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Individualisation of Inflight Catering Meals—An Automation Concept for Integrating Pre-Ordered Meals during the Flight for All Passengers

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Abstract: Inflight catering services are crucial for air travel. Airlines provide food and beverages to the passengers during the flight with different options depending on, e.g., the flying class, distance, and type of service. Our contribution outlines previous efforts to optimise the inflight catering processes and highlights the possibilities to individualise the current services. Individualisation is a growing trend and may challenge the processes that are possibly not wholly prepared to deliver a customised meal for each passenger onboard the aircraft. We present our passenger survey which confirms the demand for the individualisation of inflight meals; we explored which dimensions can be supported by incorporating automation. We performed an analysis of the current inflight catering process for developing automation concepts. Subsequently, an automation concept for the individualisation of inflight meals through pre-ordering is introduced, followed by an evaluation scenario. Within the evaluation, it was possible to consider the feasibility of the individualisation of inflight catering meals and to deliver requirements for the further development of automated services.

Keywords: inflight meal; individualisation; automation; aircraft cabin

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1. Introduction

The individualisation of meals and beverages to fulfil customers' unique needs is a growing trend in the food industry [1]. It directly impacts supply chain logistics [2]. Individualisation considers modifying one product or service attribute for a better requirement fulfilment [3]. Thus far, the individualisation of inflight meals has not been provided for all passengers and, typically, airlines offer two meals on long-haul flights. Integrating individualised meals for all passengers will impact on different tasks and change operational procedures such as specific heating times or distributing and tracking meals [4]. In this contribution, the terms 'individualisation', 'personalisation', and 'customisation' are used synonymously [5–7]. The personalisation of meals is already integrated by delivery restaurants through online orders, for example, primarily due to digitalisation possibilities [8,9]. The inflight catering service market is highly competitive, pushing down the profit margin per meal and impacting the airline choice from the passenger side [10–12].

Individualisation could support inflight catering services (ICSs), especially if more passengers can be served with customised meals, e.g., in economy class. The current manual distribution of individual inflight meals for all passengers would potentially exceed the service time and increase flight attendant workload, because each individual meal must be assigned to each passenger and seat. The individualisation of meals onboard could be achieved by pre-ordering meals before boarding, which would reduce the amount of work required to prepare them on the aircraft, similar to the current system of pre-ordering special meals. Nevertheless, process changes and the optimisation of current procedures

would be required to avoid potential service delays and additional workloads. This contribution focuses on the integration of pre-ordered meals to achieve individualisation for all passengers.

Airlines are expanding what they offer with ancillary products, particularly during the online ticket buying process, e.g., baggage options, seat reservations, and special meals [13,14]. In this context, the existing process of pre-ordering meals, by making the choice of the desired inflight meal in advance, could enable the individualisation of inflight catering services for all passengers. However, pre-ordering is mostly used for selecting special meals, e.g., vegetarian or halal, and it is mainly motivated by diet, allergies, or religious issues. Airlines may offer the choice of pre-ordering special meals during the ticket booking process, as shown by the example in Figure 1. Additionally, further menu options with extra costs are provided, although no explicit changes in the menu are available, e.g., changing portion size [15].

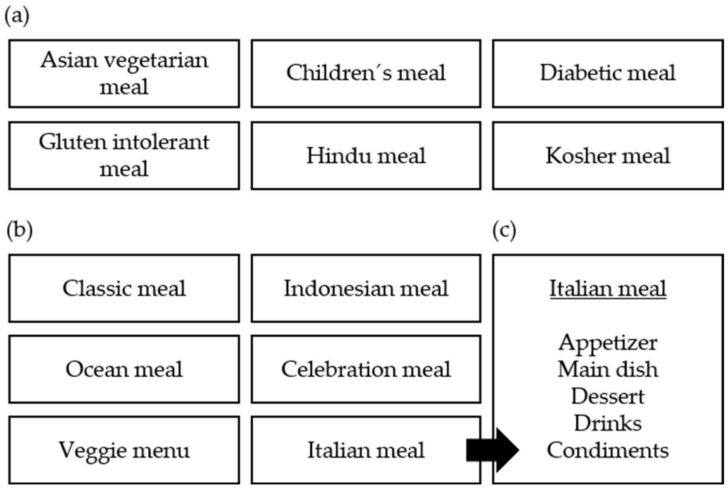

Figure 1. Based on an extract of the pre-ordering options for economy class of an intercontinental flight [15]. (**a**) special meals due to diet, allergies or religious issues (extract), (**b**) further menu options and (**c**) menu detail.

There has been an increase in food allergies among the population, which may impact the choice of inflight meals [16]. Another aspect is the possibility of using pre-ordering to reduce waste [17]. In 2017, airlines generated 5.7 million tons of cabin waste, of which at least 20% consisted of untouched food and beverages [18]. The importance of involving all stakeholders and governing bodies is decisive for improving waste management [19]. In this scenario, although pre-ordering poses advantages for passengers and airlines, the awareness and their use are not broadly acknowledged among passengers. This fact could be stated by the literature review, and confirmed by our survey shown in Section 3.

The optimisation of ICSs has mainly been investigated regarding the ergonomics of flight attendant operations, particularly considering the position and handling of equipment as well as health in general [20–24].

Currently, in full-service carriers (FSCs), the distribution of pre-ordered meals to passengers is mostly not included in the standard meal distribution process; it occurs separately. It is still a subject of observation because little to no public written information documents the procedures, and each airline handles the topic individually. Nevertheless, it can be stated that there is no completely integrated system for including pre-ordering onboard the aircraft, which could enable customised meals for all passengers. This requires the orchestration of the stakeholders involved, e.g., caterer, airline, cabin crew, and passenger, with supply chain processes and services onboard the aircraft cabin. Essentially, the solution must be able to provide individualised meals to all passengers without exceeding the service and turnaround times.

Our research contribution presents a literature review in Section 2 regarding the individualisation of inflight meals and the efforts for optimising the inflight catering services. In Section 3, the methodology is presented in four parts: Firstly, in Section 3.1, we offer the key results of the passenger survey for the individualisation of inflight catering services, which is presented with all questions in the Appendix A; Section 3.2 shows the analysis of the involved processes together with a task classification, for which we derived a metric for the evaluation of optimisation concepts, as also shown in the Appendix A; In Section 3.3, we present an automation concept for integrating pre-ordered meals for all passengers together with a general reference architecture; A validation scenario for individualised inflight meal services with a demonstrator inside a mock-up aircraft cabin is explained in Section 3.4. The results of an initial validation with our demonstrator are shown in Section 4; the focus is on the time impact on the meal-distribution process. The contribution closes with a summary of the critical insights and outlooks for further research in Section 5.

2. State of the Art

This section is divided in two main subsections. Firstly, the current status of inflight catering services is briefly reviewed and the innovations for optimising the inflight catering services are highlighted. Secondly, aspects related to meal individualisation are investigated.

The interconnection of individualisation with automation and digitisation, together with the demands towards sustainability, from social, ecological, or economical natures, will change the ways in which inflight catering services are performed today [2]. The literature review performed with the chosen aspects reflects this view.

2.1. Inflight Catering Services

Inflight catering services have been changing over the years. It is possible to observe the increase in the number of options offered, the types of dishes, and new preparation methods and ingredients. Additionally, the aircraft kitchen—the galley—has constantly been improved, particularly regarding weight and space reductions [25,26]. It is a modular structure with containers, called standard units, and trolleys or service carts used to store and distribute meals and beverages. There are also devices used for meal and beverage preparation, called galley inserts (GAINs), e.g., coffee makers, convection ovens, and microwaves [25]. Usually, the galley is loaded and unloaded by the caterer and is used by the cabin crew, also called flight attendants. A galley may contain more than 10,000 different items for catering to more than 300 passengers, depending on the aircraft, flying route, airline, and carrier type. Weight and space are essential factors inside an aircraft; thus, there is a trade-off between fuel consumption and the number of seats for achieving a profitable business. To allow more space for seats, the galleys are kept lightweight and compact. There are two main standards that define the galley container sizes, KSSU and Atlas/ARINC, although most airlines currently opt for the Atlas/ARINC standard [27].

The aviation catering industry has been considered an immensely "nervousness-sensitive industry". The demand is hardly predictable, because the exact amount ordered depends on the number of passengers, which may only be confirmed immediately before departure [28]. The estimation of the catering amount is a subject of interest, and efforts for optimally adjusting the amount of catering can be seen; different scenarios with over- and undercatering were evaluated within a Markov decision process for identifying the minimum cost for meal ordering [29]. Concerns about improving snack inventory replenishment decisions could be seen, with the estimation of demand also posing a challenge for low-cost carrier (LCC) airlines [30]. Additionally, food waste is a topic which has increasingly been investigated while identifying and reducing the waste produced during inflight catering [31]. The relationship between food quality and passenger satisfaction has been investigated; the results show a direct impact on waste reduction [32]. Even life cycle analysis (LCA)-based methods have been applied to evaluate the substitution of food packaging to achieve a more sustainable food chain [33]. A model for the sustainable

development of catering supply chains has been designed to improve processes and limit waste [34].

There have already been efforts to improve inflight catering services; for instance, by optimising beverage distribution, e.g., SkyTender. This is a system for dispensing drinks, whereby the preparation takes place on-site. Soft beverages consist of water and a flavour concentrate. It is also possible to add carbon dioxide to the drinks. The flavour concentrate is stored in a syrup container. Product variations also enable coffee and tea preparation [35].

Examples of award-winning concepts intended to improve inflight catering services by changing the galley are abstracted shown in the Figure 2, e.g., the SPICE galley system. The SPICE galley has been designed to be more ergonomic and space-saving; however, activities are mainly carried out manually, and there is a low level of digitisation. The core elements are a foldable trolley and various storage modules, e.g., boxes for drinks. The storage modules are located behind sliding doors. In addition, the concept includes a transfer table which is guided on rails in front of the galley. This allows the storage modules or oven racks to be moved more easily [36].

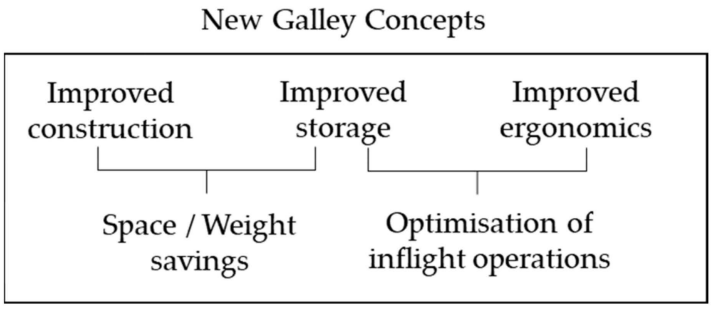

Figure 2. Main approaches for new galley concepts.

A further optimisation concept which was developed, "The Flying Cart", enables the passengers to move freely while being served by the flight attendant. This is possible because the trolley is mounted on a rail system, which is fixed under the ceiling [37,38]. "Concept 2" has the approach that the galley is located below deck for efficient storage management; in this concept, the galley is automated by a robot which takes care of storage and preparation. The galley below the deck works fully automatically [37]. The "ARCA Galley System" is a concept which eliminates the need for standard trolleys. Instead, the galley uses customised meal-packs in carrier boxes that can be loaded onto foldable trolleys. The carrier boxes are stacked in refrigerated full-height compartments. Passengers can pre-order meals from home, prepared in meal-packs and stored in carrier boxes [39]. However, none of the concepts presented in the literature have been implemented in real aircraft.

A summary of the state of the art of innovations in inflight catering services is presented in Table A1 in the Appendix A, together with a high-level assessment of the features, regarding process-level integration and the level of automation. The evaluation considers four process steps for the process level integration: (1) loading the galley; (2) commissioning the galley and preparing trolleys; (3) meal and beverage distribution to passengers; and (4) unloading the galley and inventory. The evaluation gives a plus (+) if more than two process steps are integrated, and a minus (−) if there are two or fewer. For the high-level assessment of the automation level, the four process steps are again used. Hereafter, if two or more processes are supported by automation a plus (+) is given; otherwise, the process is assigned a minus (−), e.g., in case of reducing the workload of the flight attendant.

Air travel has been seriously impacted due to the COVID-19 pandemic. The number of flights decreased as measures to contain mobility were adopted, e.g., as shown by an analysis of Spanish routes with LCCs [40]. Alternatives have been proposed to maintain the air transportation infrastructure and provide passengers with a safe journey, e.g., a safety–hygiene air corridor (SHAC) to minimise the risks of COVID-19, after which, safety and hygiene protocols could be implemented [41]. Additionally, assistance systems in the

airports for supporting tracking and guidance have been analysed to coordinate passenger's distances between to each other [42]. Inflight catering services have been affected during the pandemic, and service limitations and alternatives have been stated, e.g., changing served meals [43,44].

2.2. Meal Individualisation

The literature review regarding individualisation investigated three main aspects: (1) meal provisioning; (2) the impact of meals on passenger satisfaction; and (3) the willingness to pay for customised meals. Under meal provisioning, mostly operative and design issues have been taken into consideration. The aspect of passenger satisfaction has investigated elements of individualisation that may affect the passenger inflight experience. Finally, the perspective of the willingness to pay more for individualised services has looked after previous efforts towards a profitable change in air travel.

The provision of individualised meals has been investigated by efforts estimating the number of meals to be produced and their delivery to an aircraft. In this case, the level of customer satisfaction could be affected if meals or options have been missed by the passengers [29].

On the ground, the turnaround operations determine further requirements for the individualisation of inflight catering services, particularly regarding the time for loading and unloading the goods onboard the aircraft [45]. In order to provide an individualised meal, the connection between loaded catering and boarded passengers must be established in order to ensure adequate meal provision. Additionally, efforts have been focused on the digitisation of turnaround processes to improve the communication and coordination of ground-handling activities for avoiding delays [46]. The proposed monitoring system collects time stamps of turnaround activities in order to take measurements for improving delay sources.

The European Commission and the aerospace industry jointly developed the research and innovation strategy called Flightpath 2050, which states that "90% of travellers within Europe are able to complete their journey, door-to-door within 4 h", although this goal is controversial, as currently approximately 90% of travellers complete their journey within 7.5 h [47]. Even though the most promising potential for improvement is to speed up the route from passengers to the airports, optimisations in turnaround processes and inflight services must be performed in order to achieve this goal. A further possibility for achieving the goals of the Flightpath 2050 strategy may arise from new aircraft designs [48], looking not only at new operations, but also into changes in aircraft cabin configurations, for enabling, e.g., a turnaround time of 15 min, consisting of a time slot for catering loading and unloading within 5 min.

Inside the cabin, some efforts have been made for improving meal delivery to the passengers, as shown in a preliminary study with a Kobuki-based robot [49]. The passengers can order meals or beverages directly from their seat. The order is be prepared by a flight attendant in the galley and delivered by a robot to the respective seat. Although the study attested to a reduction in the flight attendant workload, no analyses or evaluations of the integration process have been presented.

A study about the minimum flight attendant requirements has been performed [50]. The focus lay on the number of flight attendants necessary for a low-cost carrier (LCC). The flight attendant's activities have been outlined and the connection between safety and passenger service has been briefly discussed. The study shows that the flight attendant workload for LCCs increases, leading to fatigue that could compromise safety activities, particularly in emergency situations.

Flight attendants are trained for specific aircrafts; thus, airlines must assign the right personal according to the aircraft, which could generate bottlenecks in cases of reduced number [51]. Automatic standard solutions that could be integrated in different aircrafts could possibly reduce the training time.

Design changes for improving inflight catering services has been investigated, e.g., by proposing an add-on system for self-service catering [35]. Additionally, a new system to improve on-seat comfort, on-demand service, and the ability to walk freely in the aisles has been developed [52]. The system was composed of five subsystems: (1) on-demand ordering; (2) inventory status; (3) automatic galley for meal and beverage preparation and loading system; (4) automatic delivery system; and (5) automatic trash retrieval system. The benefits regarding weight, reducing emissions, and improving passenger comfort have been evaluated and compared with the current system.

In order to increase the situation awareness among flight attendants, a smartwatch assistance application to optimise the communication onboard the aircraft has been proposed. The use of collaborative tools may improve cabin safety as well as optimise the passenger service, e.g., by better coordinating the flight attendant workload [53].

Research on the fatigue of flight attendants and ergonomics related to their activities is extensive. The focus of this literature review is a general overview of the main issues related to it, which may affect the provision of meals. In this sense, the number of steps taken by flight attendants during long-haul flights has been analysed, which showed the potential for fatigue and psychological impacts, that could lead to a decrease in service level or the inadequate execution of safety procedures [20]. Additionally, for short-haul flights, similar aspects regarding the fatigue of flight attendants were investigated, in this case identifying the most impacting activities before, during, and after duty [54].

The aspect of individualisation can also be found in the hospitality branch; in one study, an overview of the use of robotics in catering in general has been presented [55]. Although none of the applications are currently found onboard aircraft, passenger expectations may be influenced by having contact with similar experiences of catering outside the aircraft.

An interesting aspect related to individualisation is the increase in options, which could turn into information overload and lead to lower service satisfaction. Efforts in research towards recommender systems have been observed, also for catering choice; in this case, the use of such systems could improve passengers' decision-making processes [56]. The impact of individualisation in catering service can be observed in case studies of outsourcing products and services to sub-suppliers to achieve mass customisation. One study showed that the early definition of the level of sub-supplier integration, together with the tools used and affected processes, are essential for achieving mass customisation in a chain-operated restaurant [57].

The novel design of meals for an ageing population, particularly regarding the preparation and consumption of homemade meal, has been investigated. Research has shown how ageing consumers decide on their meals, pointing out a relevant potential for individualisation [58].

Passenger satisfaction is a broad issue of research; one survey assessed the decrease in customer service between 1995 and 2000 throughout the airline industry. The research looked for a connection between "air rage" and passenger dissatisfaction, possibly related to the frustration of service expectations [59].

The impact of meals on passenger satisfaction was investigated to relate passengers experiences of dissatisfaction with the responses of airline staff. The analysis showed that passenger satisfaction during a journey is affected by a series of events, called "part-encounter", while meal and beverage services are composing elements. One aspect showed that various flight attendant responses related to a missing pre-ordered meal resulted in a different level of satisfaction by the passenger. The case study highlighted that the responses are variable and can be related to the level of experience of the flight attendant and the availability of information [60].

The quality of meals and beverages in the re-flying intention of passengers was highlighted by a theoretical model in the full-service airline context [61]. In the model, quality was divided into three categories: core quality (taste, quantity, freshness, quality, temperature, health, and nutrition), external quality (presentation, colour, and menu variety), and delivery quality (timely, accurate manner and personal service).

Additionally, business jet companies are looking for alternatives for improving inflight catering services, showing that the demand for more options and better quality is higher than the what is currently offered on the market [62].

The individualisation strategy is also related to the topic passenger satisfaction. A classification was proposed for individualisation strategies with three main categories: (1) product adaptation performed by the company; (2) product adaptation performed by the customer; and (3) adaptable value added to predefined product variants. From the results, the challenge is to balance the customer benefit with the induced internal variety [3].

A design for customer satisfaction surveys has been proposed for assessing airline service quality. In addition, the research provided a literature review on the main service attribute, including "food and drinks", "flight attendant", and "special services" aiming to define passengers' preferences for the most suitable strategy for increasing their satisfaction and improving the provided service [63].

The economical aspect of individualisation influencing passengers was considered by analysing the "willingness to pay" potential of green products in air travel, e.g., organic on-board food [64]. The performed survey pointed out that 20% of passengers who were willing to pay for supplementary services were also interested in paying for green products. The survey investigated aspects related to sustainable options, e.g., purchasing an upgraded meal (two options) instead of a standard meal included in the flight; passengers could choose a premium or organic meal.

An assessment of the willingness to pay for ancillary services on long-haul flights was performed, where five ancillary service were investigated, including (1) checked baggage, (2) inflight meal, (3) seat selection, (4) priority boarding, and (5) onboard Wi-Fi. The findings led to the conclusion that leisure passengers were willing to pay more for most ancillary services; millennials showed a different willingness to pay than older passengers; and that the flight duration has a contrasting impact on the willingness to pay [65].

Our literature review reveals a triangle of tension between (1) individualisation opportunities including meal provisioning, passenger satisfaction, and willingness to pay, (2) innovations to optimise inflight catering in the aircraft cabin, and (3) current inflight catering services. A summary of the demand resulted from the literature review regarding individualisation can be seen in Table A2 in the Appendix A. It is therefore worth exploring which dimensions of meal individualisation are relevant to passengers. Based on the confirmation of the dimensions, it is crucial to understand how the current inflight catering process works and how changes can be fulfilled by a technical system. Our approach aims to meet the individualisation requirements by automating tasks without exceeding the time required to perform inflight catering services, and without increasing the workload for the flight attendants.

3. Methodology

The methodology used in this contribution is presented in Figure 3. Firstly, a survey was performed in order to specify the demand for the individualisation of inflight meals; subsequently, a process analysis is presented for defining the as-is process and the requirements for a technical solution; furthermore, the concept for individualised inflight catering services is shown; and finally, the section closes with the validation of the test scenarios with the concept.

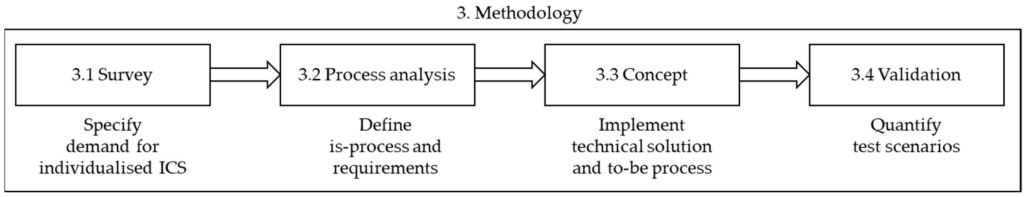

Figure 3. Overview of the methodology presented in Section 3.

3.1. Survey on the Individualisation of Inflight Meals

Our quantitative passenger survey was performed in January 2022 with around 1000 passengers from Germany; the focus lay on consumer expectations and attitudes towards the individualisation of meals on air travel with an exploratory research perspective. Therefore, the dimensions detailed in Table 1 were established and guided the survey questions.

Table 1. Individualisation dimensions for the research model.

	Dimensions
D1	Current technology is not able to attend to passengers' needs.
D2	Current inflight catering services do not meet the expectations of the majority of passengers.
D3	More options are desired for most passengers.
D4	The majority of the passengers have relatively low awareness regarding inflight catering.
D5	Most of the passengers intended to pay more for individualised services.
D6	The expectation is related to service price for most of the passengers.
D7	Pre-order options are not known or seldom used by most passengers.
D8	Mealtime is important for most passengers.

From the dimensions defined in Table 1, possible actions were derived. The impact on the ICS processes was considered, and the focus was directed towards the possibilities that could be achieved with the automation of ICS. From this procedure, we derived a research model, as shown in Figure 4. The research model intended to establish a relationship between demand (market pull) and a possible solution (technology push). Briefly, if the need for individualised/customised meals and beverages is relevant, it may imply a process change that could be achieved through automation support, enabling the optimisation of the current processes, a possible reduction in the workload, and the generation of new revenues.

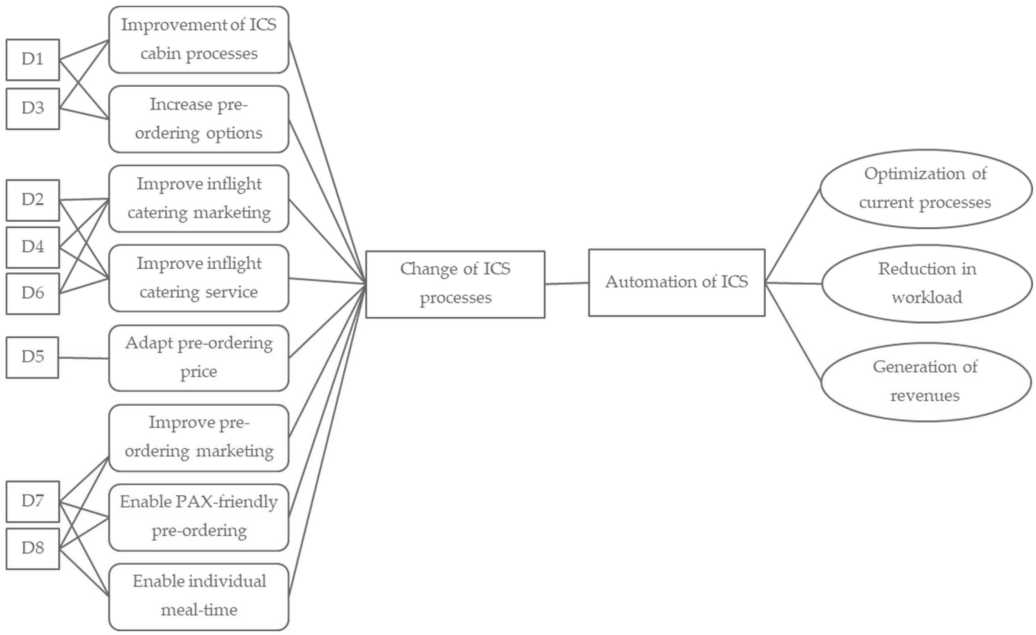

Figure 4. Dimensions-based research model for meal individualisation.

The approach for exploratory research at this stage is to check the proposed dimensions to generate future requirements for optimising the ICS. Throughout the survey, a Likert scale with five levels was used for answering the questions, varying from 1, do not agree at all/not important at all, to 5, agree completely/very important. The acceptance of the dimensions was assessed through the average, considering the top two levels

from the Likert scale. In this sense, a question supported the dimension if most of the interviewed population was positive towards the asked dimension, meaning the top two levels of the Likert scale, or if the average was above 3.0. In this case, the dimension was considered supported if a portion of the interviewed population was unsure about the answer (3 = neither agree nor disagree). The answer was then considered to represent a slight trend towards the asked dimension. Nevertheless, some questions were presented in the negative form; in these cases, the dimension was deemed to be supported if most people were negative towards the asked dimension, if the average was lower than 3.0. Those questions are marked with an *.

The Table A3 in the Appendix A shows the survey socio-demographics data from the asked flying population in Germany. There is nearly equal gender distribution and a population-representative age, monthly household net income, and education. In addition, the survey results enable the analysis of different groups through flying profiles, including flight frequency, travel reasons, and acquaintance with possible fellow travellers.

Some of the survey's key results are presented through the comparison of the two groups, flight frequency and age; the complete survey is shown in the Appendix A. Further assessments will be part of a future contribution.

The eating behaviour of the asked population was assessed as shown in Figure 5. It is possible to see that people who fly more often have higher expectations regarding their eating habits.

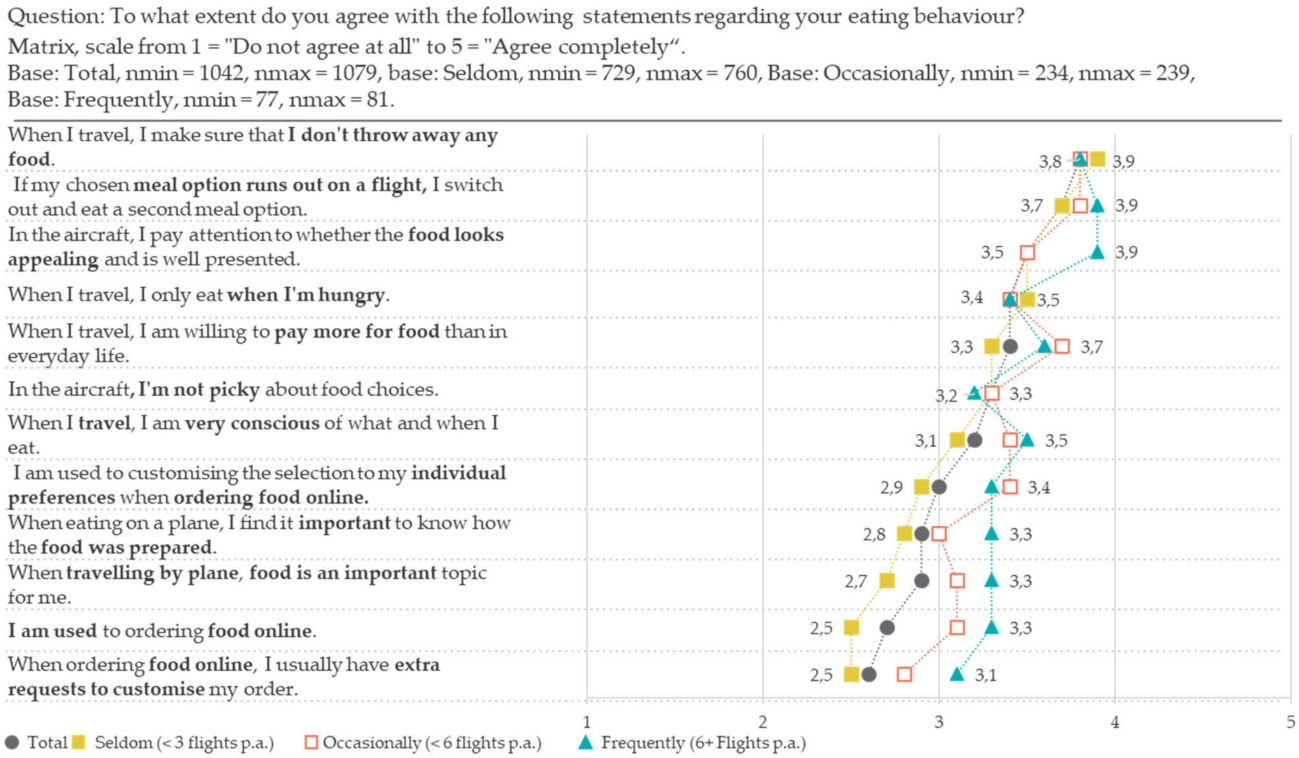

Figure 5. Statements on individuals' eating behaviour (in Avg.) by flight frequency.

The survey shows that from the respondents, older people have lower expectations in terms of their eating habits than other age groups, as shown in Figure 6.

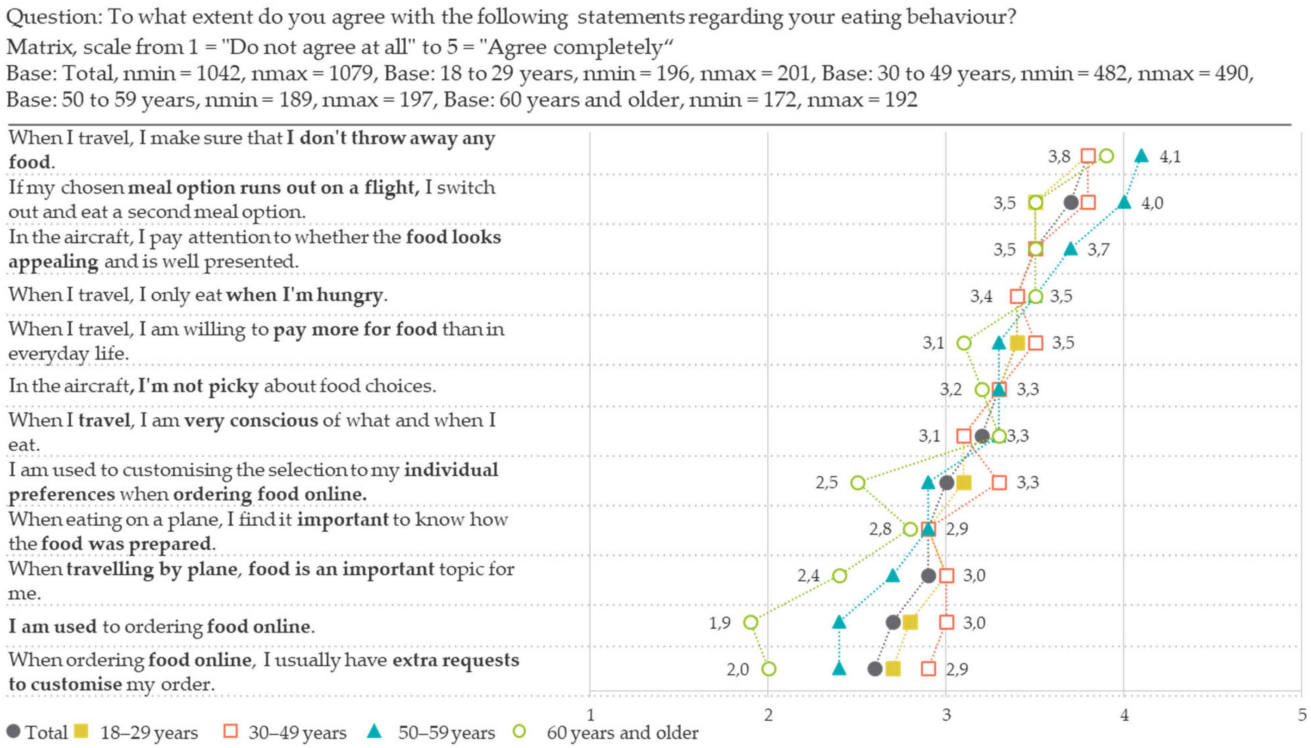

Figure 6. Statements on individuals' eating behaviour (in Avg.) by age group.

The interest in pre-ordering is higher among people who fly more frequently, as shown in Figure 7. For instance, individually selectable times at which the meal is served was more important for passengers who were frequent flyers.

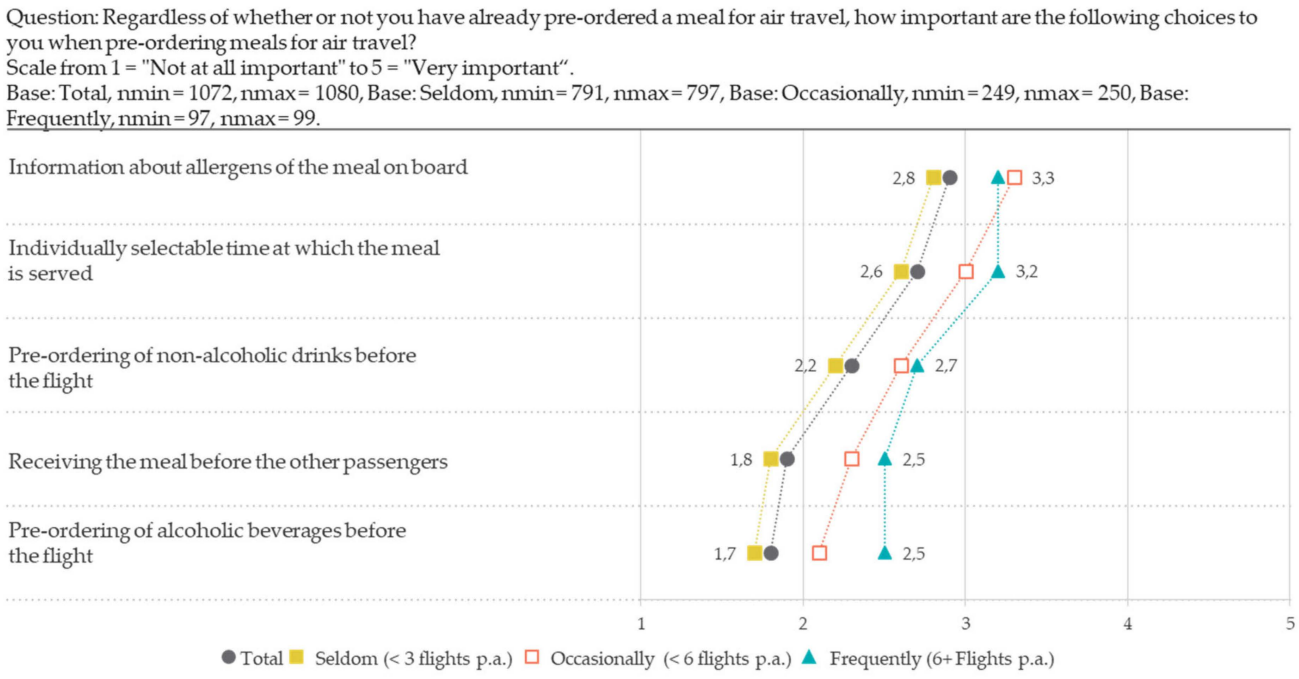

Figure 7. Pre-order choices (in Avg.) by flight frequency.

People of different ages have different views on pre-ordering, as shown in Figure 8. In this case, the interest of receiving information about, e.g., allergens, seems to be more important for younger passengers than for older passengers.

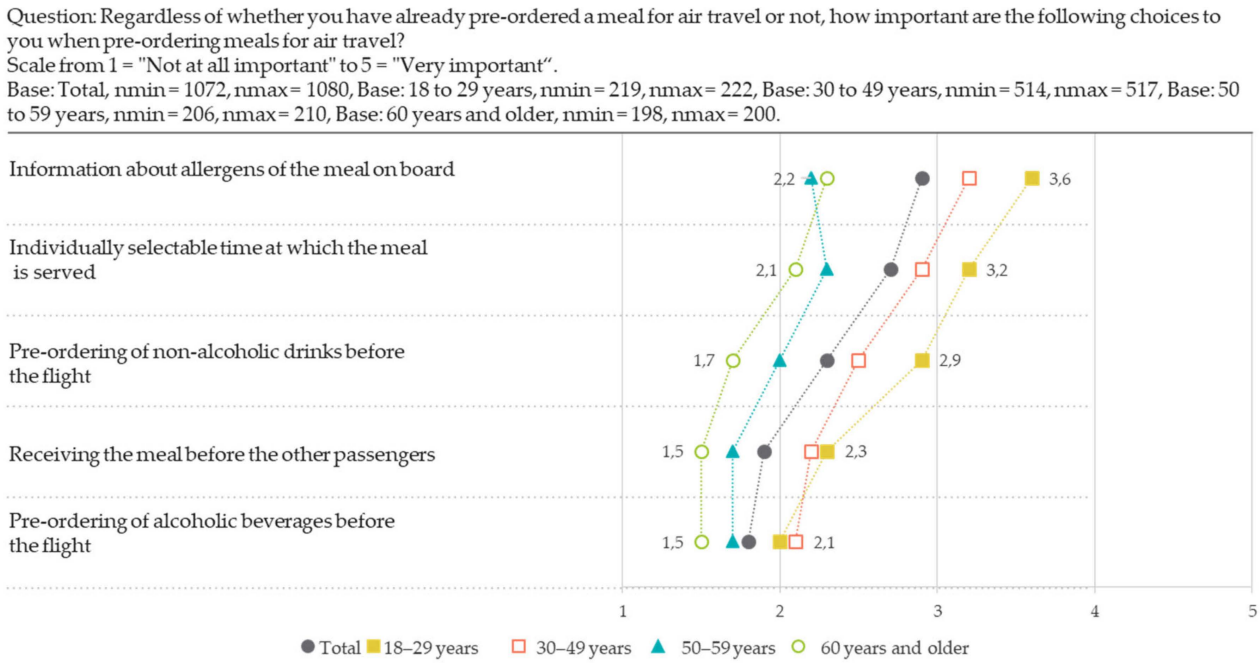

Figure 8. Pre-order choices (in Avg.) by age group.

Another aspect regarding individualisation and flying frequency can be seen in Figure 9. For frequent flyers, it would be more important to individually define the number of meal courses, for example.

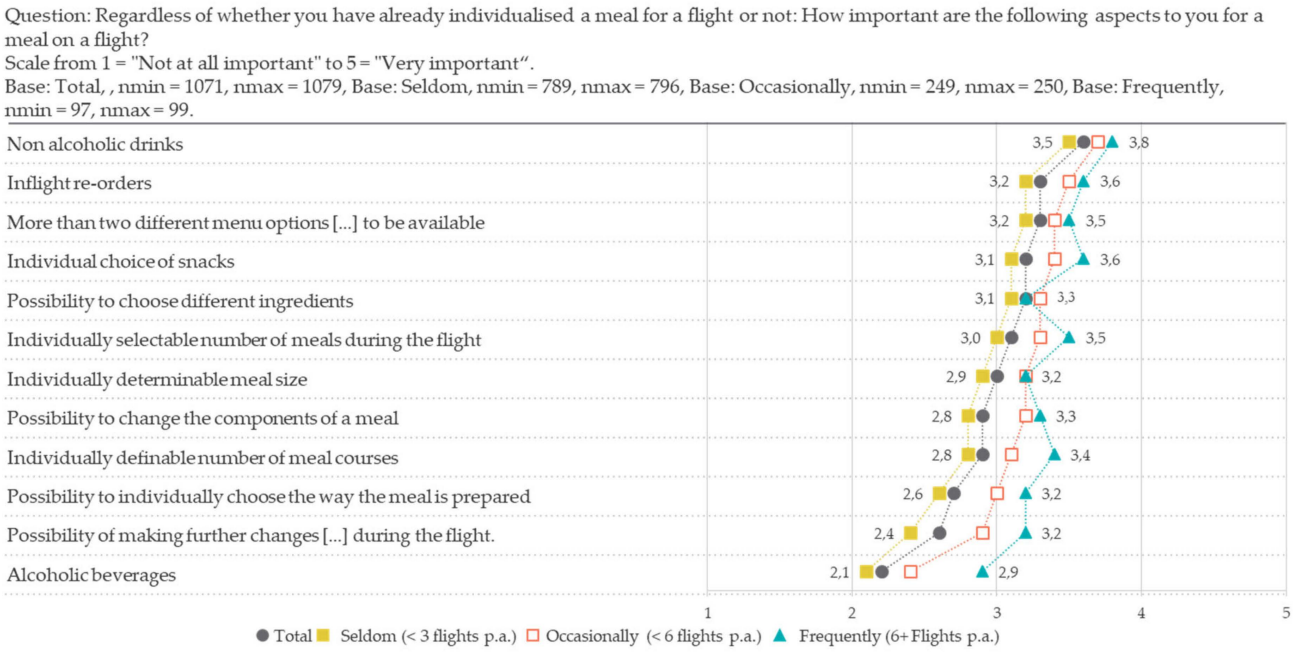

Figure 9. Importance of individualisation aspects (in Avg.) by flight frequency.

The respondents were also asked about their willingness to pay a surplus for customised meals; from 73% of the respondents, 69% of them were willing to pay up to EUR 4 extra to customise a menu, as shown in Figure 10.

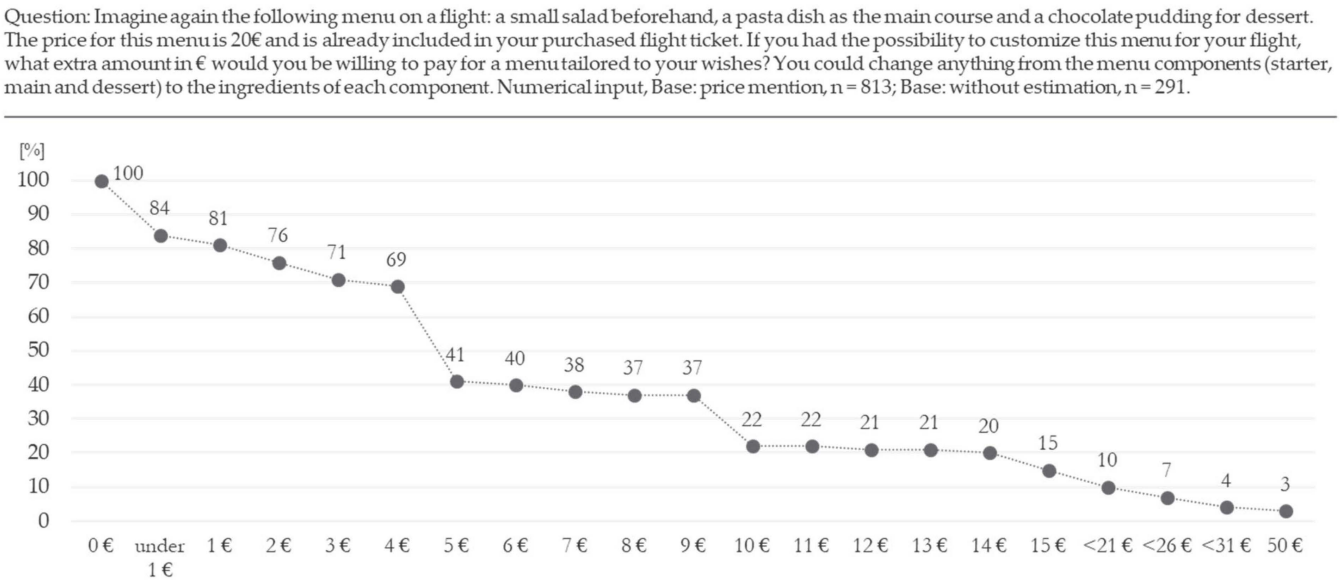

Figure 10. Readiness to pay extra (in %).

From the survey, it is possible to state that there was an interest in individualisation from passengers, particularly from frequent flyers and passengers younger than 40 years old. The dimensions defined from Table 1 were mostly satisfied by the exercise, as shown in the Appendix A in Table A4. In this case, the survey results supported the definition of variations, e.g., the number of options, which were considered throughout the development of an automation concept for the individualisation of inflight meals, and subsequently for integration and validation inside the mock-up cabin.

Considering the review of the state of the innovations and current efforts towards individualisation, it is possible to state that there is a gap for improvement. Particularly, the information flow among stakeholders such as airlines, caterers, and airports with associated process occurring inside and outside the aircraft could improve the inflight catering services. In this sense, the digitisation, and thus, the exchange of information is decisive as a first step for optimisation, e.g., enabling individualisation options for meals and reducing overcatering onboard the aircraft, as well as improving the planning capacity of catering production and enhancing airline ancillary products.

3.2. Process Analysis

The process analysis of inflight catering services was performed by observation and interviews with experts and former flight attendants and by the description of aircraft cabin activities in the literature [66–68]. A general overview of stakeholders with tasks is shown in Table A5 in the Appendix A.

To illustrate the tasks for a lunch service onboard the aircraft, an example flight was chosen, which was based on observations and interviews with flight attendants. It consisted of a 10 h flight, and only considered the lunch service for economy class. In this case, 226 passengers were served by four flight attendants. The tasks involved the loading and unloading of ovens, the commissioning of trolleys, meal distribution with full-size trolleys (FSTs), and the preparation and distribution of beverages with half-size trolleys (HSTs). The service ended with the collection of waste and stowing the trolleys in the galley; an overview is shown in Figure 11.

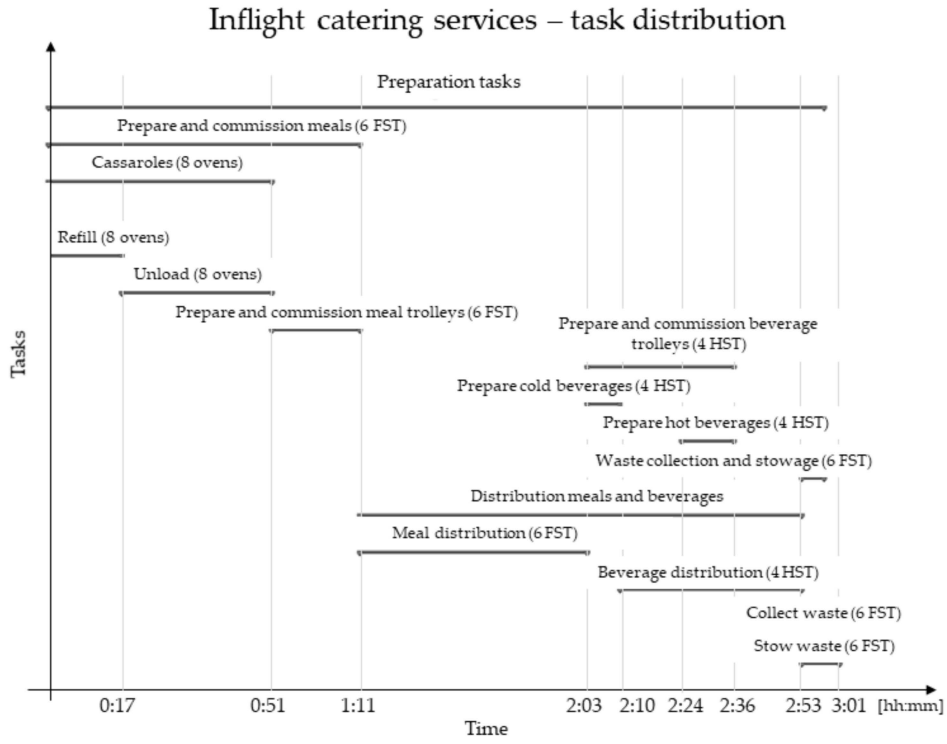

Figure 11. Example inflight catering service (e.g., lunch) for a long-range flight of 10 h, with 226 passengers and 4 flight attendants.

An abstraction of the tasks distribution is shown in Figure 12; the most time demanding tasks involve the distribution of meals and beverages to the passengers, followed by preparation tasks, which are tasks performed in the galley and are associated with the commissioning of the trolleys. The task group "stow" considers the storage of trolleys and standard units back into the galley, and "transform" is a group of tasks aiming to, e.g., turn a meal trolley into a waste trolley.

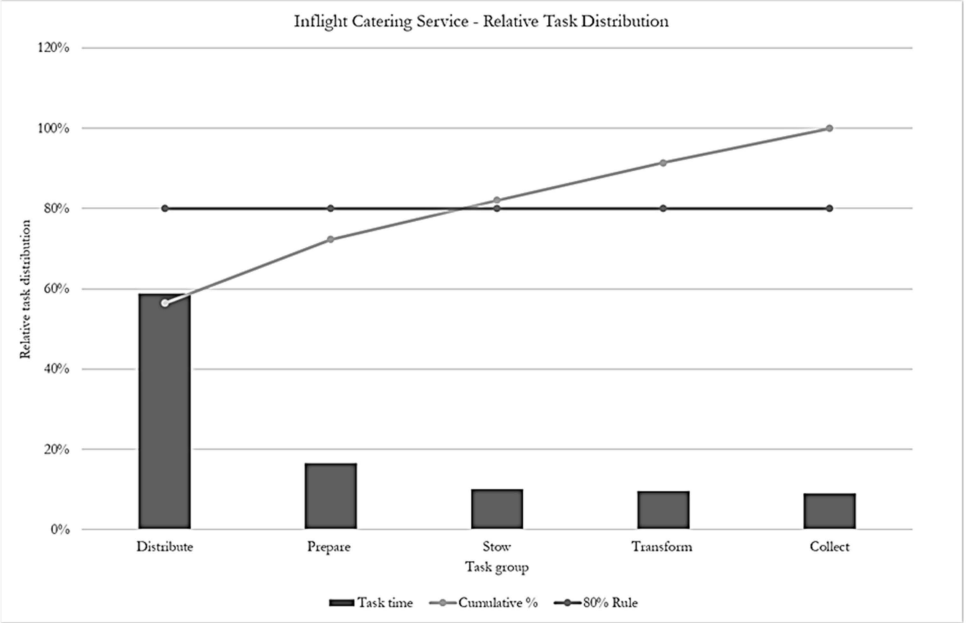

Figure 12. Example task distribution of a full-service, long-haul flight with a lunch service.

From the process analysis, we derived a connected view of inflight catering services to understand the inter-relations among processes, as well as to communicate with stakeholders as well as to identify critical aspects. In Figure 13, the inflight catering services are divided into four main steps: (1) check in; (2) set up; (3) service; and (4) check out. This division enables the clear grouping of tasks belonging to a process step. Check in is the loading of the galley with catering goods, which is performed on the ground; the next step, set up, includes the commissioning of the galley and the associated preparation of the distribution devices, e.g., trolleys; step three, service, is the distribution of the meals and beverages to the passengers, and subsequent waste collection; and finally, step four, check out, considers the unloading of the galley and inventory.

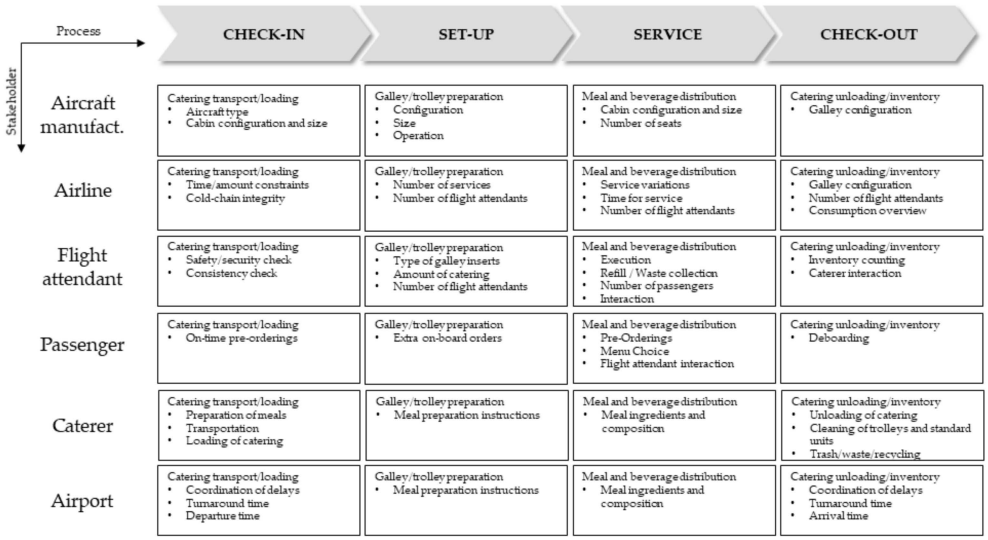

Figure 13. Four main steps of inflight catering services with stakeholders.

The four steps presented in Figure 13 support the development concept for inflight catering services. In this sense, optimisation concepts must consider the interconnection of the process steps and stakeholders to provide a consistent solution. Nevertheless, the comparison among optimisation concepts is still a challenge, because the concepts may focus on different tasks. For filling this gap, the authors propose the indexes in Table A6 in the Appendix A or a concept comparison.

While looking into the individualisation of inflight meals through pre-ordering, information about the meal location and the passenger to be served are essential parameters for successfully integrating scaled-up pre-ordering into inflight catering services. Therefore, the impacts on the distribution task and time must be evaluated. The next section builds upon the process analysis for the development of a new concept for the integration of meal individualisation for all passengers onboard the aircraft.

3.3. Proposed Concept for Inflight Meal Individualisation

The individualisation of inflight catering services can be achieved through pre-ordering. In this case, passengers can proceed by choosing an individual meal, similarly to when ordering a special meal during the ticket booking process, e.g., making a vegetarian meal choice. However, today, these meals are distributed by the flight attendants to the passengers in a separate service. In our case, increasing the number of pre-ordered individualised meals up to 100% of the passengers will incur a process change. The meals must be assigned to the correct passenger in the right seat, and there must be a way to consider changes, e.g., seat changes. The workload of the flight attendants must be evaluated, considering the service time for distributing individualised inflight meals.

The authors have developed a concept for inflight meal individualisation. The concept integrates all process steps and stakeholders. It is a comprehensive digital infrastructure,

including a reference architecture for software and hardware inside and outside the aircraft to guarantee the complete tracking of goods and transport units through the whole flight catering supply chain, as shown in Figure 14. The concept enables a digital real-time inventory system with authentication and communication capabilities to optimise the on-board catering service and coordinate the related turnaround processes, directly integrated into the aircraft. The concept matches data from passengers, aircraft, airline, cabin crew, caterer, catering, and airports, leading to a higher level of connectivity in the aircraft cabin and integration in the current process.

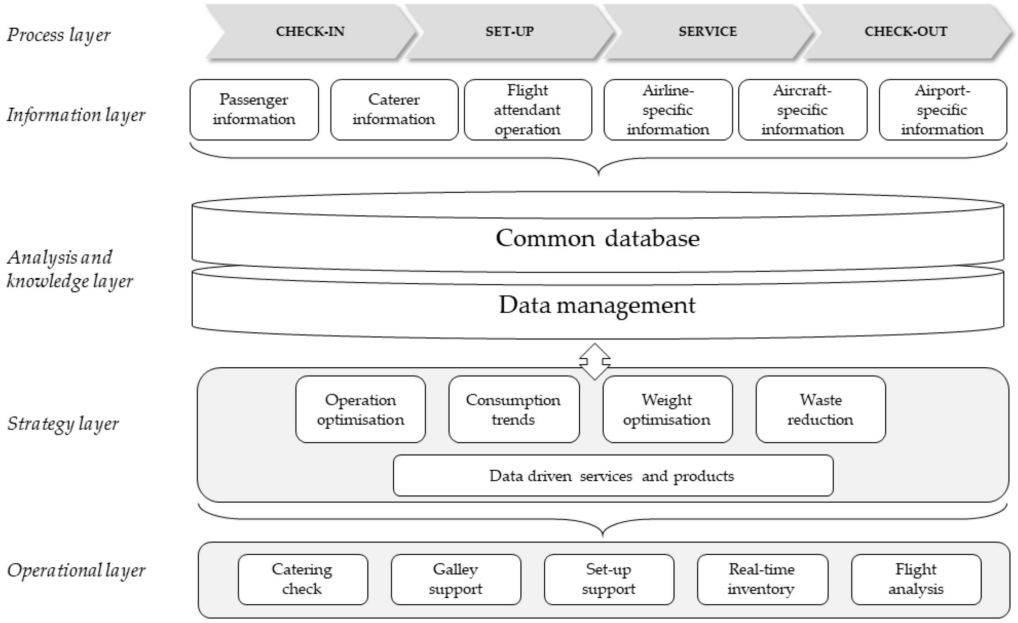

Figure 14. Reference architecture for digitising the inflight catering services.

The focus of this contribution is to evaluate how the distribution of pre-ordered meals can be included in a standard distribution service. Hereafter, a simplified process visualisation of the current standard service is shown in Figure 15. It shows the abstracted process steps for standard meal distribution to a passenger. It is composed of five steps performed by the flight attendant: (1) moving the trolley to the passengers; (2) taking meal orders; (3) commissioning the meals (e.g., removing the trays from the trolley); (4) serving meals to the passengers, performing the same procedure for passengers seated on the same row; (5) finally, the flight attendant moves the trolley to the next row. The inner box highlights the pre-ordering process scenario. Hereafter, the distribution of a special meal occurs separately from the distribution of non-pre-ordered meals. It is hardly possible to fully generalise this procedure for all airlines. Nevertheless, according to the expert interviews performed during process analysis and observation, it can be assumed that this scenario is used. Our process layer has been extended with "kitchen", because catering checks are performed by caterers in the flight kitchen.

In this scenario, Figure 16 shows the concept demonstration. It is an add-on system used with a standard meal trolley, and it is composed of hardware—tablet, QR-scanner, and fixing unit—and software—backend with the trolley loading plan and the aircraft cabin seat map, as well as a frontend with a graphical user interface (GUI).

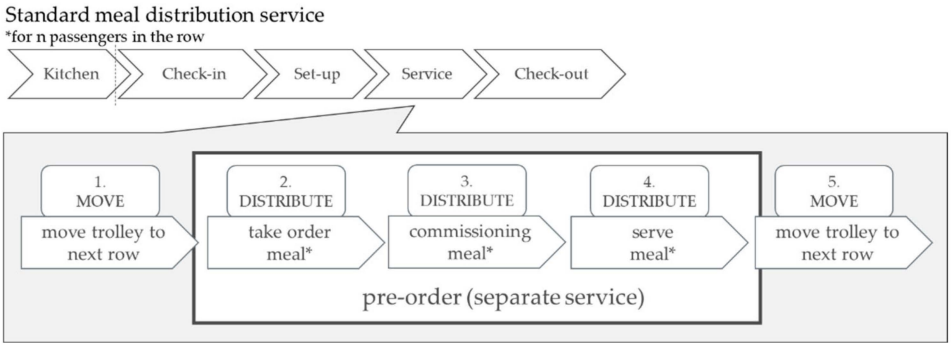

Figure 15. Process steps of a standard meal distribution service to a passenger.

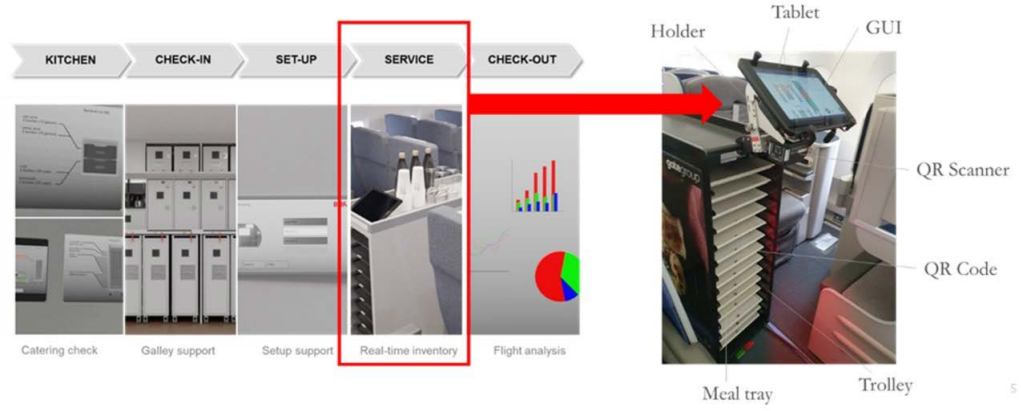

Figure 16. Concept demonstration for inflight meal individualisation.

The demonstration enables real-time inventory management during service meal distribution, because each tray is scanned while being retrieved. The flight attendant has an overview of the meals in the trolley via the GUI and visualisation of the seating plan with the passengers' pre-orders.

3.4. Validation

A set up was built to validate the concept, as shown in Figure 17. It represents an aircraft cabin with two aisles, from rows 34 to 37 and seats A to K. The highlighted seats were used to compare the standard service with the new concept service, in this case with 14 passengers, changing the number of meal options as well as the degree of pre-ordering inside the trolley.

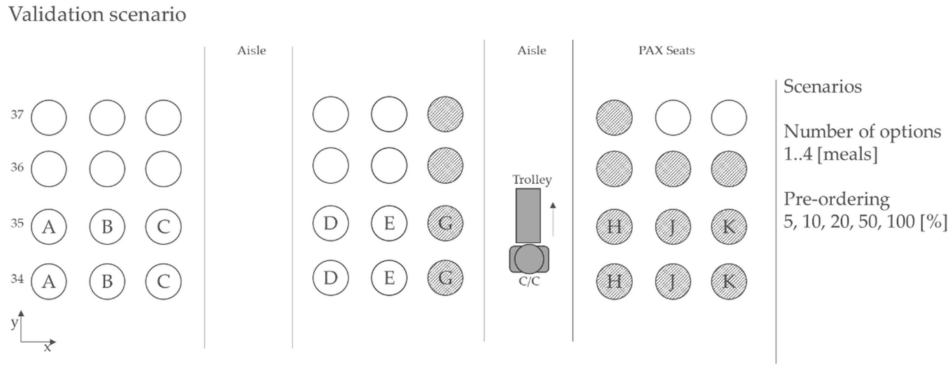

Figure 17. Validation scenario.

A fictitious passenger seat map was used for the validation performed inside an aircraft cabin mock-up. A flight attendant conducted the service with and without the demonstrator. The validation occurred without real passengers at the time; COVID-19 restrictions did not allow the gathering of many people. The flight attendant's interactions with the passengers were reduced to a minimum. The flight attendant just mentioned the options, and each fictitious passenger selected one option according to a predefined order plan for all seats. However, for the scenario and the evaluation of the main features of the new concept, it was sufficient to proceed in this way. The validation set-up is shown in Figure 18. In the future, further steps and possible deeper analysis will be suggested.

Figure 18. Validation set-up, from left to right: demonstrator, cardboard for passenger orders, and GUI demonstrator.

The evaluation of the demonstrator was performed by observation and time registration; the recording settings are presented in Figure 19, with three cameras and a timer included in the software, which was triggered by the scanning of the trays.

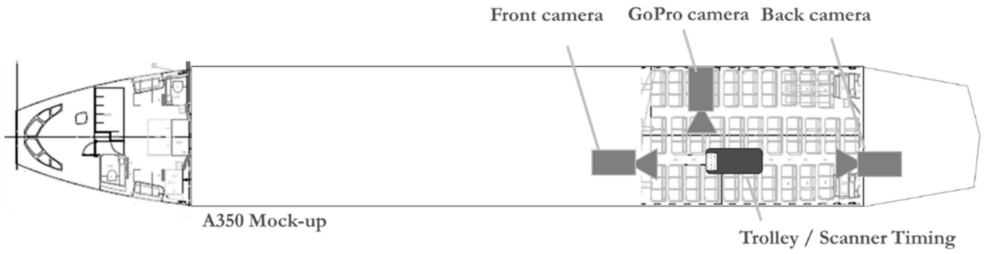

Figure 19. Validation recording settings.

The loading plan for the trolley and the passenger orders is defined in Figure 20. There were two types of loading plans: L.1 for increasing the number of options without pre-ordering, and L.2 for increasing the number of pre-orders. In L.1, the number of options (A–E) varied from one to five, and the passenger orders occurred randomly. In L.2, the pre-ordering increased from 5% to 100%, and passengers without pre-orders occurred randomly. The pre-orders in L.2 are marked with an *.

Trolley loading plan and passenger orders

(a) L.1 trolley loading plan, (b) L.2 trolley loading plan with pre-orderings, (c) L.1 passenger orders for L.1 and (d) passenger orders for L.2. Meal options A–E, and * represents a pre-ordered meal.

(a)

Tray	1	2	3	4
1	A	A	A	A
2	A	A	A	A
3	A	A	A	A
4	A	A	A	B
5	A	A	A	B
6	A	A	B	B
7	A	A	B	B
8	A	B	B	C
9	A	B	B	C
10	A	B	C	C
11	A	B	C	D
12	A	B	C	D
13	A	B	C	D
14	A	B	C	D

(b)

Tray	1- PO	2-PO	3-PO	7-PO	14-PO
	5%	10%	20%	50%	100%
1	A	A	A	D*	D
2	A	A	A	A	A
3	C*	A	C*	A	C
4	A	A	A	A	C
5	A	A	A	C*	C
6	A	E*	A	E*	E
7	A	A	E*	E*	E
8	B	B	B	D*	D
9	B	B	B	B	C
10	B	B	B	B	B
11	B	D*	B	B	D
12	B	B	B	B*	B
13	B	B	C*	C*	C
14	B	B	B	B	B

(c)

PAX	1	2	3	4
1	A	A	C	D
2	A	B	B	A
3	A	A	A	A
4	A	A	A	C
5	A	B	A	B
6	A	A	B	B
7	A	B	C	D
8	A	B	A	A
9	A	B	A	C
10	A	A	C	B
11	A	A	C	D
12	A	A	B	B
13	A	B	B	D
14	A	B	C	C

(d)

PAX	1- PO	2-PO	3-PO	7-PO	14-PO
	5%	10%	20%	50%	100%
1	A	B	A	A	D
2	B	D*	B	B	A
3	A	B	E*	E*	C
4	B	B	B	D*	C
5	A	A	B	A	C
6	B	A	C*	C*	E
7	C*	A	C*	A	E
8	B	B	A	B	D
9	A	A	B	C*	C
10	A	B	A	B*	B
11	B	E*	B	E*	D
12	B	B	B	D*	B
13	B	A	A	B	C
14	B	A	A	B	B

Figure 20. Trolley loading plan and passenger orders.

4. Results

The results show the scenarios for a standard meal trolley service with up to four meal options, a meal trolley service with the new concept with up to five meal options, and finally, a meal trolley service with the new concept with up to 100% pre-ordering.

In Figure 21, the service time of tray distribution to each passenger is presented. The timer started after serving the first passenger. Comparison was performed between a standard service and the new concept service for passengers 1 to 14 with up to two meal options.

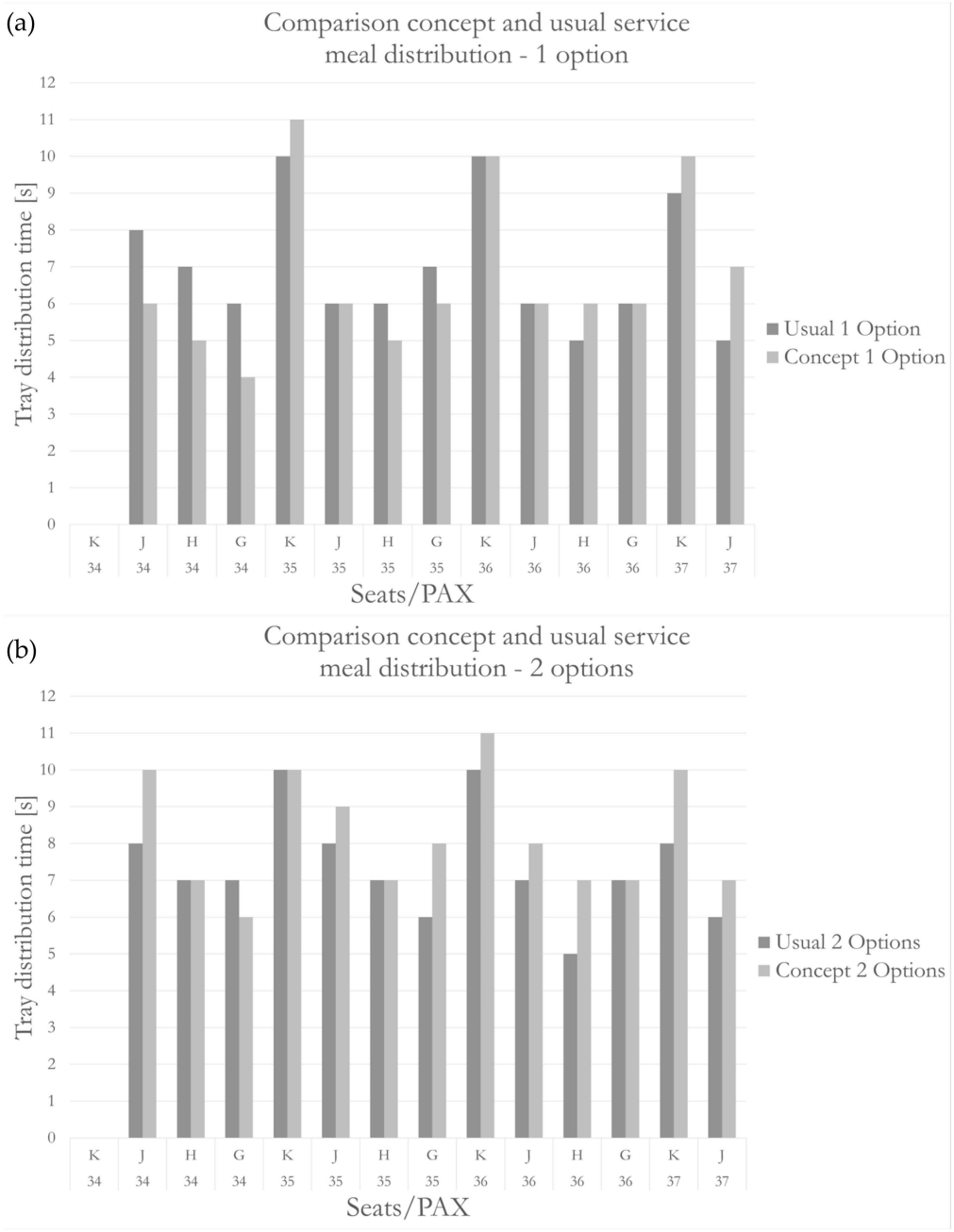

Figure 21. Service time for distribution with (**a**) 1 and (**b**) 2 meal options.

Figure 22 shows the results for the service times of tray distribution to each passenger with three or four meal options. Comparison was performed between a standard service and distribution with the new concept.

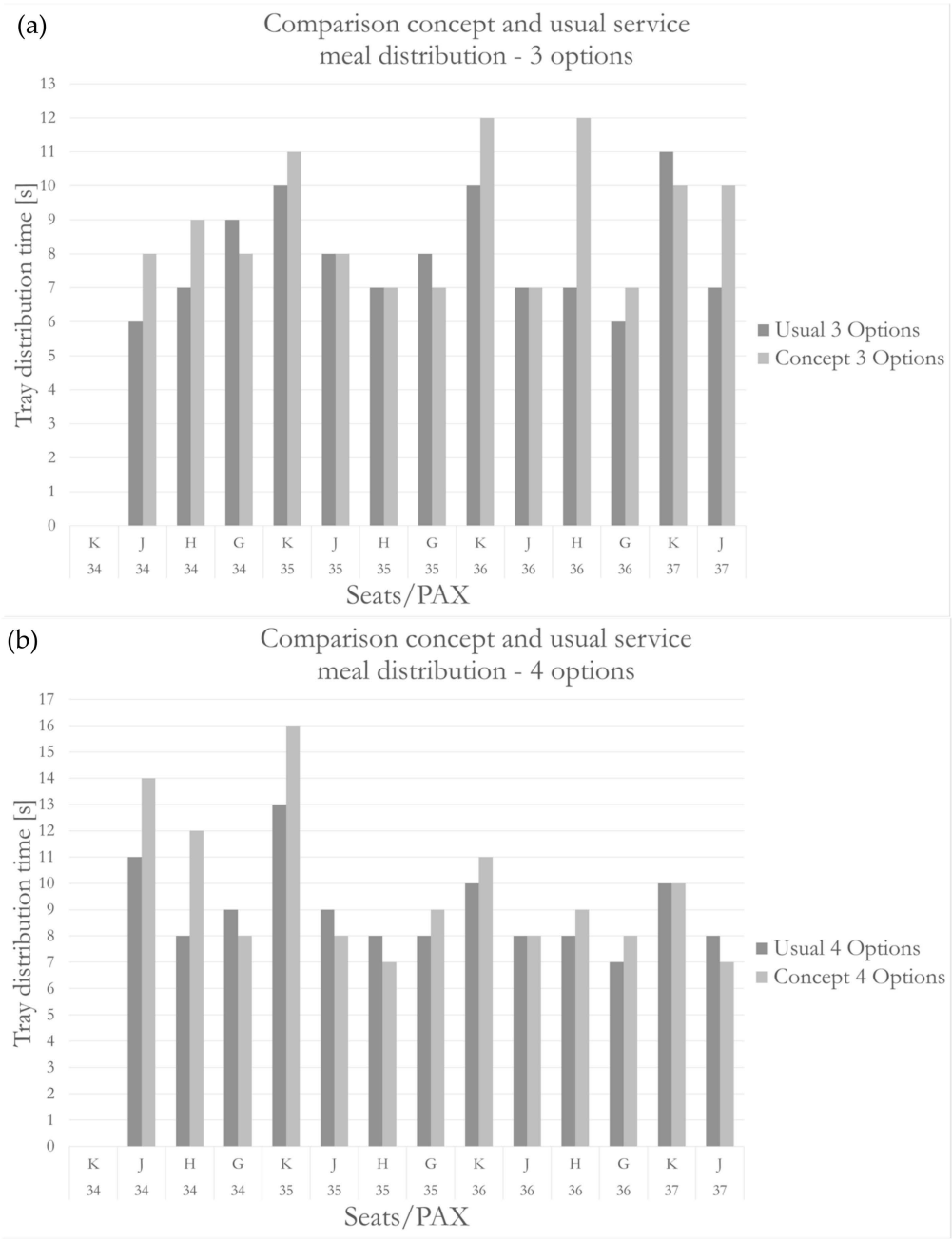

Figure 22. Service time for distribution with (**a**) 3 and (**b**) 4 meal options.

The general comparison between all tests regarding the increase in meal options and the average meal distribution time per passenger is shown in Figure 23.

In general, the service time increased with more options; in our tests, the handling between the passenger and the flight attendant included the listing of the meal options. Therefore, this time increase is also related to the handling of options. Importantly, the flight attendant had not been trained to use the new concept, nor had the GUI in the frontend of the demonstrator been optimised for a fast service.

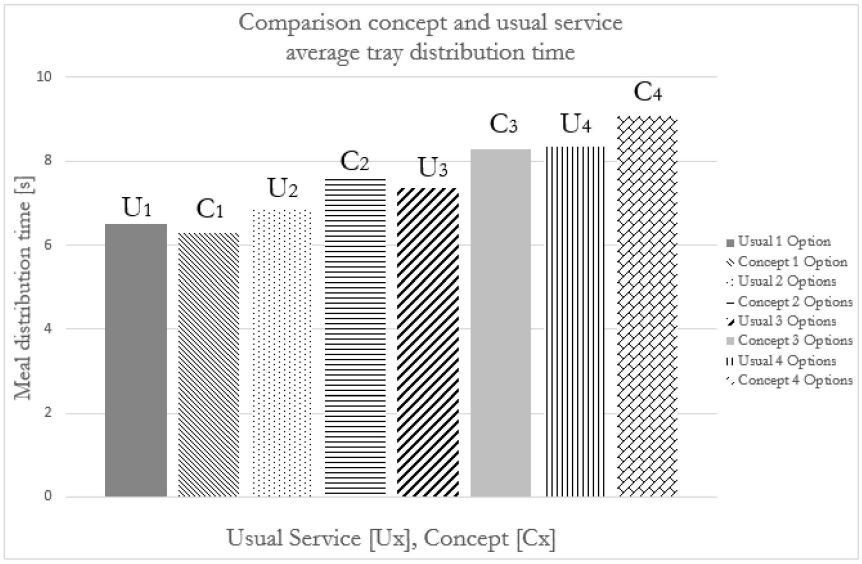

Figure 23. Comparison of the standard service with the new concept service.

The test results for the meal distribution service including 5%, 10%, and 20% pre-ordering are presented in Figures 24 and 25. The baseline for comparison is the standard meal service with two options for simplification.

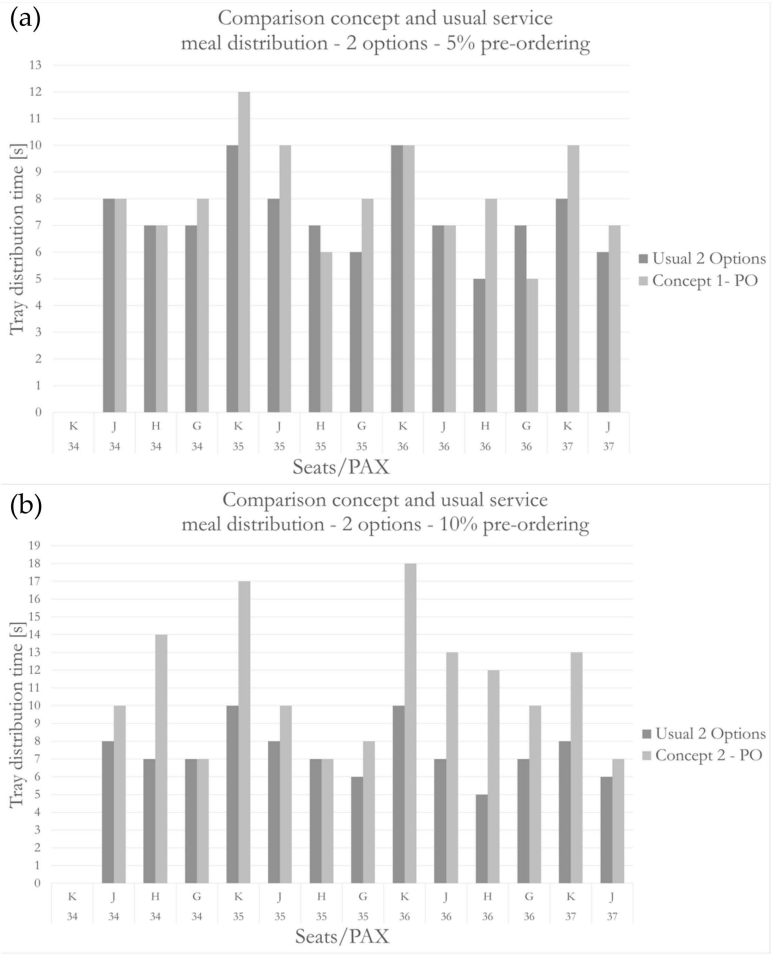

Figure 24. Meal service distribution with (**a**) 5% and (**b**) 10% pre-ordering.

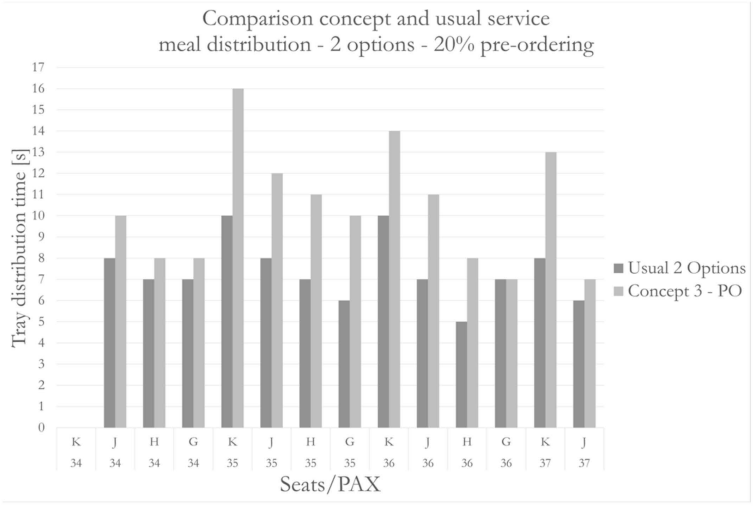

Figure 25. Meal service distribution with 20% pre-ordering.

In Figure 26, the meal service distribution time for each passenger is shown for 50% and 100% pre-ordering.

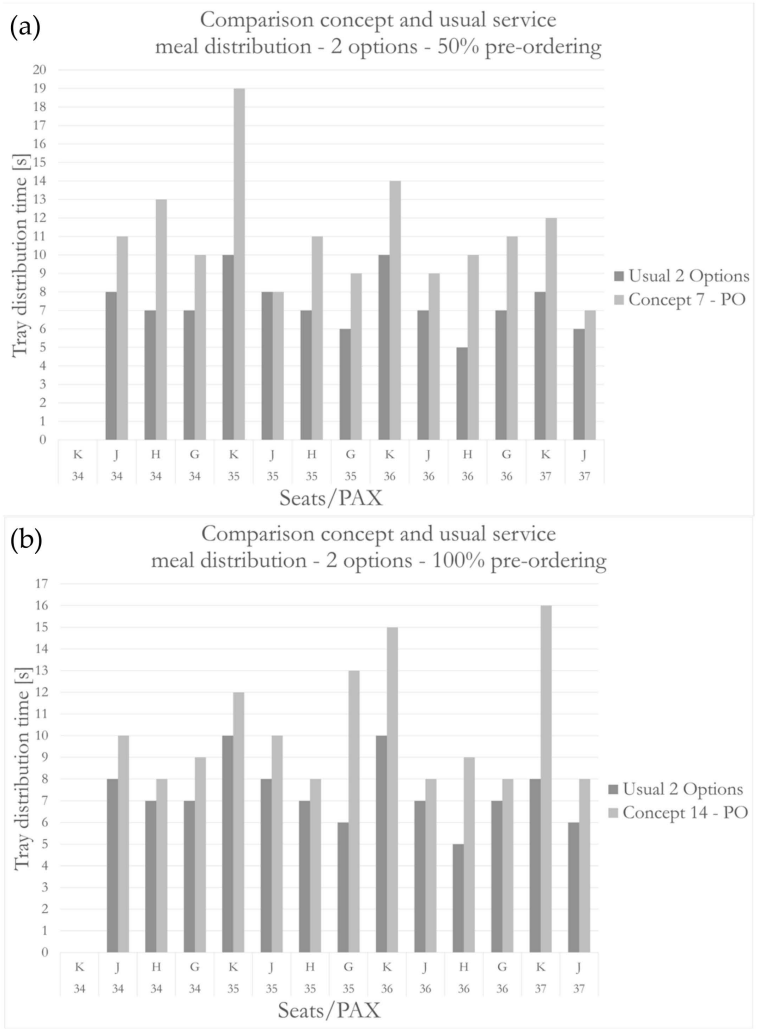

Figure 26. Meal service distribution with (**a**) 50% and (**b**) 100% pre-ordering.

An average time comparison is shown in Figure 27; hereafter, the average meal distribution time did not increase above 10% pre-ordering (C2,p).

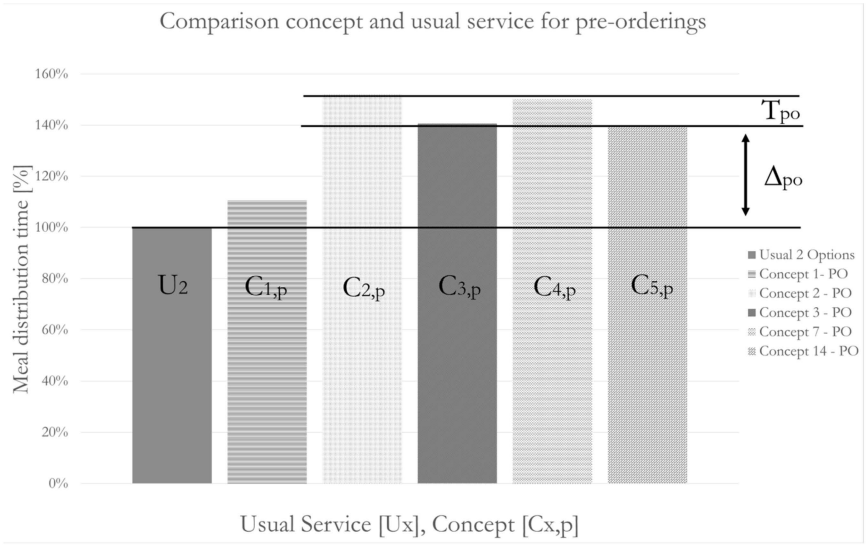

Figure 27. Comparison of meal distribution service time with an increased number of pre-orders, shown in percentages.

In scaling up to more passengers, there is a time-saving potential in accordance with the number of pre-orders. The difference between a standard distribution service without pre-ordering and the distribution service with the new concept was Δ_{po}. After a certain amount of pre-ordering, the process distribution time (T_{po}) stayed roughly constant, as shown in Figure 27.

Further observations were also performed to evaluate the use of the new concept for the distribution of inflight meals. Briefly, those were related to ergonomics and passenger approaches. Hereafter, the passenger approach by the flight attendant was slightly altered. Additionally, differences in grasping the tray by the flight attendant could be stated; possibly due to the size of the demonstrator, avoiding collisions. Another practical aspect was the position of the QR code; it was placed in the middle of the tray for the test, which possibly compelled the flight attendant to grasp it differently.

The validation was closed using the indexes proposed by the authors to evaluate the concept. The results for further comparison with other concepts are shown in Table A7 in the Appendix A.

5. Conclusions and Outlook

Our contribution describes the previous efforts made to optimise inflight catering processes within aircraft cabins based on a literature review. It has been shown that the optimisation of inflight catering services has, thus far, not focused on individualisation. The perspective of individualisation has been analysed from the literature with aspects related to meal provisioning, passenger satisfaction, and willingness to pay. It was possible to find a gap for individualisation requirements that can lead to a technical solution. The gap was explored with eight individualisation dimensions and a research model.

Furthermore, the results of a new passenger survey on the demand for the individualisation of inflight catering meals have been presented. Accordingly, there was potential for the greater individualisation of in-flight catering, especially for frequent flyers and passengers under 50 years old.

An analysis of the current inflight catering services was conducted, examining stakeholder relationships and processes. A distribution of tasks for a selected flight scenario was shown and used for the novel classification of inflight catering services into four main

steps. A concept for individualising inflight catering services through pre-ordering has been presented, followed by an evaluation scenario.

It has been shown that a new concept for integrating pre-ordering into the standard service is feasible, with only a small time impact. However, the additional service time with the new concept remained constant, regardless of the number of options. The service time for more than 10% pre-ordering was also roughly constant.

Nevertheless, the current pre-ordering distribution service still needs to be evaluated for an overall comparison, as well as the other involved tasks that may be affected by the concept, e.g., preparation time in the galley. It is possible that the time saving potential will increase after a comprehensive evaluation.

Even though the individualisation of inflight meals could be achieved through pre-ordering, a fully integrated approach will require the active involvement of airlines and caterers to create a robust solution for the entire supply chain. Nevertheless, this contribution has highlighted some essential aspects, such as the demand for individualisation from the passenger side and an evaluation of implications on the operations side.

Although the focus of this paper was not to find new solutions to air transport crises, such as that caused by the COVID-19 pandemic, we are confident that our approach can contribute to a more resilient inflight catering service, particularly by improving the flow of information, generating higher revenues through individualised services, and reducing the workload in the aircraft cabin, as well as generally optimising current processes.

As an outlook, it would be worthwhile conducting further investigations with more passengers, as well as more meal options and pre-ordering. It would also be particularly interesting to include complication scenarios in the validation (e.g., missing meals, changing seats, and allergies). New approaches have been proposed for improving the concept as a whole, such as the optimisation of the user interface and the further development of hardware design, together with different alternatives for the QR code position.

Additionally, the evaluation of possible improvements in ergonomics and fatigue, and therefore, the effects of workload reduction in flight attendants, could be interesting to investigate in a comparative study.

Another important aspect is sustainability. Although this contribution did not aim to assess the impact on waste reduction, there is a clear potential for reducing waste and weight through pre-ordering. The potential for waste reduction reaches beyond the aircraft cabin, because the demand prediction also would imply less stocking by the caterer and more consistent planning. The appropriate amount of inflight catering inevitably reduces the need for overcatering and leads to less weight, which, in turn, leads to less fuel consumption and consequently, lower CO_2 emissions. The authors plan further analyses regarding sustainability in a new contribution.

6. Patent

The following patent resulted from the reported work in this manuscript, EP35529 62A1—System for inventory management of on-board refreshments for a vehicle [69].

Author Contributions: Conceptualisation, R.M.E.; methodology, R.M.E. and M.F.; software, R.M.E. and M.B.; validation, R.M.E., M.R., M.B. and A.B.; formal analysis, R.M.E. and M.F.; investigation, R.M.E.; resources, M.B., A.B. and M.R.; data curation, R.M.E.; writing—original draft preparation, R.M.E.; writing—review and editing, R.M.E. and M.F.; visualization, R.M.E.; supervision, A.B. and M.F.; project administration, R.M.E. and M.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Table A1. Summary state of the art for inflight catering services innovations.

Innovations	Main Change	Main Effect	Reference	Year	Process Integr.	Automation Level
Streamliner	Distribution device	Fast service	[70]	2007	–	+
SPICE	New Galley New Trolley	Space/Weight savings	[36]	2008	+	–
FlexGalley	New Galley	Space/Weight savings	[71]	2012	–	+
The Flying Cart	New Galley	Fast service	[38]	2013	-	+
Loose Galley Concept	New Galley	Space/Weight savings	[72]	2014	–	+
Concept 01	New Galley	Space/Weight savings	[37]	2019	–	+
Concept 02	New Galley	Space/Weight savings	[37]	2019	–	+
Smart Galley	New Galley	Space/Weight savings	[73]	2018	+	–
Galley 2019	New Galley	Space/Weight savings	[74]	2019	–	+
Generation 3	New Galley	Space/Weight savings	[39]	2019	+	–
Skybar Splash	Beverage Trolley	Weight savings/faster service	[35]	2012	+	+
Galley-Bar-Module	New Galley	Space/Weight savings	[75]	2018	–	–
M-Flex	New Galley	Space/Weight savings	[76]	2019	+	–
Sophy	Connectivity System	Trolley Monitoring	[77]	2020	+	+
Arca	New Galley	Space/Weight savings	[39]	2020	+	–

The evaluation considers four process steps for the process level integration: (1) loading the galley; (2) commissioning the galley and preparing trolleys; (3) meal and beverage dis-tribution to passengers; and (4) unloading the galley and inventory. The evaluation gives a plus (+) if more than two process steps are integrated, and a minus (−) if there are two or fewer. For the high-level assessment of the automation level, the four process steps are again used. Hereafter, if two or more processes are supported by automation a plus (+) is given; otherwise, the process is assigned a minus (−), e.g., in case of reducing the workload of the flight attendant.

Table A2. Summary demand derived from inflight meal individualisation after the literature review.

Demand Derived from Meal Individualisation	Reference
Meal provisioning	
Provide the right amount of catering for each flight and passenger.	[29]
Focus marketing on individualisation perceptions.	[78]
Provide consistent information about allergens inside meals.	[16]
Evaluate integration of current/future technologies for improving options for individualisation.	[2]
Demand for more efficient loading and unloading of catering goods, particularly in case of individualisation.	[45]
Integration of automatic solutions with current processes and aircraft design.	[49]
Evaluate cross-aircraft solutions for catering operations to reduce training effort.	[51]
Optimise current processes to reduce cabin crew workload, and therefore, less fatigue.	[50]
Improve on-ground and inflight operations for fulfilling Flightpath 2050 goal.	[47]
Reduce current turnaround time to enable new catering models.	[48]
Evaluate new inflight catering models based on design changes.	[35]
Integrate solutions into flight catering supply chain and compare them with possible alternatives.	[52]
Evaluate the use and integration of collaborative tools/technologies into operation models.	[53]
Improve ergonomics of inflight catering services to avoid unnecessary walking and flight attendant fatigue.	[20]
Support flight attendants in most demanding activities for reducing fatigue.	[54]
Improve communication and coordination of activities on ground through digitisation to reduce turnaround time.	[46]
New approaches for improving cabin design; therefore, flight attend operations must be evaluated and compared.	[79]
Possible impact on passenger expectation on automatic catering services.	[55]
Investigate use of recommender system after a certain level of individualisation.	[56]
Evaluate impact in the value chain regarding individualisation efforts with sub-suppliers.	[57]
Investigate each demographic's impact on individualisation of inflight catering meals.	[58]

Table A2. *Cont.*

Demand Derived from Meal Individualisation	Reference
Impact of meals on satisfaction	
Support flight attendants with proper tools for improving passenger response in case of failure.	[60]
Need of establishing a connection between meal quality and individualisation.	[61]
Definition of a strategy for individualising inflight catering services regarding different compromises between internal variety and customer benefit.	[3]
Establish common comparison features for individualisation of inflight meals to improve service quality.	[63]
Willingness to pay for ind. meals	
Need to investigate the relationship of individualisation with sustainability and understand how the individualisation of meals could increase the willing to pay (WTP), also from sustainable factors.	[64]
Assess variations in inflight meals for understanding WTP for higher level of individualisation.	[65]
Identify individual customers' needs and desires for developing a proper solution.	[59]

Table A3. Survey socio-demographic data.

Characteristic	Percentage
Overview socio-demographics	
Gender	
Male	48
Female	52
Age	
18–29	19
30–49	45
50–59	18
60 and older	18
Monthly household net income (EUR)	
<1.300	7
<1.700	7
<2.600	20
<3.600	22
<5.000	23
<10.000	13
<18.000	1
>18.000	1
Not specified	5
Education	
No school-leaving qualification	0
Elementary/secondary school	9
Realschule certificate	36
High school diploma	27
(Technical) higher education	27
Other qualification	2
Passenger profile	
Annual flight frequency	
1–2 times	70
3–5 times	22
6–10 times	6
10–20 times	1
20 times or more	0
Less than once a year/never	0
Most frequent ticket category	
Economy Class	76
Premium Economy Class	13
Business Class	9
First Class	3
Main reason for air travel	

Table A3. *Cont.*

Characteristic	Percentage
Private	5
Business	82
Both	13
Most frequent flight route—Private travel	
Short haul	14
Medium haul	51
Long haul	33
I do not fly for the reason	2
Most frequent flight route—Business travel	
Short haul	14
Medium haul	10
Long haul	6
I do not fly for the reason	70
Frequent fellow traveller	
Alone	17
+1 Person	55
+2 People	15
>2 People	13
Type of fellow travellers	
Family member	85
Friend	11
Work colleague	4
Mostly alone	0

Table A4. Survey individualisation of ICS—questions and results.

Dimension	Question Number	Question	n	Average, ø	Acceptance, α [%]	Individualisation Dimension
D2, D4, D5, D7	B8 (1..12)	To what extent do you agree with the following statements regarding your eating behaviour Type: Matrix, scale from 1 = "Do not agree at all" to 5 = "Agree completely"	1042..1079			
D4	B8 (1)	When I travel, I make sure that I don't throw away any food.		3.8	65	Supported
D4	B8 (2)	If my chosen meal option runs out on a flight, I switch out and eat a second meal option.		3.7	66	Supported
D4	B8 (3)	In the aircraft, I pay attention to whether the food looks appealing and is well presented		3.5	53	Supported
D4	B8 (4)	When I travel, I only eat when I'm hungry.		3.4	51	Supported
D5	B8 (5)	When I travel, I am willing to pay more for food than in everyday life.		3.4	51	Supported
D2	B8 (6)	In the aircraft, I'm not picky about food choices.		3.3 *	44	Not supported
D4	B8 (7)	When I travel, I am very conscious of what and when I eat.		3.2	40	Supported
D7	B8 (8)	I am used to customising the selection to my individual preferences when ordering food online.		3.0	41	Supported
D4	B8 (9)	When eating on a plane, I find it important to know how the food was prepared.		2.9 *	30	Supported
D4	B8 (10)	When travelling by plane, food is an important topic for me.		2.9 *	32	Supported
D7	B8 (11)	I am used to ordering food online.		2.7 *	27	Supported
D7	B8 (12)	When ordering food online, I usually have extra requests to customise my order.		2.6 *	28	Supported

Table A4. *Cont.*

Dimension	Question Number	Question	n	Average, ø	Acceptance, α [%]	Individualisation Dimension
D7	C9	Have you ever pre-ordered a meal for air travel? Yes: 29% No: 64% I do not remember: 7% Type: Single choice, Basis: Total	1083			Supported
D2	C12	How well did you like your last experience of pre-ordering a meal for air travel? Type: Scale from 1 = "Not at all good" to 5 = "Very good", Basis: People who have experience with pre-ordering	314	4.0 *	77	Not supported
D6	C13	When exactly did you last pre-order the meal for a flight? After the ticket purchase: 49% During the ticket purchase: 39% I do not remember: 12% Type: Single choice, Basis: People who have experience with pre-ordering	312			Supported
D7	C15	When travelling by air, how important is it to you to order meals in advance? Type: Scale from 1 = "Not at all important" to 5 = "Very important", Basis: Total	1075	2.4 *	28	Supported
D1, D3, D8	C16 (1..5)	Regardless of whether or not you have already pre-ordered a meal for air travel, how important are the following choices to you when pre-ordering meals for air travel? Type: Scale from 1 = "Not at all important" to 5 = "Very important", Basis: Total	1078..1080			
D1	C16 (1)	Information about allergens of the meal on board		2.9	39	Not supported
D8	C16 (2)	Individually selectable time at which the meal is served		2.7	31	Not supported
D3	C16 (3)	Pre-ordering of non-alcoholic drinks before the flight		2.3	22	Not supported
D3	C16 (4)	Receiving the meal before the other passengers		1.9	12	Not supported
D3	C16 (5)	Pre-ordering of alcoholic beverages before the flight		1.8	12	Not supported
D1	C17	By when would you like to have at least the possibility to pre-order your meal for a flight? 10 days before the flight: 11% 5 days before the flight: 20% 2 days before the flight: 20% 1 day before the flight: 17% 8 h before the flight: 3% 4 h before the flight: 3% 1 h before the flight: 3% I do not want to pre-order but order during the flight: 23% Type: Single choice, Basis: Total	1065			Not supported

Table A4. *Cont.*

Dimension	Question Number	Question	n	Average, ø	Acceptance, α [%]	Individualisation Dimension
D7	D18	When travelling by air, how important is it to you to individualise the pre-ordering of meals? Type: Scale from 1 = "Not at all important" to 5 = "Very important", Basis: Total	1081	2.7 *	28	Supported
		Regardless of whether you have already individualised a meal for a flight or not: Imagine the following menu on a flight: a small salad beforehand, a pasta dish as the main course and a chocolate pudding for dessert. How many variations would you like to have (e.g., different sauces or ingredients)?	1069			
D3	D19	If ordering the meal during the flight: None: 29% 2–3 variations: 56% 4–6 variations: 13% 7 or more variations: 3%	1064			Supported
		If the meal is ordered in advance before the start of the flight: None: 24% 2–3 variations: 43% 4–6 variations: 27% 7 or more variations: 5% Type: Single choice, Basis: Total When travelling by air, would you prefer to choose the ingredients of a meal freely or select them yourself from different menus prepared in advance?				
D3	D21	Choice from various menus compiled in advance: 54% To freely choose the ingredients of a meal: 23% I have no preference: 23%	1077			Supported
		Type: Single choice, Basis: Total Regardless of whether you have already individualised a meal for a flight or not: How important are the following aspects regarding individualisation to you for a meal on a flight? Type: Scale from 1 = "Not at all important" to 5 = "Very important", Basis: Total				
D1, D3	D20 (1..12)		1071..1079			
D3	D20 (1)	Non-alcoholic drinks		3.6	58	Supported
D1	D20 (2)	In-flight re-orders		3.3 *	47	Not supported
D3	D20 (3)	More than two different menu options [. . .] to be available		3.3 *	46	Not supported
D3	D20 (4)	Individual choice of snacks		3.2 *	45	Not supported
D3	D20 (5)	Possibility to choose different ingredients		3.2 *	42	Not supported

Table A4. *Cont.*

Dimension	Question Number	Question	n	Average, ø	Acceptance, α [%]	Individualisation Dimension
D1	D20 (6)	Individually selectable number of meals during the flight		3.1 *	39	Not supported
D3	D20 (7)	Individually determinable meal size		3.0 *	39	Not supported
D3	D20 (8)	Possibility to change the components of a meal		2.9	34	Not supported
D1	D20 (9	Individually definable number of meal courses		2.9	31	Not supported
D3	D20 (10)	Possibility to individually choose the way the meal is prepared		2.7	28	Not supported
D3	D20 (11)	Possibility of making further changes [. . .] during the flight.		2.6	24	Not supported
D3	D20 (12)	Alcoholic beverages		2.2	20	Not supported
D2, D5, D6	D23 (1..5)	To what extent do you agree with the following statements? Type: Scale from 1 = "Do not agree at all" to 5 = "Agree completely", Basis: Total	1071..1077			
D2	D23 (1)	For me, a standardised meal is quite enough.		3.7 *	58	Not supported
D5	D23 (2)	I am willing to pay a reasonable additional charge for a meal tailored to my wishes.		3.2	45	Supported
D6	D23 (3)	A meal tailored to my preferences is very valuable to my in-flight experience.		3.1	37	Supported
D6	D23 (4)	It is important to me that a meal on a flight is sustainable.		3.1	36	Supported
D6	D23 (5)	I would prefer to eat an individualised meal during the flight instead of a standard meal.		3.0	33	Supported
D1, D2, D3, D6	D22	How important are the following aspects to you when having a meal on a flight? Type: Scale from 1 = "Not at all important" to 5 = "Very important", Basis: Total	1076..1080			
D6	D22 (1)	Hygiene		4.7 *	92	Not supported
D6	D22 (2)	Quality		4.4 *	89	Not supported
D6	D22 (3)	Food at a suitable temperature		4.2 *	84	Not supported
D6	D22 (4)	Price		3.8 *	64	Not supported
D3	D22 (5)	Quantity/portion size		3.7	63	Supported
D3	D22 (6)	Healthy meal		3.7	59	Supported
D3	D22 (7)	Included ingredients		3.6	54	Supported
D2	D22 (8)	Service by the flight attendant		3.4 *	46	Not supported
D1	D22 (9)	Preparation method		3.2	39	Supported
D3	D22 (10)	Origin of the ingredients		3.1	36	Supported
D5, D6	D24	Imagine again the following menu on a flight: a small salad beforehand, a pasta dish as the main course and a chocolate pudding for dessert. The price for this menu is EUR 20 and is already included in your purchased flight ticket. If you had the possibility to customise this menu for your flight, what extra amount in euros would you be willing to pay for a menu tailored to your wishes? You could change anything from the menu components (starter, main and dessert) to the ingredients of each component. Numerical input, basis: price mention, n = 813; basis: without estimation, n = 291	813			Supported

* question in negative form.

Table A5. General overview of stakeholders with tasks.

Stakeholder	*Primary Role*	*Main Responsability*	*General Tasks*
Aircraft manufacturer	Designer	Provision of hardware and software	Aircraft type Cabin configuration and size Number of seats/galleys Type of galley inserts Galley configuration Galley size Galley operation
Airline	Business owner	Definition of operation‘s model	Choice of aircraft Choice of cabin configuration Definition of service’s type and number Amount of catering Catering check Galley and trolley commissioning
Flight attendant	Service executor	Execution of operation‘s model	Meal and beverage preparation Meal and beverage distribution Waste collection Inventory management
Passenger	Consumer	Consumption of goods and choice of services	Passenger interaction Pre-orderings choice Menu choice onboard Flight attendant interaction
Caterer	Supplier	Provision of consumable goods	Provision of meals and beverages Transport to aircraft Loading and unloading of galleys Meal preparation instructions Definition of meal ingredients Cleaning of trolleys and standard units Waste disposal and recycling
Airport	Coordinator	Infrastructure provision and ground operations	Coordination of turnaround activities Coordination of landing and departure slots Gate and boarding coordination

Table A6. Comparison Indexes for ICS automation concepts.

	Index	**Description**	**Formula**
1	Storage Index	Usable storage volume as opposed to the total volume of the galley	$\frac{\sum \text{Usable storage volume of the monuments}}{\sum \text{ Total volume of the monuments}} \times 10^3$
2	Space Efficiency	How many square meters of galley per passenger	$\frac{\text{Galley's area}}{\text{Number of passengers}} \times 10^3$
3	Galley Workspace Ratio	Comparison between the entire space of the galley and the monuments inside	$\frac{\text{Monument area} \times 100}{\text{Total galley's area}}$
4	Catering Index	How much volume of catering per passenger must be carried. Relation to number of services, type food (volume), type beverages (volume) and number of passengers.	$\frac{\text{Number of services} \times (\text{Total food volume} + \text{Total beverage volume})}{\text{Number of passengers}} \times 10^5$
5	Catering Efficiency	How much usable storage volume of the galley is filled by required volume. How effective the storage space is used. Number of passengers and services, volume of food and beverages, and available galley space.	$\frac{\text{Storage Index} \times \text{Catering Index}}{10^3}$

Table A7. Inflight catering service indexes.

	Index	Standard Service with 100% Catering	Standard Service with 10% Overcatering	Standard Service with 20% Overcatering	Standard Service with 10% Pre-Ordering	Standard Service with 50% Pre-Ordering	New Concept Service with 10% Pre-Ordering	New Concept Service with 50% Pre-Ordering	New Concept Service with 100% Pre-Ordering
1	Storage Index	215.4	197.4	184.9	215.4	215.4	215.4	215.4	215.4
2	Space Efficiency	88.5	100.4	112.3	88.5	88.5	88.5	88.5	88.5
3	Galley Workspace Ratio	60.0	64.7	68.5	60.0	60.0	60.0	60.0	60.0
4	Catering Index	94.2	103.6	113.0	1265.1	6481.0	94.2	94.2	94.2
5	Catering Efficiency	20.3	20.5	20.9	272.5	1396.0	20.3	20.3	20.3
	Simplified assumptions								
A.1	Total number of passengers	226	226	226	226	226	226	226	226
A.2	Total number of passengers with pre-ordering				23	113	23	113	226
A.3	Total number of meals	452	497	542	452	452	452	452	452
A.4	Flight distribution services	2	2	2	2	2	2	2	2
A.5	Extra way for pre-ordering service distribution [m]	0	0	0	25	136	0	0	0
A.6	Number of extra meals	0	45	90	0	0	0	0	
A.7	Number of pre-ordered meals	0	0	0	45	226	45	226	452
A.8	Usable storage volume of the monuments [m^3]	6.46	7.25	8.03	6.46	6.46	6.46	6.46	6.46
A.9	Total volume of the monuments [m^3]	30.00	36.72	43.44	30.00	30.00	30.00	30.00	30.00
A.10	Galley total area [m^2]	20.00	22.69	25.38	20.00	20.00	20.00	20.00	20.00
A.11	Galley monument area [m^2]	12.00	14.69	17.38	12.00	12.00	12.00	12.00	12.00
A.12	Food volume/passenger/meal [m^3]	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
A.13	Beverage volume/passenger [m^3]	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
A.14	Number of meal trolleys	16	18	20	16	16	16	16	16
A.15	Number of beverage trolleys	6	7	8	6	6	6	6	6
A.16	Number of galley inserts	16	16	16	16	16	16	16	16
A.17	Oven volume [m^3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
A.18	Full-size trolley volume [m^3]	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
A.19	Number of standard units	16	16	16	16	16	16	16	16
A.20	Volume of standard units [m^3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

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