beverages [kWh]
Variant 1	100%	600	0	11	11
Variant 2	110%	660	60	12	11
Variant 3	120%	720	120	14	11

The numbers in Table 1 indicate the potential savings that can be achieved by implementing each variant. Once the business management selects one of the variants, its implementation is supported by the developed system with corresponding savings.

3. INTERACTION OF PROCESS AND SYSTEM MODEL

A system model defines the structure, behavior, and various views of a system. It comprises system components

and subsystems that interact and work together to realize the overall system functionality. To model a system, it is necessary to understand the wants and needs of prospective users. These requirements are modeled by so called use cases. A use case represents a piece of functionality in the system that provides a user with a result of value. Use cases capture the functional requirements of the system. Altogether the use cases describe the complete functionality of the system. In addition, use cases drive the design, implementation, and testing of the system. [18].

The use case model is described using SysML use case diagrams. Use case diagrams are central to modeling the behavior of a system or subsystem. They show use cases, actors, and their relationships, supporting the visualization, specification, and documentation of an element's behavior. By presenting an outside view of how elements may be used in context, they make systems and subsystems more approachable and understandable. An actor is someone (e.g. a user) or something (e.g. another system) that interacts with the system being developed, whereas a use case represents a pattern of behavior exhibited by the system. Each use case consists of a sequence of related interactions performed by the actor and the system in a dialogue. Furthermore, use cases can be structured through include, extend, and generalization relationships, while actors can be structured using generalization relationships [19]. A use-case diagram is used to graphically depict a subset of the model to simplify communications. There will typically be several use-case diagrams associated with a given model, each showing a subset of the model elements relevant for a particular purpose. The same model element may be shown on several use-case diagrams [20].

Business processes are beneficial for the purpose of requirements specification. The goal of requirements specification is to describe what the system should do by specifying its functionality [19]. The activities of the process that will be supported by the newly developed system are identified. A use case is then derived from each of these activities. The remaining activities are performed by humans and are therefore excluded from the use case model. Every activity may have an associated behavior, which can be modeled using an activity diagram. If this behavior includes activities that are supported by the newly developed system, additional use cases can be derived from these activities. These use cases are then related to the corresponding parent use case through either an include or an extend relationship.

As mentioned in Section 2.3, there are three variants of pre-ordering. To support these variants, a one-to-one derivation approach is applied, in which each modeled activity is transformed into a corresponding use case. In this work, the use cases derived from the process model are classified into multiple use-case diagrams. Each diagram represents a group of use cases that share common objects and closely related responsibilities. In addition to use cases and actors, blocks are modeled in the use case diagram to represent the context of each use case and to illustrate the relevant interfaces identified in the process model. Each block corresponds to one or more activities in the process model that are directly connected to the activity from which the respective use case is derived. This representation establishes a clear link between the process model and the use case model and provides a structured view of the interactions and system boundaries relevant to each use

case. As illustrated in Figure 12, the use cases derived for variant one are organized into two use case diagrams. The first diagram represents the booking system and includes the use case “*book a flight*”, which in turn includes the use case “*select meals*”. This inclusion relationship reflects that the selection of meals is performed as part of the flight booking. Both use cases are represented together with their respective contexts, including the relevant interfaces identified in the process model. The second use case diagram represents the catering and potable water ordering system and contains the use case “*order catering and potable water*”, which includes the use case “*estimate amount of beverages*”, together with its corresponding context. Figures 13, and 14 illustrate the derived use cases for variants two and three, respectively. A key difference between the derived use cases across the three variants is that, in variant one, the use case “*select meals*” is carried out without estimating the required meal quantities, since all passengers select their meals when booking the flight. Consequently, the required quantities are already known when the order for meals and potable water is placed, while the amount of beverages is estimated.

In contrast, the variants two and three include the use case estimation the number of meals and amount of beverages, as passengers book their flights without selecting meals. Therefore, the required quantities must be estimated by the airline before the catering order is placed. In variant two, this estimation is based on the passenger ID and corresponding information. As illustrated in Figure 13, the use case “*estimate number of meals and amount of beverages with ID*” is included in the use case “*order catering and potable water*”. In the third variant, the corresponding estimation is performed without using passenger ID. The resulting derived use cases for variant three are illustrated in Figure 14. The actors defined in these diagrams are “*Airline*” and “*Passenger*”. The activities from which the use cases are derived are assigned to the corresponding stakeholder swim lanes. Therefore, the stakeholders responsible for these activities are represented as actors in the use case diagrams.

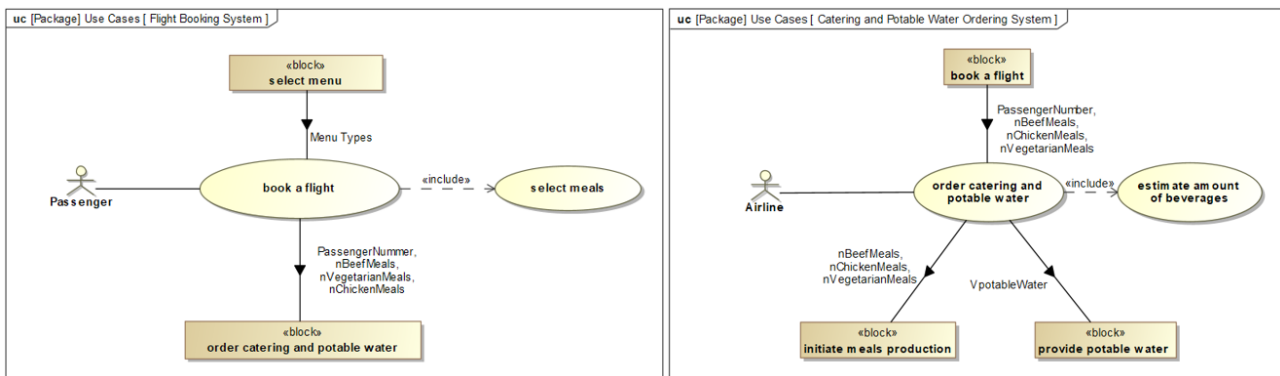


FIG 12. Derived use cases from the first process variant in process model.

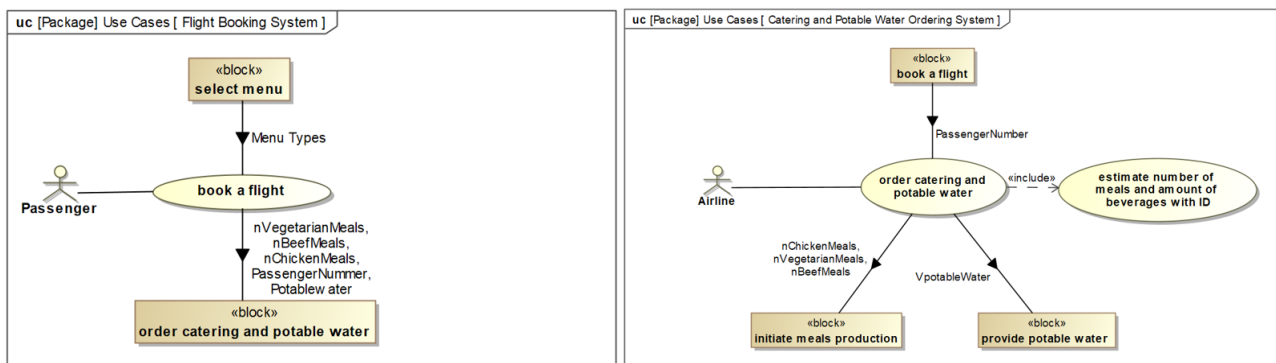


FIG 13. Derived use cases from the second process variant in process model.

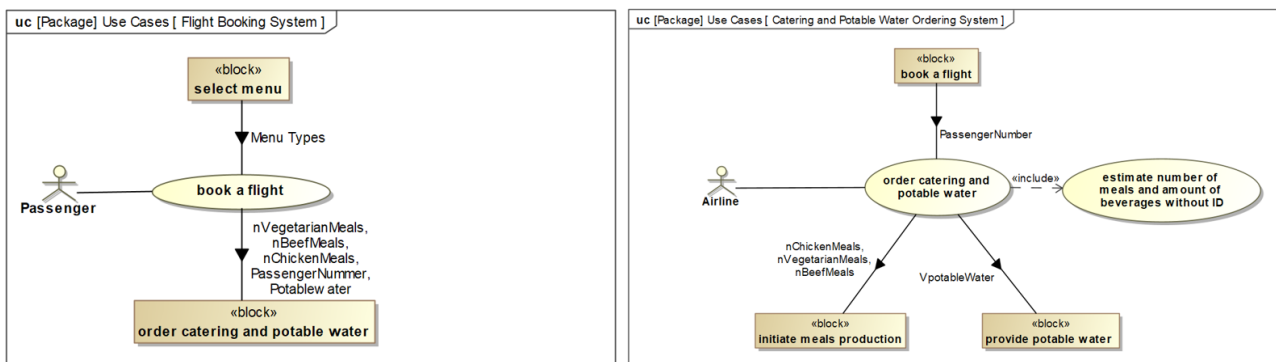


FIG 14. Derived use cases from the third process variant in process model.

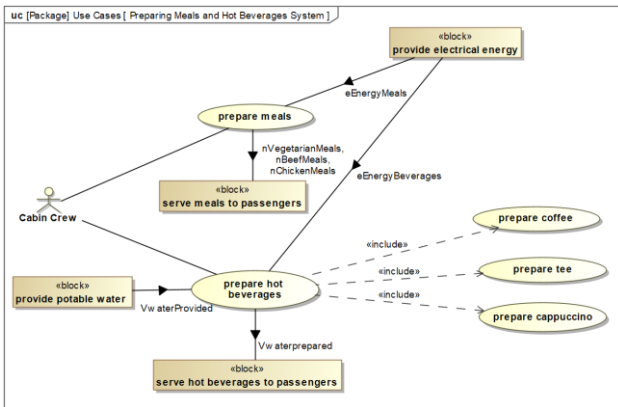


FIG 15. Derived use cases from the activities “prepare meals” and “prepare hot beverages”.

In the same way, use cases are derived from the activities illustrated in Figure 15, namely “*prepare meals*” and “*prepare hot beverages*”, along with its internal activities “*prepare coffee*”, “*prepare cappuccino*”, and “*prepare tea*”.

4. RESULTS AND DISCUSSION

To conserve resources and reduce CO₂ emissions, it is important to understand in detail and to carefully analyze the activities involved in the in-flight catering service as well as the galley system used for this purpose. To achieve this, the strength of SysML lies in its ability to describe complex systems in an interdisciplinary, standardized, and holistic manner. In particular, it can model the structure and behavior of systems, as well as use cases, requirements, and parameters of physical or mathematical laws. To understand volume requirements, mass, and electrical power consumption in detail and to calculate the resulting CO₂ emissions, SysML was used for system and process modeling with the goal of improving the system's effectiveness and efficiency. Table 2 shows the effects of the system-supported process under consideration on the mass of meals, the number of trolleys with their corresponding volume, the mass of required potable water, and the amount of electrical energy for heating meals and beverages. These figures in Table 2 apply to a Turkish Airlines Boeing 777-300ER aircraft flying with 300 passengers in economy class, who are served with two meal cycles and three rounds of hot beverages from three galleys in use. The parameters were calculated assuming mashed potato meals with a mass of approximately 220 g plus an external aluminum container of 10 g. A hot beverage mass of 150 g was assumed, which is consistent with commercially available 150 ml cups for hot beverages

and aircraft cabin coffee cups [21]. The trolleys under consideration are ATLAS full-size trolleys [22].

Table 2 shows the three catering options:

- Variant 1, based on pre-ordering, includes two meals each for 300 passengers, as well as three cycles with 150 ml hot beverages each.
- Variant 2 is the same as variant 1, but includes an additional 2 × 30 meals to allow a few passengers on board to change their minds at the last-minute during service.
- Variant 3 corresponds to variant 1 but includes 2 × 60 additional meals to allow passengers on board an unrestricted selection of beef, chicken, or pasta. A 120% surplus corresponds to a catering option in which passengers choose a meal spontaneously on board, i.e., without pre-ordering.

Table 2 clearly advertises for variant 1, which is the most economical option in terms of mass transport, use of volume, and consumption of electrical energy. And, variant 3, without pre-ordering is less effective and the most inefficient. This results in a 46 kg increase in mass transport and a 0.26 m³ increase in required storage volume. The electrical energy requirement is also 3 kWh greater in this case. As expected, variant 2, which offers a last-minute choice, falls somewhere between variants 1 and 3 regarding effectiveness and efficiency.

The operational CO₂ emissions associated with the catering mass refer again to the above-mentioned Turkish Airlines flight from Istanbul to Los Angeles with a Boeing 777-300ER aircraft. The great-circle distance between the two airports is calculated according to [23] and results in 11,000 km. For the transport of 1 kg payload per 1,000 km the specific fuel consumption is 0.025 kg [24]. The mass of CO₂ produced by the combustion of 1.0 kg of kerosene (assumed to be a mixture of hydrocarbons of the formula C₉H₁₈ ... C₁₆H₃₄) was calculated stoichiometrically. According to this stoichiometric relationship, 3.15 kg of CO₂ is produced per kg of kerosene, i.e., 0.078 kg CO₂ result from the transport of 1.0 kg catering mass per 1000 km. Using these values and mass data, the CO₂ contribution of catering variant 1 is 332 kg CO₂. Variant 2 and 3 refer to 356 kg and 395 kg, respectively. This clearly demonstrates that, when considering only the transport of catering mass, the pre-ordering variant 1 contributes to a CO₂ reduction of 63 kg on this flight. By comparison, this reduction is roughly equivalent to the amount of CO₂ emitted when transporting an additional weight of 45 kg, i.e., approximately two checked bags.

TAB 2. Impact of system-supported process variants on the mass, volume and electrical energy.

	Mass of Meals [kg]	Required Meal Trolleys (equals a storage volume of [m ³])	Mass of Loaded Trolleys [kg]	Mass of Required Potable Water [kg]	Total Mass of loaded trolleys and potable water [kg]	Total Required Electrical Energy [kWh]
Variant 1	138	6 (= 1.5 m ³)	248	135	383 (= 248 + 135)	22
Variant 2	152	6 (= 1.5 m ³)	262	135	397 (= 262 + 135)	23
Variant 3	166	7 (= 1.76 m ³)	294	135	429 (= 294 + 135)	25

5. CONCLUSION

The entire catering operation – and, for the purpose of the studies presented here, the process phase from flight planning through the flight itself to landing – constitutes a fundamental business process for an airline. This process involves a significant volume of catering deliveries and therefore requires storage space on the aircraft as well as substantial amounts of electrical energy for cooling and heating beverages and meals. To conserve resources and reduce CO₂ emissions, this paper presents the combination of system and process modelling using the SysML and applies this modeling for an analysis of the efficiency and effectivity of an aircraft galley system which is a central element in the catering process. The objective of this work is to demonstrate an approach for linking process modeling and system modeling. The analysis is conducted from the perspective of an aircraft manufacturer. The approach focuses on how opportunities for improving efficiency identified in the process model can be transferred to the system model and incorporated there, thereby supporting their implementation in the process and realizing the associated cost savings. In this paper the system model of the aircraft galley serves as a representative example to illustrate this approach which can be expanded and enriched by incorporating the perspectives of other stakeholders or even transferred and applied to other systems and associated processes. Using the SysML model, the process can be analyzed and the catering parameters can be defined and propagated through the process activities. This approach makes it possible to identify opportunities for more efficient operation and a more effective system; opportunities that would remain hidden if one were to consider only a specific galley layout with installed electrical appliances. The identified potential is transferred into the system model by deriving relevant use cases from the process activities that require technical support from the developed system. These use cases form the basis for the subsequent, more effective system design and the customization of features to support an efficient catering process. Based on three process variants, the results show that this method can demonstrate significant reductions in catering mass, catering volume, and electrical energy consumption in the aircraft cabin.

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