# AUTOMATION OF INFLIGHT SERVICES

## Development of a multicriteria decision-making framework for the assessment of automation concepts for inflight catering services inside the aircraft cabin

Vom Fachbereich Produktionstechnik

der

UNIVERSITÄT BREMEN

zur Erlangung des Grades

Doktor der Ingenieurwissenschaften (Dr.-Ing.)

genehmigte

Dissertation

von

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Tag der mündlichen Prüfung: 01.12.2023

# Dedication

I want to dedicate this dissertation to my wife Birte and my children Paula, Caio and Olivia; without their support, I would not be able to accomplish this work. I would also like to thank my mother, Heloísa, and my father, Henrique. They gave me the motivation to keep going. Another special thanks goes to Horst and Annemarie, who always had an open ear and supportive words.

I would also like to thank Professor Dr.-Ing. Michael Freitag, who supervised me on this journey and enabled the constant improvement of this work through discussions. Also, many thanks to Professor Dr.-Ing. Johannes Fottner for taking on the role of the second reviewer.

Further special thanks go to my friend Matthias Reiß, whose openness and always fruitful discussions significantly expanded the possibilities that made this work possible.

I thank many colleagues at the BIBA-Bremen Institute for Production and Logistics for listening to my ideas and challenging the approaches taken in this work.

I would also like to thank my Airbus colleagues, on behalf of Ralph Kagelmann, who believed in me and encouraged to start this journey.

I am deeply grateful for this opportunity; it was a great chance for me to grow and face the challenge of putting all these ideas together.

# Zusammenfassung

Diese Dissertation befasst sich mit der Forschungsfrage "Wie ist es möglich, die Bordverpflegung zu automatisieren?". Bordverpflegungsdienste sind mit anspruchsvollen Herausforderungen in einem komplexen Umfeld verbunden. Auf der einen Seite steht die Luftfahrtindustrie mit ihren Lieferanten, Caterern und Fluggesellschaften, auf der anderen Seite die Passagiere. In diesem Zusammenhang bedeutet die Verbesserung von Systemen und Prozessen innerhalb des Flugzeugs auch die Veränderung von Prozessen außerhalb des Flugzeugs.

Für die Entwicklung neuer Automatisierungskonzepte zur Optimierung der Bordverpflegung wurde ein neuer Ansatz gesucht, um neue Konzepte konsequent vergleichen und auswählen zu können.

Zu diesem Zweck wurde eine enge Zusammenarbeit mit der Flugzeugindustrie durchgeführt, um bisherige Erfahrungen, Kenntnisse und Anforderungen zu sammeln sowie die durchgeführten Arbeiten in der Literatur auszuwerten.

Der Trend zur Individualisierung wurde als Beispiel für den Wandel innerhalb des Flugzeugs herangezogen, um neue Entwicklungen voranzutreiben, da die derzeitigen Systeme nicht in der Lage sind, die neuen Anforderungen zu erfüllen. Um die tatsächlichen Bedürfnisse zu spezifizieren und Anforderungen an ein neues technisches System abzuleiten, wurde eine Passagierbefragung mit 1000 Passagieren durchgeführt.

Die entwickelte Methode ermöglicht die Entwicklung von Automatisierungskonzepten für das Inflight Catering auf der Grundlage eines spezifischen Rahmens, der einen konsistenten Vergleich und eine Bewertung der Konzepte ermöglicht.

Letztlich wurde mit dieser Arbeit nicht nur ein wissenschaftlich wenig erforschtes Gebiet beleuchtet, sondern auch ein neuer Ansatz entwickelt, der Aspekte des Produktdesigns und der Prozessanalyse mit Methoden der Entscheidungsfindung verbindet und damit neue Möglichkeiten für die frühzeitige Entwicklung von Automatisierungskonzepten mit konsistentem Vergleich eröffnet.

# Abstract

This dissertation addresses the research question, "How is it possible to automate inflight catering services?". Inflight catering services are associated with challenging issues in a complex environment. On one side is the aviation industry with its suppliers, caterers and airlines; on the other side are the passengers. In this context, improving systems and processes inside the aircraft also implies changing processes outside the aircraft.

For the development of new automation concepts for the optimisation of inflight catering services, a new approach was sought in order to be able to consistently compare and select new concepts.

For this purpose, close cooperation with the aircraft industry was carried out to gather previous experience, knowledge, and requirements and to evaluate the work conducted in the literature.

The trend towards individualisation was used as an example of change within the aircraft to drive new developments, as current systems cannot fully meet the derived new requirements. A passenger survey to specify the actual needs and derive requirements for a new technical system was conducted with 1000 passengers.

The designed method allows the development of automation concepts for inflight catering based on a specific framework that enables consistent comparison and evaluation.

Finally, this work not only sheds light on an area little explored by the scientific community but also developed a new approach that combines the aspects of product design and process analysis with decision-making methods, thus opening up new possibilities for the early development of automation concepts with consistent comparison.

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# List of abbreviations

| | |
|---|---|
| A/C | Aircraft |
| ACA | Aircraft catering association |
| ATC | Air traffic control |
| C/C | Cabin crew or flight attendant |
| CLB | Climb |
| CPACS | Common Parametric Aircraft Configuration Schema |
| DSRM | Design science research methodology |
| EASA | European Union Aviation Safety Agency |
| ES | Engine Start \| Preparation phase |
| FST | Full size trolley |
| HST | Half size trolley |
| IATA | International Air Transport Association |
| ICAO | International Civil Aviation Organisation |
| ICS | Inflight Catering Services |
| JAA | Joint Aviation Authorities |
| KPIs | Key performance indicators |
| LoA | Level of automation |
| MaaS | Mobility as a service |
| MCDM | Multicriteria decision making method |
| MTOM | Maximum take-off mass |
| T | Taxi |
| TO | Take-off and initial climb |
| TRL | Technology readiness level |

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# Glossary

| | |
|---|---|
| Aircraft Configuration | Planned utilisation layout of aircraft interior space. |
| Aircraft payload | The weight of passengers, baggage, cargo and mail and includes both revenue and non-revenue items. |
| Baggage | Equivalent to the term "Luggage", means such articles, effects, and other personal property of a passenger as are necessary or appropriate for wear, use, comfort, or convenience in connection with his trip. Unless otherwise specified, it includes both checked and unchecked baggage. |
| Booking | An arrangement whereby something, especially a seat, room, or space is booked or reserved. |
| Business Class | A class of service with seating standards which may be superior to those provided on premium economy/economy class but less liberal than standards provided in first class. |
| Cabin | All areas of an aircraft where passenger seats are installed (also known as fitted interior). |
| Cabin crew / flight attendant | Crew members, other than flight deck crew, e.g. pilots. |
| Casserole | A bowl commonly made of aluminum or plastic that can contain an individual hot meal part. |
| Cockpit | That part of an aircraft from which the flight crew control the aircraft. |
| Data | A representation of facts, concepts or instructions in a formalised manner suitable for communication, interpretation or processing by human beings or by automatic means. |
| Data Integrity | The transmission of electronic data as accepted, without alteration. |
| Data Security | The denial of unauthorised access to, or transmission of, electronic data. |
| Dead load | Baggage, cargo, mail , ballast and equipment in compartments not included in dry operating weight of the aircraft. |
| Dead load index | Index effect of the dead load. |
| Departure | The day/time of the flight on which the passenger is booked/ticketed to travel. |
| Destination | The ultimate stopping place according to the contract of carriage. |
| Domestic Flight Leg | A flight between two stations to which the same ISO country code applies. |

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| Drawer | An open-topped box that can be slid in and out of service carts and Standard Units. Drawers commonly contain any kind of service item, and they may also be placed on the topside of service carts to store casseroles there. |
| Duplicate Leg | A single non-operational leg that, for commercial/technical reasons, is displayed under more than one flight number by the operating carrier, or is displayed by a different airline designator/flight number by an airline other than the operating carrier. |
| Fare | The amount charged by the carrier for the carriage of a passenger and his allowable free baggage and is the current fare which a Member, in the publication it normally uses to publish fares, holds out to the public, or the appropriate segment of the public, as being applicable to the class of service to be furnished. |
| Flight | The movement of a passenger-carrying aircraft, serving two (single sector flight) or more (multi-sector flight) airports under one flight number of an airline, as published in the airlines schedules and reservations systems. |
| Flight deck | The cockpit of a large aircraft. |
| Galley | The integral part of the aircraft where pantry/catering material is stored. |
| Inventory | Assurance that inventory for a particular product is available and will be fulfilled. |
| Latch | A fastening for a door, hatch or any device to secure it in a desired position. |
| Leg | The space between two consecutive scheduled stops on any given flight. |
| Load configuration | Planned utilization layout of aircraft hold. |
| Load Sheet | A legal document which states the weight data and the balance condition of the loaded aircraft for each individual flight. The term load sheet includes provisional load sheet, final load sheet, ACARS load sheet or any other approved form of transmission. |
| Long-haul | A long-haul flight is a flight that is relatively long in distance, typically more than 3,000 miles (4,800 kilometers). These flights may take many hours to complete, and may involve multiple stops or layovers. Examples of long-haul flights include flights between continents, or flights between major cities on different sides of the world. |
| Middle-haul | A medium-haul flight is a flight that is longer than a short-haul flight, but shorter than a long-haul flight. These flights typically have a distance of 1,500 to 3,000 miles (2,400 to 4,800 kilometers) and may take several hours to complete. Examples of medium-haul flights include flights between major cities in different regions of a country, or flights between neighboring continents. |

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| Mission profile | A mission profile typically includes information about the aircraft and crew, the route and destination of the flight, the payload and any special equipment or resources that will be needed, as well as any environmental or operational constraints that must be considered. |
| Oven insert | A rack that can be inserted into a galley oven. The oven insert carries casseroles that contain individual hot meal parts. It ensures sufficient spatial separation between the casseroles to achieve a sufficient flow of hot air for heating. |
| Over-booking | A condition which exists when more seats have been booked on a flight than seats allowable for sale. |
| Pantry | Removable catering equipment |
| Passenger | Any person, except members of the crew, carried or to be carried in an aircraft with the consent of the carrier. Any person carried on an aircraft and covered by a ticket. |
| Passenger Type Code | A code used to identify the type of passenger, e.g., adult, infant, etc., in order to determine the type of fare. |
| Premium Economy Class | A class of service with seating standards which may be superior to those provided on economy/tourist class but less liberal than standards provided in business class. |
| Seat Map | Display which indicates positioning, availability status and/or characteristics of specific seats for a given flight/date. This typically contains information about cabin classes, location of cabin components, etc., as well as, an indication of which seats have been reserved and which are still available. |
| Seat Pitch | The distance between the front edge of one seat in an aircraft and the front edge of the seat immediately in front when both are in an upright position. |
| Seating configuration | Planned utilisation layout of aircraft cabin section/zone. |
| Self-service | The process by which a customer can do one or more of the following tasks without assistance by another person: make/change a reservation, purchase a ticket, change a ticket, obtain a boarding pass, obtain baggage tags, board a flight, etc. |
| Service cart/ Trolley | A cart that is used to deliver food or beverages and to collect back waste inside an aircraft cabin. The dimensions of trolleys are such that they can be moved along the cabin aisles. |
| Short-haul | A short-haul flight is a flight that is relatively short in distance, typically less than 1,500 miles (2,400 kilometers). These flights are usually within a single country or region, and may take a few hours to complete. Examples of short-haul flights include flights between cities within the same state or country, or flights between neighboring countries. |

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| Standard Unit | A box commonly made of aluminum that can contain various catering goods and items. |
| Turnaround | The station in an aircraft rotation, where the flight number changes. |

# Preface

This dissertation was written during my work as a research associate at BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen under the supervision of Professor Dr.-Ing. Michael Freitag and in cooperation with Airbus Operations GmbH in Hamburg. Part of the results and conclusions described in this document come from 18 projects carried out between 2017 and 2022. From the projects, seven inventions were registered as patents. The starting point was the investigation of automation and digitalisation potentials in the aircraft cabin, especially in the area of inflight catering. A fascinating bouquet of topics emerged from the analysis of processes and the exploration of new ways to perform very demanding tasks in a complex environment, the aircraft. In the course of the projects, the topics of automation and digitalisation were inevitably expanded to include aspects of sustainability and became a new field of research for another dissertation topic. My dissertation aims to shed some light on the topic of automation of inflight catering services, which has not yet been explored in depth by the scientific community. From the results of this dissertation, I expect not to give the reader the final solution to all challenges related to the automation of inflight catering services but to show a solid path towards the step-by-step optimisation of inflight catering services through a holistic view of the processes and actors involved. The MDPI Aerospace Journal Volume 9, Issue 11 from November 2022 and the ELSEVIER Transportation Research Procedia Volume 65, 2022, have published parts of the results of this dissertation.

# 1 Introduction

Catering services have a long and rich history, dating back to ancient civilizations where feasts and banquets were a common occurrence. Today, catering services are a vital part of many industries, including hospitality, events, and transportation. In the case of aircraft inflight catering, the focus is on providing high-quality food and beverages to passengers during their flights (Foskett *et al.*, 2016).

This dissertation focuses on aircraft inflight catering services (ICS), which are an integral part of the airline industry, providing passengers with food and beverages during their flights. These services have evolved significantly over the years, and today they are a vital part of the overall passenger experience (Jones, 2011).

One of the significant trends in aircraft inflight catering services is the increasing use of digital technologies and automation. In this work, the evolution of aircraft inflight catering services will be explored, as well as the current state of the industry and the trends and challenges that are shaping its future. The role of automation in aircraft inflight catering services is going to be examined, and its potential benefits and challenges will be discussed.

## 1.1 Initial situation and research problem

Service concentrates on people's interaction rather than converting tangible goods (Palmer, 2008). Services are part of the tertiary sector of the economy and comprise many different businesses, e.g., banking, retail, gastronomy and communication (Schönsleben, 2019). The service industry is changing rapidly with new technologies, especially with digitization and automation (Marija Cubric, 2020).

The **individualization** of meals and beverages to fulfil customer's unique needs is a growing trend and directly impacts on the ICS, e.g., changing operational procedures such as specific heating times for meals or challenges for distributing and tracking pre-ordered meals (Derossi *et al.*, 2020a). The personalization of meals arrives primarily due to digitalization possibilities, e.g., online orders (Georgiou *et al.*, 2010; Costers *et al.*, 2019). The ICS market is highly competitive, pushing down the profit margin per meal and impacting the airline choice from the passenger side (Akamavi *et al.*, 2015; O'Connell and Williams, 2005).

It is possible to state that the **optimization** of operations and ergonomics of ICS inside the aircraft was distressed to the limit of the possibilities without changing the aircraft cabin layout. This observation can be followed by many studies regarding ergonomics of cabin crew operations, where mainly the position and handling of equipment could be optimized (Agampodi *et al.*, 2009; Avers *et al.*, 2011; Dismukes *et al.*, 2018; Hagihara *et al.*, 2001a; Li, 2015; Mahony *et al.*, 2008; Mumtaz, 2017; van den Berg *et al.*, 2015). Also, scheduling the cabin crew activities, known as rostering, is broadly considered an issue for airline operations (Kohl and Karisch, 2004; Medard and Sawhney, 2007). Direct effects on the health of the cabin crew could be stated by many authors, varying from issues related to mental stress (Mumtaz, 2017), workload (Glitsch *et al.*, 2007), and associated fatigue (Li, 2015) up to knowledge retention after training (Mahony *et al.*, 2008).

The research on **ICS automation** is not extensive. Here, digital and physical automation approaches were considered, the first for optimizing information flows and the second for the improvement of material handling. Within a preliminary literature review, three main approaches were observed: meal distribution automation, assistance systems, and digitization of processes. **Inflight meal distribution** is a significant, time-consuming task involving the majority of the cabin crew. It is mainly performed by using trolleys to distribute meals and beverages to passengers along the aircraft aisle. Some concepts for automating inflight meal distribution involve new trolley ideas, e.g., mobile service robots (Santos *et al.*, 2017) and delivery systems mounted under the overhead bins (Frank *et al.*, 2016). **Assistance systems** could also be found to optimize communication among flight attendants, e.g., by the use of wearables such as smartwatches to improve collaboration during service (Wong *et al.*, 2017, 2018). Another assistance approach uses an add-on device to help the cabin crew move the trolley (Mortensen Ernits *et al.*, 2019a). The vision of a more ergonomic and efficient cabin was already the topic of many publications, especially regarding the optimization of the galley (aircraft kitchen) topology, trolley movement support, and repetitive activities. Most concerns are related to fatigue and health issues which correspond to strenuous activities (Li, 2015; Mahony *et al.*, 2008; van den Berg *et al.*, 2019; Agampodi *et al.*, 2009). The **digitization of inflight catering** content could be observed by, e.g., the tracking and tracing of trolleys through RFID tags (Bauer *et al.*, 2010), and an inventory system for inflight catering (Mortensen Ernits *et al.*, 2019b). However, none of the few concepts found in the literature were implemented inside the aircraft.

The **industry** has also made efforts to improve the ICS, e.g., SPICE-SPace Innovative Catering Equipment (Butterworth-Hayes, 2009), which was a project with significant dimensions, changing the way catering is provided and operated inside the aircraft. The Lower Deck Catering project (Boos *et al.*, 2016), assessed possibilities of moving the primary storage of meals to the lower deck of the aircraft. Airbus led both projects, and they were not further developed. A report of the reasons was not found in the literature. Airbus is still engaged in identifying cabin crew activities that could be automated from the passenger perspective (Becker and Bruns, 2013).

The possibilities with automation are also changing with emerging technologies, and therefore, they can enable the exploitation of new opportunities for the optimization of ICS. Currently, there is no specific methodology for implementing automation in ICS, nor is there an overview of the possible degree of automation based on functions and systems. By contrast, levels of automation (LOA) have been increasingly used, e.g. SAE levels of driving automation, enabling a shared understanding of automated functions and supporting decisions about the impact on human interaction due to automation (Barabás *et al.*, 2017).

Although there is a numerous variety in the taxonomy of the level of automation (LOA) (Wilhelm *et al.*, 2020; Vagia *et al.*, 2016), even for cockpit automation (Billings, 2018), there is no specific scale for ICS. Even though automation systems are dedicated systems based on tasks and derived functions executed by assigned devices (Riedl et al., 2014), there are methods applied in other areas that could be transferred to the ICS. In tourism hospitality, many elements are similar to ICS conditions, e.g., multiple needs of users of hotels as a one-stop tourism service (Zheng *et al.*, 2015) or meal delivery robots for room service (Li *et al.*, 2016). Also, in gastronomy, robots serving in restaurants can be found (Ivkov *et al.*, 2016).

It is also necessary to establish a connection between a specific LOA for ICS and the current requirements and challenges to provide a reliable comparison among automation solutions. There is no **multicriteria decision-making framework** available for choosing which concept would be most suitable for ICS automation. Methods like PROMETHEE have a general approach and do not consider the specific issues regarding catering service automation with the specific constraints involved (Vučijak *et al.*, 2015).

In a nutshell, the findings from the reviewed **state-of-the-art** are:

- Automation of ICS was developed and evaluated only as a sub-system without a holistic view of the entire inflight catering service process.
- Ergonomic issues regarding cabin crew operations are still unsolved or were only improved to the limits of the cabin layout.
- Personalization of inflight meals generates new challenges for processes and operations of the flight catering industry.
- A link between ICS and optimization through automation was not yet established.

## 1.2 Objectives and research questions

Based on the identified research gap, the leading **research question** is derived:

**"How is it possible to automate the inflight catering services?"**

The derived research sub-questions and approaches and methods to be applied are summarized in the table 1.

**Table 1 - Research sub-questions and approaches and methods to be applied.**

| | Sub-question | Approach/methods |
|---|---|---|
| **Q1** | What are the needs and requirements of the stakeholders for optimizing the ICS? | Requirements engineering for ICS. |
| **Q2** | What are the necessary criteria to implement automation inside the aircraft cabin and their relations to the processes and stakeholders? | Methodology for modelling, analysis and evaluation of ICS tasks. |
| **Q3** | To which extent would it be feasible to automate the ICS? How would technical solutions look like? | Test and validation of concepts for ICS automation. |
| **Q4** | What are the benefits, drawbacks, and consequences of the automation of ICS in the aircraft cabin? | Technological benchmarking of automated service processes. |
| **Q5** | How could automated ICS adapt to ever-changing cabin configurations? | Assessment transferability of concepts and the effects on system design. |

## 1.3 Boundaries and assumptions

The primary purpose of this research activity is to provide understanding and support in the early stages of the development of automation concepts for inflight catering services. The elaboration of business cases, as well as the processes derived from the technology transfer, e.g. manufacturing efforts, marketing strategy or certification, are not in focus. The processes at the caterer are presented in a simplified manner, and mostly, the interfaces to the aircraft are presented. In the same way, the airport procedures are just included in the interface. Passenger satisfaction and technology acceptance are important subjects for the final implementation of a new technology, but they were not deeply considered at this point of development as most of the validation tests occurred in laboratory conditions. Indeed, the direct involvement of all stakeholders would contribute to the complementation and approval of the method and approach. However, due to the timeframe and contract issues, it has been decided to proceed in this way. The product deployment is not completely fulfilled; in this case, the experienced work reached a comparable technology readiness level of five, with technology being tested in reality near laboratory scenarios; the further stages of the method development are theory-based.

## 1.4 Procedure model for research design

The research strategy is structured through a phase model based on the Design Science Research Methodology – DSRM (Peffers *et al.*, 2007). Three main objectives are aimed to be achieved within this methodology: consistency with previous work, a reproducible workflow, and a comprehensible model for the presentation and evaluation of the results. It consists of six phases: problem identification and motivation, the definition of the objectives for a solution, design and development, demonstration, evaluation, and communication (Hevner *et al.*, 2004).

1. In the first phase, most of the issues already presented in the introduction are going to be extended in a systematic literature review to connect the knowledge and provide a comprehensive overview of the current state of the art. A literature review classification will be done based on the method proposed by (Lezoche *et al.*, 2020), linking the use of technology and stakeholders' requirements. The identification of specific requirements will be explored through a questionnaire with stakeholders. The first phase closes with the identification of automation potential for ICS.

2. The second phase consists of defining the proposed research objectives. It involves the description of the leading research question and sub-questions and the definition of the approaches and methods to be used.

3. In the design and development phase, the involved tasks in the ICS gathered through previous industrial research projects with Airbus, are going to be modelled with the Business Process Model and Notation (BPMN) using a logistical approach (Hompel *et al.*, 2011). A model will be designed for representing the current ICS tasks and new automation concepts following the approaches from the literature (Krallmann *et al.*, 2013). In the development of concepts, results from previous industrial research projects involving automation of ICS with Airbus, are formalized and further developed. These concepts are going to be modelled and inserted into the developed framework. A multicriteria decision-making method framework is developed for assessing, selecting and integrating automation concepts for ICS. At first, a specific taxonomy is defined to represent the level of automation of ICS, and then key performance indicators (KPI) are established and grouped according to requirements, e.g., logistics, automation, service and sustainability. The selection step is performed through a questionnaire based on the taxonomy and KPIs, enabling the ranking of the automation concepts (Straub, 2015). The integration of the concepts is oriented in a technology portfolio to complement the technology roadmap (Pfeiffer *et al.*, 1990).

4. The demonstration is done with a prototype implemented in realistic scenarios. Therefore, the main functionalities are selected and implemented in a Cabin Mock-up, "Cabin Zero", at Airbus/Hamburg. The demonstration enables collecting information about process changes, e.g., process time and the number of saved process steps and the validation.

5. The evaluation of the concepts will be performed qualitatively through expert questionnaires. A comparison with currently available multicriteria decision-making methods is performed and the findings will be discussed to answer the research question (Behzadian *et al.*, 2010).

6. The last step of the phase model closes the research proposal with the documentation of the findings and publication of the results.

## 1.5 Structure of the dissertation

The chapters of this dissertation are structured within the design science for research methodology and the content is distributed as shown in Figure 1.

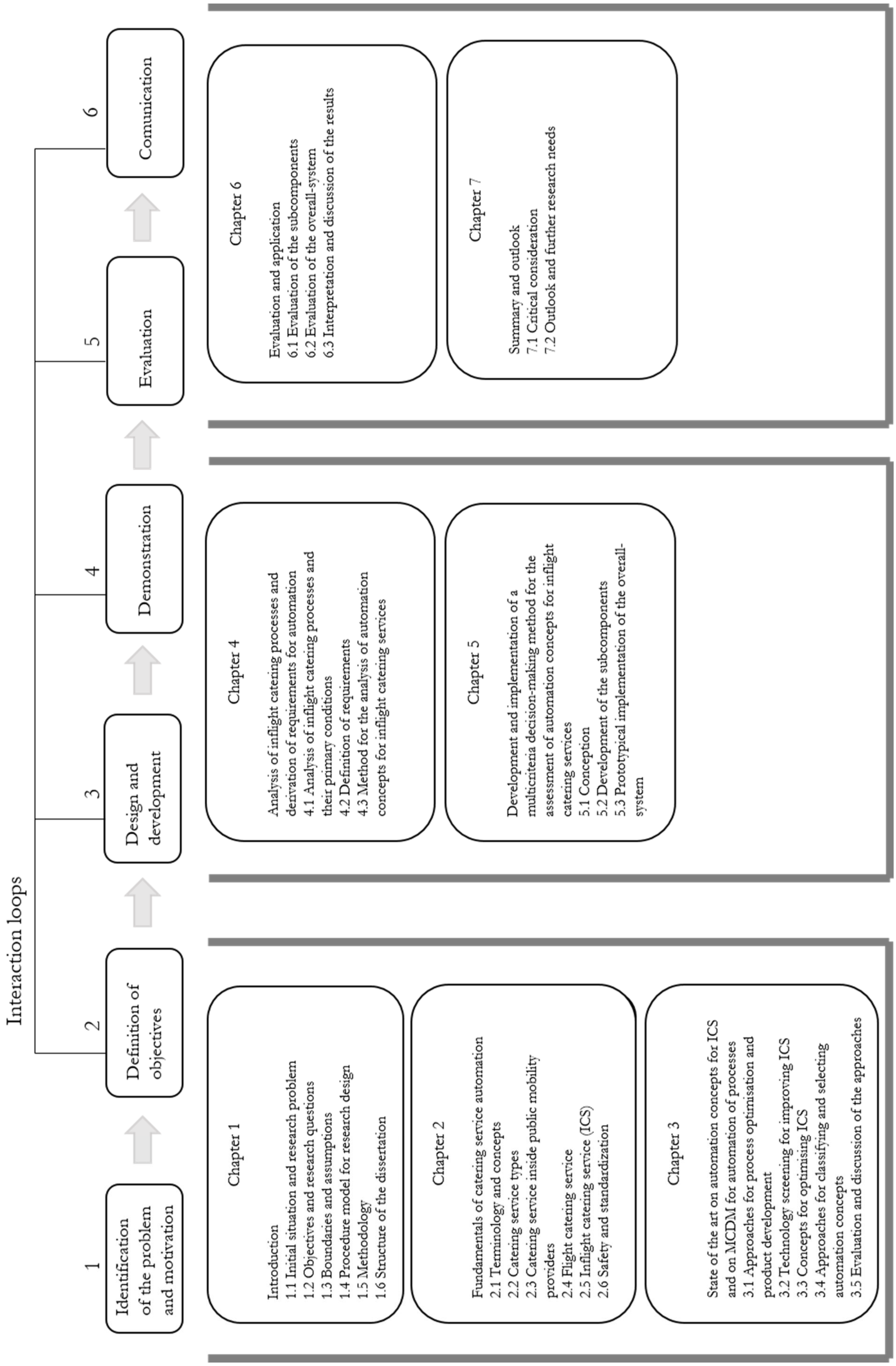



**Figure 1 - Research model overview with chapters.**

# 2 Fundamentals of catering service automation

This chapter is organized as follows: firstly, the most significant terms are defined according to the context of this research. Subsequently, the catering types are briefly explained, and a categorization is derived. According to this classification, catering services for public mobility providers are discussed to establish possible comparisons and derive common solutions. Further, an overview of the state of the art is given, while a differentiation between flight catering and inflight catering services is performed, exemplifying the involved stakeholders, processes and constraints. Afterwards, the issues regarding safety and standardization, which could influence automation efforts, are enumerated.

## 2.1 Terminology and concepts

*Inflight catering services*

This dissertation is motivated by the aircraft inflight catering services (ICS). Catering services focus on providing food and beverages to people (Foskett *et al.*, 2016). ICS comprises the loading, preparation, commissioning, distribution, and unloading of meals and beverages by the cabin crew for passengers inside an aircraft cabin (Jones, 2011).

The Merriam-Webster dictionary defines the verb cater as: “ 1: to provide a supply of food. 2: to supply what is required or desired”. The first known use of cater was in 1580 as a "buyer of provisions " (Merriam-Webster, 2022a).

The provision of food inside aircraft began with the first passenger flights in 1919(Guinness World Records, 2022) and intensified after flying turned into a mass transportation means (Statista, 2022a). In the beginning, inflight catering services comprised very luxurious and laborious dishes, even with cooks on board (Jones, 2011). It was primarily possible due to the generous travel space conditions, as passengers had more space than today.

*Services*

The definition of service used in this work follows the meaning 4b ": useful labour that does not produce a tangible commodity - usually used in plural ". Service concentrates on people's interaction rather than converting tangible goods (Palmer, 2008). Services are part of the tertiary sector of the economy and comprise many different businesses, e.g., banking, retail, gastronomy and communication (Schönsleben, 2019).

Following the etymology definition, catering services is more than merely the provision of food; but involves the intangible dimension of service regarding people's interaction. In this sense, the complexity of catering services involves not only logistics parameters intrinsic to storage, transportation, distribution, and waste management but also an intangible component usually present in satisfaction studies and surveys. The service industry is rapidly changing with new technologies, especially digitisation and automation (Marija Cubric, 2020).

*Aircraft cabin*

An aircraft is divided into the following main components: 1. Fuselage, 2. Wing, 3. Horizontal tail, 4. Vertical tail, 5. Engine, 6. Landing gear, and 7. Control surfaces. The cabin is a configuration option for the fuselage (Rossow *et al.*, 2014). The aircraft design is defined by its purpose of use; in the case of passenger transportation, the cabin is the fuselage configuration choice. The aircraft cabin must be designed with suitable features and personnel for fulfilment of required level of comfort for the passengers. According to (Sadraey, 2013), factors that influence comfort are related to, e.g. seat adjustability, leg/head/move room, flight attendant number and service, air temperature/humidity and pressure, interior design, and carry-on bag compartments. Besides, the aircraft cabin may be divided into different classes, e.g., first, business and economy, with different comfort requirements.

*Automation*

Automation is understood as any effort through a device, process, machine or hardware that reduces workload and increases process efficiency. Automation is part of the control-engineering field, which deals with the automatic control of individual work processes as well as closed production processes. The opportunities for automation are increasing with computational power (edge or cloud) and networking through digitisation (Zacher and Reuter, 2017).

*Multicriteria decision-making method*

Multicriteria decision-making methods (MCDM) are used in different branches, primarily for the selection of alternatives within complex contexts. Hereafter, MCDMs are specific and can be found in different areas such as construction (Tan Tan *et al.*, 2021), cloud service evaluation (Hamzeh Alabool *et al.*, 2018) or even for forest management and planning (Jayanath and Gamini, 2009). Multicriteria decision-making, in general, follows six steps, including, (1) problem formulation, (2) identifying the requirements, (3) setting goals, (4) identifying various alternatives, (5) developing criteria, and (6) identifying and apply decision-making technique (Davood Sabaei *et al.*, 2015).

*Concept*

A concept results from the conceptual design phase, which is part of the system design and development process. According to (Sadraey, 2013), "it is an early and high-level lifecycle activity with the potential to establish, commit, and otherwise predetermine the function, form, cost, and development schedule of the desired system. An appropriate starting point for design at the conceptual level is identifying a problem and associated definition of need".

*Individualisation*

Individualisation considers modifying one product or service attribute for better requirement fulfilment (Kuhl and Krause, 2019). 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 different tasks and change operational procedures such as specific heating times or distributing and tracking meals (Derossi *et al.*, 2020b). In this contribution, the terms 'individualisation', 'personalisation', and 'customisation' are used synonymously (Merriam-Webster; Merriam-Webster; Merriam-Webster).

*Framework*

A framework is a set of principles, rules, or guidelines that provide a structure for something. It is as a kind of scaffolding or blueprint that helps to shape and guide the development or implementation of something (Merriam-Webster, 2022b).

## 2.2 Catering service types

Catering services provide food and drinks for a specific event or occasion. Catering services typically include the preparation, presentation, and service of food and drinks, and the provision of any necessary equipment or staff. Catering services are often used for weddings, parties, conferences, or business meetings. A restaurant, catering company, or other food service provider may supply a catering service. The quality and variety of food and drinks offered by a catering service can play a significant role in the success of an event, and careful planning and coordination are often required to ensure that the catering service meets the needs and expectations of the event organizers and guests. There are also other types of catering services, e.g. mobile catering and airline catering. According to (Splaver, 1975), catering services can be categorized into two main clusters: on-premises and off-premises. This classification is mostly based on the kitchen availability - whether directly at the consumption place (on-premises) or not (off-premises). This classification, unfortunately, doesn´t directly consider the customer. Therefore, in order to establish a relationship between the customer and the service provider, a rough classification can be done in order to figure out preliminary aspects, as shown as follows:

Table 2 - Service classification according to mobility of provider and customer

| | Customer | Provider | Example |
|---|---|---|---|
| 1 | Stationary | Stationary | Cafeteria |
| 2 | Stationary | Mobile | Food truck |
| 3 | Mobile | Stationary | Restaurant |
| 4 | Mobile | Mobile | Aircraft |

This classification is based on the background of food away from home (FAFH) - mobile food providers, e.g. food trucks (Reznar *et al.*, 2019). Within this classification, it is possible to assume that the complexity of the logistic supply chain increases from 1 to 4. Through this general classification, e.g. (1) a cafeteria or restaurant inside a company has both customer and service provider stationary. It means a) the customer is in the same place as the provider for a long period and b) the choice of the provider is limited.

Catering services provided, e.g. (4) inside of an aircraft, means a) the customer´s location changes while the service is being performed, and b) the provider´s location changes while the service is being performed. While looking into the involved logistics for comparison, there are expressive differences from (1) to (4). Some factors could be a) catering must be stored on board, b) no replenishment is possible, c) eventually the preparation and distribution of the catering are required, d) mostly all customers are served at the same time frame or sequentially and e) the customer is confined. From this classification and analysing of case 4, while the customer and provider are mobile, it is important to understand what are the impact factors for catering services that would affect both the customer and provider. For that, the provision of catering will be analysed in 4 public mobility providers: bus, ship, train and aircraft. The identification of the impact factors is based on the concept of Mobility-as-a-Service (MaaS), particularly in the aspects of travel demand modelling, supply-side analysis and business model design (Jittrapirom *et al.*, 2017), defining mobility as a flexible, personalized and on-demand service.

Table 3 - Identification of the impact factors is based on the concept of Mobility as a Service (MaaS) (Jittrapirom *et al.*, 2017).

| Core Characteristic | Description MaaS context | Impact on catering service |
|---|---|---|
| Integration of transportation modes | Multi-modal transportation | Catering provision and expectations are different among public transportation systems |
| Tarif option | Mobility package, pay-as-you-go | Catering offer and associated logistics is challenged |
| One platform | Digital platform for users | Integration of stakeholders, supply-chain and processes |
| Multiple actors | Interaction among stakeholders; demand generator, supplier, platform owner and associated service providers. | Characteristic already present in catering, and is probably going to be intensified |
| Use of technologies | Combination of different technologies | Integration and validation of new technologies with service requirements |
| Demand orientation | Multimodal trip planning feature and inclusion of demand-responsive services | Fluctuation of demand, amount and variety |
| Registration requirement | The end-user is required to join the platform to access available services. | Possible issues with data security |
| Personalisation | Personalisation ensures end users' requirements and expectations are met more effectively and efficiently by considering the uniqueness of each customer | Identification of individual needs |
| Customisation | Customisation enables end users to modify the offered service option in according to their preferences. | Process, product and service changes for enabling different levels of customisation |

The impact of MaaS on catering services changes the perspective of how catering services in public transport providers are offered. In this case, the consideration of mobility as a service poses a new challenge in how catering can be performed. A possible way to integrate catering in a MaaS concept is to compare the mobility providers with impact factors that affect how catering is being done today. In this sense, before providing an intermodal catering service, at first, the core characteristics of MaaS from 2 to 9 are seeking to be satisfied before integrating in a bigger context.

## 2.3 Catering service inside public mobility providers

Going deeper into **catering services** provided **inside of public mobility providers** - as aircrafts, trains, buses and ships, some exemplary influence factors could be listed as shown in the following table:

Table 4 – Influence factors for catering services inside public mobility providers, based on (Flixbus, 2022), (Fjordline, 2022) and (European Environment Agency, 2021).

| | Aircraft (short haul) | Train (intercity) | Bus (intercity) | Ship/Ferry (intercity) |
|---|---|---|---|---|
| Example | Amsterdam to Paris | Amsterdam to Paris | Amsterdam to Paris | Hirthals to Bergen |
| Journey time | 1h15 | 3h20min | 7h40min | 16h30min |
| Distance | 467km | Between 500 and 750km | 516km (car distance) | 410km |
| Journey interruptions | None | 5 stops | 2 stops | 1 Stop |
| Catering storage space | Galley | Galley | None | Galley |
| 1 leg passenger fluctuation | None | High | High | None |
| Weight impact | Relevant | Not relevant | Not relevant | Not relevant |
| Service expectation | Medium | Low | Low | High |

In this example, these influencing factors, considering the number of interruptions or stops during the journey, can change the catering options. The trade-off between storage space and passenger space needs to be assessed and adapted to the design of the public mobility provider. Inherent passenger fluctuations during transport also affect how food and service expectations are provided. The importance of the catering weight per passenger plays a role, especially about the environmental balance of a public transport provider, e.g. fuel consumption.

Due to the comparable conditions of a modern train and a modern passenger aircraft, this modality should also be examined for possible innovations in catering. Both on a train and in an aircraft, space is tight, and food has to be prepared and distributed in a confined space, which makes innovations in these modalities transferable in principle. However, one profound difference between catering on trains and planes is the presence of a dining wagon on many train journeys. There is no designated dining wagon in the aircraft economy class, and its introduction does not make sense due to the already cramped conditions and economic constraints. In this work, the search for innovations focused on the Central European and Asian markets. These two markets were chosen because train travel is a typical method of travel in Central Europe and East Asia, the rail networks are densely developed, and the trains are mostly modern.

Efforts have been made to analyse passenger expectations, e.g. in terms of rail catering services, needs and changes in logistics (Krishnakumar and Kavitha, 2020). New catering services with perishable food for high-speed trains are also the subject of research, especially about the supply chain (Wu *et al.*, 2019). They are making catering services more flexible and aiming to meet the time constraints associated with the new challenges of high-speed travel (Jiang *et al.*, 2020). Artificial intelligence techniques, notably machine learning, are employed for forecasting food consumption and present a pertinent area for enhancement. The German railway company, Deutsche Bahn, has actively endeavoured to mitigate potential challenges in inventory management, planning the integration of automated reordering systems for cash registers. Furthermore, prospective passengers could have the capability to place meal orders online, facilitating the delivery of these orders directly to seats in the first-class compartment or enabling retrieval from designated areas such as the dining wagon or on-board bistro in the second class. This concept has been tested since the end of 2018 on the ICE route to Paris in a pilot project (Fuchs, 2018). In the Chinese market for rail travel, which is characterised by solid growth, comparable innovations in the area of catering have also been tried out in recent years. On board the high-speed trains of the Chinese state railways, meals can be ordered from selected delivery services via the Chinese state railways app, delivered to the seat when the train pulls into the previously selected station. It consistently transfers the popular ordering principle for meals to the transport sector (China Discovery, 2018). In addition, meals can also be ordered to the seat, whereby the seat is assigned by scanning a QR code at the seat rather than manually entering the seat number to avoid misunderstandings. The Indian company Travel Khana follows a similar principle to that of the Chinese state railway. Via the Travel Khana app, meals can be ordered at selected restaurants and snack bars at Indian railway stations that meet specific quality standards and are delivered to the seat when the train enters the respective station (TravelKhana, 2022).

A direct comparison between train and air travel in terms of comfort was presented (Wang *et al.*, 2021). It then analysed which factors influence comfort; a similarity of factors between high-speed trains (HST) and narrow-body aircraft was found, with comfort being influenced by the 'passenger interface'. Interestingly, the study shows that for wide-body aircraft, it is mainly "food and beverage" and "in-flight entertainment" that influence passenger comfort. In this case, comfort could refer to experiences that go beyond expectations, such as luxurious service and satisfying food or drink (Wang *et al.*, 2021).

Innovations in catering on rail journeys can thus be divided into two categories: On the one hand, established rail companies are trying to digitise their service and optimise it through app ordering, pre-ordering and more efficient inventory management. On the other hand, further companies, are trying to integrate external providers into the catering process and transfer the principle of ordering services to the transport sector. These innovations can be used as building blocks for aircraft inflight catering concepts.

## 2.4 Flight catering services

In the context of this dissertation, a differentiation is done between inflight catering services and flight catering services. Although both involve the same stakeholders, the passenger, the airline, the caterer and the caterer´s suppliers, for the sake of simplification, flight catering services is the generic term involving all processes outside and inside the aircraft, while inflight catering services are focused on the processes occurring inside the aircraft. The **Figure 2**, an overview of flight catering with involved topics, is presented.

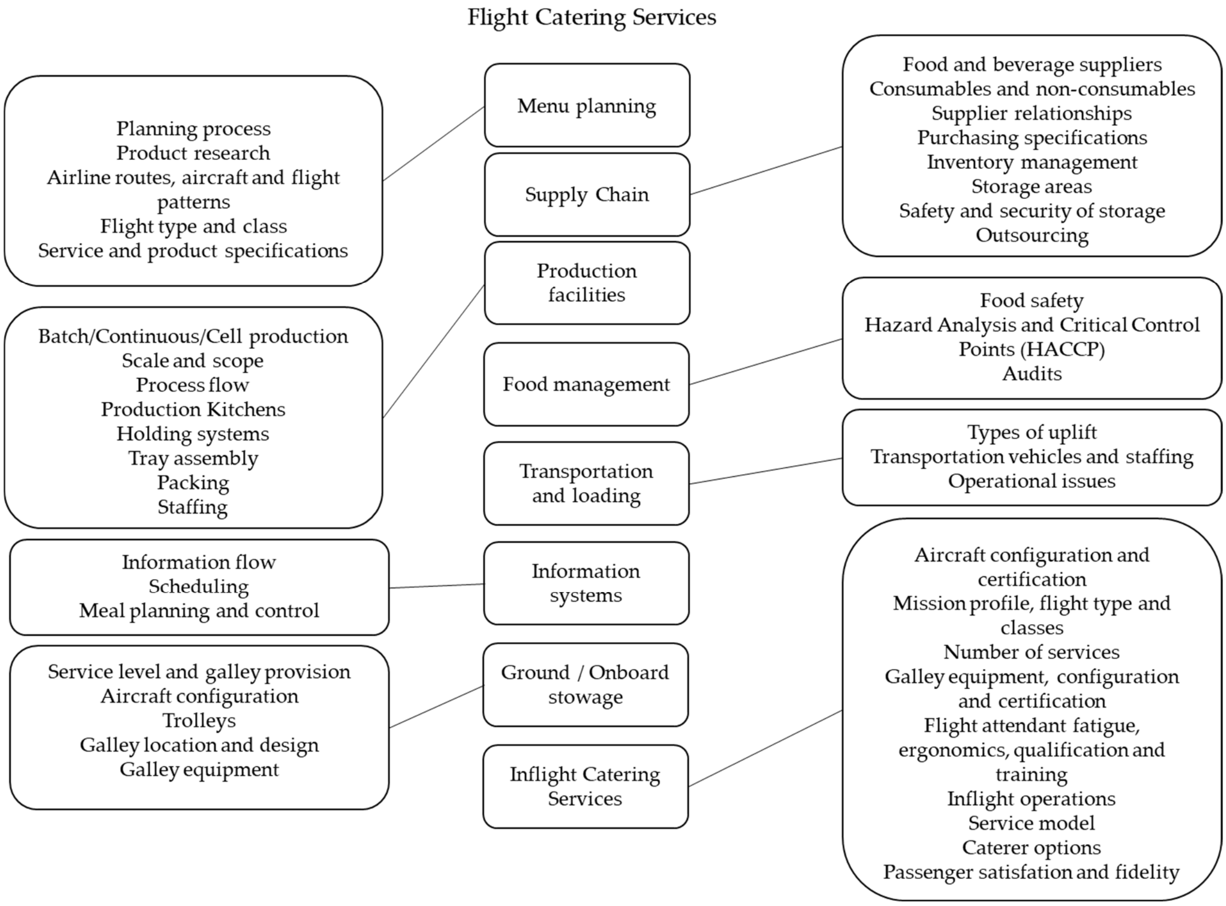



**Figure 2 - Overview of flight catering services with involved topics.**

The catering offer has a significant influence on passengers' choice of airline to use for their flight. Depending on the class chosen, the expectations of the meals served also increase. Passengers are not aware of the logistical effort involved, which is not comparable to a conventional restaurant (Jones, 2011). Some central issues involving the main topics presented in **Figure 2** are briefly described as follows:

*Menu planning*

Menu planning for flight catering is designing and organising the food and drink offerings for an airline's inflight catering service. For flight catering, menu planning involves selecting the food and drink items that will be offered on a particular flight, taking into account factors such as the duration and destination of the flight, the preferences and dietary needs of the passengers, and the availability and cost of ingredients. Menu planning for flight catering is a complex and challenging task, as it must balance the need to provide a wide range of appealing and satisfying options with the constraints and limitations of in-flight food service.

The catering companies provide the airline with all the goods needed during the flight. Equipping the aircraft galley with all the necessary goods requires considerable effort, as storage space within the airfield is scarce. The catering must be prepared according to the airline's specifications, representing the direct customer for the catering companies. Many airlines have their own catering companies to control the processes involved better (Jones, 2011).

*Supply Chain*

The supplier companies deliver goods to caterers or airlines directly. It includes goods that are consumable or non-consumable. The special regulations within the aircraft result in different requirements for these goods than in conventional restaurants (Jones, 2011).

Most airline catering companies operate worldwide. Companies in the industry, such as LSG Group, produced 719 million meals in 2018, according to its own figures, and generated consolidated revenue of €3.217 billion with 35,512 employees in 59 countries. The company's numerous joint ventures and partnerships, especially in Eastern Europe, China, Latin America and the United Kingdom, generated a further 1.4 billion euros in sales (LSG, 2018).

The supply chain for flight catering refers to the network of organisations, processes, and activities involved in delivering food and drink to an airline's inflight catering service. The supply chain for flight catering typically includes a wide range of suppliers, such as farms, food processors, distributors, and logistics providers, as well as the airline and its catering partners. The supply chain for flight catering is a critical component of the overall inflight catering service, as it is responsible for ensuring that the food and drink offered on a flight is of high quality, safe to eat, and appealing to passengers. The supply chain for flight catering is typically managed by the airline and its catering partners, who work closely with suppliers to coordinate the flow of food and drink from the farm or factory to the aircraft (Gou *et al.*, 2013).

The caterer can also be considered as a sub-actor of the in-flight catering process. However, since the aircraft door has been defined as the system boundary for this process, a detailed description of the caterer's tasks in the overall process is omitted, and reference is made to more in-depth literature (Jones, 2011). Most caterers operate kitchens directly at the airport. However, for cost reasons, only meals for business and first class are prepared in these kitchens. Due to the high cost of commercial space near the airport, the meals for the economy class are often outsourced and merely defrosted at the airport (Becker, 2007). Airlines usually conclude complex contracts with the caterers, providing the cooperation with detailed framework conditions. The development of individual menus within the framework of a rotation principle of meals takes place in close cooperation between the caterer and the airline. The caterer usually follows the airline's specifications. As part of the meal ordering process, the airline provides the caterer with regular updates on demand to improve the caterer's ability to plan. These updates take place until shortly before departure. The final picked meals are then loaded into a catering truck with scissor kinematics and transported to the aircraft by the caterer or an external service provider. The staff of the catering truck then loads the standard units and trolleys according to the explained loading plan of the airline and has the receipt of the goods confirmed by the flight attendant (Jones, 2011). The role of the caterer in the part of the process relevant to this work is thus comparatively small.

There are efforts in optimising the supply chain, most of the issues related to ground handling and avoiding delays on the critical path (Huang *et al.*, 2019; Norin *et al.*, 2012; Okwir *et al.*, 2017; Schmidt, 2017a; Tabares and Mora-Camino, 2019). Within ground handling, boarding is extensively considered, with new boarding concepts (Fuchte, 2014) and new aircraft layouts (Schulz, 2017; Yildiz *et al.*, 2018), even an approach for predicting aircraft boarding through machine learning (Schultz and Reitmann, 2019). A heuristic-based model was developed by (Sze *et al.*, 2012) for scheduling the loading operation of catering goods inside of an aircraft in order to optimise the loading process and avoid ground handling delays.

*Production facilities*

The flight catering production facility prepares and assembles food and drink for an airline's inflight catering service. The production facility of flight catering is typically a large, specialised kitchen or food-processing plant equipped with the necessary equipment, facilities, and staff. The production facility of flight catering is a critical component of the overall inflight catering service, as it is responsible for ensuring that the catering goods are of high quality, safe to eat, and appealing to passengers. The production facility of flight catering is typically managed by the airline and its catering partners, who work closely with suppliers and logistics providers to coordinate the flow from the production facility to the aircraft (Sundarakani *et al.*, 2018a).

Preparing food on the ground already presents companies with major logistical hurdles, as the commercial kitchens are enormous in size. One example is the most extensive airline kitchen in the world for the Emirates airline based in Dubai. Here, 225.000 meals are daily produced for Emirates machines and various other airlines, mostly by hand (Narishkin, 2019).

Flight catering is a complex food service industry involving many logistic operations and actors (Rossow *et al.*, 2014; Jones, 2011). Flight catering logistics differs from classical material flow, especially regarding the tight flexibility of schedules (Hovora, 2001). Production and delivery are highly connected, and schedule disruptions may compromise the complete supply chain. Another relevant issue is that inflight meals provided to passengers are a quality indicator for measuring service on an aircraft (Sundarakani *et al.*, 2018b)(Law, 2011).

*Food management*

Food management for flight catering involves coordinating and overseeing the various activities and processes involved in providing food and drink to an airline. It includes ingredient sourcing and procurement, food production, storage and transport, and quality control. (Becker, 2007).

Interestingly, some of the mentioned food service problems by the end of the 1960s are still present to a certain degree (Sell, 1967). Challenges regarding meal counts and orders can be confirmed as many meals are untouched and discarded (El-Mobaidh *et al.*, 2006). Storage space is generally an issue, as there is a connection among the number of passengers, and seats, and the amount of carried catering (Blanca-Alcubilla *et al.*, 2018).

*Transportation and loading*

The transportation and loading of flight catering mean the movement and loading of the food and drink items offered on a particular flight. Therefore, the food and drink are transported from the production facility to the airport and loaded onto the aircraft. The transportation and loading of flight catering is a critical component of the overall inflight catering service, as it is responsible for ensuring that the food and drink are loaded onto the aircraft in a timely and efficient manner (Alonso Tabares and Mora-Camino, 2017).

The catering loading and unloading are part of the ground services of an aircraft at the airport. The process time is called the turnaround time (TRT), and it is defined as the time between the on-block and off-block of the aircraft. The critical path is the sequence of activities that affects directly the turnaround time, and it is determined by the cabin activity chain (deboarding, catering, cleaning, cabin preparation and control, and boarding). It is important to emphasise that turnaround time is not a fixed value even for the same type of aircraft, and the timing and duration of each task varies due to dependency on aircraft cabin layout, flight operations and infrastructure (Tabares and Mora-Camino, 2019).

In this context, the infrastructure of the airports is essential for ground-handling operations. Airports are considered large airfields to allow aircraft to take off and land. However, apart from take-off and landing, airports have to perform a large number of other tasks and services. Therefore, airports are equipped with various facilities for handling passengers, baggage and cargo, maintenance facilities for aircraft and facilities for air traffic control, among others (Richter, 2013).

These ground handling services include all services at the airport and are considered the link between the operation of aircraft on the route and the airport infrastructure, which leads to various dependencies such as capacity bottlenecks at the airports and, among other things, disruptions in the flight schedule due to the diversity of aircraft types (Schlegel, 2010).

The processes that take place during the turnaround can be divided into three areas that affect the passengers, the aircraft and the baggage or cargo. Deboarding, cleaning, catering and boarding are counted as passenger services while refuelling, and water and waste services are counted as aircraft services. Baggage handling is considered a separate field with the unloading and loading of containers and loose baggage. These are the basic processes carried out during ground handling on the apron to prepare the aircraft for the next take-off. These processes are interdependent and specify a certain sequence, which can be characterised by both parallelism and asynchrony (Fuchte, 2014).

To complete the list of actors for ground handling, the airline, air traffic control (ATC), airport, federal police, cockpit crew and cabin crew should be added. The high number of actors involved adds to the complexity and management of the processes (Tabares and Mora-Camino, 2019; Kovynyov and Mikut, 2019).

In **Figure 3** a typical layout for the ramp activities at the gate position for a single-aisle aircraft is shown. There are many parallel and in-series activities which combined result in the total turnaround time, shown in the Gantt-chart. Deboarding occurs through the passenger bridge at the same time as cargo unloading performed by the container or bulk loader and the refillment of potable water. In the sequence, waste is collected and catering, cleaning and refuelling tasks start. The catering tasks during the turnaround process include loading and unloading of galleys with trolleys and standard units. After the cleaning of the aircraft cabin, e.g. seats, and the refuelling of the aircraft is completed, the boarding of the passengers starts (Schmidt, 2017a).

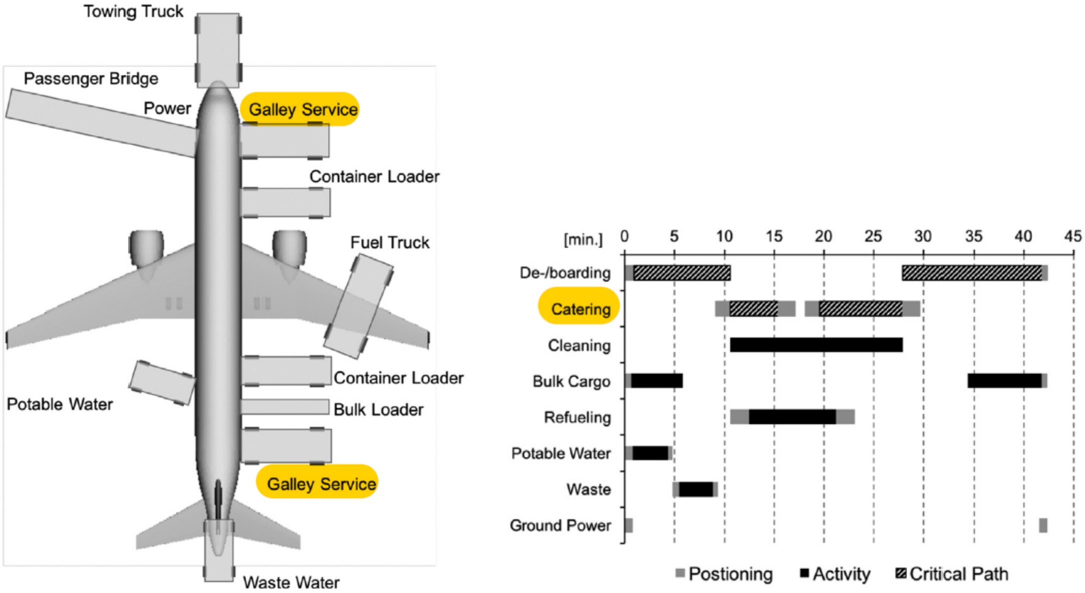



**Figure 3 - Ramp layout and turnaround Gantt-chart for a single aisle aircraft (Schmidt, 2017a).**

The logical chain, regulations and constraints due to limited space on the apron around the aircraft result in a strict chronological order for specific handling processes. Reducing the time spent on the relevant processes would thus reduce the processing time, affecting gate utilisation and the number of flights an aircraft can perform per day. For single-aisle aircraft with 100 to 200 passengers, the average turnaround time is 35 minutes (with a maximum of 51 minutes). In comparison, the average time for regional aircraft is 17 minutes and for two-aisle aircraft 61 minutes. However, a passenger aircraft's actual turnaround time must be determined stochastically, as it also depends on the number of passengers, the amount of fuel refilled and the baggage load. Airlines try to manage this deviation by including buffer times, which leads to a large deviation of the planned on-block times compared to the OEM guidelines (Schmidt, 2017b).

According to EUROCONTROL, "Airline operations delays account for around 30% of delays and an average of almost four minutes per flight" (EUROCONTROL, 2018).

Depending on the flight mission and airline service type, there are different loading strategies, e.g., a full uplift usually means loading the aircraft with meals, drinks and other catering equipment and re-equipping the cabin with blankets and pillows. Return catering can be classified as a complete load or a return load. In the case of a complete load, semi-finished meals are stowed in containers on the aircraft, processed at the caterer's production site at the destination, and then reloaded on the aircraft. In the so-called return load, the already loaded trolleys for the outbound flight are stowed together with the trolleys for the return flight and used on the return flight without further processing by the caterer. A top-up service is the delivery of additional catering goods when the number of passengers is higher than the number of meals initially assumed. When the caterer loads the aircraft, all trolleys and standard units must be checked by the cabin crew. This is a time-consuming process step that must be carried out under significant time pressure. In case of an incomplete load, this is reported to the caterer, and the caterer will make a subsequent delivery. In the case of a complete load, the receipt of the goods is acknowledged by the cabin crew (Yi-Chi Chang and Jones, 2007).

*Information systems*

Information systems used in flight catering may include inventory management systems, food safety and quality control systems, logistics and transportation management systems, and customer relationship management systems. These systems may be standalone or integrated with other systems used by the airline, such as reservation and booking systems or customer service systems (Kovynyov and Mikut, 2019).

*Ground / Onboard stowage*

Ground stowage involves storing the food and drink in a temperature-controlled environment at the airport and organizing it to allow easy access and loading onto the aircraft. Ground stowage of flight catering is a critical component of the overall in-flight catering service, as it is responsible for ensuring that the food and drink are fresh, safe, and of high quality when it is loaded onto the aircraft. The airline and its catering partners typically manage ground stowage of flight catering and work closely with logistics providers to coordinate the storage and movement of food and drink at the airport (Meincke *et al.*, 2018).

Onboard stowage of flight catering involves organizing and storing the food and drink items that will be offered on a particular flight. It concerns loading the food and drink onto the aircraft to ensure its safety, quality, and appeal and organizing it to allow easy access and service to passengers. The airline and its catering partners manage the onboard storage of flight catering and work closely with the flight crew to coordinate the loading and storing food and drink on the aircraft (Seren Bilge Yılmaz and Eda Yücel, 2021).

*Inflight Catering Services*

The topic of inflight catering services – ICS, is going to be detailed in the next section.

## 2.5 Inflight catering service (ICS)

Moving towards to **inflight catering services** - the service provided by the airlines to the passengers directly inside of the aircraft, the main aspects with an overview of the areas and their intrinsic relationships are shown in **Figure 4**.

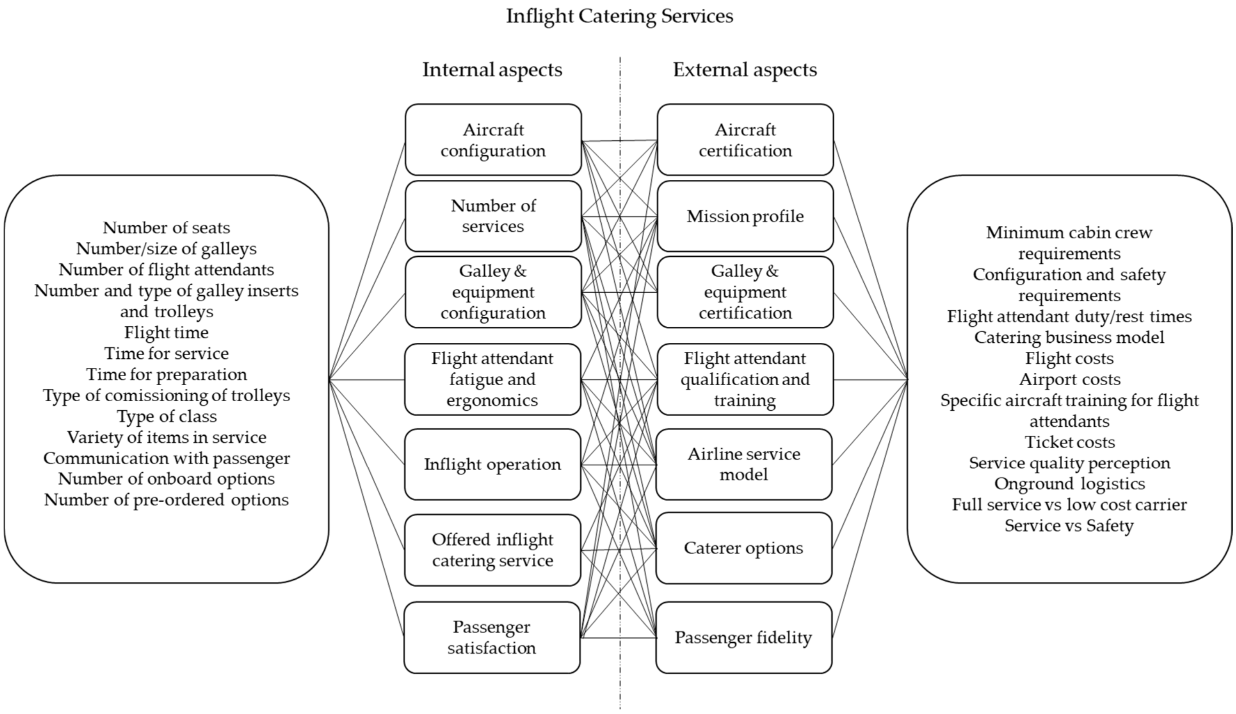



**Figure 4 - Inflight catering service overview with main topics.**

*Aircraft cabin configuration*

The aircraft cabin configuration includes, e.g., cabin crew stations, passenger seats, designated stowage areas, lavatories, galleys, crew rest areas and cabin dividers. The configuration changes according to the mission and airline business model. A classification of aircraft is given by (Maurer, 2007); it considers the fuselage shape, e.g., narrow body or wide body; the range, e.g., short or long-haul; the propulsion type, e.g., propeller or jet; the number of engines and the maximum take-off mass – MTOM. The current available aircraft by 2017 are shown by (Hünecke, 2017) with the associated range and number of passenger seats.

An aircraft cabin configuration refers to the arrangement and layout of the interior of an aircraft, including the location and number of seats, the placement of doors and emergency exits, the location of restrooms and other amenities, and the overall design of the cabin. The cabin configuration can vary depending on the size and type of aircraft, and the specific needs and preferences of the operator or manufacturer. For instance, a passenger airline may have a different cabin configuration than a cargo aircraft or a small regional aircraft may have a different configuration than a large wide-body aircraft. The cabin configuration plays a crucial role in the comfort and safety of passengers and crew and is an essential factor in the overall design of an aircraft (Dresel and Boutros, 2001).

Depending on the aircraft and airline, the seating areas can be divided into different classes. The seating classes differ in the number of seats, the spatial conditions and the quality and presentation of the catering. Each galley can be assigned to a defined area that is going to be catered. The galley plays a central role in the catering process, and they are equipped according to the specific requirements related to the type of aircraft and airline (Jones, 2011). Basically, the galleys are arranged in such a way that the walking distances for staff are as short and efficient as possible. The galleys are equipped differently depending on the manufacturer and airline, but their position follows a basic pattern, allowing integration in the aircraft and considering seating zones.

Besides safety and security, it is worth mentioning that weight and fuel consumption are driving elements in the aircraft business. E.g., material or design changes in storage compartments change the weight and fuel consumption of the aircraft. However, it also implies modifications in process and information flow, and operational changes regarding waste disposal, maintenance and cleaning (M. Nila, 2010; Jonas *et al.*, 2009).

In addition, designing a new aircraft cabin or modifying an existing one is a unique challenge since the human interface is critical to the successful operation of the aircraft. Therefore, parameters such as safety, usability, manufacturability, maintainability, and training must be considered along with other design parameters such as economics, aircraft requirements, and physical design constraints such as weight, drag, and volume (McMullin *et al.*, 2008). Due to the growing passenger demand and the competition among airlines, there is growing attention towards improving passengers' quality of travelling. In this sense, not only by technically improving the systems towards efficiency, e.g., sustainability, but also the role of the cabin interior regarding comfort and well-being are increasingly changing passenger´s choices, the human-centred design and evaluation have been receiving more research attention, also by the use of tools as virtual reality (Crescenzio *et al.*, 2019).

There is also an open source simulation tools allowing the design improvement of the cabin layout within; besides the seat and monument choice, it is possible to simulate different boarding situations and configurations (Engelmann *et al.*, 2020). The simulation is based the on Common Parametric Aircraft Configuration Schema – CPACS and allows the validation of different layout configurations with different aircraft and associated missions.

A generic cabin configuration of an Airbus A350-900 is shown in Figure 5, it consists of a widebody aircraft that can carry up to 440 passengers and it has a range of 15000km (Airbus Operations GmbH, 2022).

The exemplary cabin layout has four entrance doors on each side and, with the reference configuration, three galley areas, as shown in Figure 6. The minimum required cabin crew number established during the A350-900 aircraft certification process is eight, therefore, two per exit pair of doors (EASA, 2020).

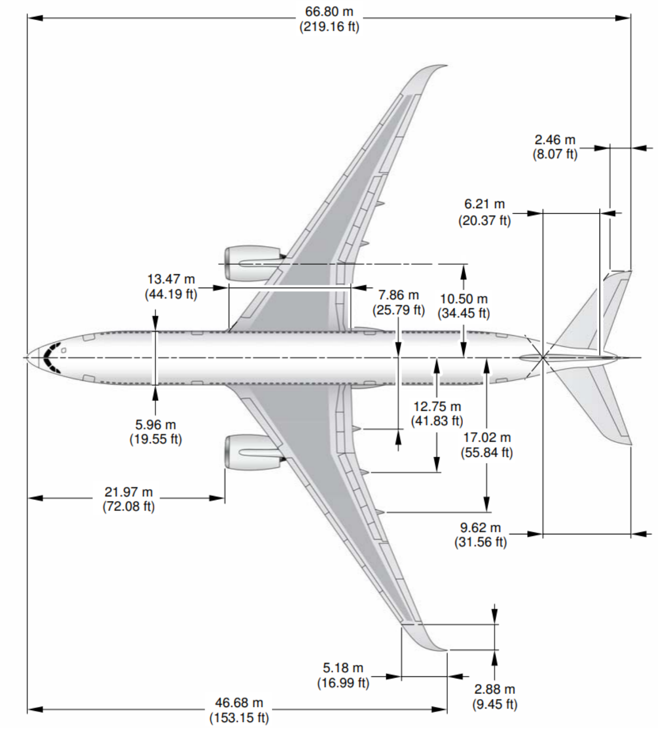



**Figure 5 - A350-900 general aircraft dimensions (Airbus Operations GmbH, 2021).**

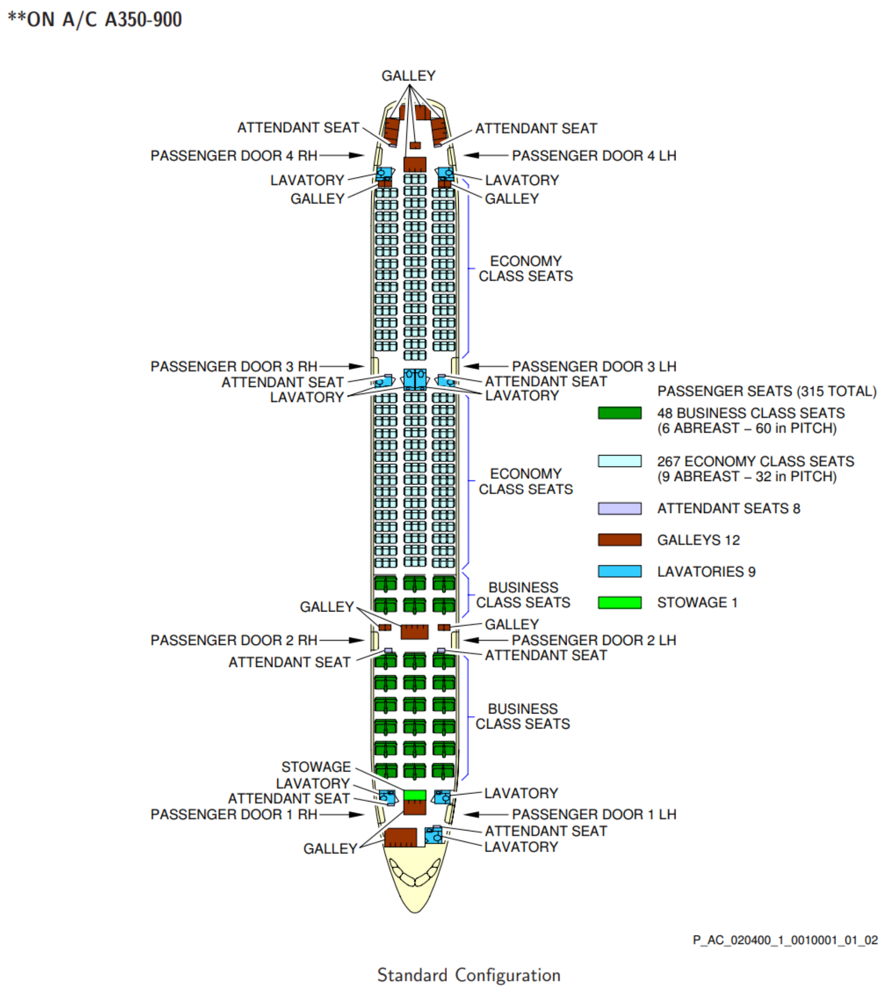
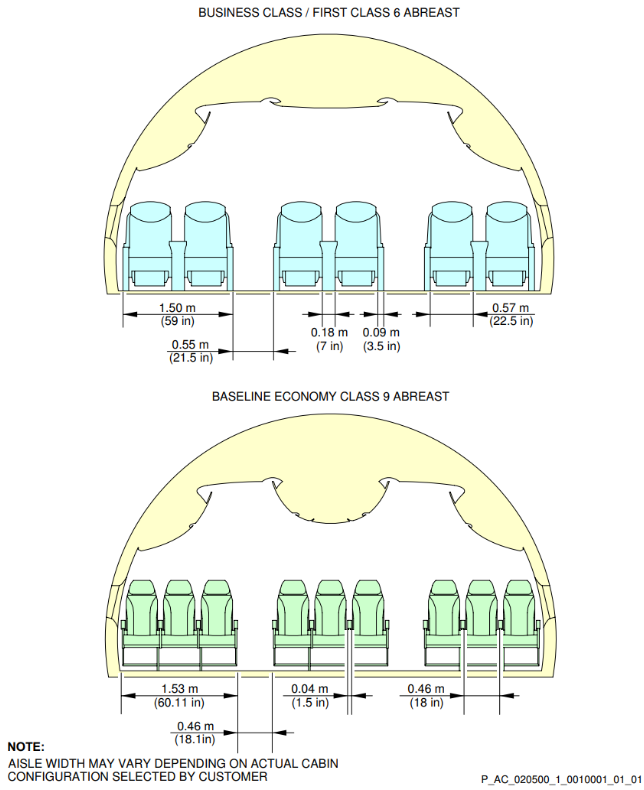



**Figure 6 - Standard A350-900 cabin configuration** (EASA, 2022b)**.**

The economy class – Y/C, consists of 267 seats, followed by the business class – B/C with 48 seats. The cabin configuration shown in Figure 6, has 8 flight attendant seats – according to the minimum required crew number, 12 galley monuments spread throughout 3 galley areas and 9 lavatories. The cabin configuration may be customised according to the airline's wishes and may have, e.g., different seat configurations, number of galleys and number of flight attendant seats (EASA, 2022b). An example of a seat distribution is shown in Figure 7, with 6 seats for the business class and 9 seats for the economy class.




Typical Configuration

**Figure 7 - Seat distribution A350-900, B/C and Y/C classes** (EASA, 2022b)**.**

Aircraft are capital goods manufactured in a one-off and small series production process. Generally, a bilateral negotiation process occurs between the manufacturer and the airline. The market for commercial aircraft is primarily covered by the two manufacturers, Boeing and Airbus, so the commercial aircraft market is small and relatively transparent (Burghardt *et al.*, 2002). The customer can help shape the product through his or her specific wishes, which influences the associated product complexity. However, it is possible that manufacturers limit customisation options to simplify production. The simplification and standardisation of an aircraft positively impacts its individual value, but has less effect on the value of an airline's fleet. Technical and market-specific requirements in terms of transport capacity, range, and safety imply a certain degree of diversity, so no complete standardisation of the end-product commercial aircraft is possible. In order to meet these sometimes mutually exclusive requirements, using modular systems and platforms is an option. A more efficient process design - as in the automotive industry, is more difficult due to the high variance of equipment features such as cabin components. The aircraft cabin configuration includes e.g., cabin crew stations, passenger seats, designated stowage areas, lavatories, galleys, crew rest areas, cabin dividers. The configuration changes according to the mission and airline business model. A classification of aircrafts is given by (Maurer, 2007), it considers the fuselage shape e.g., narrow body or wide body; the range e.g., short or long-haul; the propulsion type e.g., propeller or jet; the number of engines and the maximum take-off mass – MTOM. The current available aircrafts by 2017 are shown by (Hünecke, 2017) with the associated range and number of passenger seats.

*Classes*

The type of service offered is determined individually by each airline. The decisive factor is whether it is a low-cost carrier with an uncompromising no-frills concept, such as Ryanair, or a full-service network provider, such as Lufthansa, with a dense route network and high-quality service. However, an airline's service can also vary within an airline if, for example, the airline takes cultural aspects into account for the respective route flown. Due to the many different services, it is not possible to define a universal process for every airline, but every flight contains certain recurring elements (Rahman *et al.*, 2020). Full service carriers usually operate long-haul flights. However, there are now also some low-cost carriers that operate transatlantic flights, for example, and transfer the concept tested on short-haul flights to long-haul flights (Renehan and Efthymiou, 2020). On short-haul flights, only drinks and snacks are usually served. In the case of full-service carriers, this is usually still included in the ticket price. For low-cost carriers, drinks and snacks can only be purchased for an additional charge. For short-haul flights, the process is, therefore, greatly simplified. On long-haul flights, one or two meals are usually served and several beverage services are provided. As a rule, passengers in Economy Class are offered two different meals. In First and Business Class, passengers are usually offered a menu with several options. The different service procedures for Economy, Business and First Class are exemplified next for long-haul flights.

In Economy Class, depending on the airline, special meals are either brought directly to the seat of the respective passenger or placed by the crew in the correct trolley for the passenger seat with a special request. In the case of a long-haul flight, wide-body aircraft are usually used, which have two parallel aisles, which must also be taken into account for the cabin service procedure. The flight attendants usually start serving a single section of Economy Class with four loaded trolleys, starting in the first and last row of each aisle within the section. Two flight attendants work on each trolley. The flight attendant pulling the trolley serves the meals by pulling a tray from it and asking the passengers for their selection. Alternatively, the service can be done in a smaller section with a single trolley per aisle. After the passengers have taken their meals, the flight attendants start collecting the waste trays. This is done by putting the trays back in the trolleys and disposing of the waste in rubbish bags or a special waste trolley. On long-haul flights operated by full-service carriers, snacks and drinks are usually provided in the galley after the main meals and other beverage services are also provided. Depending on the length of the flight, another snack or full meal is served before landing (Zehender, 2018).

In Business Class, after the passengers have boarded the aircraft and taken their designated seats, cold drinks are usually served to welcome them. The following processes are similar to those in economy class, but the service is much more staff-intensive, and the selection of drinks and meals is usually larger. In Business and First Class, meals are served on separate plates and then directly at the seat. Disposable products are not used, and catering products made of metal and glass are used. The meals served are usually designed as multi-course menus and are served to the passengers one after the other. Several beverage services follow, and shortly before landing, another meal is served. The plates on which the meals are served are collected after the meals have been eaten and then put back in the trolleys (Jones, 2011).

In First Class, the service is even more personal than in Business Class and the meals served are of higher quality. Meals are also served at the seat, and the service is comparable to high-end restaurant service on most airlines. Drinks and meals are served to order and are not bound to fixed serving times. Some airlines provide a buffet in addition to the a la carte meals. The preparation processes for meals and drinks in First Class are comparable to those in Economy Class.

*Aircraft certification*

Aircraft certification refers to evaluating an aircraft to ensure it meets particular safety and performance standards. This process is typically carried out by a government agency or regulatory body and involves a thorough review of the aircraft's design, manufacturing processes, and operating procedures. Once an aircraft has been certified, it is considered safe for operation and can be used for commercial or private purposes. The certification process is an integral part of ensuring aircraft safety and reliability and helps protect passengers, crew, and the general public. (EASA, 2022b).

*Mission profile*

The mission profile of an aircraft refers to the specific tasks and objectives that the aircraft is designed to perform. This can include things like the type of missions the aircraft is intended to fly (e.g. air-to-air combat, long-range bombing, air-to-surface attacks), the range and endurance of the aircraft, the type of payload it can carry, and the specific operating conditions it is designed to handle (e.g. high altitude, extreme temperatures, rough terrain). The mission profile of an aircraft is crucial in determining its design, performance, and capabilities. It plays a vital role in determining whether an aircraft is suitable for a specific task or operation. Air travel can be categorized as regional, continental, or intercontinental transport. Furthermore, according to the travel distance, short-haul, medium-haul, and long-haul denominations are used as shown in Table 5 (Mensen, 2013).

Table 5 - Air travel classification on travel distance (Mensen, 2013).

| Range | Transport distance | Transport time |
|---|---|---|
| Short-haul flights | up to 1000 km | Up to 1h |
| Medium-haul flights | between 1001km and 3000 km | between 1h and 3,5h |
| Long-haul flights | more than 3000 km | more than 3,5h |

2. Fundamentals of catering service automation

Fuel burn drives the airlines' business model, determines design constraints, and generates weight requirements for new aircraft cabin systems and equipment (Niţă and Scholz, 2011). The fuel mass consumption can be calculated by:

$$\frac{m_F}{m_{mto}} = 1 - m_{ff}$$

$$m_{ff} = \frac{m_{i+1}}{m_i}$$

$$m_i = mass\ at\ beginning\ of\ flight\ phase\ (i = TO, CLB, CR, \ldots)$$

$$m_{i+1} = mass\ at\ start\ of\ next\ flight\ phase$$

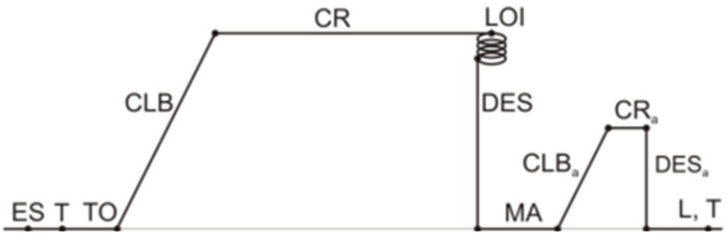



**Figure 8 - Typical flight mission phases (Scholz, 2002).**

The mass fraction for the cruise phase can be established with the Breguet factor,

$$\frac{m_{LOI}}{m_{CR}} = e^{\frac{S_{CR}}{B_S}}$$

Where

$$S_{CR} = cruise\ distance$$

And the Breguet factor is given as: $B_S = \frac{E.V}{TSFC\ .g}$

With TSFC as the thrust-specific fuel consumption, E as the lift-to-drag ratio and V as speed.

A brief description of the flight phases next based on Scholz, 2002 is given.

ES – Engine Start | Preparation phase: in this phase, all preparations for the actual flight are made. This includes the crew's boarding, the catering's loading, the galley's safety checks and the preparation of the first service. This first service takes place during or after the boarding of the passengers and includes the distribution of a "welcome drink".

T – Taxi out: during the taxi out, the flight attendants conduct welcome and safety briefings to prepare passengers for possible emergencies. At the same time, the flight attendants perform a final safety check of all safety-critical parts within the aircraft.

TO – Take-off and initial climb: during this phase, the flight attendants must ensure the safety of the cabin and prevent passengers from getting out of their seats.

CLB – Final climb: the aircraft, which has now taken off, reaches its maximum altitude during this phase. The captains transmit a signal when it is possible for the flight attendants as well as the passengers to leave their seats again. During this phase, the flight attendants respond to possible calls from passengers, distribute small amenities such as newspapers or pillows, and prepare the cabin and galleys for the following services. This includes the initial picking of catering goods into the appropriate section of the aircraft and the labelling of meals.

CR – Cruise: this is the longest phase and describes the period between reaching the maximum flight altitude and the start of the landing approach. In addition to general safety checks and assisting passengers in various matters, catering is one of the main tasks during this phase. This includes serving appetisers, the main course (lunch or dinner) and the second meal (breakfast). This includes optional services such as inflight sales of merchandise or accessories, a service-on-demand when there is a need for an additional meal and an intermediate service in the form of snacks or sandwiches on very long flights. In addition to tasks such as the preparation and follow-up of the services, general things such as a rest period for the flight attendants are also part of the listed processes.

DES – Descent: this phase marks the beginning of the landing approach. The flight attendants' tasks include supplying passengers with refreshment towels, cleaning up and securing the galley, and informing passengers of their arrival.

LOI – Loiter: loiter in the context of aircraft flight, refers to a manoeuvre in which an aircraft remains in a specific location or area for an extended period. This can be done for various reasons, such as surveillance, reconnaissance, or as part of a search and rescue operation. When an aircraft is in loiter, it will typically fly in a circular or rectangular pattern around a specific location, maintaining a constant altitude and airspeed. While an aircraft is in a loiter, the flight attendant's responsibilities will depend on the specific mission and the duration of the loiter. In general, the cabin crew's primary responsibility is the safety and comfort of the passengers, so they may perform tasks such as checking on passengers, providing refreshments and meals, and answering any questions or concerns that passengers may have. They may also need to be prepared for any emergency situations that may arise during the loiter. If the loiter is expected to be a long one, the cabin crew may also need to perform additional tasks such as cleaning and restocking the cabin, conducting safety checks, and performing other routine maintenance tasks.

MA – Mission Abort: it is a term used to describe the termination of a flight mission for any reason, such as an emergency, mechanical failure, or other unforeseen event.

L – Approach, Final approach and Landing: during the approach, various safety checks are carried out, and the cabin is prepared for landing. Similar to take-off, flight attendants must monitor safety during this phase.

T – Taxi-in: after the successful landing, the flight attendants perform a farewell procedure, familiarising the passengers with general information and procedures at the arrival airport.

Parking: during and after the parking of the aircraft, the flight attendants assist passengers in leaving their seats and gathering their personal belongings.

Mission Closure: this phase describes how the flight attendants assist passengers in exiting the aircraft. Afterwards, the cabin and galley are subjected to various checks to find possible defects. After cleaning up the cabin, the crew also leave the aircraft and the flight is closed.

*Airline service model*

The airline service model pertains to the way in which an airline offers its services to passengers. This encompasses various factors such as the type of aircraft utilized, the routes and destinations covered, the frequency of flights, and the extent of customer service provided. Airlines have different service models, which depend on various factors such as the airline's unique needs, preferences, and the market it operates. Some airlines may offer low-cost and basic services, while others may focus on providing passengers with a luxurious experience, including premium amenities and comfort. The success and competitiveness of an airline are influenced by its service model, which is a crucial factor to consider in the market (Fiig *et al.*, 2018).

An overview of inflight catering goods with an A380 aircraft flying from Munich to Los Angeles for 509 passengers shows the variety and amount of what can be carried during a flight (Deutsche Lufthansa AG, 2018). In this aircraft for this exemplary flight, around 960 trolleys with containers and boxes, as well as 780 meat meals and 420 vegetarian meals are carried. Over 40.000 separate items must be loaded inside a big aircraft size A380; this also includes beverages, catering equipment like cutlery and chinaware, reusable plastic items, bonded items and duty-free.

Looking narrower into **air travel**, alongside their core service, i.e., passenger transportation, air carriers increasingly provide numerous extra services that are not directly related to transport. On the one hand, airlines are enlarging the scope of paid services provided on board an aircraft by, among other ways, splitting the air ticket fee and singling out the costs of such services as catering on board, checked-in luggage and airport check-in (Rebezova *et al.*, 2012). Concerns about the increase in the number of provided services and the minimum number of cabin crew can also be observed, especially for low-cost air carriers (Kyung-in and Mun-kyung K., 2018).

*Catering options*

Catering options are the different ways in which an airline or organization can provide food and beverages to its passengers. This may include the types of meals offered during flights, the available caterer options, and the market in which it operates. Some common caterer options include providing pre-packaged meals on flights and offering a selection of hot and cold meals. A tray configuration is shown in Figure 9. The caterers are responsible for providing the loading plan for each flight, including the corresponding weight and location of the goods(Yılmaz and Yücel, 2021).

It is possible to observe improvements in packaging, for instance, meals packed in cubic cardboard boxes and thus do not take up the passenger's entire folding table (Boye, Joyce I. and Arcand, Yves, 2012).

The meals inside an aircraft must meet several requirements, some of which differ significantly from those on the ground. Particular focus is placed on the so-called performance of the product. This means the meals are optimised to be cooled down, stored and then reheated with as little loss of quality as possible after preparation. Furthermore, the food is produced under strict hygiene standards, and the ingredients are also selected with regard to perishability (Jones, 2011).

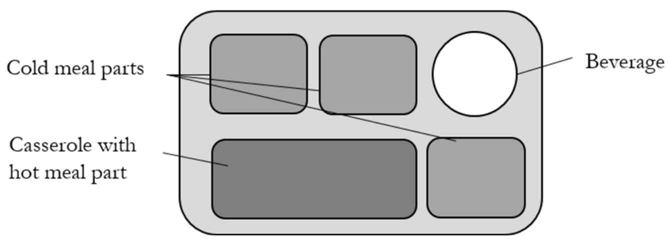



**Figure 9 - Possible tray configuration with meals composed of hot and cold components.**

The airlines' menu planners prepare standardised recipes for the caterer's kitchens and define how the dish will be served. These specifications are recorded in so-called "dish specifications" for individual dishes and "meal specifications" for a complete tray with an entire meal (Becker, 2007).

Another important aspect is so-called special meals (SPMLs), for example, vegetarian meals or meals tailored to special religious needs. These meals accounted for about 2.1% of all meals at US Airways in 2001. The share is considered to be steadily increasing, especially in regarding allergies; a US survey showed an increase of 300% of the allergic population by 2040 (Sampath *et al.*, 2021). The production of these meals involves a great deal of effort and is usually carried out in separate areas of the caterer's commercial kitchens. As part of the cabin service, special meals are usually served first and brought directly to the passenger's seat outside the regular cabin service. The trolleys the caterers deliver are usually labelled with notes indicating that special meals are included (Yi-Chi Chang and Jones, 2007).

The meal design is important; it is closely linked to an airline's desired image or brand identity. Much effort is put into meal design to fulfil the customers' needs. These needs vary depending on the flight route, i.e. the passengers' main nationality. Also, the aircraft used and its available space and type of flight, i.e. whether it is an overnight or daytime flight. The airline's service strategy, e.g. a low-cost airline, will accordingly attach less importance to a high-quality design of the menus than airlines offering a premium product. Another factor is the class served; high-quality meals in the business or first class require much more effort than meals in economy class. Based on the selection of the caterer, the airline has various options; these are based on the location of the catering flight kitchen and the local supply chain. Airlines have been compared through different platforms, sharing different rankings and criteria, but onboard service and catering options (Skytrax, 2022).

Airlines provide the possibility of pre-choosing the meals in advance; the amount of options is airline-specific. Special meals can be classified in the following exemplary manner (KLM - Royal Dutch Airlines, 2022):

- Vegetarian
- Medical health-care
- Religious
- Children/Infant

There is also the possibility to extend the choice to enhance the passenger experience (Chang *et al.*, 1997).

*Number of services*

The number of inflight catering services provided during a flight can vary depending on the specific airline, type of aircraft, and flight length. In general, passengers can expect to be offered at least one meal and one snack during a long-haul flight and may also have access to a selection of beverages (Arif *et al.*, 2013).

*Galley & equipment configuration*

The galley and equipment configuration refers to the specific layout and arrangement of the kitchen area, as well as the type and quantity of equipment and supplies used to prepare and serve food and drinks during flights. It includes ovens, refrigerators, coffee makers, and storage cabinets. The galley and equipment configuration is crucial in determining the efficiency and effectiveness of the inflight catering operation. It is designed to maximise space utilisation and minimise weight. The configuration of the galley and equipment may vary depending on the specific requirements and preferences of the airline and the type of aircraft (Moir and Seabridge, 2012).

The galleys' general structure and geometric conditions are defined through standards but are still highly customizable (Olive *et al.*, 2006). Figure 10 shows a generic galley divided into three levels. The first and lowest level is the trolley level, where the trolleys are stored. Level two is the gadget level. This level is where various equipment for the preparation of inflight meals and beverages are located, e.g. ovens or water boilers. The top and last level is the standard unit level, where the standard unit containers are stowed, these are filled with e.g., meal or beverage supplements.

With the beginning of the 21st century, improvements or new approaches are continuously emerging in the aircraft industry. More galley concepts are being developed, and catering concepts of the future are being demonstrated. Low-maintenance constructions, easy assembly procedures and possibilities for upgrading and expanding the galley are the decisive requirements (Gumpinger *et al.*, 2011).

In addition, the galleys used must have a certain flexibility in their adaptability in terms of equipment and design (Jonas *et al.*, 2009). It is possible to observe that the design of modular product families is increasing, allowing the number of components to be kept low or reduced (Krause *et al.*, 2017).

A central element of the current inflight catering process is the so-called trolley. A trolley is a mobile, box-shaped and lockable structure with slots for trays. The dimensions of trolleys are standardised and are based on the ATLAS or KSSU standards (Jones, 2011). Trolleys are manufactured in different versions, in different dimensions and for different purposes. A distinction is made between full-size trolleys and half-size trolleys. One variant is the so-called waste trolley, which is designed for storing waste. Furthermore, some manufacturers offer so-called lightweight versions of their standard trolleys. In addition to the models described, other variants have been developed, such as transparent trolleys for duty-free sales or heated variants for storing hot food.

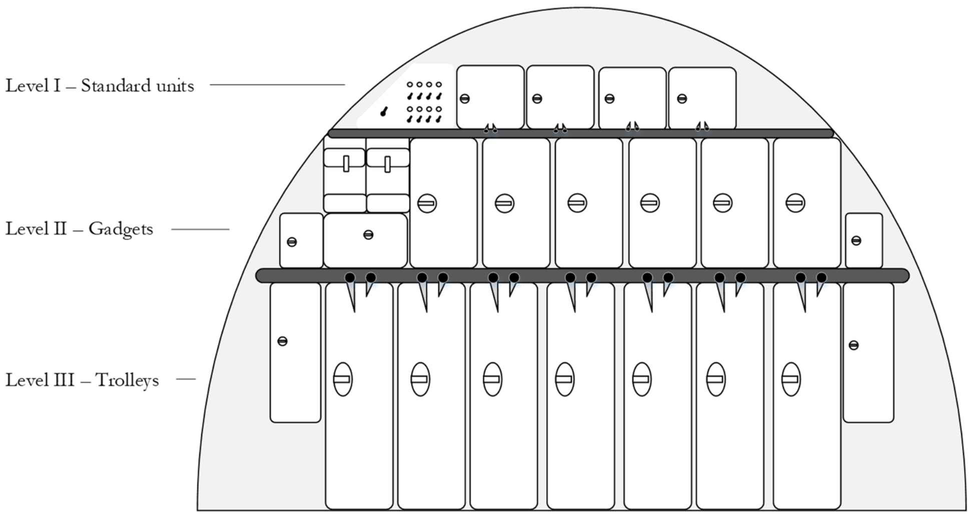



**Figure 10 - Galley levels based on** (Aeroexpo, 2022)**.**

In Figure 11 an example of an ATLAS-compliant full-size trolley is shown. The different tray sizes are shown inside the trolley. The different tray sizes are used depending on the airline offered service and the class. A full size trolley has fourteen levels, allowing 28 full size trays or, 42 “2/3” trays or, 56 “1/2” trays or, 84 “1/3” trays.

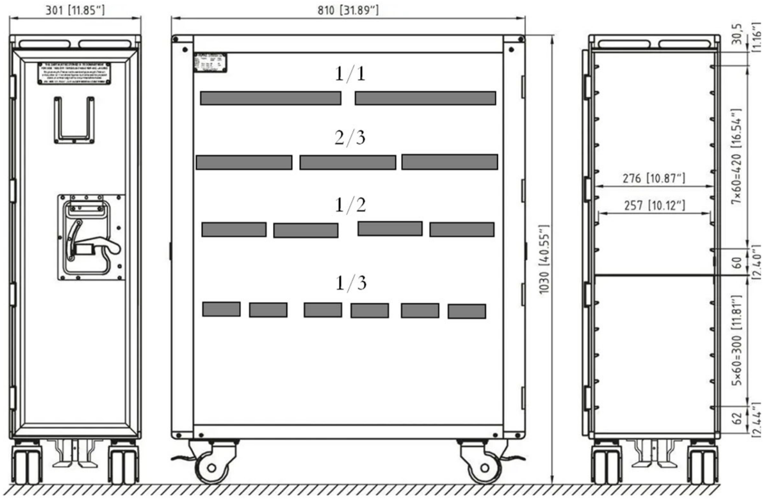



**Figure 11 - Different tray sizes and distribution inside a full-size trolley based on (Olive *et al.*, 2006).**

For safety reasons, the trolleys have a foot-operated braking system that must always be locked if the trolley is not moving, including inside the galley. In order to meet the requirements of the lowest possible weight, the trolleys are usually made of aluminium. The frame is made exclusively of aluminium, and the panelling is usually made of an aluminium-foam sandwich material. Since trolleys are loaded and filled with high frequency, they are exposed to high loads and must be constructed accordingly robustly. The fact that the trolleys are usually owned by the airline means that the airline must always have a sufficient number of replacement trolleys due to the wear-intensive environment. Typically, an airline has three sets of trolleys: the trolleys waiting to be loaded at the departure airport, the trolleys on board an aircraft, and the trolleys to be unloaded at the destination airport (Yi-Chi Chang and Jones, 2007). There are many galley inserts, including steam ovens, water heaters, coffee makers, bum warmers and oven racks (Korita Aviation, 2019).

Although aircraft coffee makers are no different from home coffee makers in terms of application, special approvals and certificates are required for use in flight operations. Furthermore, there are numerous variants and designs, such as Nespresso, Espresso, Cappuccino or ordinary coffee machines, mostly with coffee pad inserts. Water heaters use rapid recovery technology to provide large quantities of hot water with optimal temperature stability. In addition to beverage chillers, refrigerators and freezers, iceboxes can be used for cooling beverages. Microwaves are designed in such a way that precisely one meal can be heated, which is particularly advantageous in the business class. However, they are often replaced or supplemented by bun warmers, which are mainly used to heat wet towels, plates and buns. The ovens are box-shaped heating modules that are closed off with walls on all sides, with one side having at least one door. The ovens are operated with an oven rack, which is loaded with casseroles (Verpraet, 2019).

From the ARINC 812 standard, the galley can be controlled by the MGCU - Main Galley Control Unit. The MGCU is a device that can be used to control and monitor the various systems and equipment in the galley, such as ovens, refrigerators, and other appliances. The MGCU is typically located in the galley itself and is used by the cabin crew to control and monitor the operation of the galley equipment. The MGCU typically has a number of functions, including controlling the temperature and operation of the ovens and other appliances, monitoring the operation of the galley equipment, and displaying warning messages or fault codes if there are any problems with the equipment. The MGCU may also be used to control and monitor the lighting and other systems in the galley, depending on the specific design of the aircraft and the equipment installed in the galley (Olive *et al.*, 2006).

*Galley & equipment certification*

In the aviation industry, certification is a process that evaluates a product or system to ensure that it meets specific safety and performance standards. This includes certification for aircraft, engines, and other types of cabin modules such as the galley and galley inserts.

The priorities in aircraft design have changed over time. Initially, the focus was on feasibility and implementation as the most important factors (Frank *et al.*, 2016). However, later on, the emphasis shifted to airworthiness and load capacity, which resulted in the weight of the aircraft becoming a critical factor in ensuring reliable construction. Nowadays, fuel efficiency and sustainability have become the most relevant factors in aircraft design (Air Baltic, 2020; AIM Altitude, 2020).

*Flight attendant qualification and training*

Flight attendants are responsible for ensuring the safety and comfort of passengers on an aircraft. Flight attendants must undergo specific qualifications and training depending on the country and airline.

The operation of aircraft is specific; the EU regulation 965/2012 allows flight attendants to operate on three aircraft types. It implies in much more planning for the airlines in case of aircraft change or missing flight attendants due to sickness absence or injuries (International Civil Aviation Organization - ICAO, 2013).

The IATA has been delivering the "Cabin Operations Safety Best Practices Guide", which includes sections regarding, e.g., risk assessment during cabin services with hot beverages, galley safety with the proper use of equipment. However, every airline has its own procedures; it is hardly possible to fully generalize (IATA, 2017). The level of personal service can be increased through the deployment of an increased number of flight attendants and increase the perceived quality of service among passengers. As part of the catering process, the flight attendant is responsible for heating the food, loading the trolleys with the heated meals, and serving them with drinks. Furthermore, the cabin crew performs numerous safety-relevant tasks outside the catering process. Regulations of the respective national certification authority mainly determine the minimum number of cabin crew. These regulations will be briefly explained in section the "Safety and standardisation".

However, most airlines staff their aircraft with more flight attendants than legally required in order to guarantee a certain level of service. There must be a substantial compromise if the number of cabin flight attendants is reduced in order to keep supporting all required tasks (Keselova *et al.*, 2019). Flight attendants must still be certified by national regulatory authorities and are usually licensed for two narrow- or wide-body aircraft. A flight attendant usually starts his or her career in economy class on short-haul routes after completing the training. With increasing seniority, a flight attendant will also be deployed on long-haul flights and will be used in business and first class. A regular flight attendant can be promoted to galley purser after a few years in active service and is given full responsibility for preparing meals. It is then possible to be promoted to the rank of flight purser, followed by senior purser, with responsibility for an entire class, and finally to the rank of chief purser, with responsibility for the entire cabin (Avers *et al.*, 2011; Damos *et al.*, 2013; Glitsch *et al.*, 2007).

*Flight attendant fatigue and ergonomics*

The tasks that have the most significant impact on the ergonomics of flight attendants are those that require them to perform physical activities, such as lifting and carrying heavy objects, standing or walking for extended periods, and bending or reaching to access storage areas or serve passengers. These tasks can put a strain on the musculoskeletal system of flight attendants and can lead to musculoskeletal disorders (MSDs), such as back pain, neck pain, and joint pain (Vejvoda *et al.*, 2000). In addition to physical tasks, flight attendants are also exposed to ergonomic risks from other aspects of their work, such as working in confined spaces, working in awkward postures, and working with vibrating equipment. These factors can also contribute to the development of MSDs and other health problems (Mumtaz, 2017).

To address these ergonomic challenges, flight attendants can take steps to reduce their exposure to physical and ergonomic risks, such as using proper lifting techniques, taking regular breaks to stretch and move around, and using ergonomically designed equipment and tools. In addition, airlines and other employers can implement measures to improve the ergonomics of the work environment for flight attendants, such as providing ergonomic training and support, and designing workspaces and equipment to minimize ergonomic risks (International Civil Aviation Organization - ICAO, 2014; Lee *et al.*, 2006).

It is possible to state that optimisation in ergonomics was distressed to the limit of the possibilities without changing the aircraft cabin layout. This observation can be followed by many studies regarding ergonomics of flight attendant´s operations, where mostly the position and handling of equipment could be firstly analysed and limited optimized (Agampodi *et al.*, 2009; Avers *et al.*, 2011; Dismukes *et al.*, 2018; Hagihara *et al.*, 2001a; Li, 2015; Mahony *et al.*, 2008; Mumtaz, 2017; van den Berg *et al.*, 2019). Also, scheduling of flight attendants activities, known as rostering, is broadly considered as an issue for airline operation (Kohl and Karisch, 2004; Medard and Sawhney, 2007). Direct effects on the health of cabin crew could be stated by many authors, varying from issues related to mental stress (Mumtaz, 2017), workload (Glitsch *et al.*, 2007)and associated fatigue (Li, 2015) up to the knowledge retention after training (Mahony *et al.*, 2008).

Due to this workload, it is not surprising that after a study with flight attendants, 21% of the participants described the job as "quite" or "very" stressful and the largest proportion (29%) said that work was a crucial source of stress in their lives. Nearly two-thirds said they had taken one sick day (one day off work due to illness) to six sick days in the past six months; 17% had taken seven or more days off due to illness in the same period. 8% had between 13 and 24 sick days in the six months during the study (Kelleher and McGilloway, 2005).

According to the Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin), more than half of full-time employees state that they often have to work standing up, and a quarter of them describe this as stressful. Lifting and carrying loads is less common in percentage terms but is perceived as stressful by a much more significant proportion. Work in forced postures, for example, bent over, affects about one-sixth of, but is also classified as stressful by more than half of those affected. Musculoskeletal disorders (MSDs) are among the most common causes of work-related illnesses and refer to degenerative changes in the spine and joints. They affect 22.5 % of all days of incapacity to work and cause a loss of production of 17.2 billion euros in Germany. Consequently, these diseases are not only of relevance to health but also to the economy in Germany. Their causes are often due to physical strain (Lück *et al.*, 2019).

Ergonomic workplace design can reduce absenteeism costs caused by physical overload and the resulting MSDs. In addition, value creation can be increased by reducing unnecessary movements (bending, twisting, etc.) and process-related waste, and the motivation and satisfaction of employees, as well as their loyalty to the company, can be increased (Landau *et al.*, 2008).

A method that can be used without ergonomic-specific knowledge is the "Ovako Working posture Analysis System" (OWAS). The aim of this method is the ease of use, as well as the unambiguousness of the results, for that a certain degree of simplification is accepted. OWAS method records the postures occurring during an activity and their temporal proportion and determines the resulting stresses. This enables an assessment to be made of the extent to which there is a need to improve individual processes at the workplace, as the situation at the workplace is broken down into four levels, the so-called action categories (Gudehus, 2010)..

Another issue related to flight attendant´s fatigue and ergonomics is related to human factors. It refers to the way in which people interact with equipment, technology, and their environment. In the context of an aircraft cabin, human factors include ergonomics, the design of controls and displays, lighting and noise levels, and the overall layout of the cabin. These factors all play a role in determining the safety, comfort, and effectiveness of the aircraft and its occupants (Orlady *et al.*, 2017). For example, good ergonomics can help prevent fatigue and strain on the body, while well-designed controls and displays can make it easier for flight attendants to operate the equipment safely (Mahony *et al.*, 2008). Overall, human factors are an important consideration in the design and operation of an aircraft cabin (Dismukes *et al.*, 2018).

The dirty dozen is a term used to refer to a group of common human factors that can contribute to accidents or errors in various industries, including aviation, healthcare, and construction (Lapesa Barrera, 2022). These factors include:

1. Lack of communication: Ineffective communication can lead to misunderstandings, miscommunication, and a lack of coordination among team members.
2. Lack of teamwork: Poor teamwork can result in a lack of trust and cooperation among team members, which can lead to errors and accidents.
3. Lack of leadership: Without strong leadership, teams may lack direction and guidance, leading to confusion and a lack of focus.

4. Lack of situation awareness: If team members do not have a clear understanding of their surroundings and the tasks, they may make mistakes or overlook important details.
5. Inattention to detail: A lack of attention to detail can result in errors or oversights that can have serious consequences.
6. Complacency: When team members become too comfortable with their tasks and procedures, they may become complacent and less vigilant, increasing the risk of errors.
7. Lack of assertiveness: If team members are not assertive in speaking up about concerns or issues, important information may not be shared, leading to mistakes.
8. Distraction: Distractions can divert a team member's attention away from their tasks, increasing the risk of errors.
9. Fatigue: Fatigue can impair judgment and lead to mistakes.
10. Stress: Stress can affect a team member's ability to perform their tasks effectively, increasing the risk of errors.
11. Pressure to complete the task: The pressure to complete a task quickly can lead to shortcuts and a lack of attention to detail, increasing the risk of errors.
12. Lack of resources or support: When team members do not have the necessary resources or support, they may struggle to complete their tasks effectively, increasing the risk of errors.

Overall, it is important for flight attendants to be aware of and address these human factors in order to minimize the risk of errors and accidents. (Lapesa Barrera, 2022).

*Inflight operations*

The term “inflight operations” in the context of this work, refers to all the activities and procedures that take place during a flight related to inflight catering services. These operations are essential for ensuring the safety and smooth running of a flight.

The airlines have been increasing their efforts in optimising cabin operations. The main driver is to maximise revenue space through enablers that may improve cabin utilisation and increase seating possibilities (Reitmann, 2004). It can be observed that airlines are increasing their “buy-on-board” food options for medium and short-haul flights, although for long-haul flights, galley innovations seem to seek more modular add-ons and multi-purpose areas. Nevertheless, the efficiency of catering and crew processes remains essential (Gavine, 2021).

The use of smartphones to streamline the inflight dining experience for business-class travellers could also be stated. The system has been trialled on three routes – Dubai-Melbourne-Auckland, Dubai-Paris and Dubai–Mauritius. Flight attendants on these flights carry Samsung Galaxy A7 smartphones, which can only be used to open a special meal-ordering app. The phone is connected to its own Wi-Fi router and is not connected to the rest of the internet, so it can be used even in countries that have restrictions on in-flight Wi-Fi usage. When a flight attendant comes to a person’s seat, they are able to take a passenger’s order and customize it to their liking. Instead of walking back to the galley to get the orders started, flight attendants can immediately send orders from the app to the galley to get passenger orders out quicker. Before a flight, the phones are loaded up with information on each passenger, including name and seat assignment, itinerary, status of the passenger, meal preferences, and any other information (Flynn, 2017).

Besides airlines have been looking after increasing ancillary revenues and retail, e.g., buy-on-board options (Retail inMotion, 2022). Hereafter, digital platforms have been introduced, for example for consumption, purchase, waste and loss statistics for improving operational efficiency and aggregating to passenger satisfaction (APEX, 2021b).

Conflicting with inflight operations for inflight catering services, flight attendants are also responsible for routine safety duties, inflight fire containment, support by turbulence or cabin decompression, passenger coordination in case of emergency landing or ditching, cabin security and first aid (Murphy, 2001). Also, the crew resource management is a major consideration for determining the minimum flight attendant numbers, in this case, the crew rest, type of aircraft or cabin, passenger categories and possible flight attendant incapacitation (Yoo and Kim, 2018).

The number of flight attendants on board is based on the maximum seating capacity of a specific aircraft type or the number of passengers carried on a particular flight. Most States use the 1:50 model (i.e., a ratio of 1 flight attendant to 50 passenger seats installed). This includes the United States and States in the European Union. This method is based on the aircraft manufacturers' certificated evacuation capability as part of the type certificate process. Australia and Canada are examples of States using different models. Canada uses a 1 flight attendant to 40 passengers on board ratio as a basis. However, Transport Canada Civil Aviation (TCCA) permits operations with the use of the 1:50 model. Australia requires 1 flight attendant to 36 passengers on board. However, the Civil Aviation Safety Authority (CASA) may grant permission to large aircraft operators to transition to a 1:50 model if the competent authority is satisfied that an acceptable level of safety can be maintained as a result of implementing this model (International Civil Aviation Organization - ICAO, 2017).

As part of the type certificate process for a new aircraft type, an aircraft manufacturer must demonstrate that the aircraft, in its maximum seating capacity, can be evacuated within a 90-second timeframe. Based on these demonstrations or analysis based on data, aircraft are certified with a minimum number of cabin crew members in relation to a number of passenger seats (International Civil Aviation Organization - ICAO, 2017).

*Passenger satisfaction and fidelity*

Many challenges involved with the operations of inflight catering are related to amount of passengers to be served, together with the variety of goods, the timeframe for performing service and the space constraints intrinsic to the aircraft cabin design. A logistics task is defined as the efficient provision of the required goods in the suitable composition and combination at the right time and in the right place (Gudehus, 2011). Inflight catering services can be interpreted as a logistic task and defined as follows: the efficient provision of the required meals and beverages to the passengers in the right composition at the right time and in the right seat.

Over time, the demands of passengers also increase. Three main criteria are most important to passengers. These are the airfare, the flight-related timetable and the service offered during the flight (Jonas *et al.*, 2009). The demands of the service lie in the catering service offered and the comfort during the flight (Frank *et al.*, 2016). However, catering services are increasingly characterised by individualised services (Gumpinger *et al.*, 2011).

Passenger satisfaction towards inflight catering services has been a subject of interest. The topics "food and beverages" and "onboard services" are the most discussed issues on digital travelling platforms after "flight irregularities"(Lufthansa Innovation Hub, 2021). In addition, a relevance-satisfaction matrix for the airline industry has shown the importance of "onboard services" and "food and beverage", as must-have with high relevance. There is an increasing demand for individual services, e.g., special meals – vegetarian, lactose-free, and anti-allergic, affecting how onboard service is performed. There is a growing drive for the personalisation of meals, primarily due to the possibilities offered by digitalisation, e.g., online orders (Georgiou *et al.*, 2010; Costers *et al.*, 2019).

Passenger satisfaction is a key objective for an airline. In 2017, IATA's annual Global Passenger Survey identified the primary drivers of satisfaction and their respective influence on overall satisfaction. Cabin service has the highest influence on overall satisfaction. It was also found that the choice of airline is based on ticket price (International Air Transport Association - IATA, 2017). Thus, when choosing an airline for the first time, service is not a decisive selection factor for most of passengers. However, excellent and efficient service during the flight can be a decisive argument for choosing an airline again in case of a second booking. This is especially true for private travel but also for business travel (Han *et al.*, 2019). The price willingness of business travellers can be considered significantly higher than private travellers. This suggests that for business travellers, the focus is even more on service, and a high-quality business class product is therefore of crucial importance for the selection of an airline in this segment. The passenger typically depends on the specified serving times to take their meals. In the first and business class of some airlines, however, so-called dine on demand offers are also available, which allow the passenger to order his meal at any time (Briedenhann, 2018).

*Sustainability*

Sustainability in the aircraft cabin refers to the efforts to design, operate, and maintain the cabin in a way that minimizes the environmental impact and maximizes the use of resources. This can include designing the cabin to be lightweight and energy-efficient, using eco-friendly materials and products, reducing waste and single-use plastics, and implementing processes to conserve energy and water (Barke *et al.*, 2022).

Recently, more concepts have been arriving for more effective handling of the waste generated during flights. The first of these concepts was the ReTrolley. This concept is based on a conventional trolley and features bins for waste separation and a hand-operated compactor mechanism. This enables the effective separation of the waste and ensures compaction already during the flight (Airbus Operations GmbH, 2019). Another concept to improve waste management inside the aircraft cabin is the so-called Mobile Vacuum Trash Compactor. This concept can be integrated into the galley and uses the pressure difference between the cabin and the atmosphere to compact the waste already during the flight (Airline Experience Association - APEX, 2017).

Sustainability is a growing issue for airlines, which can be seen in different case studies directly from airlines (Karaman and Akman, 2018; Mak and Chan, 2007), e.g. arriving from "overturism" as low-cost carriers increased the tourism levels (Capocchi *et al.*, 2019) and the exposure of the environmental impact of air travel to passengers (Hagmann *et al.*, 2015). As a result, efforts towards building a new green image for air travel became more important, e.g. through the use of bioderived fuels (Chiaramonti *et al.*, 2014) (Chuck and Donnelly, 2014). Also, the passengers' sustainable behaviour has been adjusted in the scenario of the inflight catering service (You *et al.*, 2019). The reduction of waste is a challenge for the whole flight catering supply chain, as a significant proportion of meals, beverages and packaging is wasted after every flight (El-Mobaidh *et al.*, 2006). Waste management during production can also be observed as demanding, as stated by (Thamagasorn and Pharino, 2019) for the halal food production.

According to the "Aircraft Cabin Waste Project Report", 23% of aircraft cabin waste is due to catering, which is wasted even when the food or beverages are sealed. Uneaten food and drink count to up to 14% of the total waste weight. The IATA Cabin Waste Handbook has a series of advice for reducing waste, among other measures as, 1. monitoring and measuring, e.g. periodic reporting of cabin waste KPIs; 2. Reduction, e.g. through pre-ordering inflight catering meals; 3. re-use and reinjection, e.g., food donation and 4. recycling, e.g., developing standard operating procedures for segregation of cabin waste (Sweet *et al.*, 2019).

Some challenges can be mentioned regarding waste disposal, e.g. restrictive regulations based on the protection of the agricultural sector (with respect to animal health). Besides, cabin waste costs are not visible in service contracts. There is also a need for more awareness on cabin waste volumes and composition. From the airport side, there is a lack of infrastructure with cabin waste recycling facilities, and stowage onboard for segregated waste is not consequently foreseen. The commitment towards a more sustainable aircraft operation is likely due to the complex interrelationships with key stakeholders involved including manufacturers, airports, cleaning and catering companies, waste management companies and regulators.

Briefly, the efforts that have been performed for reducing cabin waste regarding inflight catering services are partly trying to increase passenger awareness towards sustainability, but also by the use of new technologies in order to, e.g., monitor consumption. Also, the reduction of single-use plastics has been noticed, and the changing of packaging, as an alternative for plastics towards compostable or recyclable materials.

*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 (Mortensen Ernits *et al.*, 2022b). Under meal provisioning, mostly operative and design issues have been taken into consideration. The aspect of passenger satisfaction investigates the elements of individualisation that may affect the passenger inflight experience, and finally, the willingness to pay more for individualised services looks after previous efforts towards a profitable change in air travel. The interconnection of individualisation with automation and digitisation, together with the demands towards sustainability, either from social, ecological or economic natures, are going to change the way inflight catering services are performed today (Zijm and Klumpp, 2017). The performed literature review with the chosen three main aspects reflects this view.

The aspect of individualised meal provisioning has been investigated, as shown by efforts estimating the number of meals to be produced and delivered to an aircraft. In this case, due to the amount of uncertainty, which could result in missing meals or options, and ultimately affecting customer satisfaction (Goto *et al.*, 2004).

On the ground, the turnaround operations determine a further requirement for the individualisation of inflight catering services, particularly regarding the time for loading and unloading the goods inside the aircraft (Schmidt, 2017b). In order to provide an individualised meal, the connection between loaded catering and boarded passengers must be established in order to ensure the proper meal provision. Also, efforts were made towards digitisation of turnaround processes to improve the communication and coordination of the ground-handling activities for avoiding delays (Wu, 2008). 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 sets that "90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours", although this goal is controversial, as currently, approximately 90% of travellers complete their journey within 7.5 hours (Grimme and Maertens, 2019). 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 arrive from new aircraft designs (Heinemann *et al.*, 2017), looking not only at new operations but also into changes in the aircraft cabin configurations, for enabling, e.g., turnaround time of 15 minutes, or water service and catering loading and unloading within 5 minutes.

Inside the cabin, some efforts were made to enhance the meal delivery to the passenger, as shown by (Santos *et al.*, 2017) with a preliminary study with a Kobuki-based robot. The passenger would be able to order meals or beverages directly from his or her seat. The order would be prepared by a flight attendant in the galley and delivered by the robot to the respective seat. Although it is attested to reduce the flight attendant workload, no analysis or evaluation of process integration has been presented.

Design changes for improving the inflight catering services were investigated, e.g. by proposing an add-on system for self-service catering (Fenech and Farrugia, 2014). Also, a new system to improve on-seat comfort, on-demand service, and the ability to walk freely in the aisles has been developed (Frank *et al.*, 2016). The system was composed of 5 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, reduction of emissions and improvement of passenger comfort were evaluated and compared with the current system.

In order to increase the situation awareness among flight attendants, a smart-watch assistance application to optimise the communication inside the aircraft has been proposed. The use of the collaborative tool may improve cabin safety and optimise passenger service, e.g. by coordinating better the flight attendant workload (Wong *et al.*, 2018).

The aspect of individualisation can also be found in the hospitality branch; in a study, an overview of the use of robotics in catering in general has been presented (Garcia-Haro *et al.*, 2021). Although none of the applications can be currently found inside the 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 of options, which could turn into information overload and lead to lower service satisfaction. Efforts in research towards recommender systems could be found, also for catering choice; in this case, the use of such systems could improve the passenger's decision-making process (Ai *et al.*, 2013). The impact of individualisation in catering service can be observed from the case study of outsourcing products and services to sub-suppliers to achieve mass customisation. The study has shown that the early definition of the level of sub-supplier integration, together with the used tools and affected processes, are essential for achieving mass customisation in a chain-operated restaurant (Chen and Hao, 2007).

The new design of meals for an ageing population, particularly regarding the preparation and consumption of homemade meals, has been investigated. The research shows how ageing consumers decide on their meals, pointing out a relevant potential for individualisation (Costa and Jongen, 2010).

A survey was conducted to examine the decline in customer service across the airline industry from 1995 to 2000, highlighting passenger satisfaction as a key research topic. The research looked after a connection between "air rage" and passenger dissatisfaction, possibly related to the frustration of service expectations (Hunter, 2006).

The impact of meals on passenger satisfaction was investigated to relate to passengers experienced 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 the flight attendant responses related to a missing pre-ordered meal, resulting in a different level of satisfaction by the passenger. The case study highlighted that the response is variable, and can be related to the level of experience of the flight attendant and the availability of information (Laws, 2005).

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 (Han *et al.*, 2019). In the model, quality has been divided into three categories: core quality (taste, quantity, freshness, quality, temperature, health, and nutrition), external quality (presentation, colour, and menu variety, delivery quality (timely and accurate manner, personal service)).

The individualisation strategy is also related to the topic of passenger satisfaction. A classification was proposed for individualisation strategies with three main categories: 1. product adaptation executed by the company, 2. product adaptation executed 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 (Kuhl and Krause, 2019).

A design for customer satisfaction surveys has been proposed for assessing airline service quality. Besides, the research provided a literature review on main service attributes, including, e.g., "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 (Bellizzi *et al.*, 2020).

The economic aspect of individualisation influencing the passenger was considered by analysing the "willingness to pay" potential of green products in air travel, e.g., organic onboard food (Hinnen *et al.*, 2017). The performed survey pointed out that 20% of passengers are willing to pay for supplementary services and are 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 has been performed. Therefore five ancillary services 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 are willing to pay more for most ancillary services, millennials have a different willingness to pay than older passengers and that the flight duration has a contrasting impact on the willingness to pay (Chiambaretto, 2021).

A summary of the literature review findings is presented in Table 6, showing the possible demand derived from meal individualisation.

Table 6 - Summary demand derived from inflight meal individualisation after literature review.

| Meal provisioning | Demand derived from meal individualisation |
|---|---|
| Goto *et al.*, 2004 | Provide the right amount of catering for each flight and passenger. |
| Eriksson and Nordgren, 2018 | Focus marketing on individualisation´s perception. |
| Sampath *et al.*, 2021 | Provide consistent information about allergens inside meals. |
| Zijm and Klumpp, 2017 | Evaluate integration of current/future technologies for improving options for individualisation. |
| Schmidt, 2017b | Demand for more efficient loading and unloading of catering goods, particularly in case of individualisation. |
| Santos *et al.*, 2017 | Integration of automatic solutions with current processes and aircraft design. |
| Clarke and Smith, 2004 | Evaluate cross-aircraft solutions for catering operations to reduce training effort. |
| Yoo and Kim, 2018 | Optimise current processes to reduce cabin crew workload and therefore less fatigue. |
| Grimme and Maertens, 2019 | Improve on ground and inflight operations for fulfilling Flightpath 2050 goal. |
| Heinemann *et al.*, 2017 | Reduce current turnaround time to enable new catering models. |
| Fenech and Farrugia, 2014 | Evaluate new inflight catering models based on design changes. |
| Frank *et al.*, 2016 | Integrate solutions into flight catering supply chain and compare them with possible alternatives. |
| Wong *et al.*, 2018 | Evaluate the use and integration of collaborative tools/technologies into operation models. |
| Hagihara *et al.*, 2001b | Improve ergonomics of inflight catering services to avoid unnecessary walking and flight attendant fatigue. |
| Shao *et al.*, 2008 | Support flight attendants in most demanding activities for reducing fatigue. |
| Wu, 2008 | Improve communication and coordination of activities on ground through digitisation to reduce turnaround time. |

| | |
|---|---|
| Xie *et al.*, 2018 | New approaches for improving cabin design and therefore flight attend operations must be evaluated and compared. |
| Garcia-Haro *et al.*, 2021 | Possible impact on passenger expectation on automatic catering services. |
| Ai *et al.*, 2013 | Investigate use of recommender system after a certain level of individualisation. |
| Chen and Hao, 2007 | Evaluate impact in the value chain regarding individualisation efforts with sub suppliers. |
| Costa and Jongen, 2010 | Investigate demographics' impact on individualisation of inflight catering meals. |
| Impact of meals on satisfaction | |
| Laws, 2005 | Support flight attendants with proper tools for improving passenger response in case of failure. |
| Han *et al.*, 2019 | Need of establishing a connection between meal quality and individualisation. |
| Kuhl and Krause, 2019 | Definition of a strategy for individualising inflight catering services regarding different compromises between internal variety and customer benefit. |
| Bellizzi *et al.*, 2020 | Establish common comparison features for individualisation of inflight meals to improve service quality. |
| Willingness to pay for ind. meals | |
| Hinnen *et al.*, 2017 | Need to investigated the relation of individualisation with sustainability and understand how individualisation of meals could increase the willing to pay – WTP, also from sustainable factors. |
| Chiambaretto, 2021 | Assess variations in inflight meals for understanding WTP for higher level of individualisation. |
| Hunter, 2006 | Identify individual customers needs and desires for developing a proper solution. |

*COVID-19 pandemic*

The COVID-19 pandemic has highlighted the importance of targeting high-risk situations for the spread of contagious diseases. In particular, the uncontrolled spread of the virus was observed during the pandemic, including in passenger transportation, particularly at airports. The rapid exchange of people through air transportation may have contributed to the spread of the virus, especially in the early stages of the pandemic before effective prevention measures and vaccines were available. To prevent future pandemics and reduce the global spread of highly contagious viruses, it is essential to address situations where prevention measures cannot be effectively implemented, such as due to faulty execution (Rohde *et al.*, 2022). The pandemic also impacted passenger trust in new technologies; in a survey, passengers were asked which of twelve measures could increase trust in air travel, e.g., contactless payment options. Pre-ordering contactless catering has been shown as the fifty measure that would most significantly increase trust in air travel (Inmarsat, 2020).

*Economical Aspects*

Airlines play a central role as they have to meet customers' needs, and at the same time, make a financial profit. The airlines' offers depend directly on customer feedback. In addition, the airline determines the number and quality of the catering it orders from the catering companies. Due to the large number of airlines, many different approaches to catering have emerged in the past (Yi-Chi Chang and Jones, 2007) (Peter Jones, 2004).

The global market for in-flight catering services was around $7 billion in 2020 and is expected to reach $23.9 billion by 2027 (Global Industry Analysts, 2022).

The differences between full-service carriers and low-cost carriers can be seen in 2021, with an average passenger fare between 253€ and 27€ (Statista, 2022b). The changes in the service offer are mainly due to the new business model with mass transport, which leads to cheaper ticket prices. Since 2000, there has been a decline in airfares for domestic flights, e.g. the changes have remained about the same over the last ten years, with most of the changes related to economic crises, leading to the assumption that the mass-transit business model seems to be proving its worth (Bureau of Transportation Statistics, 2022).

Another compelling aspect is the service offered and the ticket price. According to this, airlines are differentiated into full-service carriers - FSC and low-cost carriers - LCC. The full-service carriers distinguish themselves on long, medium and short routes by offering passengers, e.g. meals and drinks on board included in the ticket price, while the low-cost carriers base their business model on low ticket prices and, e.g. meals and drinks on board are served on request and are not included in the flight price (Renold *et al.*, 2019).

A survey by the travel search engine "fly.com" found that one-third of the 1003 respondents could imagine doing without flight attendants on the plane, on the premise that this would also reduce airfares, as shown in Figure 12.

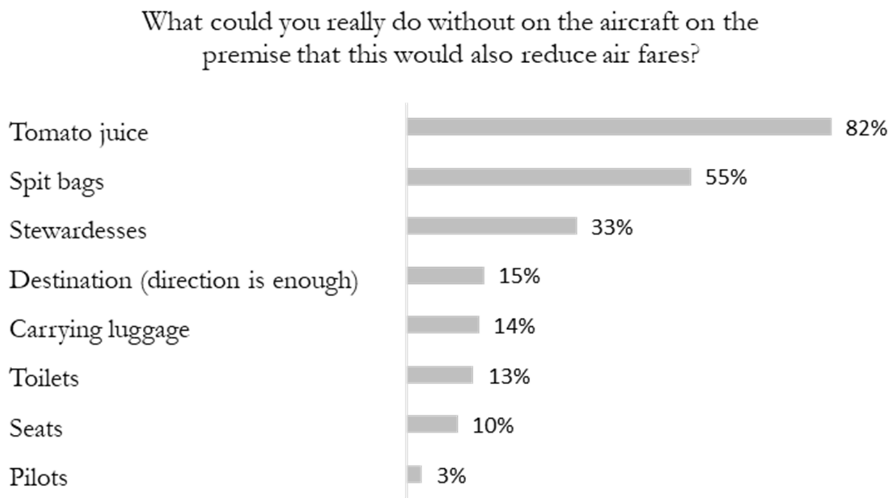



**Figure 12 - Survey of deprivations on the plane** (Statista, 2022a).

However, with the existing galley or the current catering concept in the aircraft, it is not possible to do without staff, as the service processes are very personnel-intensive. Likewise, for safety reasons, a certain number of service personnel must be on board to provide assistance and intervene in the event of incidents.

If flight attendants could be saved by a new galley or a new catering concept, this would lead to an enormous reduction in personnel costs. Depending on the airline, the average basic salary of a flight attendant (cabin crewmember) is approximately between 12,000 euros (Emirates) and 20,000 euros (Lufthansa) per year, as shown in Figure 13.

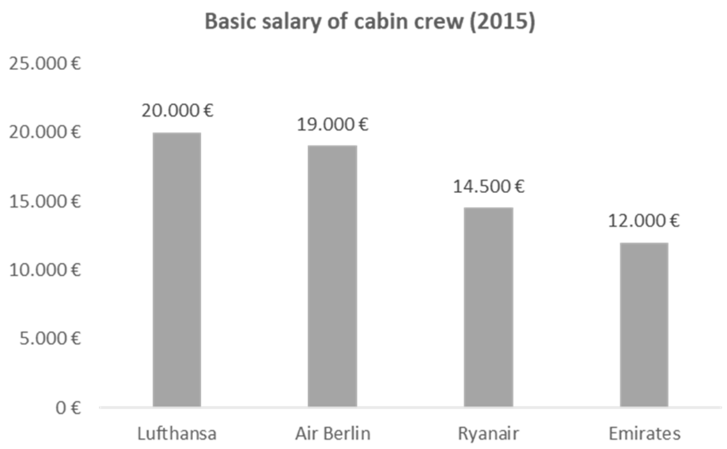



**Figure 13 - Basic salary of cabin crew** (Statista, 2022b)**.**

In addition, there are percentage shift bonuses of about 16.3% (Lufthansa), which, according to the Deutsche Presse Agentur, leads to an annual salary of between 30,000 euros and 63,400 euros. Some airlines, such as Lufthansa's subsidiary Eurowings, cap the salary at 34,000 euros.

A distinction must be made here between "low-cost carriers" (LCC) and "full-service carriers" (FCC). Low-cost carriers such as Ryanair usually offer flights at significantly lower prices compared to traditional airlines and therefore forego comfort features in order to reduce costs. The high seat occupancy rate, the fact that usually only one type of aircraft is used by the airline in order to be fuel-efficient and the provision of food and drinks on the plane is usually only possible for an extra fee are key features of these airlines (DLR 2018). In contrast, traditional airlines place much emphasis on outstanding and balanced service.

A study conducted an analysis of injury statistics and ergonomic assessment of the physical demands of flight attendants' jobs. The study surveyed 177 flight attendants of a Canadian airline. A distinction was made according to both the reason and the part of the body affected (Kelleher and McGilloway, 2005). About 58% of flight attendant injuries were musculoskeletal injuries to the back, neck or shoulders, as shown in Figure 14.

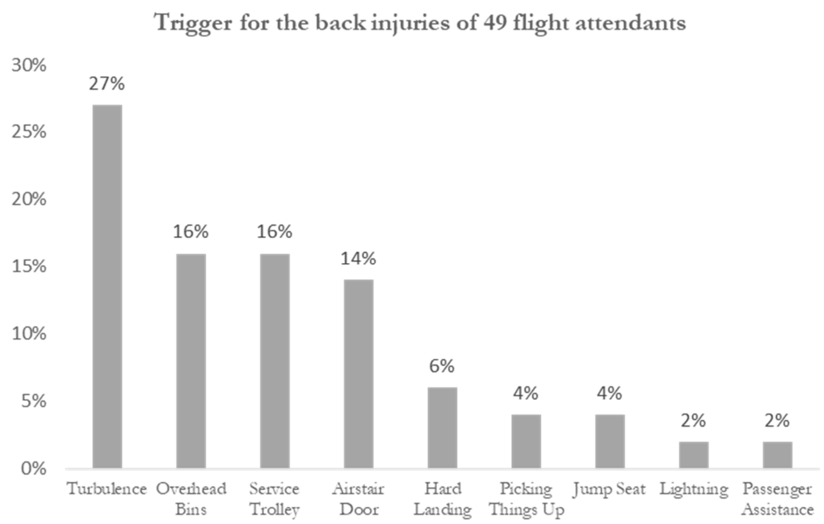



**Figure 14 - Factors associated with 49 flight attendant back injuries (Kelleher and McGilloway, 2005).**

Average absenteeism due to injuries is highest for shoulder injuries at 52 days, as shown in Figure 15. Upper back injuries lead to an average of 36 days of absence from work, and lower back injuries to 29 days. Neck and arm/hand injuries lead to 9 and 8 days of staff absence respectively.

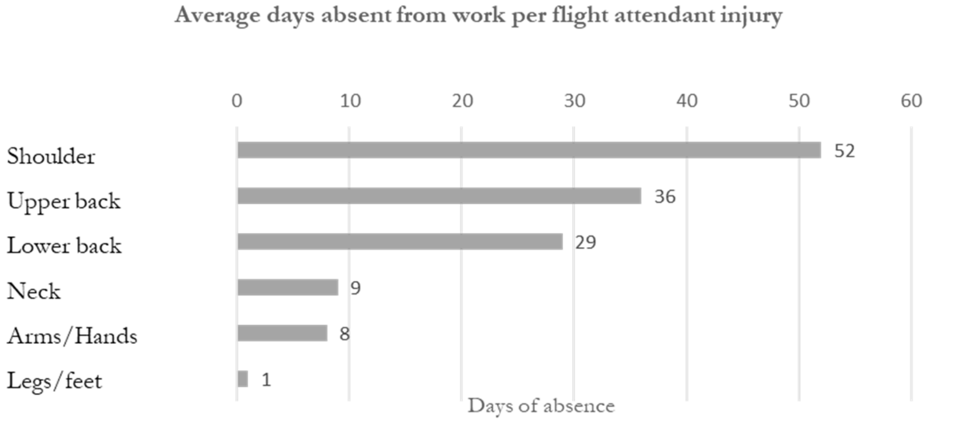



**Figure 15 - Average days absent from work per flight attendant injury (Kelleher and McGilloway, 2005).**

Based on these statistics, it can be deduced that flight attendants represent a significant factor in the operational costs of airline operations. If the human workforce is absent from work due to injuries, this not only leads to longer-term absences due to treatment of the injuries but also to considerable costs. For this reason, it makes sense to optimise the existing galley so that the flight attendants can be ergonomically relieved to reduce the risk of injury and thereby save costs.

## 2.6 Safety and standardisation

An overview of the air transport institutions is given in Figure 16. For the national institutions, the overview is based on Germany´s institutions.

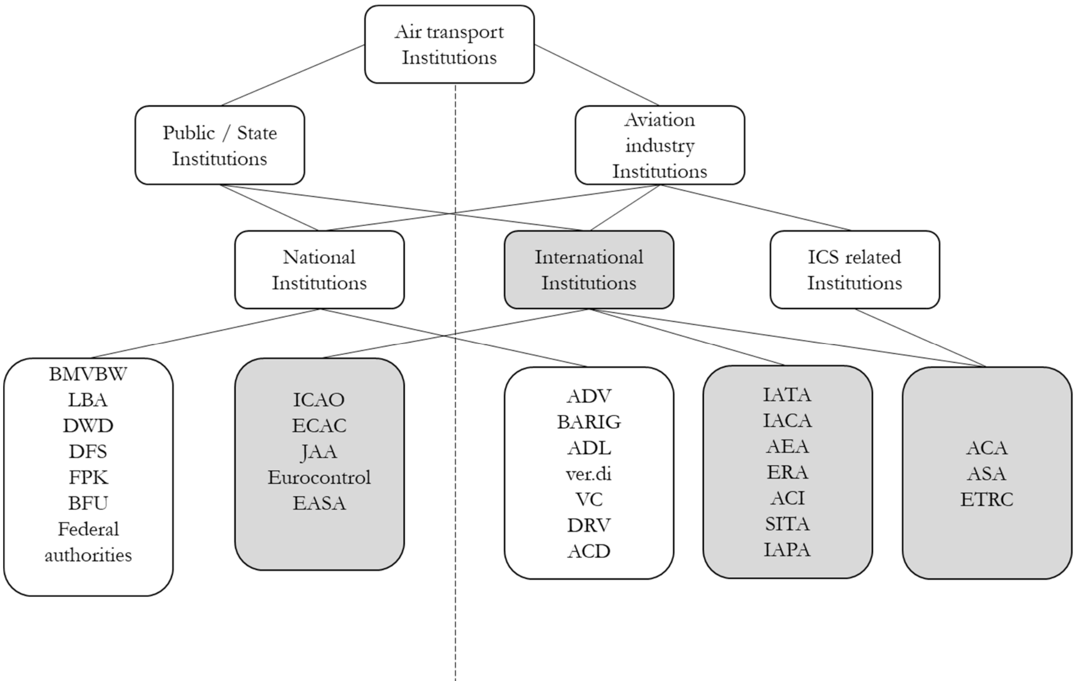



**Figure 16 - Overview air transport institutions, based on Conrady (Conrady, 2019).**

The institutions are divided into 2 main categories: public/state and aviation industry institutions. The representations follow different interests and have different responsibilities. In this section, some points relevant to safety and standardisation are briefly discussed. The topic is quite extensive and exceeds the scope of this work, so in this chapter, the following points are going to be highlighted:

- What are the consequences of changes in the galley and in the cabin that impact safety and standardization?
- What changes can be performed without changing standards?

In aviation, the term airworthiness defines the safety of passengers and crew. The aircraft certification service is broad, and depending on the level of change, different requirements are necessary. For instance, new designs are changing the aircraft body or engines or new parts from manufacturers and design modifications (Florio, 2016). Airworthiness requirements consider the standards to define the design criteria to produce the airworthiness certification. The related procedures and requirements that may be impacted by changes in the galley and, consequently in the cabin could be in a first approach directed to the following chapters:

- JAR21. Certification procedures for aircraft and related products and parts
- FAR 21. Certification procedures for products and parts
- JAR 26. Additional airworthiness requirements for operations
- JAR-OPS 1. Commercial Air Transportation (Aeroplanes)
- JAR-MMEL/MEL. Master minimum equipment list/minimum equipment list
- FAR 119. Certification: Air carriers and commercial operators
- FAR 125. Certification and Operations. Aircraft having a seating capacity of 20 or more passengers or a maximum payload capacity of 6000 pounds or more; and rules governing persons on board such aircraft

Interestingly, the airworthiness requirements recognise that standards could block the aeronautical progress; in this case, facing innovations, the JAR/FAR 21, paragraph 16 and EASA Part 21, paragraph 21A give a response for this situation with the denomination "special conditions". In this sense, the idea is to provide an equivalent level of safety coherent to the aimed certification.

The concept of airworthiness requirements involves stalling speed – related to the landing speed; crashworthiness – what happens with the aircraft in case of a crash; fire protection – defining "fire zones" and the strategies of abandoning the aircraft; fire containment and active protection, safety assessment, fatigue strength – related to load issues on structures (Florio, 2016).

The international certification authorities are, e.g., following Figure 16,

- International Civil Aviation Organization (ICAO)
- European Aviation Safety Agency (EASA)

They are responsible for the standards for aviation safety and for approving design, manufacture, or maintenance of aircraft or components, moreover, for monitoring the implementation of the safety rules.

The Design Organization Approval (DOA) defines if a Design Organization is able to comply with a series of duties and responsibilities associated with the designer´s perspective. In this case, the approval gives an organization the certification for designing aircraft/components and as well as to demonstrate and check the compliance. In addition, to check the job from partners/subcontractors. Further on, all aspects involved with the documentation and reporting to the authorities until the inspection and necessary tests for checking the validity of the statements of compliance are shown in Figure 17.

In the scope of this work, the primary issue pertains to the modification of product design with respect to aircraft. The modification of cabin and product is focused on retaining the product while altering features inside it. Hereafter, there is the classification of modifications in minor and major, which directs how the certification process will work and who is responsible. For minor changes in the type design, they can be classified and approved either by the agency, e.g., EASA or the Design Organization under a procedure agreed with EASA (EC 1702/2003, subpart D, 21A, 95 Part 21). On the other hand, major modifications can be classified by the type certification holder but can only be performed under the surveillance of the authority (Niţă, 2012).

The European Aviation Safety Agency (EASA) is the regulatory authority for civil aviation in the European Union. It is headquartered in Cologne, Germany, and was established in 2002. The EASA's mandate is to promote the highest common standards of safety and environmental protection in civil aviation. It does this by developing and implementing regulations, standards, and guidance for the aviation industry and by providing technical assistance and support to member states (EASA, 2022a).

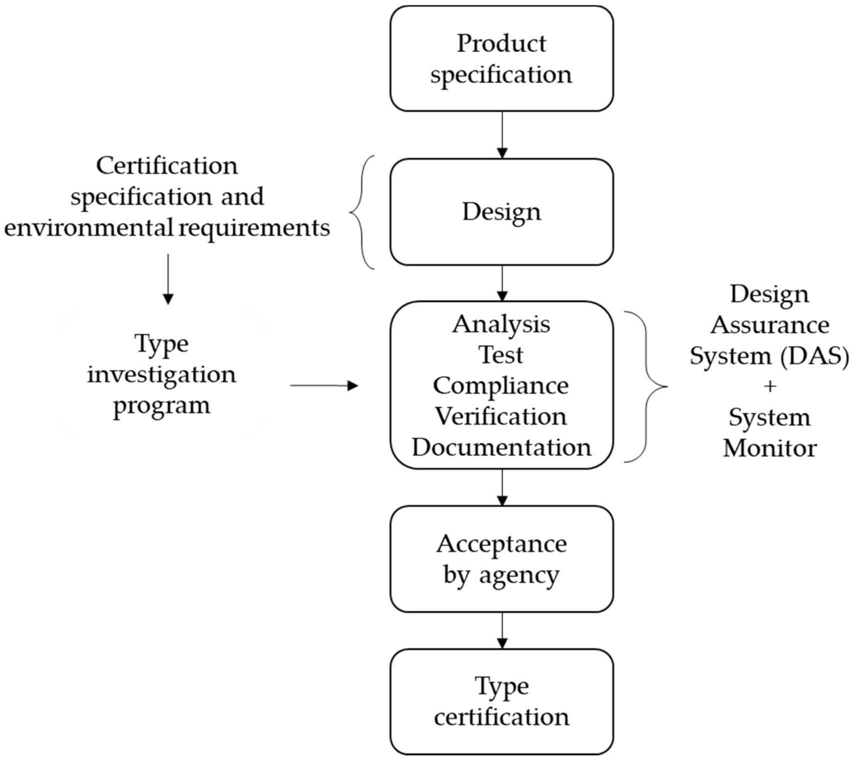



Figure 17 - Relationship between design, design assurance and type investigation based on (Florio, 2016).

The International Civil Aviation Organization (ICAO) is a specialized agency of the United Nations. It has its headquarters in Montreal, Canada, and it was founded in 1944. The ICAO's mandate is to promote the safe and orderly development of international civil aviation. It does this by setting standards and regulations for the industry, providing guidance and assistance to member states, and facilitating cooperation and collaboration among nations. The ICAO has more than 190 member states, and its standards and recommendations are used by more than 190 countries. It plays a key role in ensuring the safety and efficiency of international air travel (International Civil Aviation Organization - ICAO, 2017).

The International Air Transport Association (IATA) is a trade association of the world's airlines. It is also headquartered in Montreal, Canada, and it was founded in 1945. The IATA's mission is to represent, lead, and serve the airline industry. It does this by setting standards and best practices for the industry, promoting safe and efficient air travel, and providing support and assistance to its member airlines. The IATA also works closely with governments and other stakeholders to ensure that the airline industry can continue to grow and thrive. It has more than 290 member airlines, accounting for more than 82% of global air traffic.

The Airline Catering Association (ACA), based in Brussels, Belgium, is a global trade association of companies in the airline catering industry. The international non-profit organisation represents and promotes the common interests of the airline catering industry. The ACA focuses, in particular, on legal, food quality and safety, and fiscal and environmental matters (APEX, 2021a).

ATA iSpec 2200 is a technical specification developed by the Air Transport Association (ATA) for the aviation industry. It is a standardized format for presenting technical information and specifications related to the design, maintenance, and operation of aircraft and their systems. The iSpec 2200 specification provides a consistent and standardized way of organizing and presenting technical information, making it easier for airlines, aircraft manufacturers, and other industry stakeholders to access and use this information. It covers a wide range of topics, including aircraft systems, structures, materials, and processes. By using the iSpec 2200 specification, airlines and other industry stakeholders can more easily share and access technical information, which can help to improve efficiency, reduce costs, and enhance safety in the aviation industry (Air Transport Association of America, 2021).

The World Health Organization (WHO) has developed general guidelines for food safety that apply to all types of food establishments, including those that provide food for airlines. These guidelines are based on the internationally recognized principles of the Hazard Analysis and Critical Control Points (HACCP) system, which is a science-based approach to identifying and preventing potential hazards in the food production process. The WHO guidelines recommend that all food establishments, including those that provide food for airlines, have a food safety management system in place that is based on the HACCP principles. This system should include measures to ensure that food is properly handled, stored, and cooked to prevent the growth of harmful bacteria and other contaminants. Additionally, the guidelines recommend that food establishments have procedures in place to prevent cross-contamination, and that they regularly monitor and test their food to ensure that it is safe to eat (Beumer *et al.*, 1994).

ARINC, or Aeronautical Radio, Inc., is a communications and engineering company that provides a range of services to the aviation industry. One of the services that ARINC provides is the development and maintenance of technical standards for the design, integration, and operation of aircraft systems. These standards, known as ARINC Standards, are widely used in the aviation industry and provide a common basis for the design and compatibility of aircraft systems. The

ARINC Standards cover a wide range of topics, including avionics, electrical power, data communications, and aircraft interfaces. By using these standards, aircraft manufacturers and operators can ensure that their systems are compatible with those of other manufacturers and can be easily integrated into existing aircraft. This can help to improve efficiency, reduce costs, and enhance safety in the aviation industry. ARINC Specification 810: Definition of Standard Data Interfaces for Galley Insert (GAIN) Equipment, Physical Interfaces and ARINC Specification 812A: Standard Data Interfaces for Galley Insert (GAIN) Equipment, CAN Communications have been developed to define galley equipment, component interfaces and communications data (Olive *et al.*, 2006).

The galleys and their equipment used today are based on various standards. For trolleys and their accessories (oven racks, standard units, trays), the airlines mainly rely on two different standards, which result in different dimensions. The most significant and most widespread standard is the Atlas standard, and it is followed by the KSSU standard. One of the smaller standards is the ACE, this is a standard developed by British Airways. In addition, there are individual airlines that prefer a customer-specific system (Jones, 2011).

# 3 State of the art on automation concepts for ICS and on MCDM for automation of processes

This chapter starts with the discussion of approaches for process optimisation and product development in general, followed by a technology screening of available solutions. A distinction between implemented technologies and concepts is performed in the next subchapter. In the sequence, the approaches for selecting, classifying and designing automation concepts are presented and categorized. An overview of the multicriteria decision-making methods (MCDM) is given. This chapter closes with the evaluation and discussion of the approaches for designing, classifying and selecting automation concepts for inflight catering services.

## 3.1 Approaches for process optimisation and product development

Product development and process optimization are interconnected (Krause *et al.*, 2014). A thorough understanding of the process, including analysis and requirement gathering, is crucial for successful product development. At the same time, understanding the specific functions and operations of a new product is essential for optimizing the overall process. In the context of inflight catering services, automation can be achieved through the development of a new automated product or the automation of the process itself. There are several common methods for product development (Michaelis, 2013), including:

- Waterfall method: this is a linear method in which each phase of the development process is completed before moving on to the next phase. This method is best suited for projects with well-defined requirements and a fixed scope.
- Agile method: it emphasizes iterative development and the ability to adapt to changing requirements. Agile development is often used for software development projects.
- Design thinking method: it involves a series of steps, including empathy, definition, ideation, prototyping, and testing. This method emphasizes the importance of empathy and iteration in the design process.

A non-extensive list of methods for process optimisation is presented as follows (Yoon *et al.*, 2015):

- Six Sigma: it uses data and statistical analysis to improve processes and eliminate defects. The goal of Six Sigma process optimisation is to achieve near-perfect quality.
- Lean: it focus on the elimination of waste and the continuous improvement of processes.
- Total Quality Management (TQM): it looks after the importance of incremental improvement and customer satisfaction in all aspects of an organisation. TQM seeks the involvement of all employees in the optimisation process.
- Process mapping: it aims to create a visual representation of a process for better comprehension and to identify areas that require improvement. Process mapping can be done with flowcharts and value stream diagrams.
- Root cause analysis: it seeks to identify the underlying causes of problems or defects in a system or process. The ultimate goal is to find a permanent solution to the issue at hand. There are several techniques that can be used to conduct root cause analysis, including the Five Whys method and the Fishbone diagram.

Besides, it is also relevant to understand how a "system" is considered in this work. According to the International Council on Systems Engineering (INCOSE), a system is a group of distinct elements that, when combined, produce results that cannot be achieved by the elements alone. These elements can include people, hardware, software, facilities, policies, and documents and are necessary to achieve system-level outcomes, such as qualities, properties, characteristics, functions, behaviours, and performance. The value added by the system as a whole is determined by the relationship between the individual elements and how they are connected. In this paper, the term "technical system" refers to a technical product. There are several factors to consider when designing technical products and systems, such as functionality, usability, safety, reliability, maintainability, cost, and sustainability. The product or system should be able to perform its intended tasks effectively and efficiently, be easy to use and understand, consider potential hazards and risks, perform consistently over time, be easy to maintain, consider the cost of materials and labour, and consider environmental and social sustainability.

Automation is a common feature in various technical fields, including production, energy, and transportation. Developing an automated solution can be costly, with engineering expenses potentially reaching up to 40%. According to research by the McKinsey Global Institute, an estimated 375 million workers (14% of the global workforce) will need to be retrained for new tasks in the coming decades as automation continues. However, experts predict that not all sectors will be affected equally. Sectors that rely heavily on repetitive manual tasks are expected to be the first to be affected by the impact of automation. Machines and computers are capable of performing a variety of physical tasks more efficiently and at a lower cost than humans perform, and they are also increasingly able to perform cognitive tasks that were previously thought to be difficult to automate, such as making judgment calls, detecting emotions, and driving. Automation will change the work tasks of people in a variety of industries, including mining, landscaping, banking, fashion design, welding, and executive positions. However, how quickly these automation technologies will be adopted in the workplace and what their impact will be on employment and productivity are still being determined (McKinsey, 2017).

Automation objectives refer to various aspects related to the operational process, including economic factors such as productivity and costs, the development of new business opportunities, and sustainability goals such as reducing emissions and energy consumption. Additionally, automation objectives may also focus on the quality of the product, including the development and production processes. Automation tasks are the ways in which these objectives can be achieved, such as monitoring, controlling, and optimizing processes. These tasks can be connected to physical processes or product variables and define the desired requirements. Automation functions, such as room temperature controllers, are the solutions to these tasks. Schnieder's BMW principle is a systematic approach to developing automation solutions that involves four steps: describing the task and problem, creating a plan for solving the problem with specific resources and procedures, implementing the solution with specific equipment or tools, and considering context factors such as knowledge, experience, standards, and time and cost constraints (Schnieder, 1999).

According to Stechert, process models have been developed in various engineering disciplines, including mechanical engineering, electrical engineering, and software development, to support effective and efficient product development. These models aim to transparently represent and organise the tasks and activities involved in product development (Stechert *et al.*, 2011). Hereafter, the process is broken down into various stages using a process model. These stages are executed by the organisation using appropriate tools and methods (Ponn, 2011). These phases represent completed subtasks that require defined input data and result in a defined outcome through the involvement of specific roles and the application of a specific methodology.

There are several reasons why it is a complex challenge to automate the work of flight attendants inside an aircraft. First, the tasks performed by flight attendants are highly varied and can range from serving meals and drinks to passengers, assisting passengers in an emergency, to providing first aid and other medical assistance. These tasks require a high level of flexibility and adaptability, which is difficult for machines to replicate. Second, flight attendants are required to interact with passengers in a friendly and helpful manner, which requires a high level of emotional intelligence and interpersonal skills. Third, the environment inside an aircraft is highly dynamic and can change rapidly, requiring flight attendants to be able to respond quickly and effectively to changing situations. In short, the work of flight attendants is highly complex and involves a wide range of tasks that require flexibility, adaptability, emotional intelligence, and interpersonal skills.

In this work, the understanding of "system automation" will be used for defining the approach used for the automation of inflight catering services.

Due to the complexity of the topic, many methods are helpful for understanding connections between product and process and deriving functions for new concepts. An overview of the methods considered during this work is shown in Figure 18, and a brief description of key aspects of this work are subsequently explained. The objective of looking after automation approaches in related fields is to establish a connection between technology push and demand pull. Technology push refers to the development and introduction of new technologies driven by the capabilities and interests of the technology provider. Demand-pull, on the other hand, refers to the introduction of new technologies driven by the needs and demands of the market.

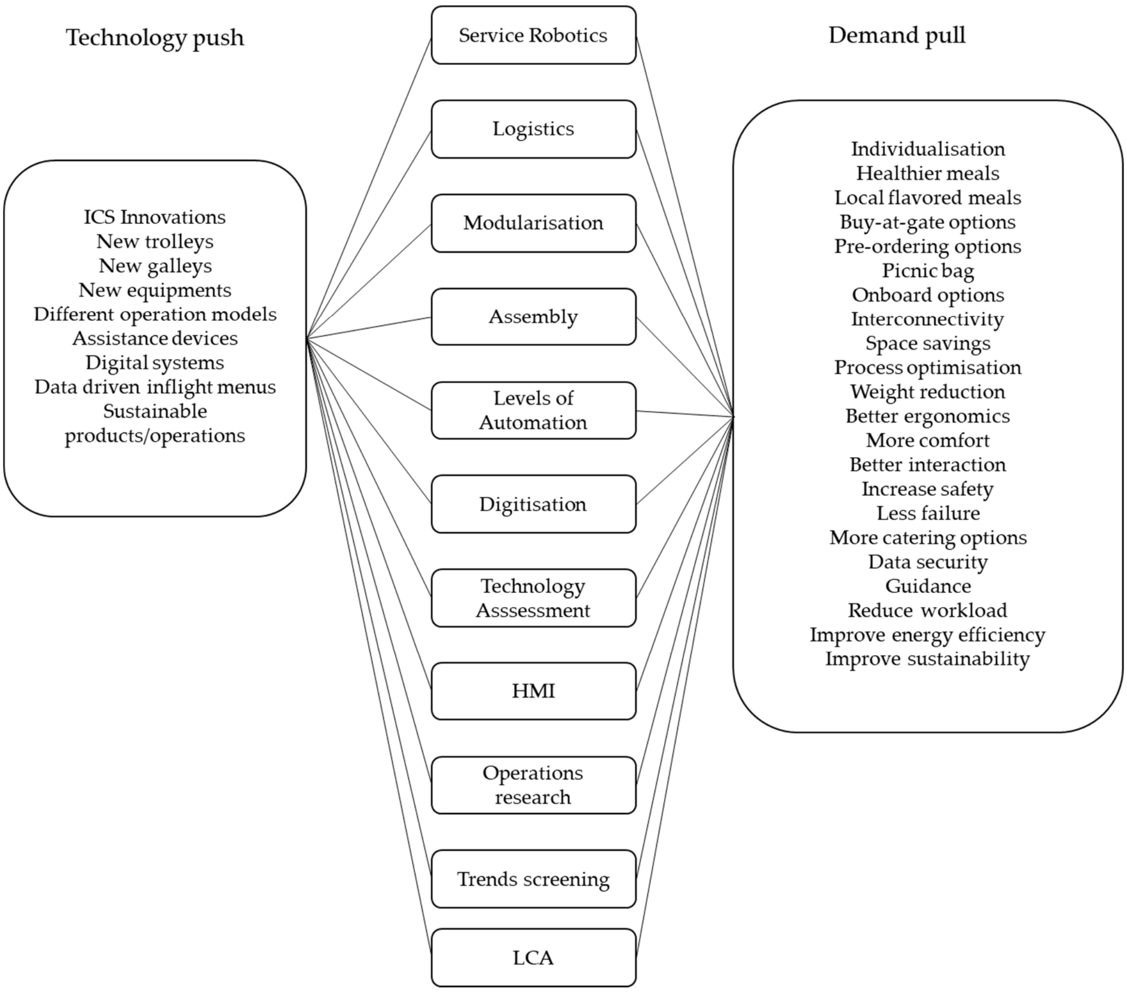



**Figure 18 - Overview of methods for optimising inflight catering services, connection between technology push and demand pull.**

*Service Robotics*

Service robotics focuses on the design and development of robots that are used to perform tasks that benefit people or society, such as cleaning, entertaining, or assisting with household or professional tasks (Baines and Lightfoot, 2013). Service robots are typically designed to operate in close proximity to people and to interact with them in a natural and intuitive way. They may be autonomous, semi-autonomous, or remotely controlled, and they may be used in a variety of settings, including homes, offices, hospitals, hotels, and other public spaces. Service robotics can address a variety of operational and external issues in service businesses (Ivanov *et al.*, 2017). On the operational side, service robots can assist with routine tasks, freeing up human employees to focus on more complex and dynamic situations. In some cases, robots may even be able to substitute for human employees completely in a sequence of service encounters (Buhtz *et al.*, 2018). On the external side, service robots can provide businesses with a unique opportunity to attract customer interest and utilise resources more efficiently, allowing them to focus more on improving service offerings. Internally, the use of service robots may change the required skills of service employees and transform existing roles (Ivanov, 2019).

Service robots are increasingly being used in the hospitality industry to improve efficiency, reduce costs, and enhance the customer experience. These robots can perform a variety of tasks, including greeting guests, carrying luggage, delivering food and drinks, and providing information and directions (Xu *et al.*, 2020). One example of the use of service robots in the hospitality industry is the deployment of robotic bellhops at hotels. These robots are programmed to navigate hotel corridors and elevators, and can be summoned via a smartphone app to deliver guests' luggage to their rooms (Tuomi *et al.*, 2021). Another example is the use of robotic servers in restaurants. These robots can take orders, deliver food and drinks, and even interact with customers through natural language processing and facial recognition technology (Kao and Huang, 2023).

*Logistics*

Logistics is the process of planning, organizing, and managing the movement and storage of goods, services, and information from the point of origin to the point of consumption (Gudehus, 2010). It involves coordinating and integrating a range of activities, including procurement, production, distribution, transportation, and warehousing, in order to ensure that goods and services are delivered to the right place at the right time in the most cost-effective and efficient manner possible (Hompel, 2009). Logistics plays a crucial role in the supply chain, and it is essential for the smooth and efficient operation of businesses and organizations of all sizes, in a wide range of industries. Automation in logistics refers to the use of technology, such as automated machines and systems, to perform tasks in the logistics process. Automation can help to improve the efficiency, accuracy, and speed of logistics operations, and it can reduce the need for manual labour and human intervention (Fottner *et al.*, 2021). For example, automation may be used in warehouses to sort and organize packages, in transportation to route and track vehicles, and in procurement to monitor and manage inventory levels. Automation can also help improve the accuracy and timeliness of information in the logistics process, by enabling real-time tracking and monitoring of goods and services (Freitag *et al.*, 2020). Overall, the use of automation in logistics can help businesses and organisations save time, reduce costs, and improve the overall effectiveness of their logistics operations.

Galleys and trolleys are storage systems, similar as a warehouse. A warehouse is a space or area where piece goods or bulk goods are stored and their quantity or value is recorded. Storage refers to the process of leaving an object within a material flow for a specific purpose. A warehouse can be seen as a node in a logistical structure, where incoming items are temporarily held or diverted to another network. Warehouses serve as delivery or reception points or as centres for dissolving and concentrating goods within a logistics system. Both storage and movement processes occur in a warehouse, with the dominant process depending on the warehouse's function. The function of the warehouse, in turn, influences the technology used and the location chosen (Hompel and Schmidt, 2005).

Warehouses can be classified based on various criteria, including the type of operation (industry) and construction, the height of the construction, the function in the distribution structure, and the position in the production process (raw materials or finished goods). For example, warehouses may be distinguished based on the type of loading equipment used, the type of stored goods, the storage means employed, and the hazard classes present. These criteria are merely examples and are not exhaustive (Hompel and Schmidt, 2005).

Figure 19 shows the systematics of storage means for general cargo. It is subdivided into floor storage, rack storage or storage on conveyors. In addition, there is a subdivision into static or dynamic storage, and examples of the subdivisions are given on the last level of Figure 19. A distinction is made between four different allocation strategies, which show different effects and are linked to different conditions. In addition to storage bin assignment and storage media, there are other technical functional elements in picking systems. It can be subdivided into conveying equipment, handling equipment and loading equipment. The change of location of a good under the influence of technical aids is called transport. If this transport is carried out within a spatially defined area, this process is called conveying. In this context, the conveying means are to be understood as working means that enable the internal material flow. Handling is understood as the creation, defined modification or maintenance of a fixed arrangement that is space-related (Pfohl, 2022).

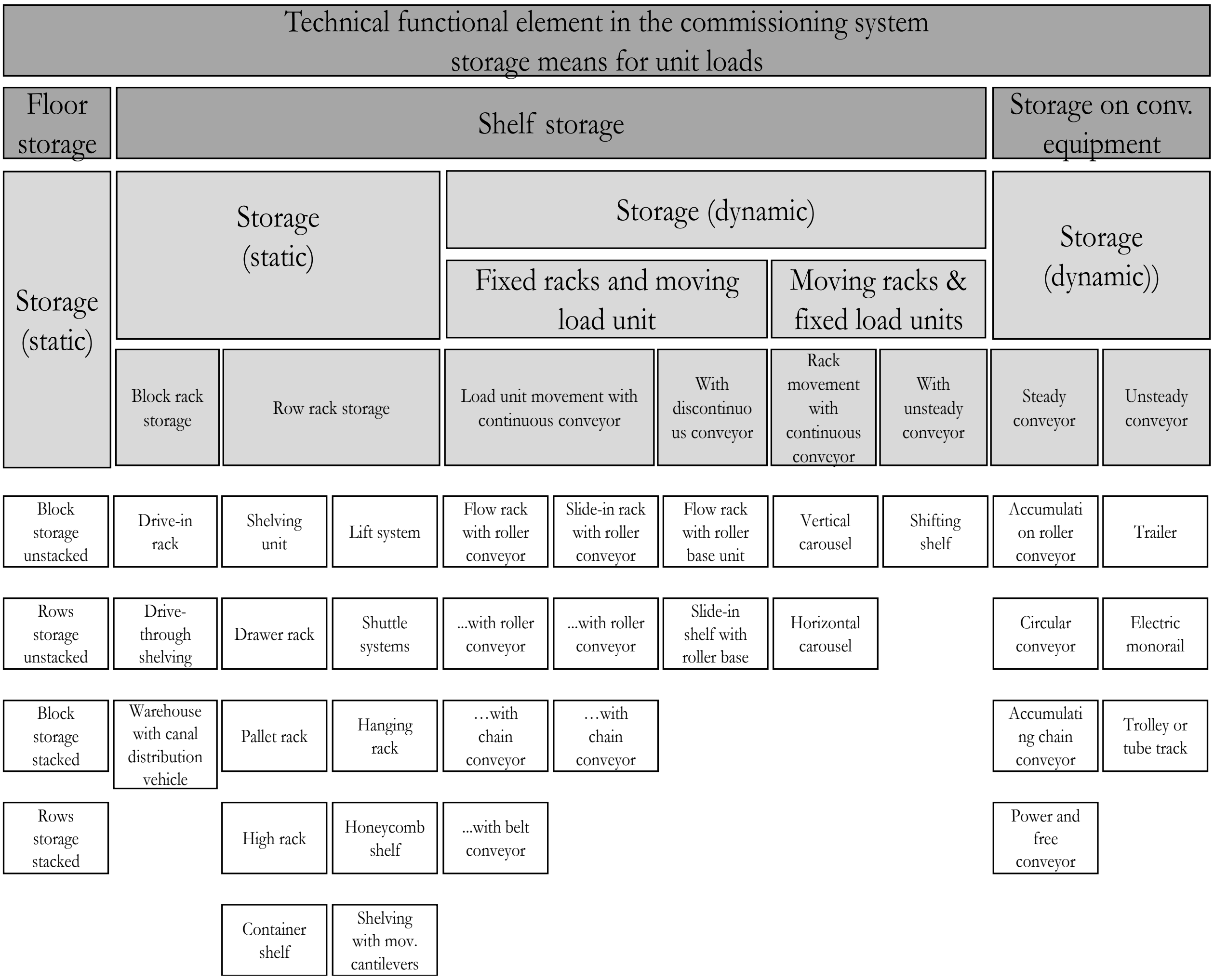



**Figure 19 - Systematics of storage means for general cargo based on Hompel (Hompel, 2009).**

| Name | Description | Consequence | Condition |
|---|---|---|---|
| Fixed storage place | Each item has a fixed storage location | Reliability in the event of loss of stock data, segregation of goods into groups | Not applicable |
| Cross-distribution | Several loading units of an article are distributed over different sections | Access security in case of malfunctions (rack conveyor) | Inventory management system with allocation identification; separation of goods |
| Completely free choice of storage bin allocation (single bin storage, chaotic storage) | Arbitrary assignment of the loading units | Increased utilisation of storage capacity | Inventory management system with allocation identification; |
| Free storage space allocation within fixed zones | Load units are only stored within predefined zones | Separation of goods groups; reduction of capacity utilisation compared to completely free storage bin allocation | Inventory management system with allocation identification; |

**Figure 20 - Storage bin allocation adapted** (Pfohl, 2022)**.**

*Modularisation*

Modularization refers to the practice of designing and organizing systems, components, or processes into modular units that can be easily combined, replaced, or modified. This approach allows for greater flexibility and adaptability in the design and operation of systems, and it can facilitate the integration of new technologies or the incorporation of changes in requirements or specifications. Modularization can also improve the reliability and maintainability of systems by enabling individual modules to be easily tested, repaired, or replaced, without disrupting the entire system. Modularization is commonly used in a variety of engineering fields, including mechanical engineering, electrical engineering, and software engineering (Gershenson *et al.*, 2003).

A module represents a unit that interacts relatively independently, both functionally and physically. Functional independence is fulfilled if the module performs one or more functions independently. Independence on the physical side is fulfilled if it can be decoupled from other modules due to the interface design. The degree of modularity is higher the more pronounced these dimensions are. Since complete independence of both dimensions is hardly ever achieved, modularity is a gradual property. It follows that the units within the architecture of the product have different degrees of modularity. Therefore, the complete fulfilment of a module's function does not have to be fully achieved or represent an independent unit; only the degree of modularity falls as a result (2012; Pahl, 2013).

Galleys are built modular, but since there are other approaches/understandings of modular products in the literature or in industry, an example with five common characteristics and properties are given as 1. Commonality of module units, 2. Combinability of the module units, 3. function binding, 4. Interface standardisation and 5. Decoupling of the modular units (Salvador, 2007).

In addition to the five features of modular products, the following section presents the advantages and disadvantages of modularisation for the user/customer and the manufacturer.

Some advantages for the customer regarding modularisation can be mentioned, as delivery times are reduced, more flexible and easier to replace, therefore better upgradable. Also, better repair possibilities and spare parts service can be done and later function changes and extensions are possible (Pahl, 2013). There are also advantages for manufacturers, as simplified calculation and pricing are possible and better assembly conditions can be achieved. Nevertheless, there are disadvantages, such as limited implementation of special requests, and therefore the adaptation for customer wishes is less extensive than with an individual design.

*Assembly*

Assembly in engineering refers to the process of putting together individual components or subsystems to form a complete system or product. In engineering, assembly is typically done according to a detailed plan or set of instructions that specify the precise arrangement and orientation of the components, as well as the methods and tools to be used in the assembly process. Assembly may be done manually, using hand tools or specialized equipment, or it may be automated, using machines or robots to perform the assembly tasks. Assembly is a crucial step in the engineering process, as it ensures that the final product is functional, reliable, and meets the required specifications.

An assembly system refers to the entirety of an assembly facility. The assembly facilities are connected to each other by means of a material flow system. Assembly systems are divided into manual assembly, semi-automatic assembly (hybrid systems) and automatic assembly (Konold and Reger, 2003).

In manual assembly, all processes are carried out manually by the worker. The worker is at the centre of the process. He or she performs assembly tasks manually with the help of his/her senses and intelligence. He or she uses tools, devices and gauges to carry out the assembly activity. However, people do not work continuously with constant performance. His or her performance depends on his or her personal condition. Even if he or she is in very good condition, he or she will not be able to work a shift (approx. 8 hours) at a constant level of performance. Performance-enhancing measures can be influenced by the workplace and the spatial design. The environmental climate, such as temperature, noise and light also play a role. Manual assembly is characterised by its high flexibility and variety of products at low investment costs and is therefore suitable for assembly processes with low quantities. Due to the non-continuous performance of the worker, productivity in manual assembly is also low (Lotter and Wiendahl, 2012).

Hybrid assembly is equipment that combines processes with manual and automated components. Hybrid assembly systems combine manual workstations with automated stations when assembling components or products. They can be classified between manual assembly concepts and automated assembly concepts in terms of variant diversity, flexibility, number of units, investment and productivity. It is mostly used for assembling small devices with a medium-sized number of pieces. The investment costs are in the medium range. The basis is always a manual assembly station, where the degree of automation is then adjusted for individual assembly tasks.

Here, the ratio between manual and automated parts must be determined (Lotter and Wiendahl, 2012).

In automated assembly systems, the processes are automated. Automated assembly is used for high quantities with a low number of variants. This results in high productivity. The low flexibility speaks against it. Due to their high investment costs and low flexibility, they are therefore only used for high quantities with low batch sizes (Lotter and Wiendahl, 2012). Due to the low flexibility, changes cannot be implemented as easily as in hybrid or manual assembly, for example.

Although some assembly processes at the caterer could be possibly considered as "hybrid-assembly", in inflight catering services the assembly occurs manually.

*Levels of automation - LoA*

There are several different ways to classify levels of automation, depending on the context and the specific characteristics being considered. In general, however, automation can be divided into four main levels (Moray *et al.*, 2000):

- Manual: This is the lowest level of automation, where humans without the assistance of machines or other automation technologies perform all tasks.
- Semi-automatic: This is an intermediate level of automation, where machines or other technologies perform some tasks, but human intervention is still required to initiate or control the automation process.
- Automatic: This is a higher level of automation, where machines or other technologies are able to perform all tasks without the need for human intervention. However, there may still be some level of human oversight or monitoring of the automation process.
- Fully automatic: This is the highest level of automation, where machines or other technologies are able to perform all tasks without any human intervention, and there is no need for human oversight or monitoring of the automation process.

A broad range of LoA taxonomies have been proposed in various research and industry fields. Also, reviews on LoA are found in the literature (Vagia *et al.*, 2016). They describe the development of LoA taxonomies since 1950s until recently, presenting an overview with different taxonomies. Some of those taxonomies are developed as general models or for specific subject areas e.g., tele robotics or aviation. Table 7 gives an extended list of the LoA taxonomies.

**Table 7 - List of LoA taxonomies (non extensive).**

| Author | Area | Approach | Number of levels |
|---|---|---|---|
| Sheridan *et al.*, 1978 | Undersea | Task entropy vs automation combinations | 10 |
| Riley, 2005 | General | Automation state composed of "level of autonomy" and "level of intelligence" | 2x6 |
| Draper, 1995 | Teleoperation / manufacturing | level of control and how to combine human operators with machine control in the context of teleoperations | 5 |

| Author | Area | Approach | Number of levels |
|---|---|---|---|
| Mica R. Endsley and Esin O. Kiris, 1995 | Ergonomics | Evaluation of performance related issues while using humans for intermediate automation levels | 10 |
| Milgram *et al.*, 1995 | Teleoperation | Extension on three dimensions: degree of machine autonomy, level of structure of the remote environment, and extent of knowledge, or modellability, of the remote world | 5 |
| Endsley and Kaber, 1999 | Air traffic control, advanced manufacturing, and teleoperations | Intend to give support to the human by means of expert systems | 10 |
| Parasuraman *et al.*, 2000 | General | Level of automation is a continuum from manual to fully automatic operations. Four broad classes of functions: 1) information acquisition; 2) information analysis; 3) decision and action selection; and 4) action implementation | 4 |
| Bernd Lorenz *et al.*, 2001 | Aviation | Different types of automation, corresponding to which of the four information-processing stages (monitoring, generating, selecting, and implementing) | 4 |
| Bruce T. Clough, 2002 | Aviation | Unmanned aerial vehicle LoA | |
| Ryan W. Proud *et al.*, 2003 | Aviation | Space flight LoA | 8 |
| International Organization for Standardization - ISO, 2021 | Automotive | Autonomous driving | 5 |
| Dennis Keiser *et al.*, 2021 | Assembly | Assembly process automation approach | 5 |
| Kern, H. and Schumann, M., 1985 | Process automation | Degree of mechanization is defined as the technical level in five different dimensions or work functions. | 5 |
| Charles E. Billings, 1997 | Process automation | The level of automation goes from direct manual control to largely autonomous operation where the human role is minimal. | 6 |
| Kotha and Orne, 1989 | Process automation | Generally employed to control a manufacturing process | 7 |
| Ruff *et al.*, 2002 | Automotive | It describes a context-specific LoA for remotely operated vehicles, or unmanned air vehicles | 3 |
| Anderson, 1996 | Telerobotics | It presents a similar context-specific LoA approach as Draper (1995) and Milgram et al. (1995) | 3 |
| Frohm *et al.*, 2008 | Manufacturing | Two separate scales, i.e. physical/mechanical LoA and cognitive/information-related LoA specific for manufacturing | 7 |
| Fottner *et al.*, 2021 | Intralogistics | Autonomous Systems in Intralogistics<br>Classification of intralogistics systems with regard to their degree of autonomy. | 5 |

Based on the presented taxonomies for automation of control and information, it can be argued that many of the presented taxonomies are designed for specific predefined tasks, and thereby might have limited applicability in other systems such as inflight catering services.

*Digitisation*

Digitisation is the process of converting information or data from a physical or analogue format into a digital format. This typically involves the use of technology, such as scanners or software, to capture, store, and manipulate the data in a way that can be easily accessed, shared, and processed by computers. Digitisation has become increasingly important in recent years as more and more information is being generated and stored electronically, and as the use of digital technologies has become ubiquitous in many areas of business and society. Digitisation can help to improve the efficiency, accuracy, and accessibility of information and it can facilitate the creation of new products and services based on digital data.

Examples of digitisation:

Building information modelling (BIM) is a digital representation of the design, construction, and operation of a building or other physical infrastructure. BIM involves the creation of a digital model of the building that captures its geometry, spatial relationships, and other relevant information, such as the materials used, the finishes and fixtures, and the systems and equipment. This model can be used to support a range of activities throughout the life cycle of the building, including design, construction, operation, maintenance, and refurbishment. BIM can improve the efficiency, accuracy, and sustainability of the building process and it can facilitate collaboration and coordination among the various stakeholders involved in the project. BIM is increasingly being used in the construction industry, and it is seen as an important tool for supporting the transition to a more sustainable and digital built environment (Azhar, 2011).

The reference architecture model Industry 4.0 (RAMI 4.0) is a framework for understanding and implementing Industry 4.0 technologies and systems. It provides a common language and a structured approach for identifying, describing, and integrating the various components and technologies (Hankel, M. and Rexroth, B., 2015). The RAMI 4.0 framework is based on six main pillars, which are:

- The digital twin which represents the digital representation of a physical system, process, or product.
- The cyber-physical system that integrates physical and digital components to enable the operation and control of a system.
- The horizontal and vertical integration referring to the integration of different systems, processes, and stakeholders within and across different levels of the value chain.
- Interoperability relates to the ability of different systems and technologies to communicate and exchange information with each other.
- Modularity is the ability to break down a system into smaller, independent modules, which can be easily combined, replaced, or modified.
- The service orientation that refers to the ability to provide and consume services that enable the creation of new value for customers and other stakeholders.

GAIA-X is a project that aims to develop a European data infrastructure that will support the development and deployment of digital services and applications in Europe. GAIA-X is being led by a consortium of European industry, academia, and research organizations, and it is supported by the European Commission. The goal of GAIA-X is to create a federation of data and technology infrastructure providers that will offer a range of services and solutions that are interoperable, secure, and compliant with European data protection and privacy laws. GAIA-X will provide a common platform for the development and deployment of digital services and applications that are designed and built in Europe, and it will support the creation of a European data ecosystem that is competitive, innovative, and sustainable (Braud, A., Fromentoux, G., Radier, B. and Le Grand, O., 2021).

*Human machine interaction*

Human-machine interaction (HMI) is the study of how people interact with machines, devices, and systems, and how machines, in turn, can be designed to better support and enhance human activities. HMI research focuses on understanding the cognitive, physical, and social factors that influence how people interact with machines and on developing technologies and design principles that can facilitate effective and efficient human-machine interaction. HMI encompasses a wide range of domains, including psychology, computer science, engineering, and design, and it has applications in many areas, such as human-computer interaction, robotics, and automation. HMI research and development can help to improve the usability, safety, and overall effectiveness of machines and systems (Wilhelm *et al.*, 2020).

*Operations research*

Operations research (OR) is a discipline that deals with the application of advanced analytical methods to help make better decisions. It is concerned with finding the most effective ways to design and operate systems, often using mathematical modelling and optimisation techniques. OR has a wide range of applications, including business, engineering, and the natural and social sciences. OR professionals use a variety of techniques, including linear and nonlinear programming, network analysis, scheduling, and simulation, to solve problems and make decisions in areas such as manufacturing, transportation, and supply chain management (Domschke and Drexl, 2011).

*Trends screening*

Trend screening, also known as trend analysis or trend monitoring, is the process of identifying and analysing trends in data or other information. Trend screening typically involves the collection and analysis of data over a period of time, in order to identify patterns, patents, or technological improvements that can provide insight into the underlying processes being studied (R.M. Wilson, 1987).

*Life Cycle Assessment*

Life cycle assessment (LCA) is a technique used to evaluate the environmental impact of a product, process, or service over its entire life cycle, from the extraction of raw materials to the disposal or recycling of the product at the end of its useful life. LCA involves the systematic gathering and analysis of data on all the inputs and outputs associated with a product or process, including the consumption of natural resources, the generation of waste and emissions, and the potential impacts on human health and the environment. The results of an LCA can be used to identify and compare the environmental impacts of different products or processes, and to identify opportunities for reducing these impacts (Bachmann *et al.*, 2017).

## 3.2 Technology screening for improving ICS

The advancement of technology, digitisation, and sustainable practices may impact air travel, and subsequently, inflight catering services. The level of maturity of emerging technologies is diverse, as shown by the Gartner Hype Cycle (O'Leary, 2008).

Systematic reviews are found in the literature as well to identify the technologies that can support a data-driven approach in production logistics, which can help address challenges such as low visibility and system rigidity (Zafarzadeh *et al.*, 2021).

There are several technology categories that can be applied in the context of aviation logistics, including electronic lifting aids or exoskeletons (lifting aids), adaptive or self-learning production control (prod control), collaborative robots (cobots), driverless transportation systems (DTS), augmented reality or assisted reality/virtual reality (AR), interactive or adaptive interaction mechanisms (interaction), and optical control systems (optical control). However, the implementation of these technologies is challenging. Personnel issues, such as qualification, training, and planning, can be a concern. There may also be strategic orientation challenges, such as defining the scope of the project and setting clear targets, as well as limitations on investment. Manual activities, such as scanning, creating lists, communicating, planning, and optimising, may also be a hurdle. In addition, a lack of flexibility in terms of fixed places, storage systems, and aircraft dimensions can be an issue. Other challenges may include meeting the needs and preferences of passengers, ensuring the availability of relevant data, managing the flow of materials, and providing system support for orders, goods, warehouses, and transports. There are also several open questions that need to be addressed, including the relationship between modifications and certification, the role of standards, and the involvement of various stakeholders such as caterers, airlines, and IATA.

There are several considerations for improving processes in cabin and catering operations, passenger services, and advanced people moving. In cabin and catering operations, some procedures are time-consuming and labour-intensive, and current tools may not fully utilise advances in information technology. In passenger services, the growth of telecommunication and media technologies has led to increased expectations among travellers, and it is important to facilitate communication and personalise services during air travel, which can be an isolating experience. Advanced people moving technologies can improve guidance and tracking of passengers, coordinate boarding orders, facilitate data transfer and access to passenger preferences, and enable quick responses to requests. In terms of new catering and service items, it is important to match contents to passenger preferences, facilitate inventory management between caterers and aircraft, and integrate electronic management processes across the entire service chain.

*Trends*

As can be seen, the market is constantly developing new solutions, ranging from relatively minor changes, such as pre-ordering, to major, potentially disruptive innovations. However, the state of research indicates that solutions have already been developed for individual problems, but no coherent overall concept for optimising or automatically supporting cabin service has yet been developed.

It is difficult to say what the new trends are for inflight catering services, as this can vary depending on the airline and the specific market they serve. However, some potential trends in inflight catering could include the following:

- Offering a greater variety of healthy and sustainable meal options: Many airlines are now offering healthier meal options and using more sustainable ingredients in their inflight catering in response to growing demand from passengers for healthier and more environmentally friendly food options.
- Personalising the inflight dining experience: Some airlines are experimenting with using data and technology to personalise the inflight dining experience for passengers, offering them customised meal options based on their preferences and dietary needs.
- Enhancing the overall dining experience: Airlines are also looking for ways to enhance the overall dining experience for passengers, by offering a wider range of food and beverage options, and by providing a more pleasant and enjoyable dining environment. This could include improvements to the design of the galley and seating areas, as well as the introduction of new dining concepts and services.

These are just some potential trends in inflight catering, and the actual trends may vary depending on the specific airline and market.

*Patent research*

In this chapter, a patent search was conducted focusing on modular galleys, beverage systems, and trolleys for use in the aviation industry. The search resulted in a selection of patents relevant to the development of a galley concept, which are listed in the table below. These patents generally focus on the use of modular components or assemblies in the design of galleys.

Table 8 - Patents of galleys and gadgets (non-extensive).

| Patent number | Description / title | Registration day |
|---|---|---|
| **EP 2 619 091 B1** | Vehicle galley | 23.09.2011 EP |
| **DE 10 2011 114 939 B4** | Galley with two shelving units and conveyor | 06.10.2011 DE |
| **DE 10 2012 005 935 A1** | Airplane galley with interchangeable carrier inserts | 26.03.2012 DE |
| **EP 2 848 531 B1** | Expandable galley | 11.09.2013 EP |
| **EP 2 727 822 B1** | Aircraft having a recessed cavity in an aft pressure bulkhead wall surface and a galley moved rearwardly into the recessed cavity increasing floor space in front of the galley | 06.11.2013 EP |
| **WO 2015/049059 A1** | Functional furniture item, on-board galley and vehicle, in particular aircraft | 06.10.2014 WO |
| **DE 10 2015 210 271 A1** | Trolley compartment and galley | 03.06.2015 DE |
| **WO 2017/191202 A1** | Storage compartment device and storage compartment system for a galley of an aircraft | 03.05.2017 WO |
| **DE 10 2017 200 734 A1** | Temperature control system for a galley | 18.01.2017 DE |
| **WO 2019/002138 A1** | Variable on-board galley in aircraft | 22.06.2018 WO |

Table 9 - Patents of beverage systems (non-extensive).

| Patent number | Description | Registration day |
|---|---|---|
| **WO 2015/142726 A1** | Dispensing architecture for a hybrid fountain beverage consumable cart and galley dispensing system | 16.03.2015 WO |
| **WO 2016/096440 A1** | Beverage preparation device for installing in an on-board galley and a method for operating same | 02.12.2015 WO |
| **WO 2019/242973 A1** | Water cart and connection station therefor for galley | 22.05.2019 WO |

Table 10 - Patents of trolleys (non-extensive).

| Patent number | Description | Registration day |
|---|---|---|
| **WO 2008/070715 A2** | Folding cart for galley | 05.12.2007 WO |
| **EP 2874 876 B1** | Meal cart for an aircraft galley | 12.07.2013 EP |
| **EP 3 323 723 A1** | Chiller galley cart, galley, and method for cooling | 09.08.2017 EP |

### 3.3 Concepts for optimising ICS

In this section, many concepts for optimising inflight catering services are presented. Some of them are not automation concepts, but they are relevant to fulfil the picture of the state-of-the-art. The main approaches regarding new galley concepts are summarized in the Figure 21; mostly, two streams for improvement could be identified: space and weight savings and optimisation of inflight operations.

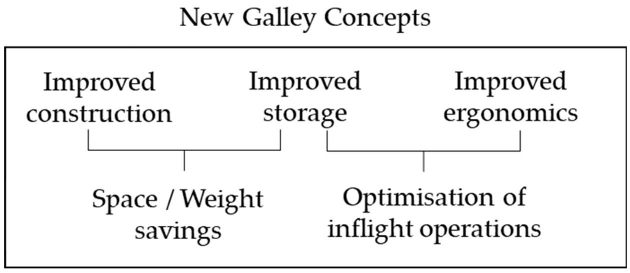



**Figure 21 - Main approaches for new galley concepts (Mortensen Ernits *et al.*, 2022b).**

A summary of the state of the art of innovations in inflight catering services is presented in **Table 11**, 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.

**Table 11 - State of the art of ICS innovations.**

| Innovations | Main Change | Main Effect | Year | On market | Process integration level | Automation level |
|---|---|---|---|---|---|---|
| Streamliner | Distribution device | Fast service | 2007 | No | - | + |
| SPICE | New Galley New Trolley | Space/ Weight savings | 2008 | No | + | - |
| FlexGalley | New Galley | Space/ Weight savings | 2012 | No | - | + |
| The Flying Cart | New Galley | Fast service | 2013 | No | - | + |
| Modular Galley Concept | New Galley | Space/ Weight savings | 2013 | No | - | - |
| Loose Galley Concept | New Galley | Space/ Weight savings | 2014 | No | - | + |

| Innovations | Main Change | Main Effect | Year | On market | Process integration level | Automation level |
|---|---|---|---|---|---|---|
| Concept 01 | New Galley | Space/ Weight savings | 2019 | No | - | + |
| Concept 02 | New Galley | Space/ Weight savings | 2019 | No | - | + |
| Smart Galley | New Galley | Space/ Weight savings | 2018 | No | + | - |
| Galley 2019 | New Galley | Space/ Weight savings | 2019 | No | - | + |
| Generation 3 | New Galley | Space/ Weight savings | 2019 | No | + | - |
| Skybar Splash | Beverage Trolley | Weight savings / faster service | 2012 | Yes | + | + |
| Innovation Galley | New Galley | Space/ Weight savings | 2018 | No | - | + |
| Galley-Bar-Module | New Galley | Space/ Weight savings | 2018 | No | - | - |
| M-Flex | New Galley | Space/ Weight savings | 2019 | No | + | - |
| Sophy | Connectivity System | Trolley Monitoring | 2020 | Yes | + | + |
| Arca | New Galley | Space/ Weight savings | 2020 | No | + | - |

The Streamliner concept is a proposal for a hybrid aircraft that combines elements of a traditional fuselage-wing aircraft with those of a flying wing design. This concept also includes a trolley and a service concept that focuses on personalized services provided using digital booking tools. The trolley is designed to move along a rail system under the aircraft ceiling and can be used as a self-service station for drinks or equipped with food trays to serve passengers. The use of the trolley is intended to alleviate back strain for operating personnel. There is no further information available about the construction of the galley in this concept (Rojahn, 2007).

The "Flying Cart" concept is similar to the Streamliner concept and involves the use of a trolley that moves along a rail system above the centre aisle of the aircraft. The trolley is stocked with drinks and has food trays that can be accessed from the front. This concept is intended to reduce back strain on operating staff by allowing them to serve passengers while standing (Seth, 2013).

The "Loose wide-body Aircraft Galley Concept" is a unique approach to designing a galley that allows passengers to move freely while being served a meal by cabin crew. This is achieved with a trolley mounted on a rail system under the ceiling, which can be smoothly moved around the cabin. This design eliminates the need for cabin crew to bend down to distribute trays to passengers, which can help prevent back or joint pain. In addition, this concept includes a self-service beverage trolley also mounted on the rail system. A unique feature of this concept is the use of corn starch tableware, which is collected by operating staff after use and compressed in a press within the galley for composting. This is intended to be more environmentally friendly (Petrova, 2018).

The Teague team has developed two concepts for future aircraft galleys. "Concept 01" is a self-service unit that allows passengers to select and retrieve the desired products independently using an app. These products, such as alcohol and headphones, are displayed in NFC-enabled boxes and can be purchased and removed through the app (Berger, 2019).

In "Concept 2," the galley is located below the deck to optimise storage management. It is automated by a robot that handles storage and preparation. The below-deck galley operates without the need for human intervention. Passengers can order their food independently, which then triggers the robot arms to select and transport the desired food to the heating area. After heating, the meal is lifted to the upper deck and handed to the operating personnel to be served to the passenger. This separation of the storage and preparation areas and the use of automation allows for more seating space and the opportunity to redesign the entrance area (Berger, 2019).

The "SPICE galley system" is a concept that aims to make the operation of a galley more efficient and ergonomic. It includes a foldable trolley and various storage modules, such as boxes for drinks, that can be accessed through sliding doors. There is also a transfer table that can be moved on rails in front of the galley, allowing for the easy movement of storage modules or oven racks. This concept is designed to be more space-saving and lightweight, which can help reduce the aircraft's overall weight. However, most activities in this concept are still carried out manually (Butterworth-Hayes, 2009). Besides, the "SPICE" concept allows airlines to increase design possibilities, use more space for passengers, reduce weight, and cut cabin service costs. (Butterworth-Hayes, 2009).

The "SPICE" concept received an IDEA Award in 2008 but was never used in conventional operations. A two-aisle commercial aircraft with a SPICE galley would have a weight saving of about 600 kg and achieve better space ratios, creating an additional two to three economy seats (Formation Design Group, 2007).

The "FlexGalley" concept is a modular and movable design for aircraft galleys developed by the Institute for Product Development and Design Technology at the Technical University of Hamburg-Harburg. The project aimed to create a flexible and customizable interior fitting system for aircraft manufacturers and airlines. The focus was on the development of a modular structure that allows for variant-oriented design and can meet all relevant customer requirements with a minimum of internal component diversity. Additionally, the concept allows for flexible positioning of individual elements within the cabin to simplify the configurability of the layout (Krause *et al.*, 2011).

Zodiac's "Modular Galley Concept" is a flexible and customizable design for aircraft galleys. The concept divides the galley into three sections, with a trolley loading area in the lower part of the fuselage and a standard unit filling area in the upper part. This design allows for a smaller galley area on the main deck, freeing up space for additional passenger rows or other purposes. The modular nature of the concept allows airlines to adjust the configuration to meet their specific operational needs and to adapt to seasonal demands (Gavine, 2021).

The "Smart Galley" is a modular galley concept that provide maximum flexibility for users, allowing for easy customization and adaptation to specific flight routes or seasonal offers. The galley is a single-chamber system with standardized components, including a configurable electrical system and touch panel for function control. It also has an energy management system and uses plug-and-play technology for easy replacement of individual elements. The electrical system automatically recognizes new modules and adaptations can be implemented in a few hours, including language adjustments for the Human Machine Interface. Sensors in the galley can identify the contents of individual compartments and transmit this information, allowing for automatic reordering and maintenance planning (Diehl Aviation, 2018).

The "Galley 2019" was unveiled at the Aircraft Interiors Expo in 2019. The new design includes a standard galley area, as well as updated cabin lighting and hidden door and compartment locks. The goal of the redesign is to create a more visually appealing and functional galley for airline use (Verpraet, 2019). The system features a customisable control panel and an artificial intelligence-supported monitoring system, and is also being developed for use with the Internet of Things. It includes a fold-out tablet that can be connected to the system and potentially to the in-flight entertainment and connectivity system. The galley also includes a refrigerated compartment that operates without separate refrigeration, saving weight and operating quietly, and an electroluminescent paint that lights up on its own, saving energy and providing a less bright light source. Additionally, the system includes a waste disposal unit that is connected to the vacuum toilet system and can be used to dispose of waste liquids and soft foods (Verpraet, 2019).

AIM "Altitude's Generation 3" galley concept includes features such as roller blinds to hide galley elements and design-optimized locking mechanisms that are integrated into the door front. These design elements contribute to a modern and sleek appearance. The galley also includes practical features like a pull-out pantry that can be used as a bar, duty-free area, or storage unit. This generation of galleys is designed to be low-maintenance, durable, and user-friendly, with a focus on weight-conscious design using standard products (AIM Altitude, 2020).

An extendable work table is also available and other useful features include a folding footboard and an ice drawer (AIM Altitude, 2020).

Manufacturer Collins Aerospace presented the "M-Flex Duet" at the Crystal Cabin Awards in 2019. This concept uses the aircraft door as a surface. When the aircraft took off, the surface of the door was previously unused. Therefore, this surface is used for the "M-Flex Galley". During take-off and landing operations, the system is stowed away. During normal flight operations, the system is deployed over the door area. It serves as an extended galley space. The passenger has the possibility to move freely in the cabin and to supply himself/herself with snacks and drinks. In addition, this area can also be used as a working area for the cabin crew. Normally, the space used by the service area means a loss of seats, which leads to an annual loss of revenue in the millions. The system thus offers no to minimal loss of seats with simultaneous amenities for passengers. This creates benefits for the airline and the passengers. In addition, it can also be installed as a retrofit solution (Collins Aerospace, 2019).

The "SkyTender" beverage trolley is a system designed to serve hot and cold drinks on commercial aircraft. The trolley is equipped with a beverage machine that does not require electricity or water and can save floor space by eliminating the need for cans and bottles. It is operated through a touch screen and has an IT system that allows for intelligent forecasting to ensure transparency and track benefits throughout the supply chain. The trolley has a capacity of 160 liters of water, which is enough to serve 1,280 drinks of 125ml each (Skytender, 2023).

The "Orbit" trolley is a concept designed to improve the delivery of food on commercial aircraft. The concept aims to address the space limitations and efficiency issues of traditional airline food carts by creating a slimmer and longer cart that can easily be navigated around flight attendants (Dunne, 2023).

The "RFID gate system" developed by EADS aims to optimize the process of loading and unloading trolleys on an aircraft. The system uses RFID tags attached to the trolleys and scans them as they are loaded or unloaded from the aircraft. This helps to keep track of the inventory of trolleys on the aircraft and eliminates the need for manual counting of paper slips or opening of the trolleys to check their contents. The RFID gate system consists of antennas that detect both the RFID tag and the direction of movement. It uses reflected signals from the RFID tag to determine the direction of movement, making it a space-efficient solution compared to other options, such as light barriers (Bauer *et al.*, 2010).

## 3.4 Approaches for classifying and selecting automation concepts

There are approaches that can be used to classify automation concepts (Groover, 2016), including:

- Functionality-based classification: grouping automation concepts based on the function they perform, such as material handling.
- Industry-based classification: ordering automation concepts based on the industry they are used in, such as manufacturing.
- Technical classification: placing automation concepts based on their technical characteristics, such as type of control.
- Hierarchical classification: organizing automation concepts into a hierarchy based on their complexity and level of integration. For example, simple automation concepts such as sensors and actuators might be considered the lowest level of the hierarchy, while more complex concepts such as robots and control systems would be higher up in the hierarchy.
- Life cycle-based classification: ordering automation concepts based on their stages in the product life cycle, such as design, development, testing and deployment.

There are also different approaches that can used for selecting automation concepts, including:

- Cost-benefit analysis: it involves evaluating the costs and benefits of each automation concept in order to choose the one that offers the best return on investment (Snell, 2002).
- Risk assessment: it concerns identifying and evaluating the risks associated with each automation concept, and choosing the one that has the lowest level of risk (Bahr, 2015).
- Feasibility study: it means evaluating the technical and logistical feasibility of each automation concept, and choosing the one that is most likely to succeed (Stevens and Sherwood, 1982).

- Prototyping: it builds and tests prototypes of each automation concept in order to assess their performance and identify any issues that need to be addressed (Liou, 2019).

In this dissertation, for early development, the following methods are going to be considered for classifying and selecting automation concepts:

- multicriteria decision decision-making methods, MCDM
- technology readiness level (TRL)
- technology assessment

*Multicriteria decision decision-making methods, MCDM*

Multicriteria decision-making methods aim to balance multiple factors in complex contexts with potentially conflicting stakeholder interests. MCDM focus lies on integrating objective measurement with value judgement as well as making explicit and managing subjectivity. It exposes the multiple, conflicting criteria for decision-making by structuring the problem. The formal models supports the focus and environment for discussion. Above all, to increase the awareness of decision-makers about the problem condition, including external and internal interests and factors by systematically providing organised and synthesed information for identification guidance for a proper decision.

MCDM methods provide analytical support to complement and challenge intuition, but it does not aim to replace intuitive judgement or experience. The process of using MCDM methods should result in better-considered, justifiable, and explainable decisions through a simple and transparent approach. However, it is important to note that expert knowledge is still necessary to effectively utilize these tools in complex environments. (Belton and Stewart, 2003).

These methods are often used in situations where there is no clear "right" or "wrong" choice, and where trade-offs between different criteria are necessary. Some common MCDM methods include:

- Analytic Hierarchy Process (AHP): This approach breaks the decision problem down into a hierarchy of criteria and sub-criteria, and then using a combination of expert judgment and pairwise comparisons to assign weights to the different criteria. The final decision is based on the criteria weights and the performance of the different options on each criterion.
- Multiattribute Utility Theory (MAUT): This method involves assigning utility values to different performance levels on each criterion and then combining these values to calculate the overall utility of each option. The option with the highest overall utility is chosen as the best option.
- Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): It seeks to identify the "ideal" option in terms of the different criteria, and then rank the other options based on their proximity to this ideal option. The option that is closest to the ideal option is chosen as the best option.
- Electre: This approach makes use of a matrix of the different options and criteria, and then employs a combination of expert judgment and pairwise comparisons to assign scores to the options based on their performance on each criterion. The option with the highest overall score is chosen as the best option.

It is crucial to understand that no universal method for MCDM that can be applied to all decision-making scenarios. The choice of method will depend on various factors such as the specific decision problem, available data and information, and the goals and preferences of the decision-maker. (Thakkar, 2021).

The use of multicriteria decision-making methods in aviation is not entirely new. Airlines employ MCDM methods to assess a range of factors such as service quality, identifying potential partners for future collaborations (such as maintenance or catering), planning the fleet to align capacity with demand, improving competitiveness to attract more passengers, enhancing financial performance to reduce costs and improve operational performance, ensuring safety, and promoting responsibility (Dožić, 2019).

Some examples of the use of MCDM methods in aviation and automation are given in the following tables:

Table 12 - Examples of the use of MCDM methods in aviation.

| **Author** | **Topic** | **Method** |
|---|---|---|
| Abdullah S. Karaman and Engin Akman, 2018 | Taking-off corporate social responsibility programs: An AHP application in airline industry | AHP |
| Himanshu Gupta, 2018 | Evaluating service quality of airline industry using hybrid best worst method and VIKOR | VIKOR |
| Kuen-Chang Lee *et al.*, 2018 | An MCDM approach for selecting green aviation fleet program management strategies under multi-resource limitations | DEMATEL, ANP, and ZOGP |
| Lihong Chen and Jingzheng Ren, 2018 | Multi-attribute sustainability evaluation of alternative aviation fuels based on fuzzy ANP and fuzzy grey relational analysis | ANP |
| Miriam F. Bongo *et al.*, 2018 | An application of DEMATEL-ANP and PROMETHEE II approach for air traffic controllers' workload stress problem: A case of Mactan Civil Aviation Authority of the Philippines | DEMATEL PROMETHEE |
| Mohamed Eshtaiwi *et al.*, 2018 | Determination of key performance indicators for measuring airport success: A case study in Libya | AHP |

| Author | Topic | Method |
|---|---|---|
| Mustafa Jahangoshai Rezaee and Samuel Yousefi, 2018 | An intelligent decision making approach for identifying and analysing airport risks | FCM |
| Payam Shojaei *et al.*, 2018 | Airports evaluation and ranking model using Taguchi loss function, best-worst method and VIKOR technique | VIKOR |
| Pedro Jose Gudiel Pineda *et al.*, 2018 | An integrated MCDM model for improving airline operational and financial performance | DANP, VIKOR |
| Selçuk Perçin, 2018 | Evaluating airline service quality using a combined fuzzy decision-making approach | DEMATEL, ANP and VIKOR |
| Slavica Dožić *et al.*, 2018 | Fuzzy AHP approach to passenger aircraft type selection | AHP |

Table 13 - Examples of the use of MCDM methods for automation.

| Author | Topic | Field |
|---|---|---|
| Armaghan *et al.*, 2006 | Industrial knowledge memory and multicriteria decision analysis | Mechanical design |
| Boucher *et al.*, 1993 | Multicriteria evaluation of automated filling systems: A case study | Manufacturing |
| Catalan *et al.*, 2007 | Evaluation of 3D scanners to develop virtual reality applications | Robotics |
| D'Angelo *et al.*, 1996 | Multicriteria evaluation model | Manufacturing |
| Galand, 2006 | Compromise solutions | Process automation |
| Kovbasyuk and Pisarchuk, 2007 | Application of methods of multicriteria analysis | Automated control systems |
| Krylov *et al.*, 2018 | Development of a multicritera approach | Manufacturing |
| Leite *et al.*, 2020 | MCDM for prioritisation of processes for automation | Intelligence and Investigation units |
| Levin *et al.*, 2020 | Automation of ergonomic expertise | Aviation |
| Macuada *et al.*, 2021 | Definition of automation degree | Sanitary industry |
| Alexander Neb and Dominik Remling, 2019 | Quantification and evaluation of automation concepts based on a MCDMA | Process automation |

| | | |
|---|---|---|
| Raj *et al.*, 2020 | MCDM for understanding barriers for automation | Automotive |
| Renaud *et al.*, 2006 | Weight determination for industrial decision | Process automation |

*Technology readiness level (TRL)*

The technology readiness level (TRL) is a measure of the maturity of a specific technology. It is often used in the development and evaluation of new technologies, particularly in the fields of aerospace and defence. The TRL scale typically ranges from TRL 1 (basic principles observed and reported) to TRL 9 (technology demonstrated in a relevant environment), with each level representing a different stage of technology development. A technology with a high TRL is generally considered to be more mature and ready for implementation, while a technology with a low TRL may require more development and testing before it is ready for use. The TRL can be a valuable tool for organisations looking to understand the potential risks and challenges associated with adopting a new technology (Mankins, 2004).

*Technology assessment*

The Gartner Hype Cycle is a methodology used to evaluate the maturity, adoption, and social application of specific technologies. It provides a graphical representation of the progression of a technology from its inception to widespread adoption(O'Leary, 2008). Technology assessment is the process of evaluating the potential impact of new or emerging technologies. It involves identifying and analysing the benefits and drawbacks of a technology, as well as its risks and challenges. Technology assessment aims to support decisions about whether to adopt a new technology and how best to implement it (Colledani *et al.*, 2016).

A technology roadmap is a tool used for strategic planning that helps organisations plan for the development and implementation of new technologies. It offers an overview of the planned progression of a technology over time and can help identify potential gaps or obstacles to the successful development and adoption of a new technology. A technology roadmap typically includes a timeline of key milestones, a description of the technology and its potential applications, and an assessment of the resources and expertise needed to develop and implement the technology (Abele, 2006).

## 3.5 Evaluation and discussion of the approaches

Creating a framework for evaluating new automation concepts for inflight catering services may be beneficial. It is easier to compare automation concepts with a consistent baseline because of the various processes, stakeholders involved, and the importance of safety and standardisation. Additionally, developing new aircraft components, systems, or processes can be very time-consuming, so it is essential to consider decisions carefully during the design process. However, even if a concept is not further pursued due to technical or economic limitations, there may still be a need for product innovation or process/service optimisation. In this situation, a consistent framework that allows for the revaluation of concepts and integrated development could improve the efficiency of the design process and potentially lead to better outcomes in the future.

# 4 Analysis of inflight catering processes and derivation of requirements for automation

This chapter focuses on the analysis of inflight catering processes and the derivation of requirements for automation. The analysis is performed after the results from the joint projects with Airbus, the available literature information and experimental set-ups. Subsequently, the definition of requirements is derived after a series of workshops and surveys. As a core result of this chapter, a method for analysing automation concepts for inflight catering services is developed. This method considers the most important aspects to be used for analysing inflight catering services and delivers a tool for the analysis.

Process analysis is a key element of process optimisation. Process analysis means to "obtain information on systems, in particular on the nature and quantity of their constituents, including their spatial arrangement and distribution as well as temporal change" (Danzer, 1987). There are different analysis principles deriving from known or newly developed technologies, e.g. object recognition. A decisive factor for a successful process analysis is the generation of a common understanding of the process among specialists and non-specialists, allowing the exchange of information necessary for optimising the processes involved (Danzer, 1987).

The process analysis performed is based on the principles listed by (Danzer, 1987). In this sense, it defines the type of processes and people involved, allows the materials and information being used and transformed along the process, the definition of the environment and the process time and constraints.

## 4.1 Analysis of inflight catering processes and their primary conditions

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 (Gibbs *et al.*, 2017; Damos *et al.*, 2013; Whitelegg, 2007). A general overview of stakeholders with tasks is shown in Table 14.

The value stream diagram presented in Figure 22, shows a simplified view of the processes involved in flight catering and inflight catering. The main actors during the operation phase are represented by the caterer with suppliers, the airline, the passenger and the flight attendant. After ticket buying, the airline closes the catering order for a specific flight, and the caterer, in connection with suppliers, produces and transports the catering goods with a high loader truck to the aircraft. After loading the galley, the content is checked by the flight attendant. Then, eventually, preparations in the galley are performed, e.g., ice preparation. During the cruise phase, inflight catering services are offered to the passengers with a selection of beverages and meals depending on the class and on the service offered by the airline. After consumption, the waste is collected and stowed back in the galley. After landing inventory, checks could be performed, and the trolleys and standard units are unloaded by the caterer.

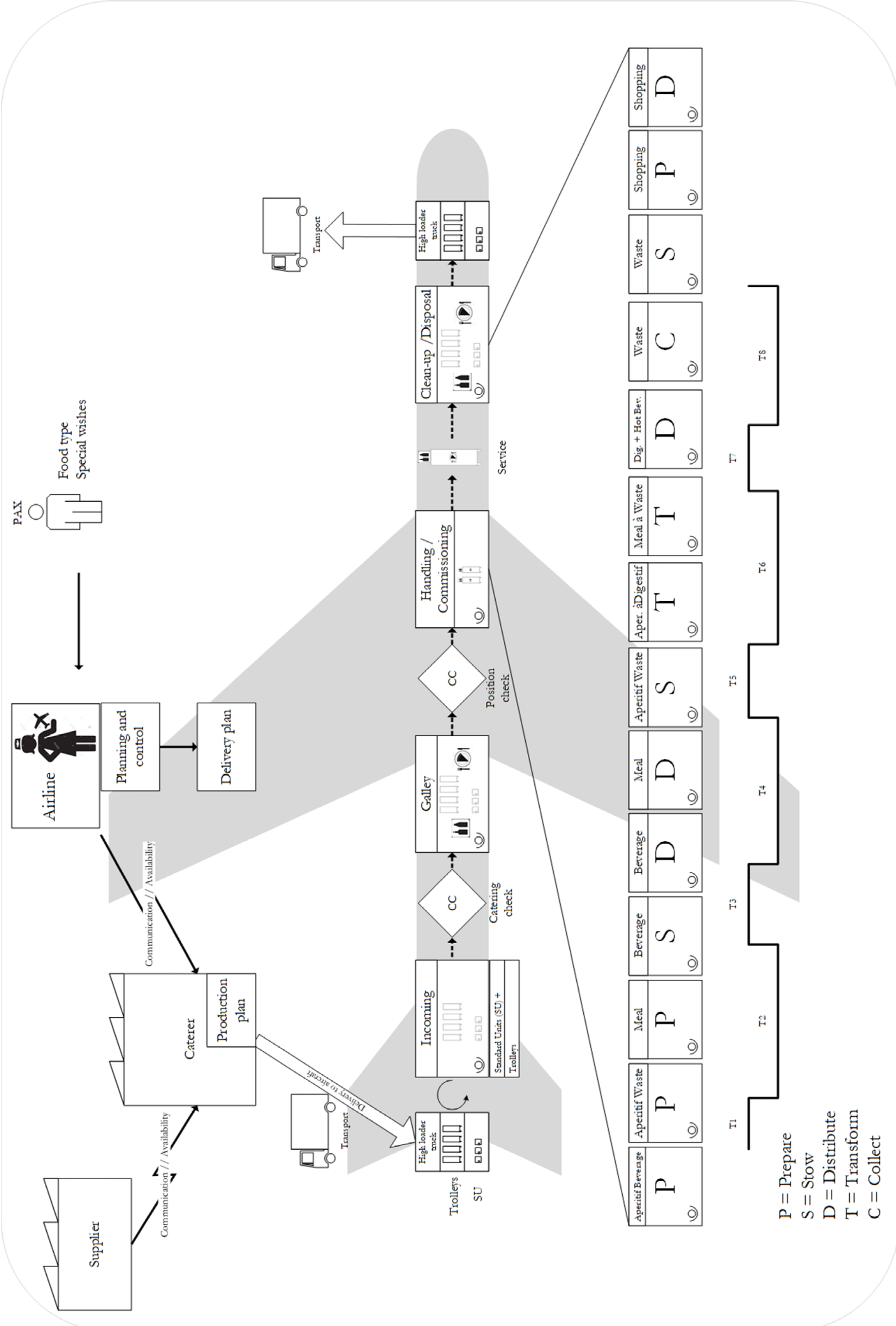



Figure 22 - Value-stream diagram for inflight catering services.

## 4. Analysis of inflight catering processes and derivation of requirements for automation

Inflight catering services involve various tasks and activities to prepare meals for passengers. However, some of these tasks do not directly contribute to the quality or functionality of the final product. Such tasks are referred to as non-value-added processes. Identifying and minimizing these processes can help improve efficiency and reduce costs. Examples of non-value-added processes in inflight catering services may include:

- Excessive waiting time for equipment, ingredients, or personnel can cause unnecessary delays and add no value to the final product.
- Producing more meals than necessary can lead to food waste if unused.
- Transporting ingredients or meals without clear purpose or value.
- "Excessive handling" refers to the unnecessary handling of items such as meals, which does not contribute to their quality or safety.
- Conducting inspections or quality checks that do not add value to the final product is considered redundant.
- Excessive paperwork that does not improve meal quality or safety.
- Unused motion refers to unnecessary movements or actions by caterers or flight attendants that do not contribute to the efficiency or quality of a process.
- Keeping excessive inventory ties up resources and adds no value.
- Poor workspace layouts lead to unnecessary movement and transport of materials.

All these points should be considered when proposing new automation concepts for inflight catering services. It is important to evaluate the impact of any improvements within the process analysis.

For illustrating 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 hours flight, and the lunch service was only considered 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.

Table 14 - Overview of the ICS stakeholders and main responsibilities.

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

An exemplary cabin layout is shown in Figure 23; the galley areas in brown are shown with the number of trolleys. In addition, the areas in red mark the working areas, and they represent the small amount of space that the flight attendants have available as movement areas within the galley.

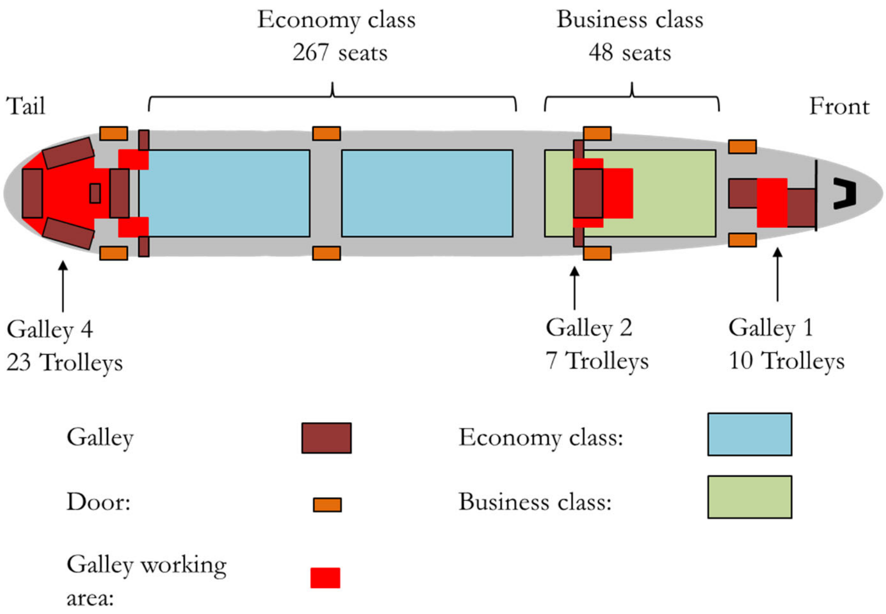



Figure 23 - Simplified example of a cabin layout.

Looking closer into the distribution of meals and beverages, a common process is shown in Figure 24. In this scenario, each full size trolley is operated by two flight attendant, serving passengers from both sides of the aisle.

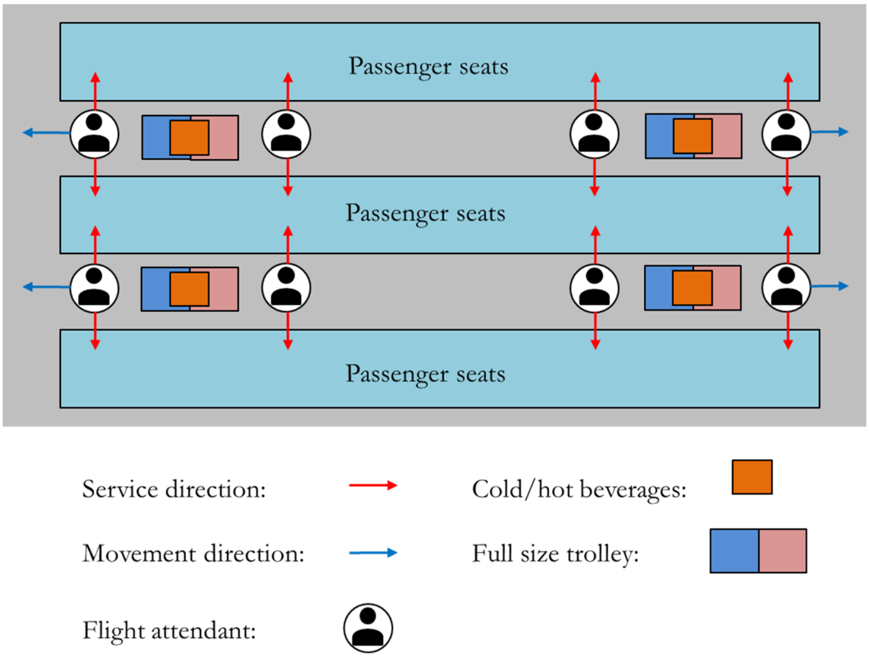



Figure 24 - Simplified process layout for the distribution of meals and beverages with a full size trolley.

Some common trolley configurations are shown in the Figure 25. On the left, a meal-full size trolley is shown, this trolley could be used in this configuration for serving hot-meals, while the casseroles are put inside the casserole drawers. The meal trays are then final assembly direct next to the passenger. On the right, a combined meal and beverage trolley configuration is shown. In this case, the meal and beverage services are performed with the same trolley. In the analysis the configuration presented on the left size, meal full-size trolley was used.

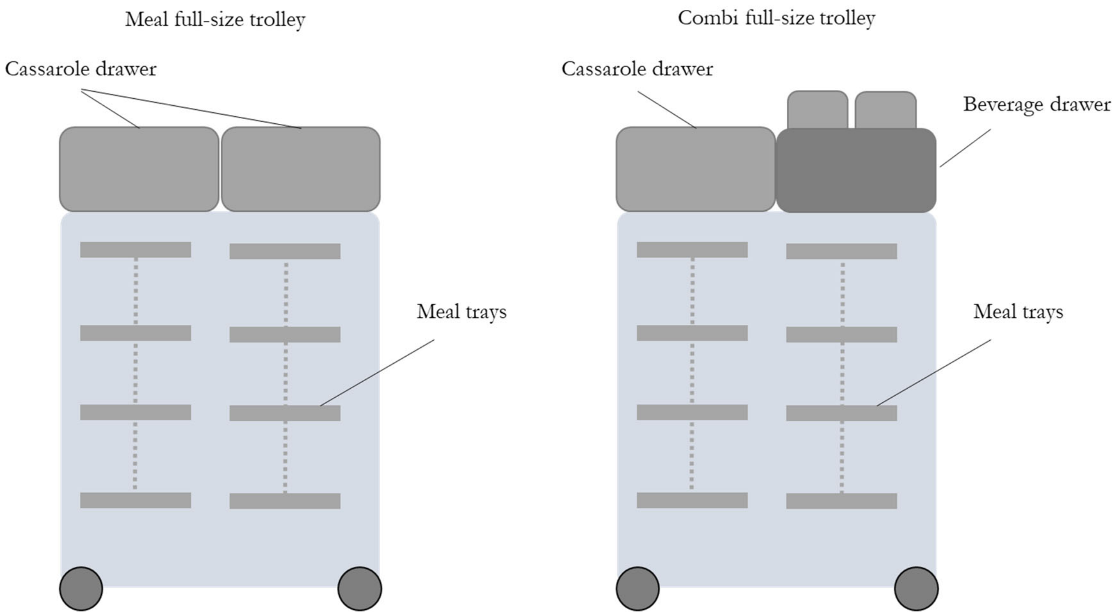



Figure 25 - Common full size trolley configurations for hot meal distribution, on the left a meal full-size trolley and on the right, a combi full-size trolley.

A top view of a galley configuration is shown in Figure 26, in this case the galley "G4" in the rear of the aircraft is composed of different monuments.

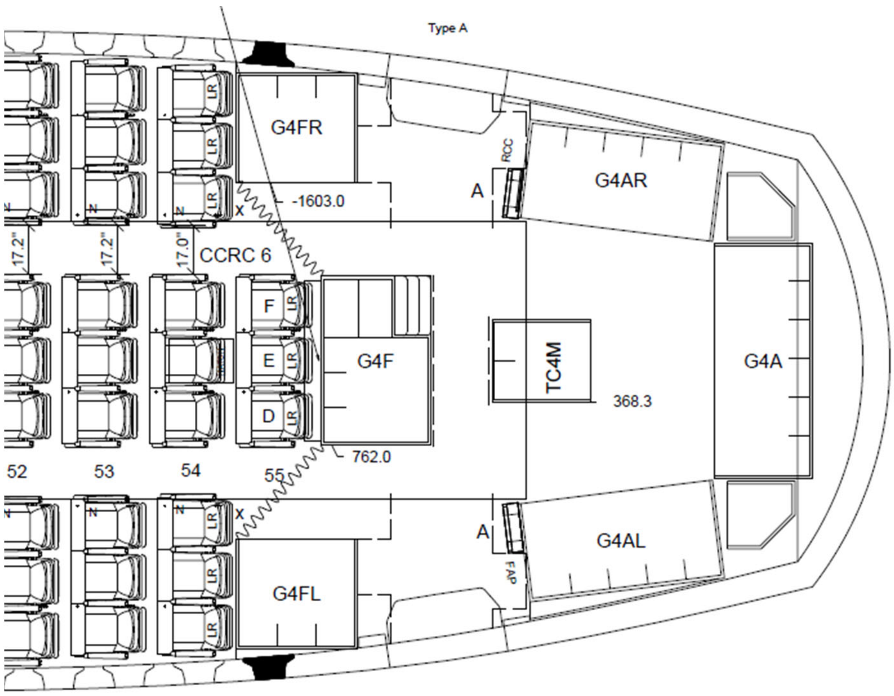



Figure 26 - Top view and technical data of the rear aircraft galley of an A350-900.

Table 15 - Estimated dimensions for Galley G4.

| Monument | Estimated dimensions [mm] | Simplification |
|---|---|---|
| G4FL | 1100 x 850 x 2000 | Estimation of the wall thickness of the monument; assumption of a rectangular body without rounding |
| G4FR | 1100 x 850 x 2000 | Estimation of the wall thickness of the monument; assumption of a rectangular body without rounding |
| G4F | 1500 x 1000 x 1100 | Estimation of the wall thickness of the monument. |
| TC4M | 640 x 850 x 1100 | Estimation of the wall thickness of the monument. |
| G4AL | 1800 x 850 x 2000 | Estimation of the wall thickness of the monument; assumption of a rectangular body without rounding; element on the left side of the monument is added with an estimated value. |
| G4AR | 1800 x 850 x 2000 | Estimation of the wall thickness of the monument; assumption of a rectangular body without rounding; element on the right side of the monument is added with an estimated value. |
| G4A | 1920 x 850 x 2000 | Estimation of the wall thickness of the monument. |

The galley is loaded according to a defined plan. Heavy equipment, such as trolleys with meals or drinks, are on the floor; lighter goods are placed above the work surface. The modular system allows the (limited) exchange and combination of equipment. Besides, the galley-loading plan helps the flight attendant with tracking goods inside the galley. An exemplary loading plan for the monument G4AR is shown in Figure 27.

Due to the spatial conditions of the galley, the crew's room to move is very limited. The loading of the goods cannot be done randomly but must follow a defined pattern in order to ensure that the processes necessary for the service run as smoothly as possible.

The task distribution is shown in Figure 28. It represents the chosen lunch service for 226 passengers from the economy class for a 10 hours flight.

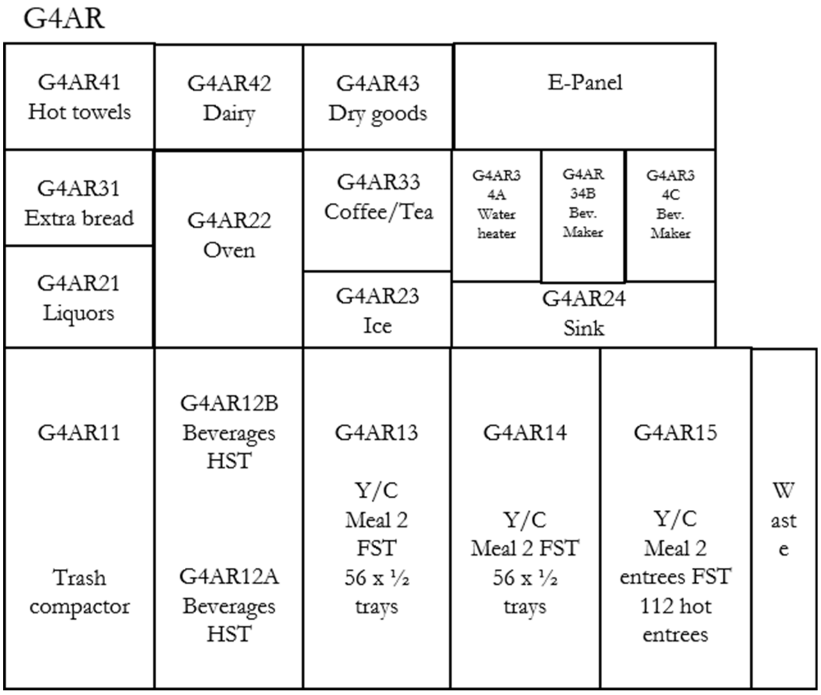



Figure 27 - An exemplary loading plan for the monument G4AR

The exemplary loading plan shown in the Figure 27, represents one of the galleys with goods varying from hot towels to full-size meal trolleys (FST). The allocation of the goods may be airline-specific, regarding the desired operations and provided services.

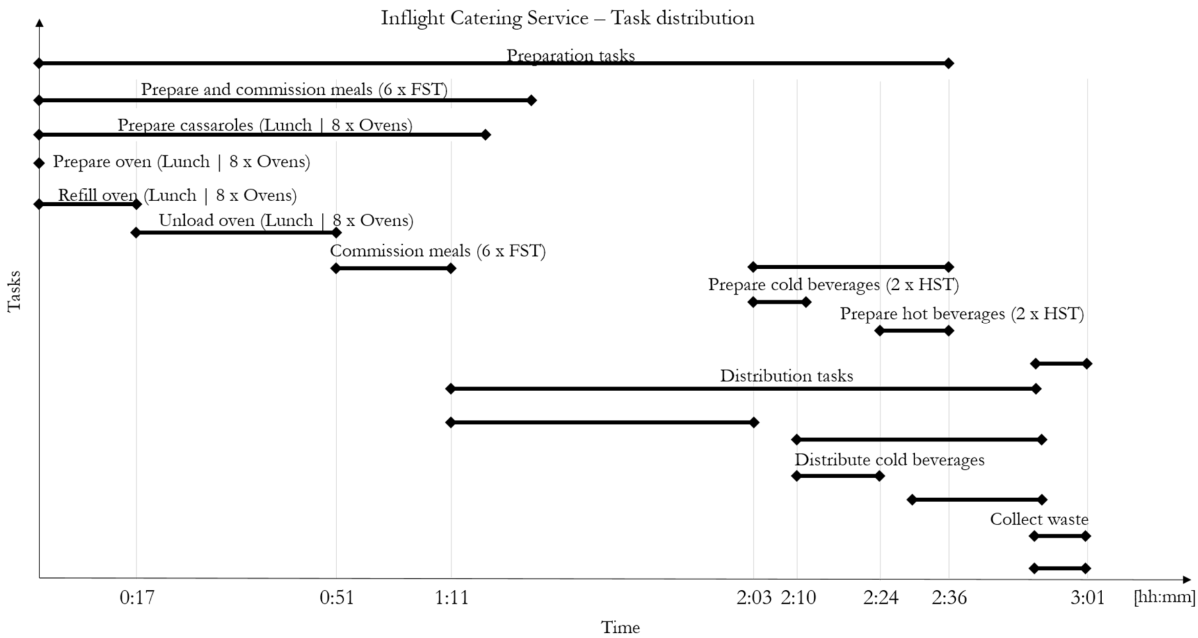



Figure 28 - Example inflight catering service (e.g., lunch) for a ten hours long-range flight, with 226 passengers and 4 flight attendants (Mortensen Ernits *et al.*, 2022b).

A first abstraction of the task distribution is shown in Figure 29; 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.

By combining the loading plan information with the galley configuration, it becomes possible to comprehend how each monument is utilised during a service. This way, individual sub-tasks can access different elements of the monuments, resulting in a high frequency of use at times.

In order to determine and graphically display the utilisation of the individual monuments within individual phases of a service, an exemplary galley is displayed in a simplified form on a 5 x 5 grid. Each monument represents one or more blocks, roughly based on the real dimensions of the galley. Not accessible areas are marked as "N.A.". In this preliminary study, the idea is to generate a "heat-map" from highly accessed monuments and compartments. With this information, it could be possible to optimise the galley loading according to the performed service and improve ergonomics.

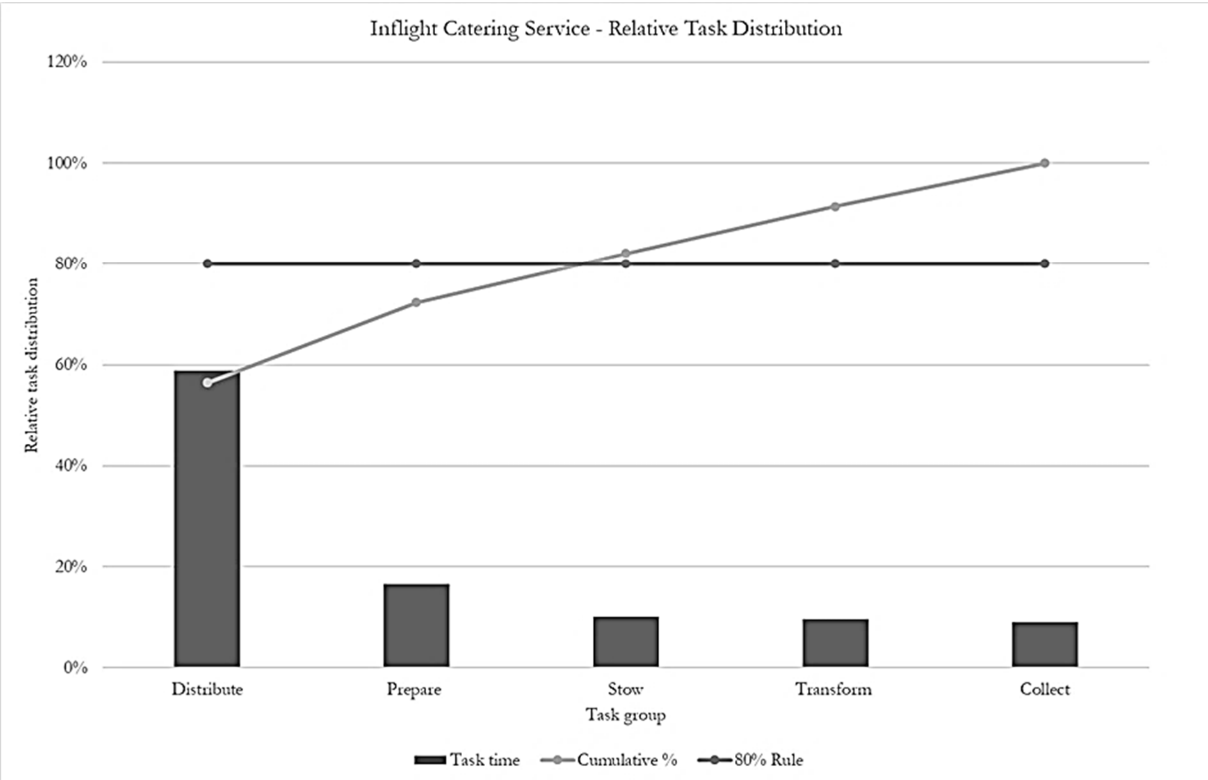



Figure 29 - Example task distribution of a full-service, long-haul flight with a lunch service (Mortensen Ernits *et al.*, 2022b).

An example of this preliminary study is given for the task of "prepare distribution devices". In this case, 62 tasks are involved with the monument G4A, as shown in the Figure 30 marked in red.

| Task Phase: | 1154 Prepare distribution devices | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| 1 | **G4FR**<br>3 | N.A | | **G4AR**<br>37 | N.A. |
| 2 | **Workspace**<br>9 | **Workspace**<br>9 | **Workspace**<br>9 | **Workspace**<br>9 | **G4A**<br>62 |
| 3 | **G4F**<br>1 | **Workspace**<br>9 | **TC4M**<br>0 | **Workspace**<br>9 | **G4A**<br>62 |
| 4 | **Workspace**<br>9 | **Workspace**<br>9 | **Workspace**<br>9 | **Workspace**<br>9 | **G4A**<br>62 |
| 5 | **G4FR**<br>3 | N.A. | | **G4AL**<br>38 | N.A. |

Figure 30 - Preliminary study of galley utilisation with heat-map.

Another approach was the analysis of the available space inside the galley. Hereafter, an experimental set-up has been arranged, composed of a monument, a worktable and a full-size trolley as shown in Figure 31 .

a b c

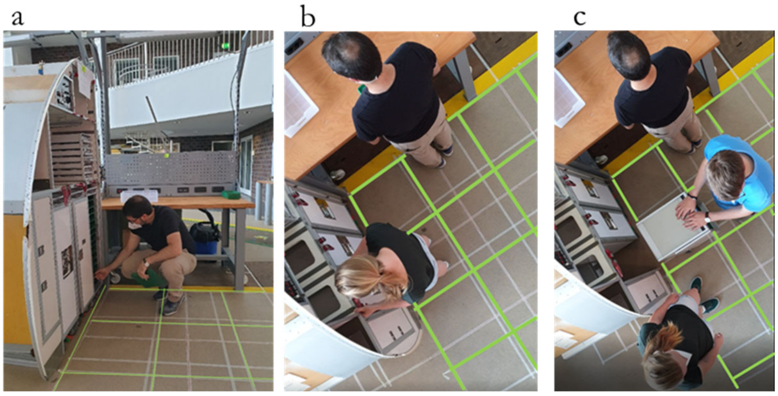


Figure 31 - Experimental set-up for galley working space evaluation.

It is possible to see that certain work processes have a defined radius of movement. In order to depict this, three actions were defined to represent common movements inside the galley. Those actions were exemplified with sub-actions listed in the Table 16.

Table 16 - Experimental set-up actions for preliminary space utilisation evaluation.

| Action | Sub-actions |
|---|---|
| Bend-over | Opening a trolley in level 1 |
| | Removing a tray |
| | Placing on level 2 of the monument |
| | Opening a standard unit / oven on level 2 |
| | Removing a filled drawer with casseroles and placing on the work surface of the monument |
| | Placing the casseroles in the trolley on level 1 |
| Preparation | Opening a standard unit / oven on level 2 |
| | Removing a filled drawer with casseroles and placing on the work surface of the monument |
| | Placing the casseroles in the trolley on level 1 |
| Trolley movement | Pulling out the trolley |
| | Placing in front of the monument |

The defined grid on the floor shows that specific actions demand more space than others, reducing the space available inside the galley. In order to understand the utilisation of the galley by a maximum and minimum number of flight attendants and possibly generate a relation of the working area with the size of the monuments, a better design and operation could be achieved. Hereafter, it could be interesting to define a model based on cells, fitting monuments and enabling the representation of “working stations” for the flight attendants.

In the first approach, after the experiments a cell from 55x55 cm was defined. For the actions "bend-over" and "prepare", the occupation is shown in the Figure 32, where the blue circle crew represents the flight attendant.

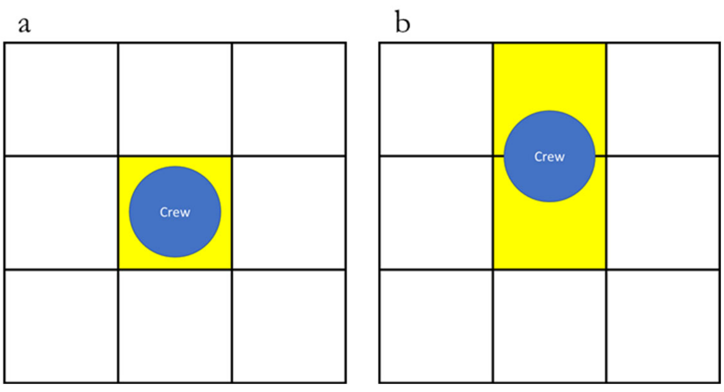



Figure 32 - Number of occupied cells by a) stand-up and b) bend-over.

If a flight attendant takes a full-size trolley, 3 cells are occupied. The variation can be done as shown in Figure 33.

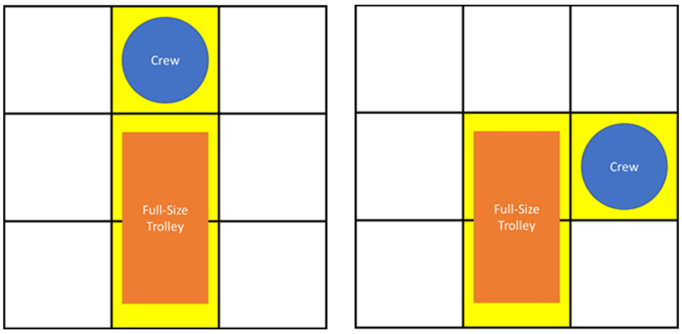



Figure 33 - Number of occupied cells by taking a full-size trolley from different positions, a) front or back and b) from the sides.

This process analysis section closes with a simplified functional model for the galley, shown in Figure 34. The functional model provides information about the internal structure of a galley as a black box. The input and output variables from the black box are processed as a functional model. It should be noted that the functional elements within the box still need to represent specific working principles, i.e. they still need to present a technical implementation. A distinction can be made here between systems of energy turnover, material turnover or signal turnover. In addition, a system boundary is set, which defines the overall function.

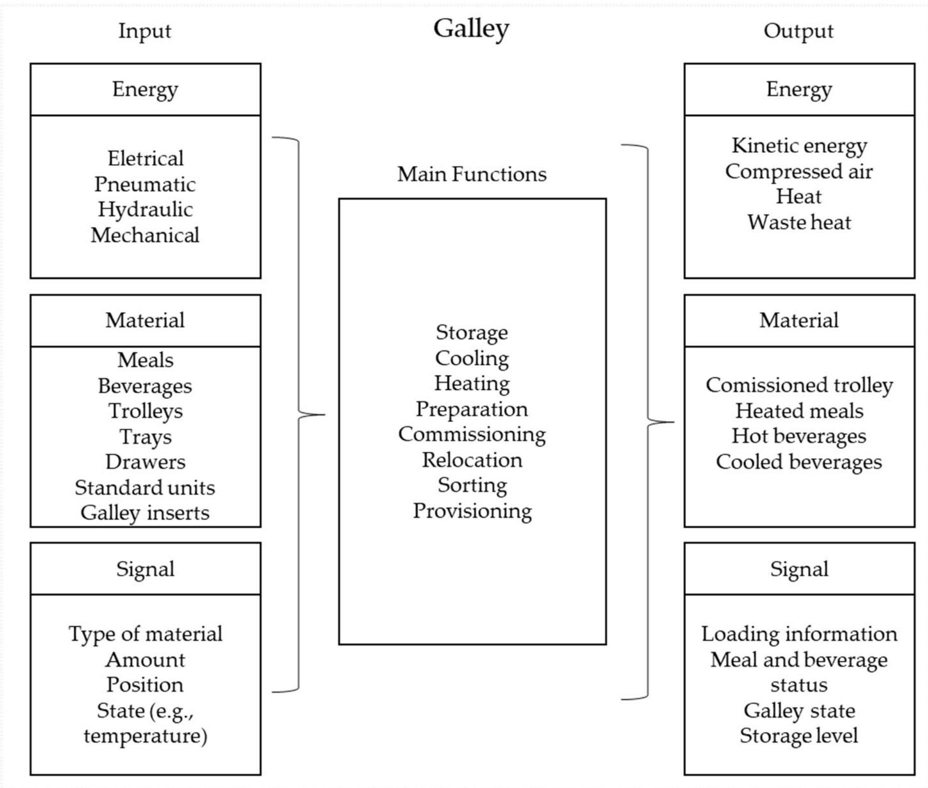



Figure 34 - A simplified functional model for the galley.

## 4.2 Definition of requirements

For the definition of the requirements for the automation of inflight catering services, an expert-workshop was performed and the results are presented in Table 17. The expert-workshop has been done with five experts, each possessing at least three years of experience in Airbus engineering division within galley development. The workshop employed a variety of methodologies, including brainstorming sessions and case studies, fostering an environment conducive to collaboration and knowledge sharing. Facilitation techniques prioritized active participation, and data collection has been done with flipchart and whiteboard, documented and sent among the experts for reviewing.

Table 17 - Results of expert workshop for definition of requirements for the automation of inflight catering services.

| Aspect | Answer |
|---|---|
| 1. A new galley should… | auto store |
| | auto prepare |
| | have a high level of integration |
| | perform multiple tasks |
| | have high added value |
| | provide work relieve |
| | enable self-service options |
| | allow quick reconfiguration after route requirements |
| | combine stowage and preparation of food |
| | support mean´s of automation |
| | get out of revenue area |
| | consider robustness and untrained crew |
| | take over repetitive tasks |
| 2. Flight attends role in today´s galley is… | laborious |
| | mostly acting like a cook, waiter, kitchen assistant and cleaner |
| | searching, stowing, operating catering goods |
| | very repetitive |
| 3. Flight attends role in the new galley will be… | more supportive |
| | performed in automated collaborations |

| | |
|---|---|
| | the interface to passenger |
| | acting like a customer |
| 4. Today´s galley strengths are… | maturity and operations-proof |
| | well stablish in terms of overall catering process |
| | common standards |
| | very robust |
| | failures do not completely shut down catering |
| | quick reaction to customer´s request |
| | modularity |
| 5. Today´s galley weakness are… | full with double structures |
| | has many manual activities and is labour intensive for flight attendants |
| | a lot of space/equipment necessary |
| | it´s not in active use during most time of the flight |
| | heavy and bulky design |
| | low integration of new technologies |
| | the standard hinders changes |
| | design stile looks like 3 decades ago |
| | energy inefficient |
| | difficult to bring significant automation with today´s architecture |
| | just for the flight attendants |
| | very narrow |
| | restricted to a specific cabin location |
| | low level of automation, e.g., decision making |
| | it takes too much space |
| 6. General aspects | the new galley should not be dependent of individual elements |
| | possible to use without training |
| | flight attendant should monitor the process |
| | look after eco-efficiency and better energy reuse |

| | |
|---|---|
| | galley should dynamic recognise its content |
| | different packaging and better alternative to trays |
| | galley concept should consider different classes requirements |
| | multiple use of the galley and equipment |
| | short- and long term vision necessary for a concrete timeline |
| 7. Scenarios examples | meal individualisation |
| | passenger did not board (e.g., pre-ordered meal) |
| | weight balance |
| | automatic loading/unloading |
| | changeable configuration (variable catering) |
| | energy management |
| | item recognition |
| | tray assembly |
| | beverage preparation |
| | space utilisation – unreachable spaces |
| 8. Functions | bulk storage |
| | on-board order sorting (after passenger order) |
| | cost-benefit of additional technology weight |
| | use of unreachable spaces and further expansion of the galley |
| | galley usability study |
| | evaluation of new standards |
| | magazine or racks instead of trolleys/trays |
| | different classes requirements |
| | structure, space between standard units, trays and trolleys |
| | evaluation of space for automation |
| | use of gravity and simple mechanics |
| | pre-cooling |

better isolation

active cooling

evaluation of space for casseroles (necessary space for heating)

number of necessary operations

combination of storage and heating

hot meals been directly transported in the galley

Afterwards, the requirements were grouped as shown in Figure 35.

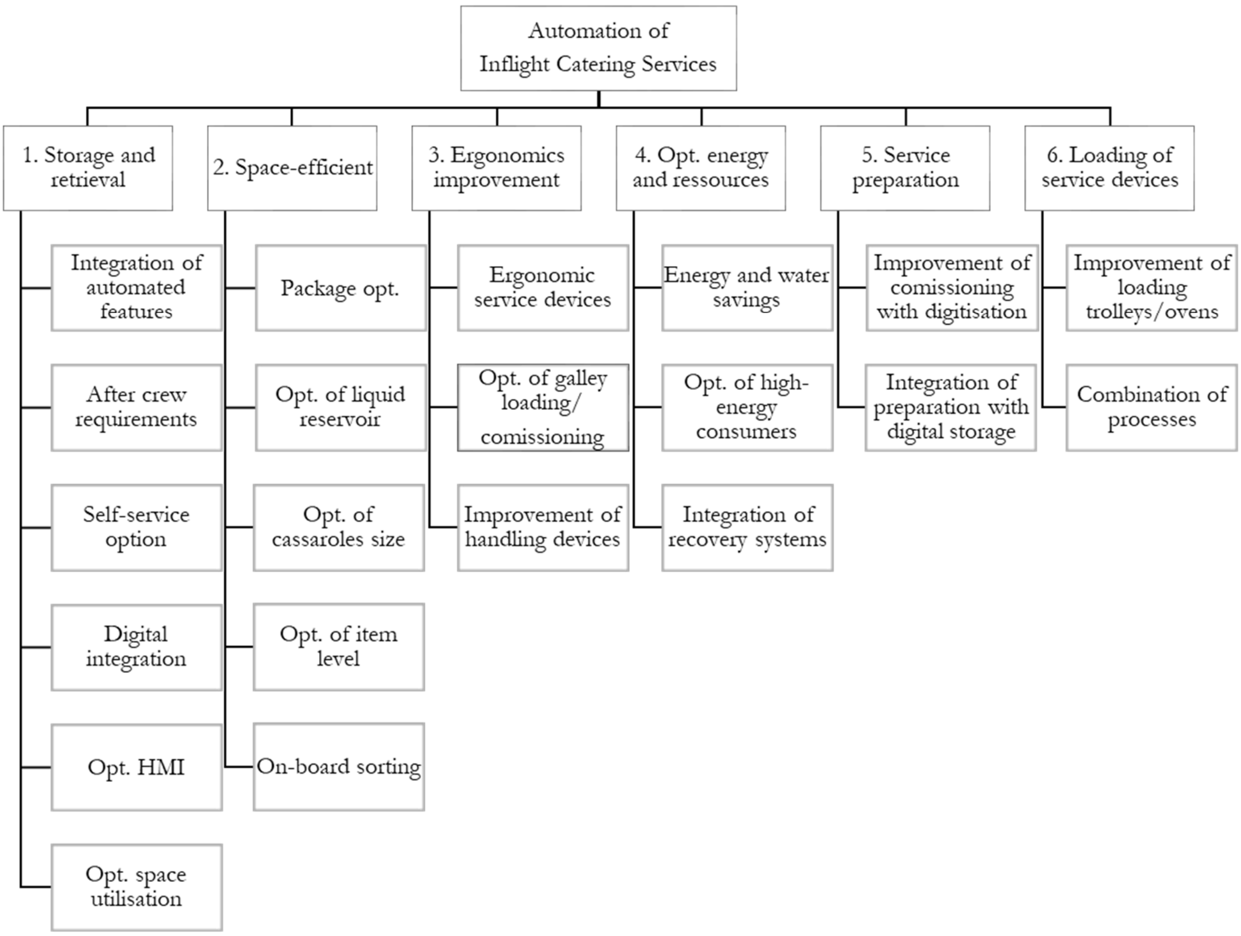



Figure 35 - Grouped requirements for the automation of inflight catering services.

Many requirements are interrelated, but the categorisation supports the orientation for developing specific solutions.

1. Storage and retrieval optimisation

The automation of inflight catering services must be designed to optimize storage and retrieval operations through interoperability, decentralization, and real-time capability. The system should be able to integrate with other systems and devices seamlessly and should be decentralised to allow for flexible and scalable deployment. It should also have real-time capability to ensure timely and efficient operation.

2. Space-efficient

A modular system should be designed to optimize space efficiency in a number of ways. Packaging optimisation demands the use of lightweight, compact materials and designs that minimize the overall volume of items stored in the galley. Optimization of liquid storage requires the use of specialized containers and dispensing systems that minimize the amount of space required for storage and handling. The size of items such as casserole must be evaluated to minimize the amount of unused space in the galley. In addition, the item level handling requires specialized racks and shelving systems that allow items to be stored in a way that maximizes the use of available space. Onboard sorting demands systems that allow items to be quickly and efficiently sorted and stored in the most appropriate location within the galley.

3. Ergonomics improvement

To reduce workload, the system should be designed to reduce as many tasks as possible, including the handling and storage of items. Possible use of automated handling and storage systems, as well as through the integration of real-time data on demand and usage patterns, must be evaluated. Besides, it is required to minimize the physical demands placed on flight attendants, such as lifting and bending. To reduce injuries, the system should be designed to minimize the risk of accidents and injuries, such as jamming and burning. The solutions must include the use of safety features, as well as the implementation of safe work practices and procedures. Also, new solutions must be designed to allow flight attendants to load and unload items into the galley easily and efficiently, possibly using a combination of automated and manual handling methods.

4. Optimisation of energy and resources

For improving energy and water savings, the system must be designed to minimise the use of these resources wherever possible. This can be achieved through using energy-efficient and water-efficient devices and systems, as well as through implementing best practices for resource conservation or new service models. To optimise the design of high-energy consumers, such as ovens, the solutions must be designed to minimise the overall energy consumption of these devices while still meeting the performance and functionality requirements. Hereafter, new insulation materials, as well as the optimisation of heating and cooling systems must be evaluated. Also, the integration of recovery systems to capture and reuse resources wherever possible, such as through the use of water recycling systems and waste reduction strategies, must be evaluated.

5. Services preparation optimisation

The new solutions for an automated inflight catering service must prioritise preparation optimisation to provide passengers a seamless and efficient experience. This includes the use of virtualisation to streamline processes, a service-oriented approach to ensure passenger satisfaction, and the elimination of waste and unnecessary activities to improve efficiency. In addition, the optimisation of service preparation must prioritise transparency in its process flow, allowing flight attendants to easily track and understand the steps involved in the inflight catering process. The evaluation of the use of artificial intelligence should be performed to optimise behaviour and decision-making within the service, while customised visuals and dashboards can provide key performance data to help identify areas for improvement and optimise service.

4. Analysis of inflight catering processes and derivation of requirements for automation

6. Optimisation of loading of service devices (also unloading)

New solutions should seek to combine processes wherever possible in order to improve efficiency and reduce the time and effort required for loading and unloading.

Besides, general non-functional requirements were derived as listed as follows:

- Performance: improve the catering process
- Scalability: the system can be used for small and big aircraft as well as for short and long range flights
- Capacity: the system can be used simultaneously by the airlines
- Availability: the system is available during the complete flight, and the information can be accessed online by the stakeholders
- Reliability: the information stored can be certified
- Recoverability : the system has backup functionalities
- Maintainability: the system can be changed, improved and scaled
- Serviceability: the system is easy to use
- Security: it can prevent unwanted access within the state-of-art data security
- Regulatory: it is accepted by all stakeholders and it holds to a standard
- Environmental: it contributes to improving the environment while reducing waste
- Data Integrity: it recognises data corruption
- Usability: the system is easy to use
- Interoperability: the system works with different platforms
- Correctness: satisfy its specification and objectives
- Reliability: expectation to perform the intended function with required precision
- Efficiency: computing resources/code
- Integrity: control access
- Usability: effort required to learn, operate, prepare input and interpret output
- Maintainability: effort required to locate and fix an error
- Testability: effort to test in order to ensure that it performs its intended function
- Flexibility: effort required to modify an operational program
- Portability: effort required to transfer a program from one hardware or software environment to another
- Reusability: to what extent can a program be reused in other applications
- Interoperability: effort required to couple one system with another

The results of the workshop in defining requirements for developing automation concepts for the aircraft galley were undoubtedly insightful, drawing from the extensive expertise of the consulted engineering experts. However, a critical reflection suggests that a broader perspective would enrich the understanding while incorporating input from departments such as marketing and human factors. Additionally, seeking confirmation and feedback from end-users, including flight attendants, airlines, and caterers, would improve the requirements definition process. Their perspectives could offer nuanced insights into real-world operational challenges, user preferences, and industry trends.

## 4.3 Method for the analysis of automation concepts for inflight catering services

In this section, a method for the analysis of automation concepts for inflight catering services is presented. The first step in this process is the definition of the process phases and identification of interfaces, which outline the interactions between different components and stakeholders of the system and enable the integration of automation technologies. Next, the development of an abstracted task catalog of inflight catering services is presented, which outlines the key tasks and activities involved in the catering process. Afterwards, key performance indicators (KPIs) for evaluating the process, including measures of efficiency are established. Overall, the approach provides a systematic and comprehensive method for evaluating automation concepts for inflight catering services, allowing for the identification of opportunities for improvement and the implementation of effective and efficient automation solutions.

From the process analysis, a connected view of inflight catering services to understand the interrelations among processes has been derived, as well as to communicate with stakeholders and to identify critical aspects. In Figure 36, 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.

In order to derive a task catalog for the process analysis, a classification has been adopted, as shown in Table 18.

A task abstraction is a high-level representation of a task or activity that is used to simplify or clarify the process of achieving a specific goal. In the context of technology development, a task abstraction may be a simplified or generalized description of a task that is used to make the technology development process more manageable or easier to understand. For example, a task abstraction might describe a complex task in broad terms without going into the details of how it is to be performed. Task abstractions can be useful in technology development because they can help to identify the key elements of a task and to break it down into smaller, more manageable components. This can make it easier to understand the requirements, dependencies, and potential challenges associated with a task and to plan for its successful completion.

| Stakeholder \ Process | CHECK-IN | SET-UP | SERVICE | CHECK-OUT |
|---|---|---|---|---|
| Aircraft manufact. | Catering transport/loading<br>• Aircraft type<br>• Cabin configuration and size | Galley/trolley preparation<br>• Configuration<br>• Size<br>• Operation | Meal and beverage distribution<br>• Cabin configuration and size<br>• Number of seats | Catering unloading/inventory<br>• Galley configuration |
| Airline | Catering transport/loading<br>• Time/amount constraints<br>• Cold-chain integrity | Galley/trolley preparation<br>• Number of services<br>• Number of flight attendants | Meal and beverage distribution<br>• Service variations<br>• Time for service<br>• Number of flight attendants | Catering unloading/inventory<br>• Galley configuration<br>• Number of flight attendants<br>• Consumption overview |
| Flight attendant | Catering transport/loading<br>• Safety/security check<br>• Consistency check | Galley/trolley preparation<br>• Type of galley inserts<br>• Amount of catering<br>• Number of flight attendants | Meal and beverage distribution<br>• Execution<br>• Refill / Waste collection<br>• Number of passengers<br>• Interaction | Catering unloading/inventory<br>• Inventory counting<br>• Caterer interaction |
| Passenger | Catering transport/loading<br>• On-time pre-orderings | Galley/trolley preparation<br>• Extra on-board orders | Meal and beverage distribution<br>• Pre-Orderings<br>• Menu Choice<br>• Flight attendant interaction | Catering unloading/inventory<br>• Deboarding |
| Caterer | Catering transport/loading<br>• Preparation of meals<br>• Transportation<br>• Loading of catering | Galley/trolley preparation<br>• Meal preparation instructions | Meal and beverage distribution<br>• Meal ingredients and composition | Catering unloading/inventory<br>• Unloading of catering<br>• Cleaning of trolleys and standard units<br>• Trash/waste/recycling |
| Airport | Catering transport/loading<br>• Coordination of delays<br>• Turnaround time<br>• Departure time | Galley/trolley preparation<br>• Meal preparation instructions | Meal and beverage distribution<br>• Meal ingredients and composition | Catering unloading/inventory<br>• Coordination of delays<br>• Turnaround time<br>• Arrival time |

Figure 36 - Four main steps of inflight catering services (Mortensen Ernits *et al.*, 2022b).

Table 18 - Task catalog for the process analysis of inflight catering services.

| Phase | Task | Subtask | Equipment | Object | Personal |
|---|---|---|---|---|---|
| Check-In | Collect | Abort | Bag | Beverage | Flight attendant |
| Set-up | Distribute | Add | Bum warmer | Bottle | Caterer |
| Service | Prepare | Adjust | Coffee Maker | Bread | Passenger |
| Check-Out | Stow | Analyse | Drawer | Can | |
| | Transform | Answer | Full-size Trolley | Casserole | |
| | | Arrange | Galley | Coffee | |
| | | Ask | Half-size Trolley | Cold food | |
| | | Assist | Jug | Condiment | |
| | | Check | Microwave | Cutlery | |
| | | Clean | Oven | Glass | |
| | | Close | Oven rack | Ice | |
| | | Coordinate | Refrigerator | Juice | |
| | | Count | Sink | Meal | |
| | | Decide | Standard unit | Napkin | |
| | | Disengage | Towel | Plate | |
| | | Dispose | Trash compactor | Snack | |
| | | Engage | Tray | Special meal | |
| | | Enter | Water heater | Tea | |
| | | Go | | Utensil | |
| | | Inform | | Waste | |
| | | Insert | | | |
| | | Load | | | |
| | | Monitor | | | |
| | | Move | | | |
| | | Open | | | |
| | | Pick | | | |
| | | Place | | | |
| | | Refill | | | |
| | | Report | | | |
| | | Serve | | | |
| | | Start | | | |
| | | Subtask | | | |
| | | Switch off | | | |
| | | Switch on | | | |
| | | Unload | | | |
| | | Wait | | | |
| | | Write | | | |

Table 19 - Description of process phases for the automation of inflight catering services.

| Phase | Description |
|---|---|
| Check-In | Check in is the loading of the galley with catering goods, which is performed on the ground; |
| Set-up | Set-up includes the commissioning of the galley and the associated preparation of the distribution devices |
| Service | Service is the distribution of the meals and beverages to the passengers and subsequent waste collection |
| Check-Out | Check out considers the unloading of the galley and inventory. |

Table 20 - Description of process tasks for the automation of inflight catering services.

| Subtask | Description |
|---|---|
| Abort | Stopping or cancelling a task or operation that is in progress |
| Add | Task of adding or incorporating specific items or ingredients to a meal or snack, or additional items to tray or trolley. |
| Adjust | It refers to the process of making changes or modifications to an object or equipment in order to meet the specific needs or preferences of passengers. This could involve adjusting the temperature, adjusting the portion size, or adding or removing specific components. |
| Analyse | Evaluating situation in order to identify opportunities for improvement, or identify trends and patterns that can support decision-making and strategy. |
| Answer | The process of responding to inquiries or requests from passengers regarding the food and drinks being served during a flight. |
| Arrange | It refers to the process of organising or setting up the food and drinks that will be served to passengers during a flight. This could involve arranging items on a tray or trolley arranging food and drinks on a tray or plate in a visually appealing manner, or arranging supplies and equipment in the galley to ensure that everything is easily accessible. |
| Ask | Making inquiries or requests of passengers regarding their food and drink preferences or needs. Inflight catering staff may ask passengers a variety of questions, such as what type of meal or drink they would like to order, whether they have any dietary restrictions or allergies, or if they would like additional items or condiments added to their meal. |
| Assist | Providing help or support to passengers with regards to the food and drinks being served during a flight, e.g., providing assistance to those with special needs, such as elderly or disabled passengers. |
| Check | Verifying or reviewing various aspects of the food and drink service being provided to passengers or equipment during a flight, e.g., checking the quality and quantity of the items being served, checking the temperature of the food and drinks, checking the appearance and presentation of the meals and snacks, or checking that all necessary supplies and equipment are available and in good working order. |
| Clean | Maintaining cleanliness and sanitation in the aircraft galley and surrounding areas. This could involve cleaning and sanitising the sink, counters, and other surfaces in the galley, as well as cleaning and disinfecting cups, plates, utensils, and other equipment. |
| Close | Closing and locking the doors to the galley, closing and securing any storage compartments or cabinets. |
| Coordinate | Coordinating with other flight attendant to ensure that all tasks are completed efficiently and on schedule, coordinating with the flight crew to ensure that meals and drinks are served at the appropriate times, and coordinating with the ground staff to ensure that the necessary supplies and equipment are available and in good working order. |
| Count | Keeping track of inventory and ensure that there are sufficient supplies on hand to meet the needs of passengers during the flight, and performing inventory after the flight, e.g., remained beverages. |

| | |
|---|---|
| Decide | To make informed, strategic decisions that will help to optimise the inflight catering operation and ensure that it meets the needs and expectations of passengers. |
| Disengage | Disengaging involve disconnecting or turning off equipment or devices that are not needed, such as the oven or the coffee maker, or braking a trolley. |
| Dispose | Getting rid of waste or other unwanted items. It involves disposing of food packaging, used cups and utensils, and other waste materials in a safe and sanitary manner. To ensure that waste is properly disposed of and does not accumulate in the galley or other areas of the aircraft. |
| Engage | Connecting or turning on equipment or devices that are needed, such as the oven or the coffee maker, or un-braking/releasing a trolley. |
| Enter | Process of entering or recording data or information into a computer or other electronic system |
| Go | Personal movement to a specific location, e.g. going to the galley or other areas of the aircraft to prepare or serve food and drinks. |
| Inform | Providing information or knowledge to others, e.g. informing passengers about the types of meals and drinks that are available |
| Insert | Using specialised equipment or tools, such as gloves to handle hot items safely. |
| Load | Process of loading or transferring items or materials onto a trolley, standard unit or other equipment, e.g., oven or oven rack. |
| Monitor | Observing or keeping track of various aspects of the food and beverage services, or processes in the galley. |
| Move | Item movement to a specific location, e.g. physical transportation of casseroles from preparation surface to over the trolley. |
| Open | Process of opening packages, trolleys or standard units in order to prepare or load/unload for use. |
| Pick | Selecting and gathering specific items or supplies that are needed for the inflight catering service |
| Place | Arranging or positioning food items or other supplies in a specific location or in a specific manner. |
| Refill | Restocking equipment or supplies that have been used during the service, such as refilling coffee pots or restocking serving utensils. |
| Report | Communicating information about the inflight catering service, e.g. issues or problems that have arisen during the service. |
| Serve | Process of providing food and beverages to passengers during a flight, e.g., hand-over of meal trays or beverages. |
| Start | Activating equipment that is needed for the service, such as activating oven for start heating. |
| Subtask | Description |
| Switch off | Turning off equipment or systems that are no more needed for the inflight catering service and deactivating. |
| Switch on | Turning on equipment or systems that are needed for the inflight catering service without activating. |
| Unload | Process of unloading or transferring items or materials from a trolley, standard unit or from other equipment, e.g., oven or oven rack. |
| Wait | Standing by or remaining in a specific location in order to be available for a task or for further instructions. |
| Write | Creating or documenting information in written form, e.g., writing out labels or tags for food items or equipment. |

A simplified overview of the main processes involved in the inflight catering services is shown in the following diagrams:

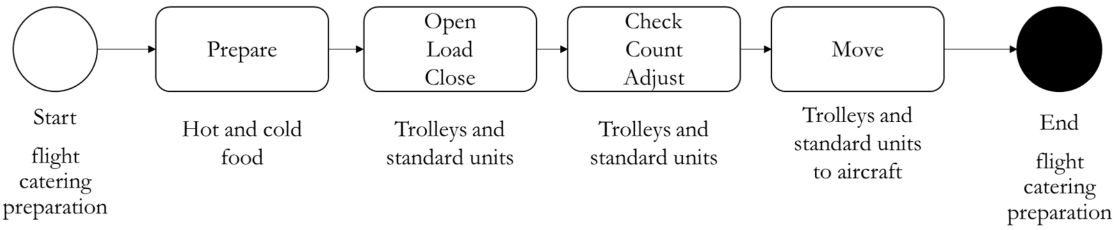



Figure 37 - Simplified process for loading and transport catering goods to the aircraft.

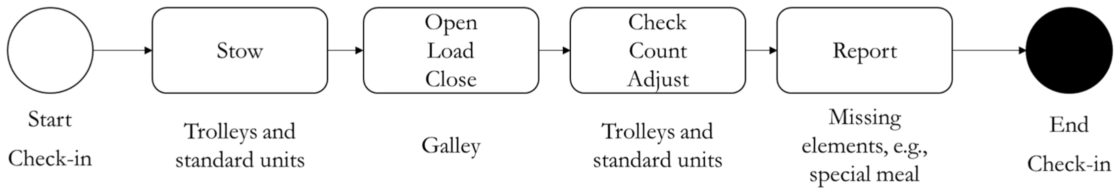



Figure 38 - Simplified process for “check-in” while loading catering goods inside the aircraft.

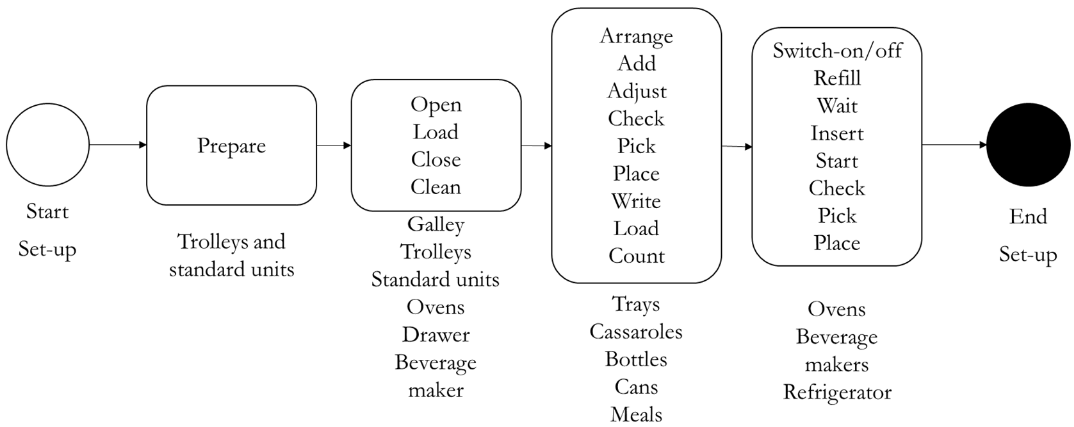



Figure 39 - Simplified process for "set-up", commissioning galley and trolleys for service.

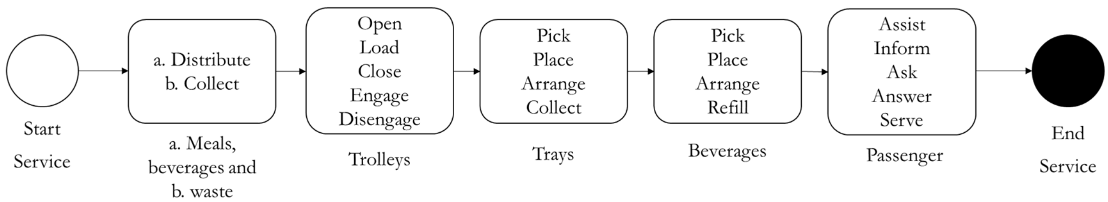



Figure 40 - Simplified process for "service", the distribution of meals and beverages to the passengers.

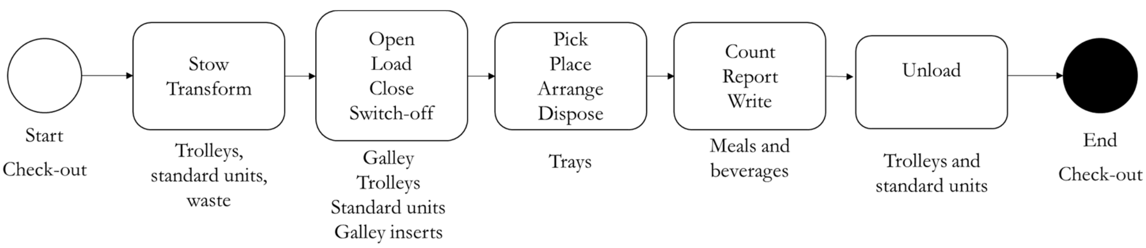



Figure 41 - Simplified process for "check-out", unloading catering goods out of the aircraft.

The key performance indicators (KPIs) to evaluate the performance of new automation concepts for inflight catering services in the early development phase are:

- Operation efficiency
- Safety and health impact
- Ease of use (zero training)
- Durability and robustness
- Impact on galley footprint
- Impact on catering chain
- Weight
- Cost (for device)
- Development lead time
- Environmental impact

Operational efficiency is a key factor, as automation can help streamline processes and reduce the amount of time and effort required to perform certain tasks. Safety and health impact is another important factor, as automation can help reduce the risk of accidents or injuries, as well as improve overall working conditions. Ease of use is also crucial, especially in situations where training may be difficult or unavailable, as automation systems that require little or no training can be more quickly and easily integrated into existing processes. Durability and robustness are also important considerations, as automation systems that are prone to breakdown or malfunction can disrupt operations and increase maintenance costs. The impact on the galley footprint and catering chain should also be considered, as automation systems that require additional space or disrupt existing workflow can be less practical. Weight and cost are also important factors, as automation systems that are too heavy or expensive may not be feasible for certain applications. Development lead time is another important consideration, as automation systems that take a long time to develop and implement may not be suitable for time-sensitive projects. The environmental impact of automation systems should be considered, as some systems may have a larger impact on the environment due to their energy consumption or material use.

# 5 Development of a MCDM framework for the assessment of automation concepts for ICS

The development and implementation of a multicriteria decision-making (MCDM) framework for the assessment of automation concepts for inflight catering services is divided into conception, development of subcomponents and prototypical implementation of the overall system.

## 5.1 Conception

The black box serves to support or facilitate the understanding of the system. This is achieved by only considering the input and output variables that flow into and out of the system. How these variables are converted is not taken into account. With this form of representation, the reduction to the purpose of the product takes place. This purpose or the main function is shown in the middle of the black box. Possible variables that flow into and out of the black box are, for example, the substance, the energy and the signal (Lindemann, 2009). The information transport from one module to the next follows the *signal* principles and fulfil three functions as described by (Danzer, 1987):

- Syntactic function: for establishing a relation to equivalent signals.
- Semantic function: for the meaning of the signals in order to characterise the content and context.
- Pragmatic function: besides establishing a relation to order signals it can be understood by the people dealing with it.

Due to the complexity of the processes and interactions with different stakeholders, a framework has been developed for evaluating automation concepts for inflight catering services. The purpose is to enable a fair comparison among different concepts, which may be developed in different maturity levels and to allow a classification, not only regarding the level of automation but also possible constraints that exceed the technology, e.g. process integration or interaction with a flight attendant. Reducing the time for an innovation to get market-ready holds high potential for lowering costs or getting major competitive advantages and leads companies to rethink their innovation strategies.

The developed multicriteria decision-making evaluation framework for inflight catering service automation is shown in Figure 42. It consists of eleven modules, starting from demand for product innovation or process and/or service optimisation until the product deployment.

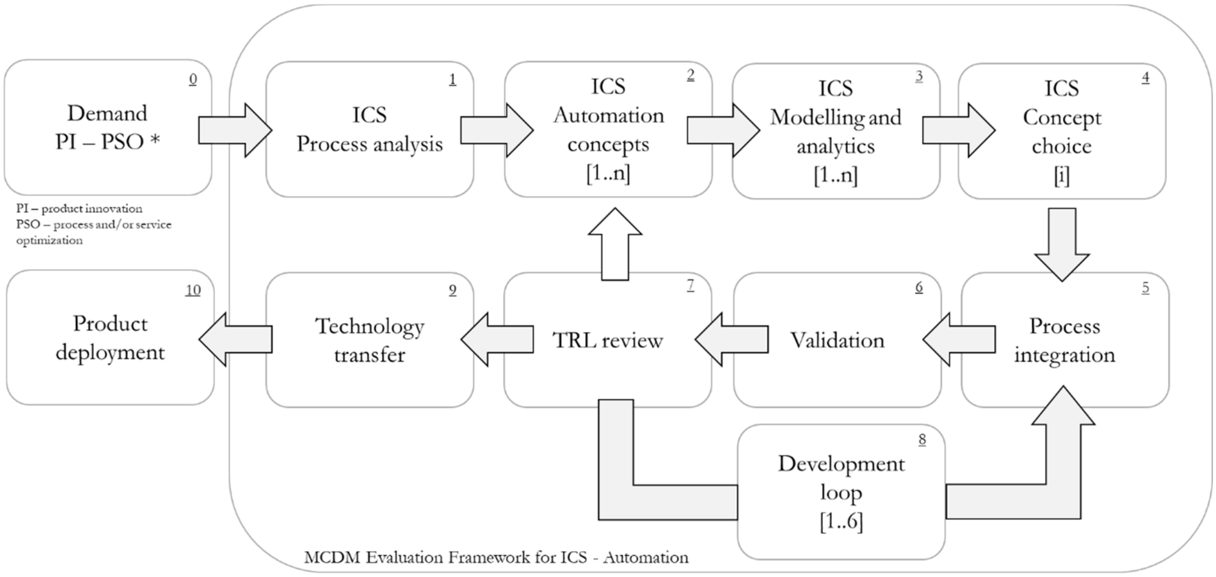



Figure 42 – Multicriteria decision making evaluation framework for the automation of inflight catering services.

## 5.2 Development of the subcomponents

The subcomponents of the method are going to be described in this chapter.

*0_PI / PSO*

The starting point of the process is the identification of the demand for product innovation and product or service optimisation. There could be different drivers for motivating this step, including market trends, customer feedback, competitor analysis, industry trends and regulatory changes. In this step, surveys can be used for identifying and specifying the demand. Many aspects of this step concerning demand were covered through sections 2.5, 3.2 and 4.1. An example will be given on the individualisation of meals in section 5.3.

*1_ICS Process analysis*

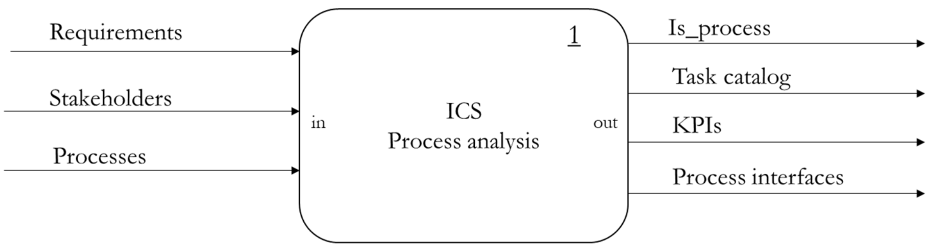



Figure 43 - Step 1, ICS process analysis.

From step 1, a process analysis of the inflight catering services is performed. The process analysis includes processing steps outside and inside the aircraft, which may be affected by a possible solution. In this case, the relation of the stakeholders is defined and structured into a flow dependency flow diagram with the major responsibilities. The process analysis refines the requirements and main objectives to be fulfilled as well as typical tasks and goals. The step 1 ICS_Process analysis has been covered in section 4 of this work; in this section, only brief explanations are going to be given. The requirements in the context of automating the inflight catering services were defined in section 4.2. The identification of the stakeholders is given in section 4.3. The involved processes have been considered from the literature reviewed and in section 4.1. A simplified example for modelling the Is_process is given in section 4.3, together with the definition of a task catalog, the KPIs and process interfaces.

*2_ICS Automation concepts*

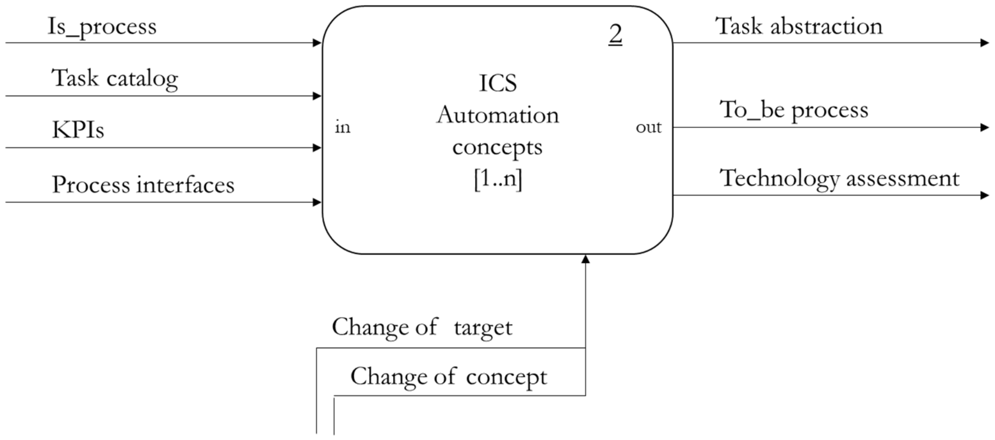



Figure 44 - Step 2, ICS Automation Concepts.

From the process analysis, step 2 is taken; hereby, the task catalog is generated in order to systemize the involved tasks into a taxonomy for organizing them into groups and categories. In step 3, automation concepts receive as input the process interfaces, the requirements and key performance indicators – KPIs, and as an output the automation concept delivers in a structured form the task abstraction based on the previously defined task catalog and as well as the "to be" process with a technology assessment.

*3_ICS Model*

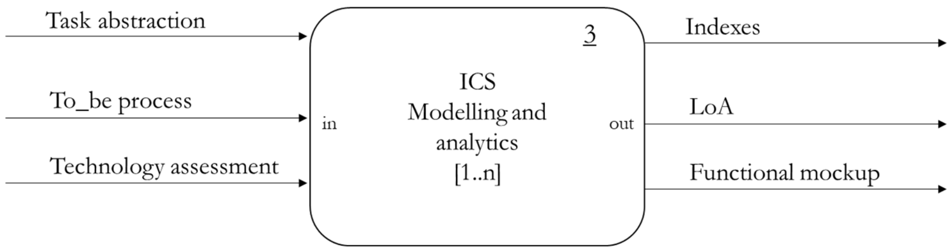



Figure 45 - Step 3, ICS Modelling and analytics.

The indexes are the numerical values that represent the performance of the concepts. The indices are used to measure the impact of technology on the aircraft cabin. They support identifying e.g., space efficiency, footprint, and catering per passenger ratio, among other factors as shown in Table 21.

Table 21 - Comparison Indexes for ICS automation concepts (Mortensen Ernits *et al.*, 2022b).

| | Index | Description | Formula |
|---|---|---|---|
| 1 | Storage Index | Usable storage volume as opposed to the total volume of the galley | $\frac{\sum \text{Usable storage volume of the monuments}}{\sum \text{Total volume of the monuments}} . 10^3$ |
| 2 | Space Efficiency | How many square millimetres of galley per passenger | $\frac{\text{Galley´s area}}{\text{Number of passengers}} . 10^3$ |
| 3 | Galley Workspace Ratio | Comparison between the entire space of the galley and the monuments inside | $\frac{\text{Monument area} \cdot 100}{\text{Total galley´s area}}$ |
| 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 | $\frac{\text{Number of services} \cdot (\text{Total food volume} + \text{Total beverage volume})}{\text{Number of passengers}} .10^5$ |
| 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 | $\frac{\text{Storage Index} \ . \ \text{Catering Index}}{10^3}$ |

### Level of Automation - LoA

The level of automation can be defined as the extent to which a system or process can function without the need for human intervention. In the case of inflight catering services, the level of automation refers to the ability of new technologies to carry out tasks and functions without human control. A technology with a high level of automation can work independently, while a technology with a low level of automation may require more human intervention to function correctly. The ICS specific levels of automation are shown in Table 22.

Table 22 - ICS specific levels of automation.

| | LoA | Description | Condition |
|---|---|---|---|
| 1 | Manual | The process/product /system/concept is manual. There is only low automated support regarding physical movement or data processing. | Automated tasks<br>< 15% |
| 2 | Manual with automated support | The process/product / system/concept is mostly manual, with automated support regarding physical movement or data processing | Automated tasks<br>< 50% |
| 3 | Automated with manual support | The process/product / system/concept is mostly automated, with manual support regarding physical movement, data processing or decision-making. | Automated tasks<br>> 50% |
| 4 | Automated | The process/product / system/concept is completely automated. There is only low manual support, regarding physical movement, data processing. Decision-making support is still necessary. | Automated tasks<br>> 85% |
| 5 | Autonomous | The process/product / system/concept is completely automated and able to dynamically react to changes. No manual support is required. Low support by decision-making. | Automated tasks<br>> 85%<br>Decision-making<br>> 50% of known scenarios |

### Functional Mock-up

A functional mock-up is a simplified or abstract representation of a system, process, or product that is used to test or evaluate its functionality. It can be composed of the elements presented in the Figure 46.

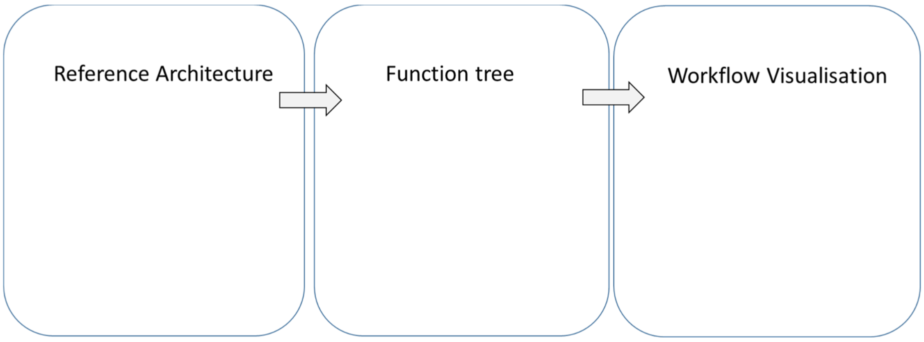



Figure 46 - Functional mock-up components.

A reference architecture is a standardised framework or blueprint used to guide the design and development of a system or solution. In the context of inflight catering services, the reference architecture is a set of principles, models, or patterns used to guide the development of new technology. A reference architecture provides a common language and best practices for technology developers. It ensures that the technology is designed and implemented consistently and coherently.

A function tree is a graphical representation of the functional decomposition of a system or process. In the context of inflight catering services, a function tree can be used to illustrate the relationships between the various components of a new technology and to show how they contribute to the overall functionality of the technology.

Workflow visualization is the process of representing the steps or activities in a workflow or process using a visual representation, such as a diagram or chart. In the context of inflight catering services, workflow visualization can be used to represent the various steps or activities involved in developing and implementing a new technology.

*4_ICS Concept choice*

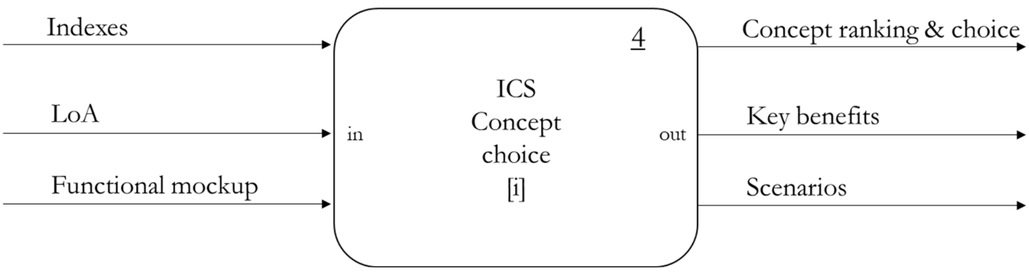



Figure 47 - Step 4, ICS Concept Choice.

The objective of step 4 is to model the automation concepts for comparison. In this step, the inputs are the set of tasks together with the "to be" process and the technology assessment; from the model, three outputs are generated: the calculated indexes, the level of automation of the concept in the process and a functional mock-up. The indexes are used to compare the impact inside the aircraft cabin related to space issues and possible increases or decreases in catering capacity per passenger. The level of automation is intended to give an orientation on the degree of optimisation related to reducing the flight attendant´s workload. The functional mock-up gives the visualisation of the concept for common understanding.

Concept ranking is the process of evaluating and comparing different concepts in order to determine their relative merits or value. In inflight catering services automation, concept ranking is used to evaluate the potential feasibility, impact, or usefulness of different technology concepts or ideas using the defined KPIs.

Key benefits are the automation concept's most significant or valuable advantages or benefits. These benefits include improvements in efficiency, cost savings, or enhanced performance or capabilities.

Scenarios are hypothetical situations that are used to explore the potential implications or outcomes of a particular concept integration. The objective is to explore the potential impact of a new concept on inflight catering services.

*5_Process integration*

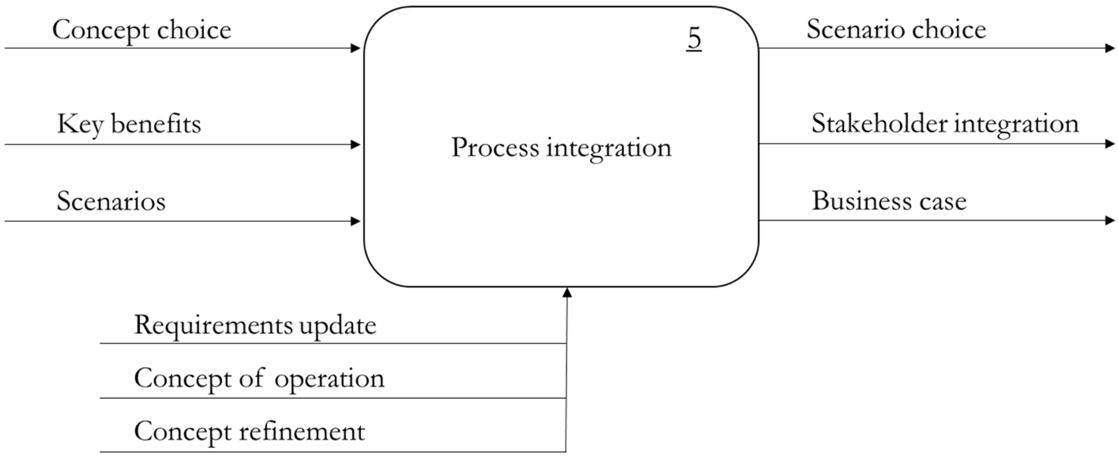



Figure 48 - Step 5, Process Integration.

Step 5 is the process integration; hereafter a scenario is going to be chosen, as well as the integration with stakeholders is going to be further detailed. Besides, a first business case draft is presented.

Stakeholder integration is the process of involving and engaging stakeholders in the development and implementation of a concept. In the context of automation of inflight catering services, stakeholder integration involves identifying and involving aircraft manufacturers, caterers, airlines and suppliers.

A business case is a document or presentation that is used to justify investing time, money, or resources in a project or initiative. The purpose of the business case is to explain the potential benefits and drawbacks of developing and implementing a new concept, and to make a compelling argument for why the technology is worth pursuing. The focus of the business case lies on highlighting the potential returns on investment and the feasibility of the project.

*6_Validation*

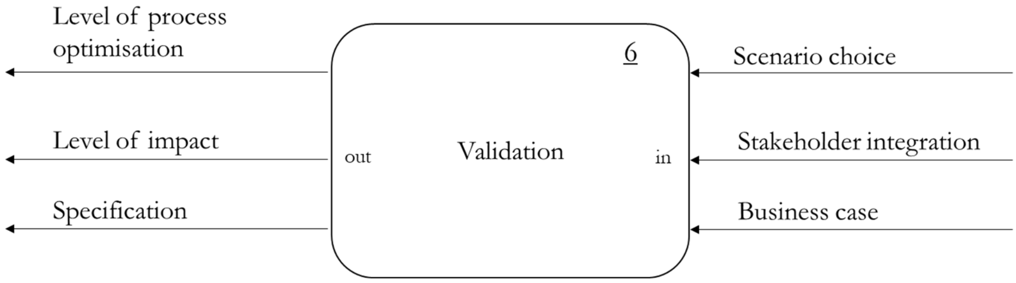



Figure 49 - Step 6, Validation.

Step 6 concerns concept validation with the evaluation of the level of impact and process optimisation as well as a preliminary specification.

A level of process optimisation measures how effective or efficient a process or system is at achieving its desired outcome. For a new automation concept for inflight catering services, the level of process optimisation might refer to, e.g., process time-savings.

The level of impact of a concept is a measure of the extent to which the technology is expected to affect or change a process. A high level of impact could be a disruptive concept pushing for changes in standards.

A technology specification is a document or set of documents that describes the technical requirements, capabilities, and characteristics of the concept. A technology specification includes detailed information about the technical features and capabilities of the concept, as well as any constraints or limitations on its use.

*7_TRL review*

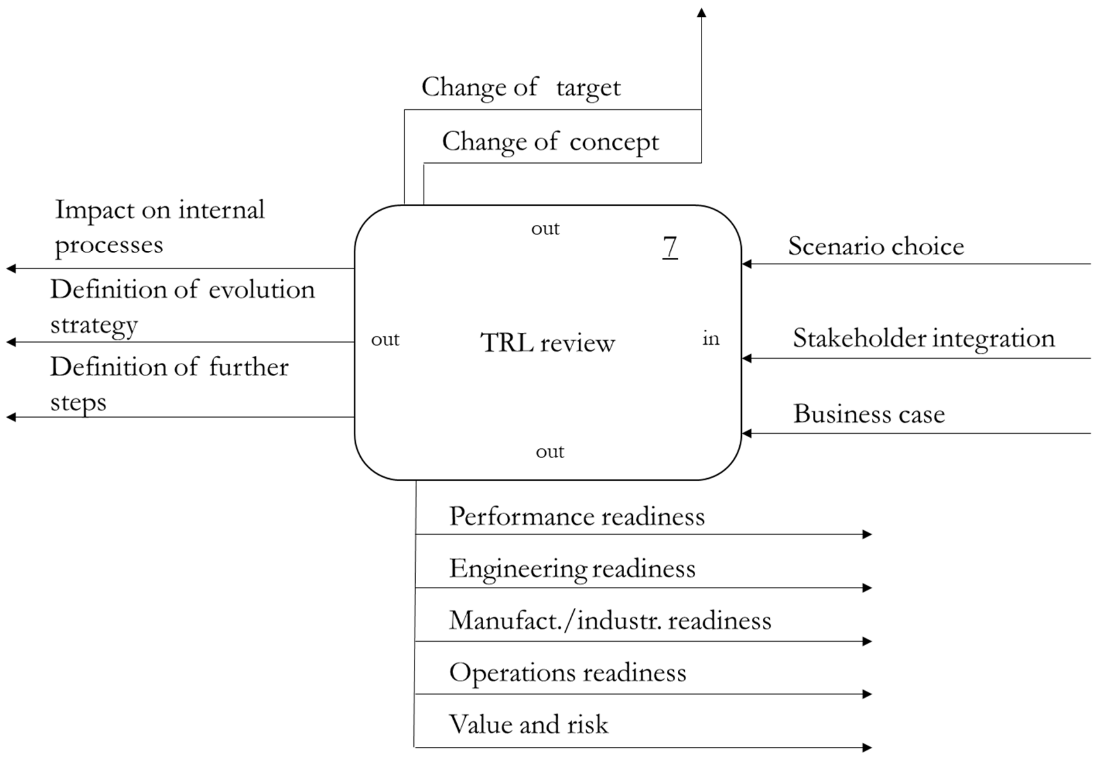



Figure 50 - Step 7, Technology Readiness Level Review.

In step 7, a specific technology readiness level (TRL) review is adopted. The adapted TRLs can provide a clearer progression of a typical innovation, from applied research to deployment, and offer a more reliable basis for evaluating and communicating a technology's maturity with detailed indicators.

An evolution strategy is a plan or approach used to develop and improve a technology concept over time. This strategy helps identify and prioritize the key areas that need improvement or enhancement, and subsequently develops a plan for implementing those improvements.

*8_Development loop*

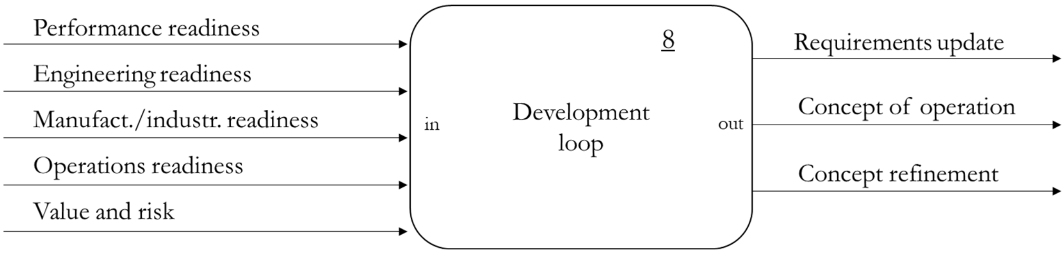



Figure 51 - Step 8, Development loop.

Step 8 is directly related to the TRL review process; parameters derived from step 7 are used for further developing the concept and updating the requirements and concepts of operations, ultimately continuously refining the solution.

Performance readiness in concept development refers to the level of preparedness of a technology and its corresponding concept to be implemented in a real-world setting. A technology that is performance-ready can carry out its intended functions with effectiveness and efficiency without the requirement of any further testing or development.

Engineering readiness refers to the level of preparation required to commence engineering or development work on a technology. An engineering-ready technology has undergone comprehensive research and testing, and there is a well-defined plan and timeline for its development.

Manufacturing readiness is the state or condition of being prepared to begin manufacturing a technology or product. It defines the extent to which the necessary technical, financial, and organizational resources are in place to begin the manufacturing process.

Operational readiness is the state or condition of being prepared to begin operating a particular concept within inflight catering services.

A value and risk assessment is used to determine the feasibility of a concept, assessing the key benefits and risks of the technology.

*9_Technology transfer*

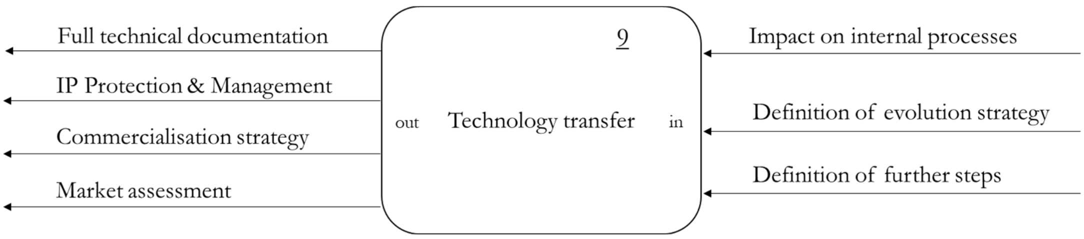



Figure 52 - Step 9, Technology transfer.

Step 9 includes the full technical documentation, including the protection of intellectual property with possible patents, the commercialisation strategy and market assessment.

Comprehensive technical documentation summarises all technical aspects of a concept.

IP protection refers to the legal measures and strategies that are used to protect intellectual property (IP) from unauthorised use or infringement.

A commercialisation strategy is a plan or approach for bringing a technology or product to market and making it available for sale or use. The focus lies on identifying the target market for a new technology, developing a plan for launching and promoting the technology, and identifying the resources and expertise that will be needed to commercialise the technology successfully.

The market assessment is used to identify the potential customers for a new technology and convince them for first-try projects.

*10_Product deployment*

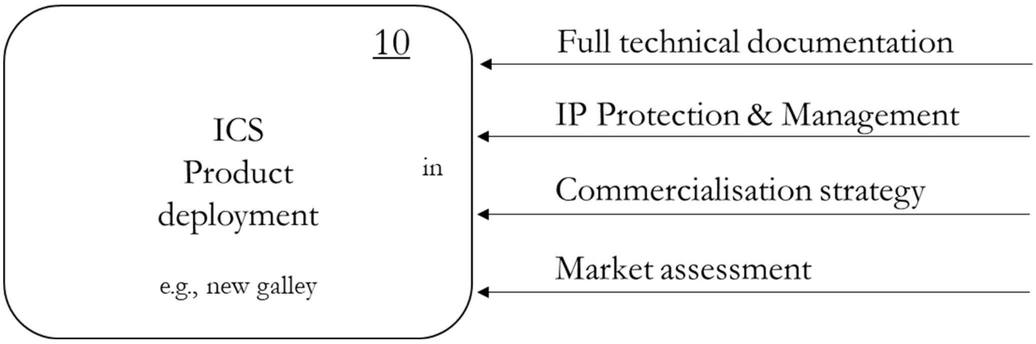



Figure 53 - Step 10, ICS product deployment.

The Step 10 closes the loop with the product deployment. Product deployment closes the multi-criteria decision making method framework and finishes the early development phase.

## 5.3 Prototypical implementation of the overall system

The prototypical implementation of the overall system is going to be exercised for the demand of individualised meals inside the aircraft cabin. Therefore, the results presented by Mortensen Ernits *et al.*, 2022b, are going to be highlighted and used as an example. In addition, references found in other sections of this work are going to be used to avoid repetition.

*0_Demand PI-PSO*

Survey on the Individualisation of Inflight Meals

A complete analysis has been performed to evaluate the importance of meal individualisation for passengers (Mortensen Ernits *et al.*, 2022b). From the literature review regarding 3 dimensions of individualisation, meal provisioning, passenger satisfaction and willingness to pay, the main aspects that are affected by the individualisation of inflight catering services were identified. Some aspects are going to be briefly shown as an example in this section.

The eating behaviour of the asked population was assessed, as shown in Figure 54. It is possible to see that people who fly more often have higher expectations regarding their eating habits.

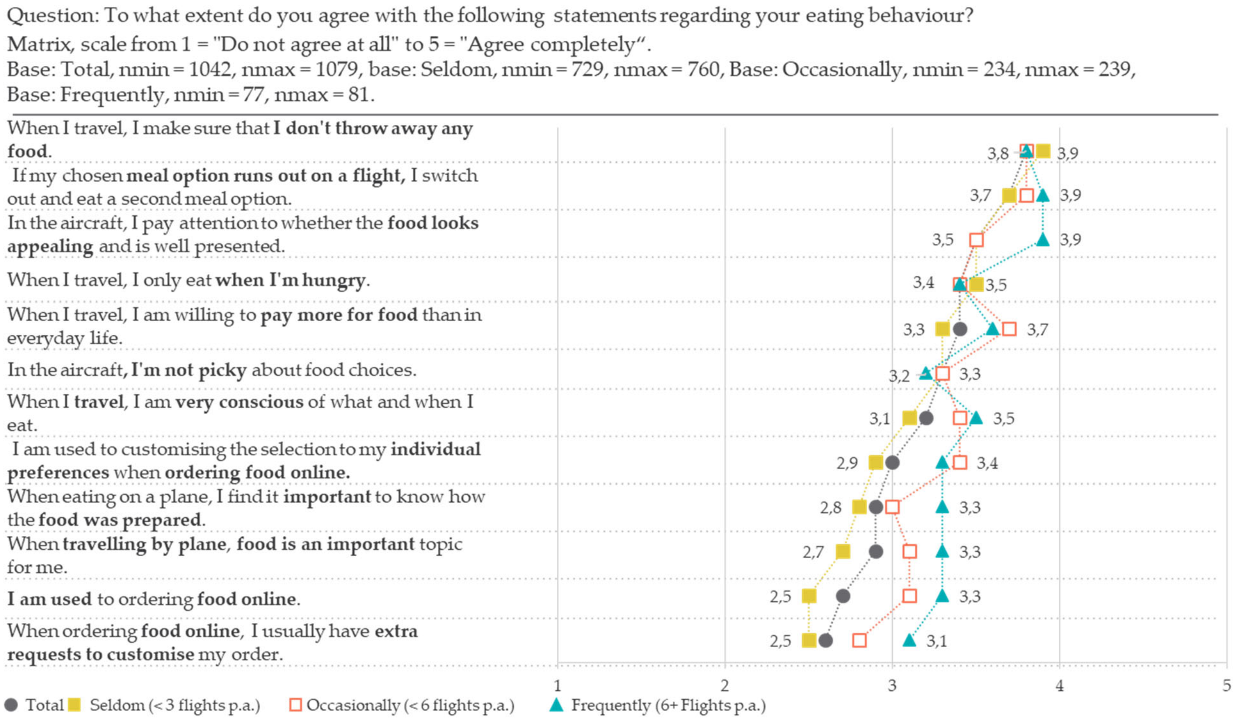



Figure 54 - Statements on individuals' eating behaviour (in Avg.) by flight frequency (Mortensen Ernits *et al.*, 2022b).

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 processes occurring inside and outside the aircraft could improve the inflight catering services. In this sense, 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.

*1_ICS Process Analysis*

The process analysis has been shown in section 4 and is going to be used as a baseline for this step.

*2_ICS Automation concepts*

During the performed projects, many concepts were developed. For the prototypical implementation of the method, three main concepts are going to be used.

The concepts that are going to be analysed for achieving the individualisation of inflight catering services are the "Food case", the "C2 Galley" and "Caterflow".

*Food case*

The food case concept is a decentral approach designed by the authors and replaces the central galley with an active "meal box" – the food case, docked on each passenger front-seat. The main features include continuous availability, the possibility for highly individualised meals and a cooling and/or heating of beverages and meals inside the associated compartments. The main goal of the concept is to serve meals to the passenger without distribution during the flight, enabling the optimisation of the process time and current required efforts. The concept provides each passenger with their desired meal and allows an individual time choice for meal consumption.

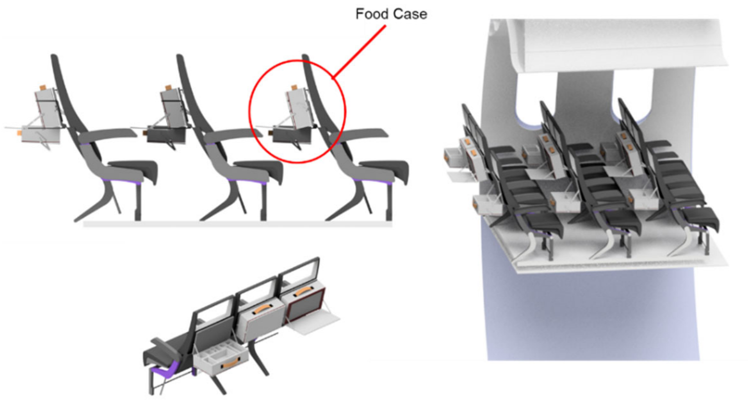



Figure 55 - Food case concept overview (Mortensen Ernits *et al.*, 2022a).

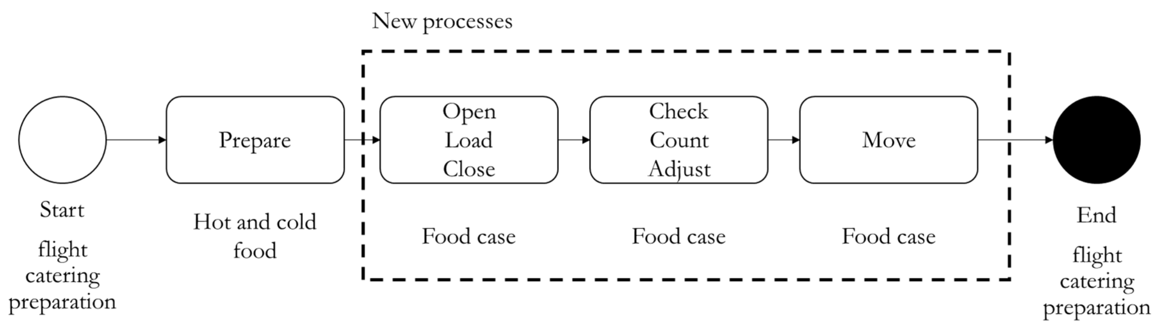



Figure 56 - Flight catering preparation with Food Case concept.

The meal inside the food cases could be pre-ordered by the passenger or it could be a pre-defined option offered by the airline. In case of the meal being pre-ordered and therefore individualized for each passenger, a grab-and-go system at check-in, at the gate, directly before boarding, or through a third party (e.g., caterer, cleaning team) could be used. This would mean that no prior placement of the food case is necessary and would guarantee that each passenger gets their order, even when they choose to change seats.

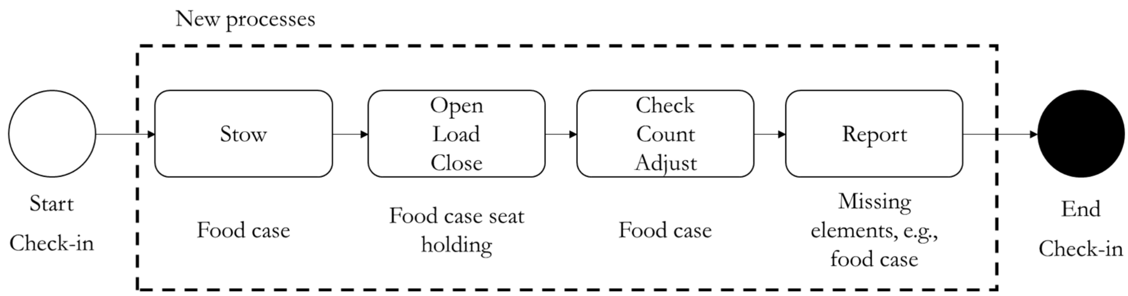



Figure 57 - Check-in, loading of catering goods, with Food Case concept.

The mechanical docking system enables the possibility to not only store the food case directly behind each passenger seat, but also integrate the food case into the inflight entertainment system.

Thus, allowing the integration of communication interfaces (e.g., displays, tablets) and a power supply.

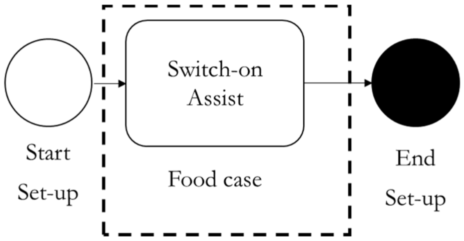



Figure 58 - Set-up phase, commissioning of the galley and trolley with Food Case concept.

The food case comprises an active or passive box composed of different compartments, individually configurable for cooling and warming inflight meals as well as passive (isolated) compartments for cutlery, bread or beverages. The concept foresees a thermal isolation of the food case to prevent passenger or cabin crew injuries (e.g., burning) and stressing the cabin air conditioning due to extra thermal load. Furthermore, a handle for easy transportation and a mechanical docking system is included.

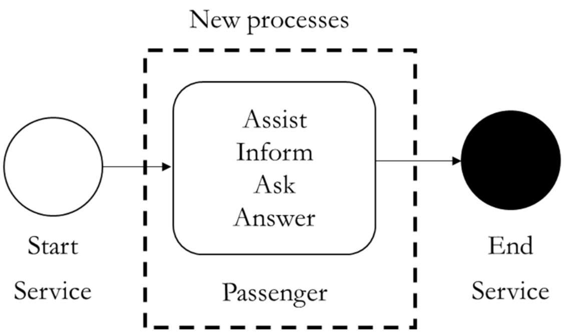



Figure 59 - Service phase, distribution of meals and beverages, with Food Case concept.

During the flight, the passenger may choose the meal-time as desired. As a result, cabin crew no longer need to be concerned with the distribution of meals, and thus are given more time to address other passenger needs

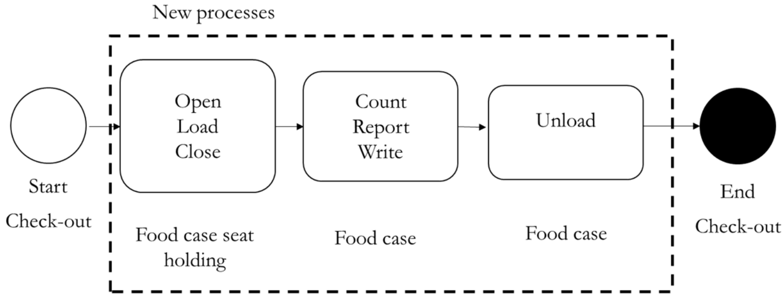



Figure 60 - Check-out phase, unloading catering goods out of the aircraft, with Food Case concept.

*C2 Galley*

The C2 galley concept is a central approach based on an automatic assembly machine. The main features include the storage of meals, preparation of hot meals, and assembly of meal trolleys.

The main goal of the concept is the automation of the preparation of distribution devices (e.g., trolleys) for inflight catering services. The galley concept automatically assembles the trolleys so that they are ready for service.

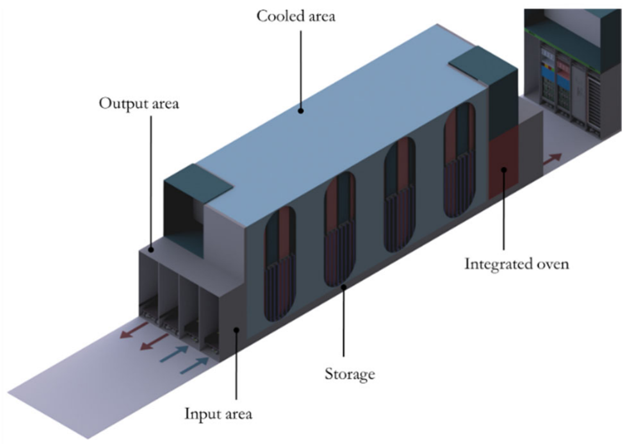



Figure 61 - C2 Galley concept overview (Mortensen Ernits *et al.*, 2022a).

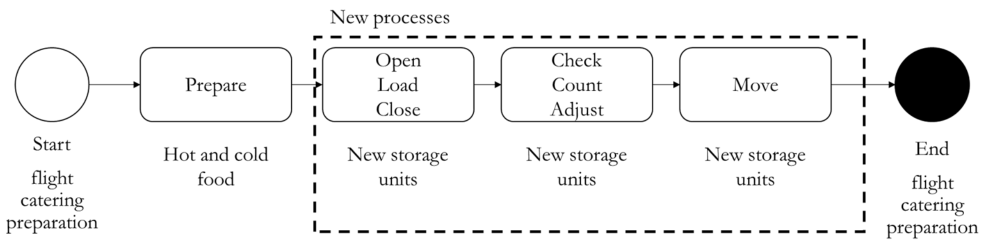



Figure 62 - Flight catering preparation with C2 Galley concept.

A new space arrangement inside of the new galley with specific functions is foreseen, within the use of new storage and distribution units. The assembly of the storage units is performed with a smaller number of movements and changes of level, directly over the distribution unit.

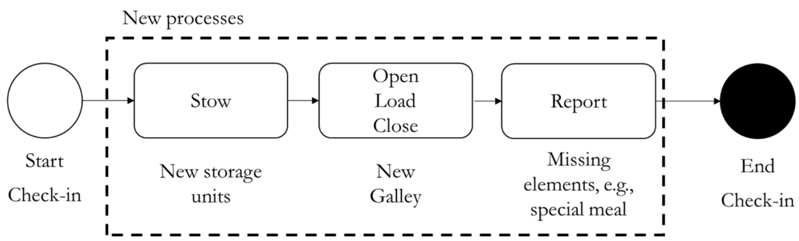



Figure 63 - Check-in, loading of catering goods, with C2 Galley concept.

The storage of units (e.g., casseroles or racks) can be placed on different levels or in normally unreachable areas, as they can be automatically moved through, e.g., a paternoster shelf or conveyer belt. This configuration allows the combination of different racks for composing the distribution device for service. Possibly, it would be the combination of two hot racks, one hot rack and one cold rack, or two cold racks, thus creating flexibility for the service process. The new system has hot and cold areas after preparation the storage units are assembled with the distribution unit.

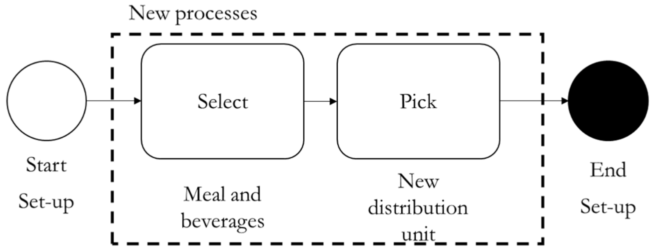



Figure 64 - Set-up phase, commissioning of the galley and trolley with C2 Galley concept.

The service is performed with a new distribution unit, featuring ergonomic functions and improved beverage dispensing functionalities.

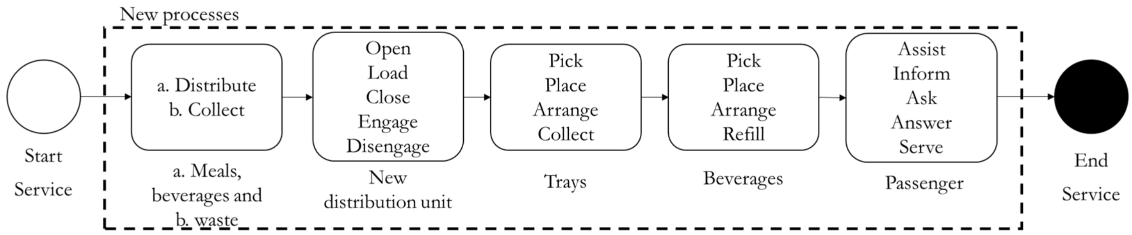



Figure 65 - Service phase, distribution of meals and beverages, with C2 Galley concept.

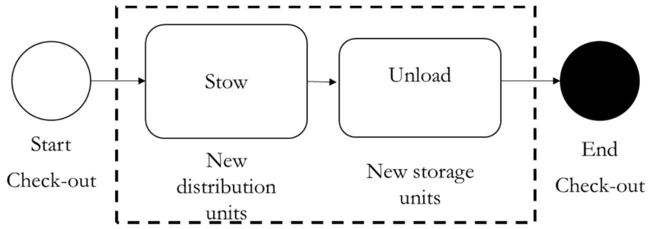



Figure 66 - Check-out phase, unloading catering goods out of the aircraft, with C2 Galley concept.

*Caterflow*

Caterflow is a comprehensive digital infrastructure with a reference architecture for software and hardware inside and outside the aircraft that ensures seamless tracking of goods and transport units across the entire flight catering supply chain. Caterflow enables a real-time digital inventory system with authentication and communication capabilities for optimising inflight catering services and coordinating related handling processes integrated directly into the aircraft. Caterflow matches data from passengers, aircraft, airlines, cabin crew, caterers, catering companies and flight planners.

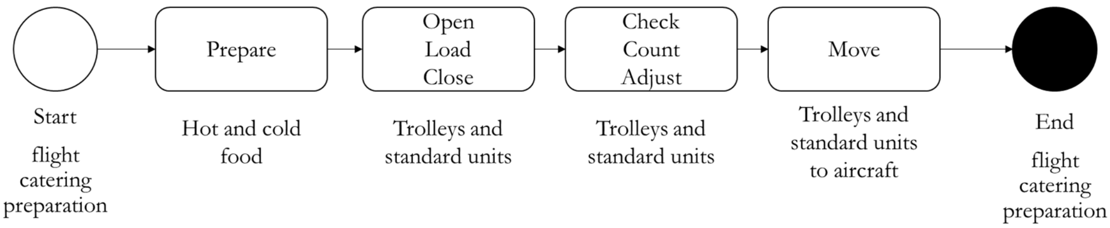



Figure 67 - Flight catering preparation with Caterflow concept.

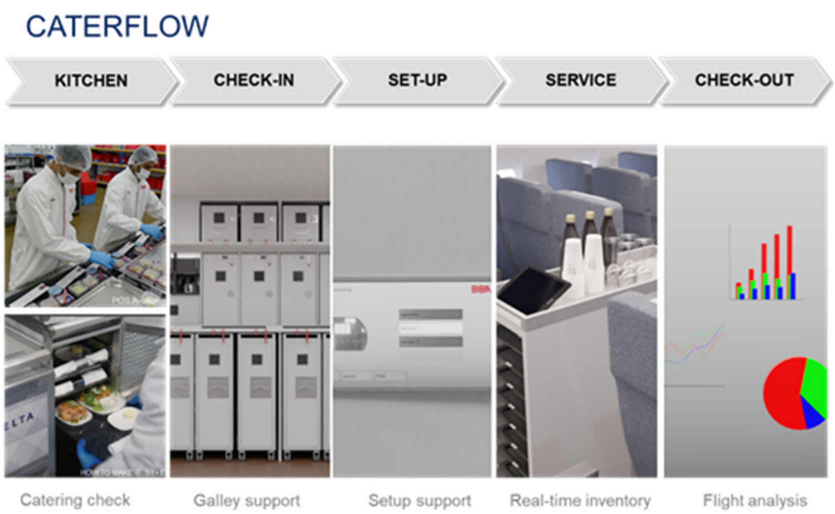



Figure 68 - Caterflow concept overview (Mortensen Ernits *et al.*, 2022b).

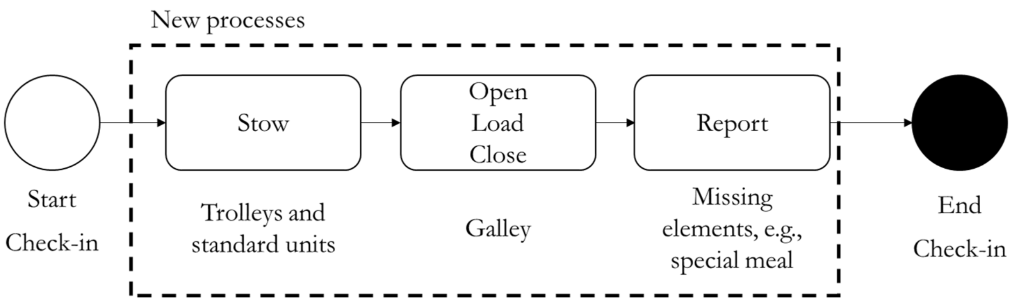



Figure 69 - Check-in, loading of catering goods, with Caterflow concept.

The system also can import and export data from various sources, including caterers and airline servers, and can synchronize with the aircraft to exchange information. It includes features for managing catering orders, including the amount of food, delivery times, and special issues, as well as loading plans and information on storage temperatures for specific orders. The system also includes features for auto check-in and caterer delivery through identification systems.

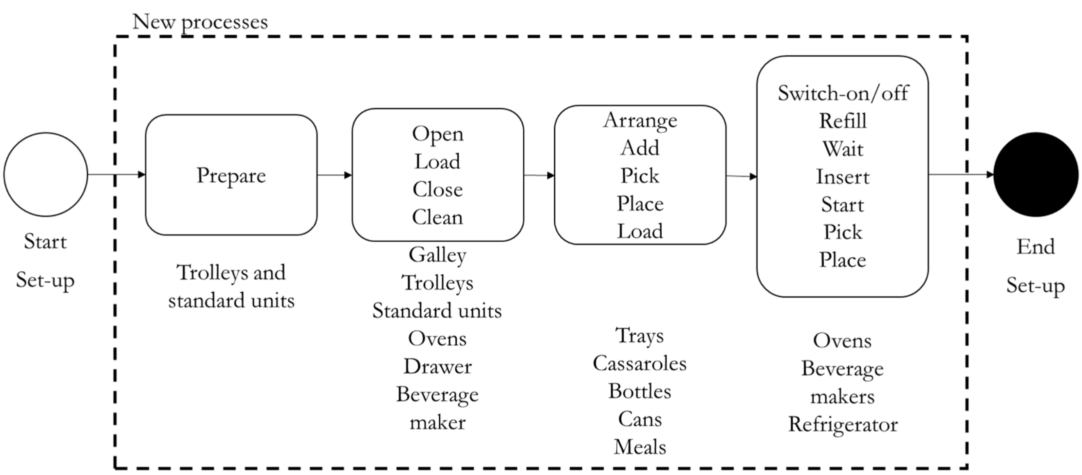



Figure 70 - Set-up phase, commissioning of the galley and trolley with Caterflow concept.

A new galley control panel is going be used to store catering information and coordinate the system. There are possible interfaces with other systems, e.g. smartphones, tablets, wearables, external devices and databases. The system can be implemented in different configurations depending on the number of functions required. The possibility of using an external storage service, such as a cloud service or a private database, extends the possibilities of data analysis and business intelligence. Flight attendant activities change minimally with system implementation and should be perceived as seamless. For the airline, it includes information on special offers and the service procedure, as well as details on the flight attendant workload and aircraft-specific information such as the cabin design and galley configuration. An auto-commissioning feature guides the flight attendant through the service preparation process, and the galley content can be visually displayed., as well as the ability to self-adjust ovens and assets for meal preparation. It provides a cabin overview, including the loading plan, passenger seat map, and status of assets, and allows for communication between cabin crew and the management of missing or extra orders.

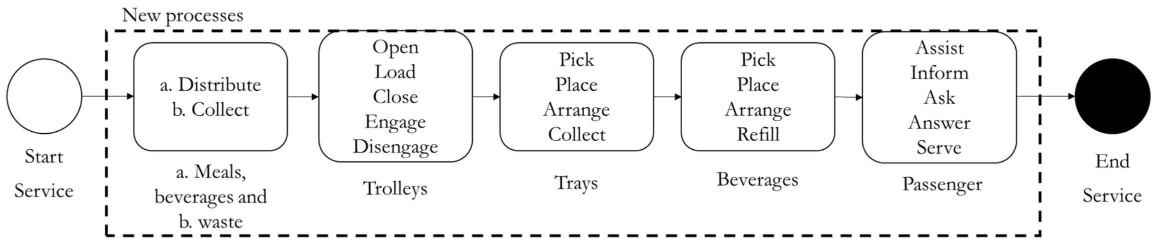



Figure 71 - Service phase, distribution of meals and beverages, with Caterflow concept.

For passengers, the system includes a digital ID system using biometric recognition and a platform for managing preferences and pre-ordering meals.

Hardware communication is divided into categories inside and outside the aircraft. The information flow at the lowest level comes from the QR code or barcode reading of the tablets. This information is sent during the service via the service tablet, which is connected to the trolley ID via the NFC tag. The tablet communicates with the Galley Control Panel via a WiFi connection and updates the contents of the Galley.

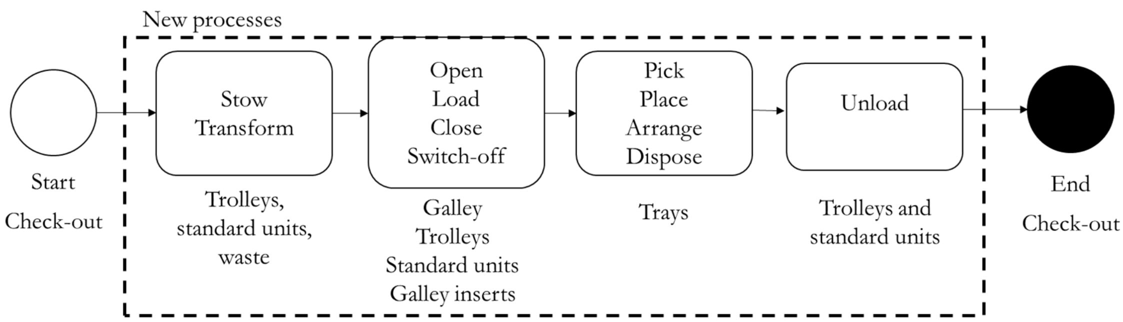



Figure 72 - Check-out phase, unloading catering goods out of the aircraft, with Caterflow concept.

Caterflow is a tool for managing and analysing food consumption and other items during a flight. It allows for the tracking of passenger consumption and the recycling of items, as well as the analysis of waste and raw data from previous flights to the same destination. After the flight, the galley control panel connects to a server outside the galley and exchanges the flight information. The server can be a local or cloud-based server with the ability to extract the data for analysis.

*3_ICS Modelling and analytics*

Table 23 - Calculation of indexes for the concepts.

| | Index | Food case | C2 Galley | Caterflow |
|---|---|---|---|---|
| 1 | Storage Index | 800,0 | 700,0 | 215.4 |
| 2 | Space Efficiency | 37,9 | 69,9 | 88.5 |
| 3 | Galley Workspace Ratio | 100,0 | 76,5 | 60.0 |
| 4 | Catering Index | 94,2 | 94,2 | 94.2 |
| 5 | Catering Efficiency | 75,4 | 65,9 | 20.3 |

Table 24 - Level of automation for the concepts and individual process phases.

| | Total tasks (is_process) | Food case | C2 Galley | Caterflow |
|---|---|---|---|---|
| Check-in | 8 | 8 | 5 | 5 |
| Check-in LoA | | 0 | 2 | 2 |
| Set-up | 22 | 2 | 2 | 17 |
| Set-up LoA | | 5 | 5 | 2 |
| Service | 20 | 4 | 20 | 20 |
| Service LoA | | 3 | 0 | 0 |
| Check-out | 14 | 7 | 2 | 11 |
| Check-out LoA | | 2 | 4 | 2 |
| Total tasks | 64 | 21 | 29 | 53 |
| %Automated tasks | | 60% | 45% | 17% |
| Overall LoA | | 3 | 2 | 2 |

Functional mock-ups (extract)

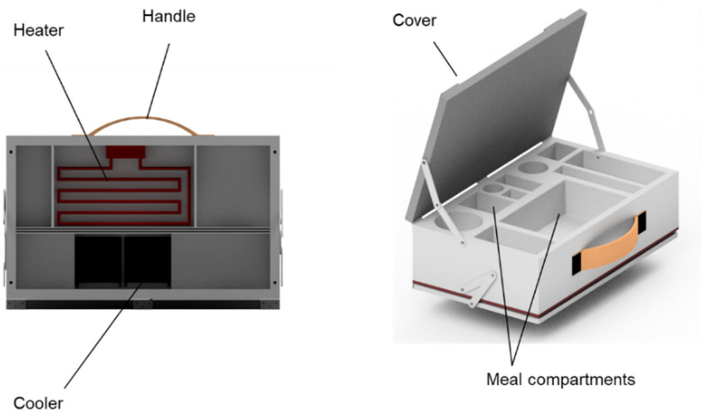



Figure 73 - Food case mock-up (Mortensen Ernits *et al.*, 2022a).

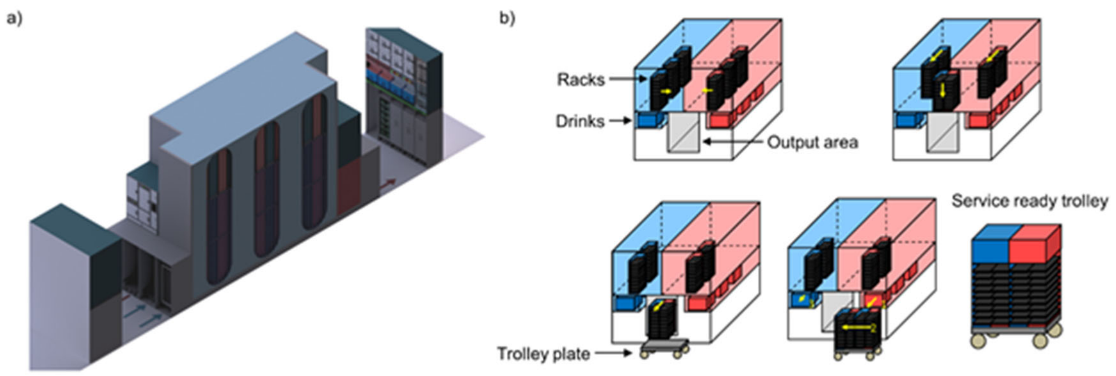



Figure 74 - C2 Galley mock-up (Mortensen Ernits *et al.*, 2022a).

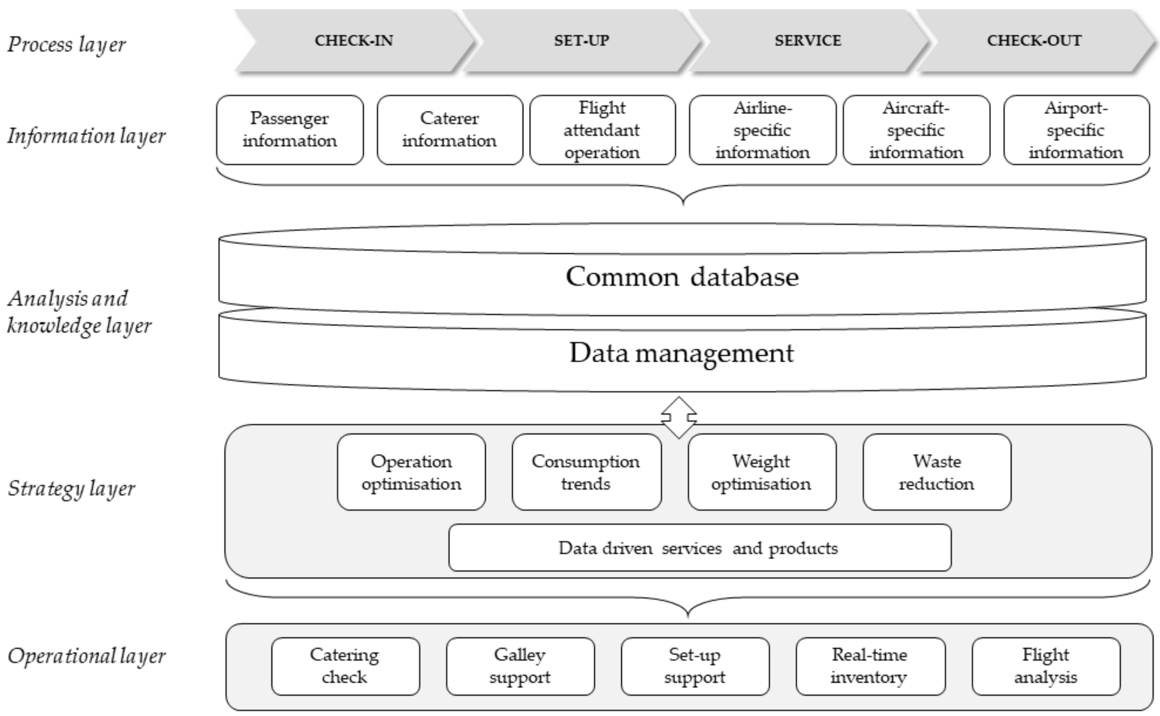



Figure 75 - Caterflow reference architecture (Mortensen Ernits *et al.*, 2022b).

*4_ICS Concept choice*

For ranking the concepts the defined KPIs were used, the criteria were weighted together with experts during a workshop. Also the developed indexes and LoA were part of the concept ranking as shown in Table 25. Five experts from Airbus galley engineering supported the weighting of the requirements (from: 0 – non relevant, to: 1 – most relevant) and afterwards the scoring of concepts (from 1: worst, to 4: best; concept in relation to each other).

The key benefits of the chosen concept, Caterflow, will be further described. Caterflow is a concept that offers several key benefits for both passengers and airlines. One of the main benefits of Caterflow is the ability to individualise meals for passengers, which can help improve the overall inflight experience and customer satisfaction. This is achieved through the ability for passengers to pre-order and express their meal preferences. Caterflow also offers a reduction in the workload of cabin crew by streamlining documentation and processes, which can lead to improvements in turnaround operations and communication. Additionally, Caterflow can help improve airlines' environmental footprint by reducing fuel consumption and waste, contributing to cost savings. Finally, Caterflow can help generate additional revenues through pre-ordering, special orders, re-catering, and data-driven service, making it a valuable tool for improving airline operations' overall efficiency and profitability.

Most of the challenges for flight catering are related to the variety and amount of items to transport, the stakeholders, and the change of location intrinsic to flight mobility. An overview of all products and equipment can substantially improve the whole process, and it can open new ways for performing the inflight catering service. Currently, there is no end-to-end solution for the entire flight catering supply chain.

The increasing degree of digitisation worldwide leads to a market environment with new overarching fields of action, forms of cooperation, and responsibilities. Flight catering is part of these changes observed in an increasing digital offer for pre-ordering inflight meals during check-in and the use of mobile devices to streamline taking passenger´s orders and customising them, especially for business class. There are also software solutions providing forecasting, onboard planning, and trolley and asset tracking. Clear industry boundaries are softening increasingly and previously independent subsystems are now networked. The new upcoming technologies enable much intensive interaction with operative processes. Information is the critical driver for integrating processes into the actual and future market demands.

An integrated inventory management system in the aircraft is a natural step for the digitisation of flight catering services; the added value can expressively change the way catering is done.

Table 25 - Concept ranking and choice.

| Criteria | Weighting | C2 Galley | Caterflow | Food Case |
|---|---|---|---|---|
| Operational efficiency | 1 | 2 | 4 | 3 |
| Safety and health impact | 1 | 4 | 2 | 3 |
| Ease of use (zero training) | 1 | 3 | 4 | 2 |
| Durability and robustness | 1 | 2 | 4 | 1 |
| Impact on galley footprint | 0,3 | 3 | 1 | 4 |
| Impact on catering chain | 0,4 | 3 | 3 | 3 |
| Weight | 1 | 1 | 2 | 3 |
| Cost (for device) | 0,8 | 1 | 4 | 2 |
| Development lead time | 0,8 | 1 | 4 | 3 |
| Environmental impact | 0,5 | 1 | 3 | 2 |
| LoA | 0,5 | 3 | 2 | 4 |
| Storage Index | 0,4 | 3 | 2 | 4 |
| Space Efficiency | 0,8 | 2 | 1 | 3 |
| Galley Workspace Ratio | 0,3 | 2 | 1 | 3 |
| Catering Index | 0,4 | 2 | 2 | 2 |
| Catering Efficiency | 0,6 | 2 | 1 | 3 |
| Ranking | | 23,1 | 29,7 | 28,9 |

*5_Process integration*

As part of the feasibility study, the system was oriented in a user story, which is encapsulated in the aircraft. It starts with 1. Check-in of the aircraft catering delivery goes to 2. Set-up of the galley for each service and to 3. Service itself and finally after the flight 4. Check-out is where the flight will be summarised, the data will be transferred to a server, and the caterer will collect the trolleys and standard units. The Economy Class is considered for the concept development. This is due to the large number of passengers that are here served in a similar manner; the saving potential is higher than in the premium classes, where usually more individualised services will be provided.

This contribution aims 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 78. 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.


Figure 76 - Overview of process steps for integrating Caterflow.

The process layer has been extended with “kitchen”, because catering checks are performed by caterers in the flight kitchen as shown in Figure 76.

Table 26 - Mission profile for evaluating Caterflow.

| Mission profile | |
|---|---|
| Aircraft type | A350-900 Long-range operation |
| Airline type | Full Service Carrier |
| Duration | 10 hours |
| PAX economy class | 226 PAX |
| Sum flight attendants economy class | 5 flight attendants |
| Thereof flight attendants for service | 4 flight attendants |
| Thereof flight attendants for galley | 1 flight attendant |

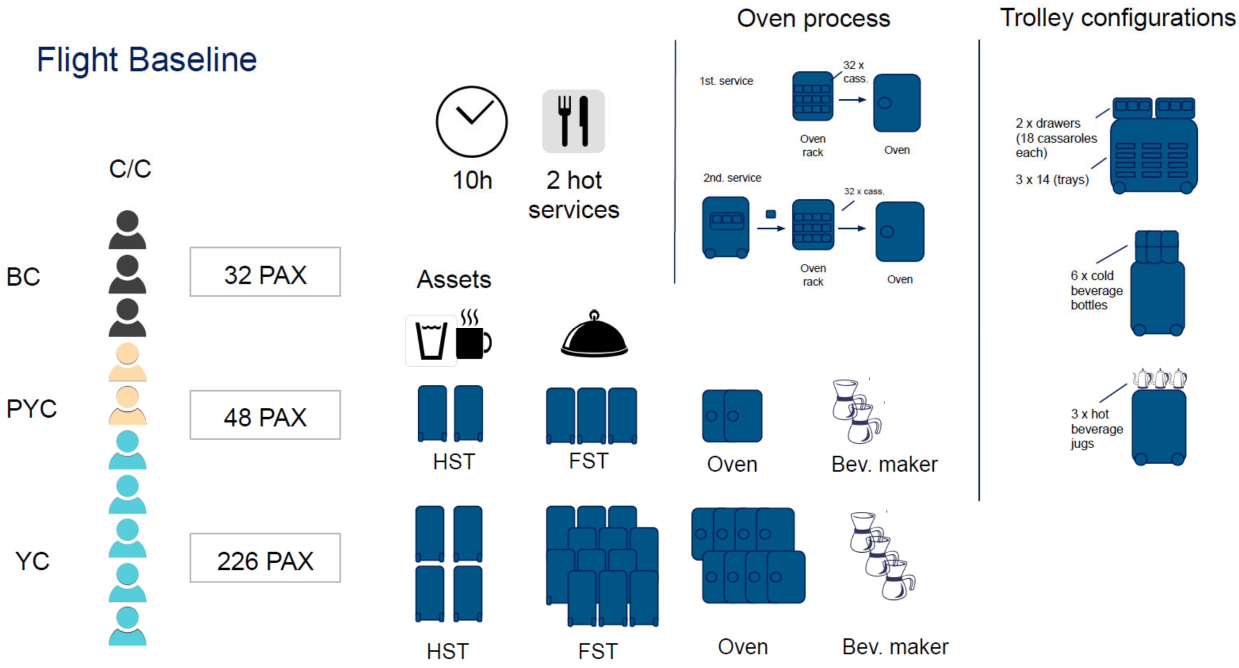



Figure 77 - Summary of flight baseline for Caterflow.

In this scenario, Figure 79 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).

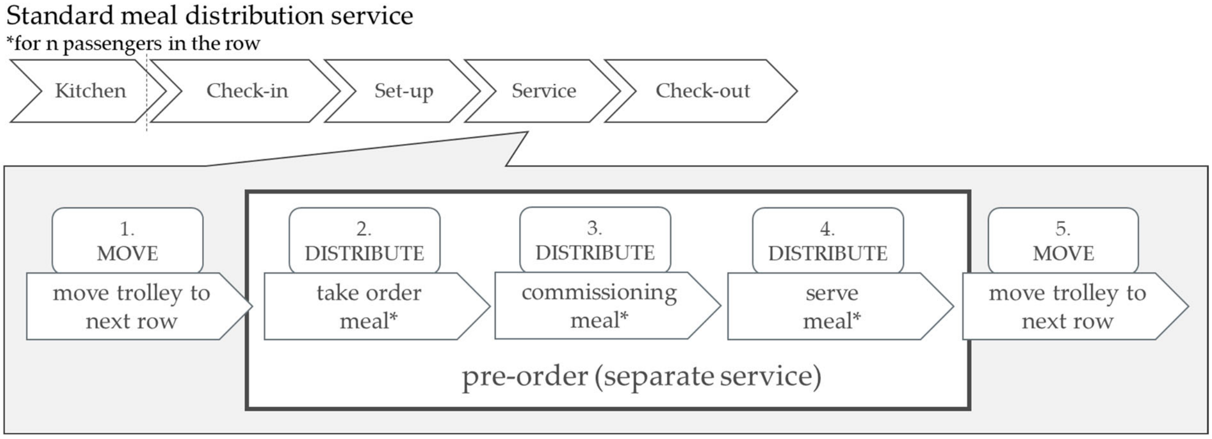



Figure 78 - Process steps of a standard meal distribution service to a passenger (Mortensen Ernits *et al.*, 2022b).

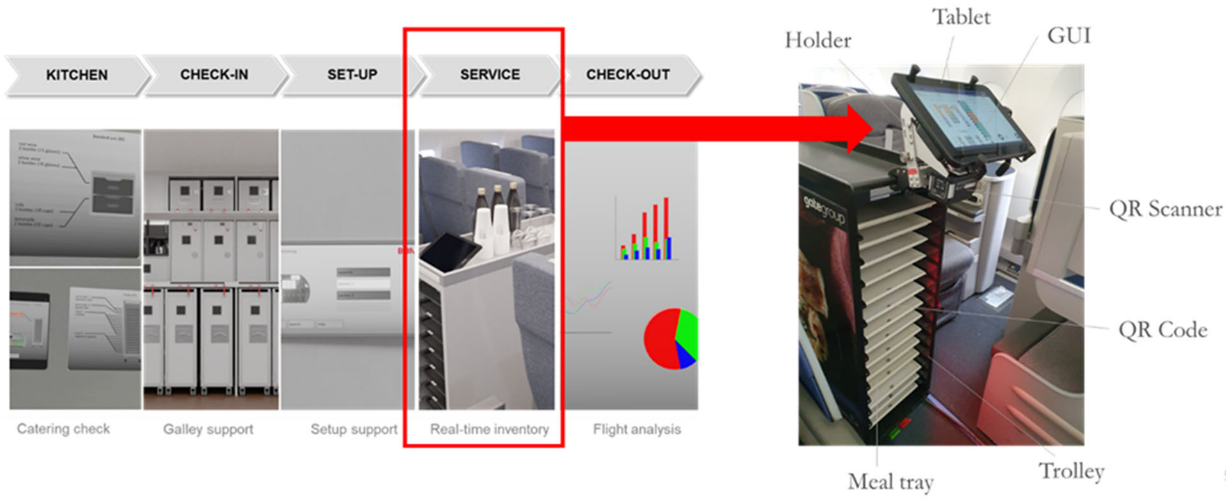



Figure 79 - Concept demonstration for inflight meal individualisation (Mortensen Ernits *et al.*, 2022b).

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.

*6_Validation*

The validation of the Caterflow demonstration is shown in detail in the published contribution. In this section, some aspects are going to be presented. A set-up was built to validate the concept, as shown in Figure 80. 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.

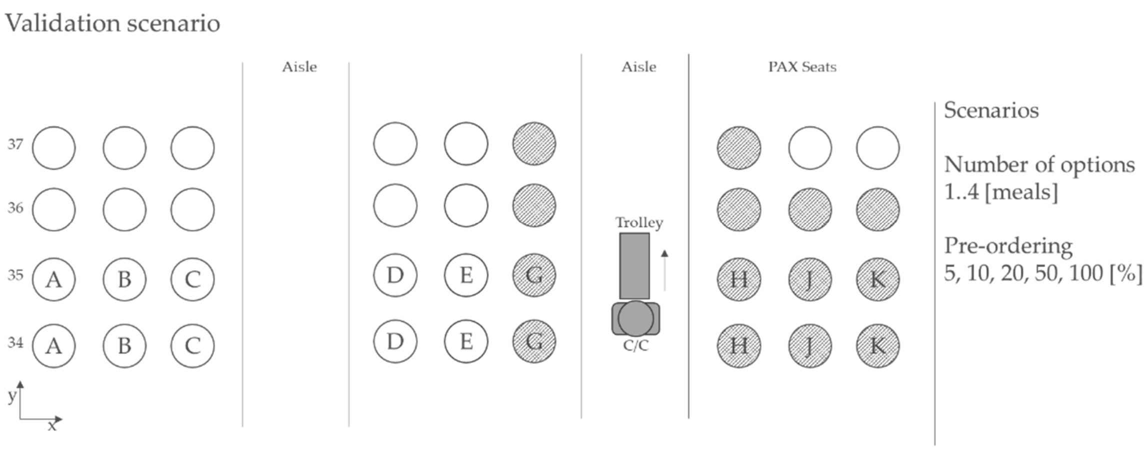



Figure 80 - Validation scenario for caterflow (Mortensen Ernits *et al.*, 2022b).

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 of many people to gather. 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 81. In the future, further steps and possible deeper analysis will be suggested.

Figure 81 - Validation set-up, from left to right: demonstrator, cardboard for passenger orders, and GUI demonstrator. (Mortensen Ernits *et al.*, 2022b)

The evaluation of the demonstrator was performed by observation and time registration; the recording settings are presented in Figure 82, with three cameras and a timer included in the software, which was triggered by the scanning of the trays.

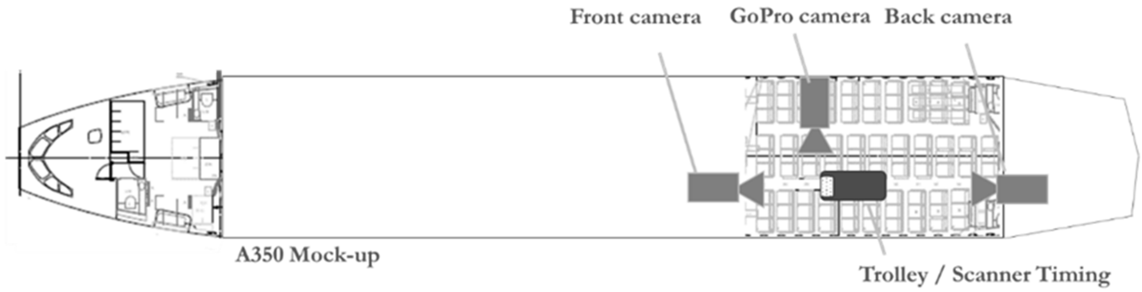



Figure 82 - Validation recording settings (Mortensen Ernits *et al.*, 2022b).

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. The comparison between all tests regarding the increase in meal options and the average meal distribution time per passenger is shown in Figure 83. In general, the service time increased with more options; in the 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.

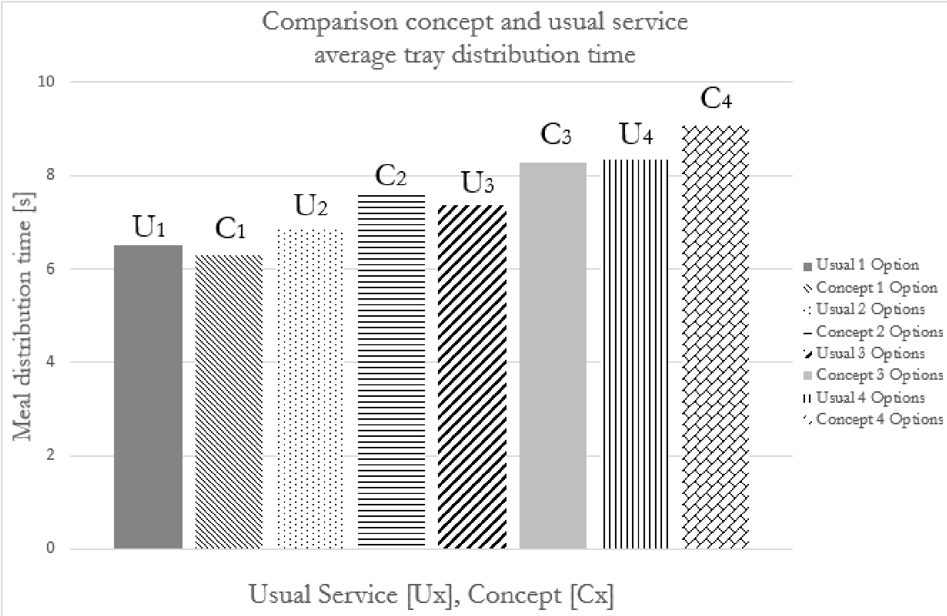



Figure 83 - Comparison of the standard service with the new concept service (Mortensen Ernits *et al.*, 2022b).

An average time comparison is shown in Figure 84; hereafter, the average meal distribution time did not increase above 10% pre-ordering (C2,p).

Scaling up to more passengers has a time-saving potential following the number of pre-orders. The difference between a standard distribution service without pre-ordering and the distribution service with the new concept was $\Delta_{po}$. After a certain amount of pre-ordering, the process distribution time ($T_{po}$) stayed roughly constant, as shown in Figure 84.

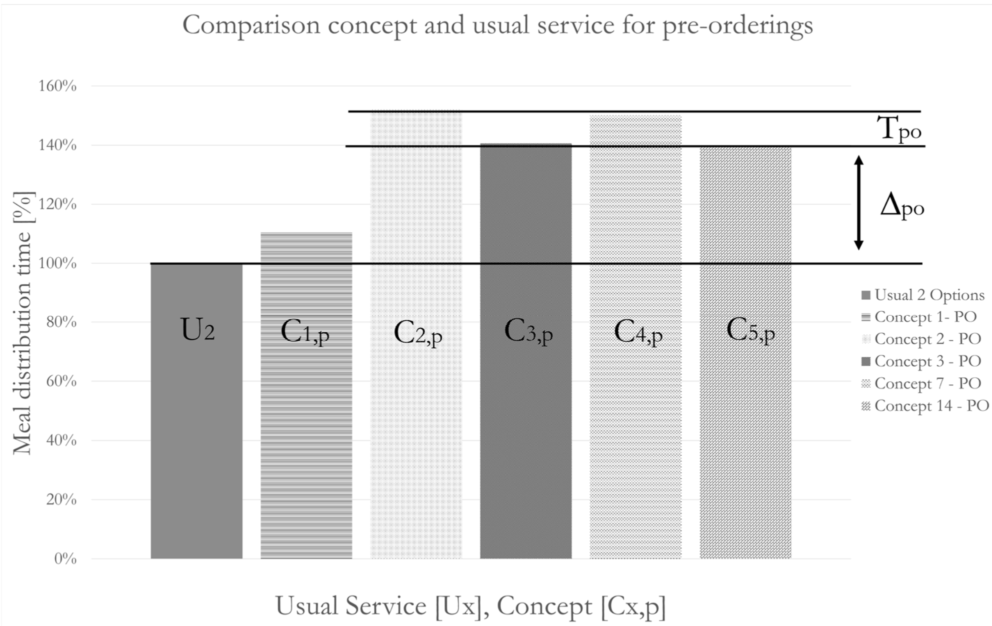



Figure 84 - Comparison of meal distribution service time with an increased number of pre-orders, shown in percentages (Mortensen Ernits *et al.*, 2022b).

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 the flight attendant's grasp of the tray 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.

*7_TRL Review*

The applied technology readiness level review – TRL Review, for the automation of inflight catering services has a strong relationship with the developed framework. For preparing the TRL Review, key aspects from different steps can be used to guide the review process. The aim is to expand the current TRL scale with aspects related to inflight catering services. In the exercise, the derivation of key aspects from the multicriteria decision-making evaluation framework for ICS automation was implemented until TRL 4.

An outlook for an evolution strategy is shown in Figure 86. The incremental automation of inflight catering services starts with the digitisation of the processes in the near term, e.g., with Caterflow. This first approach looks for low efforts for optimisation based on today 's standards. If follows concepts that may profit from digitisation, e.g., trolley support unit, where small changes aiming on reducing flight attendant´s workload are implemented without changing standards, further, to highly automated and autonomous systems disrupting current processes and changing standards.

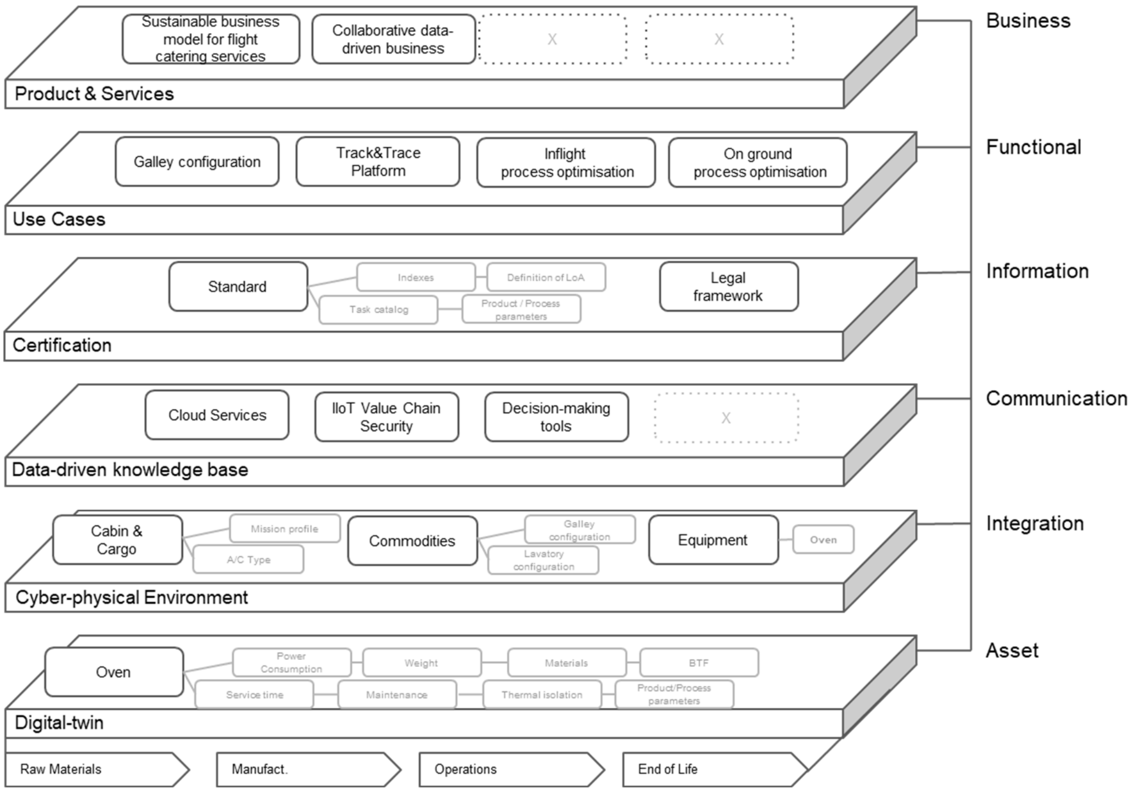


Figure 85 - Caterflow evolution based on cyber physical systems (Mortensen Ernits *et al.*, 2022b).

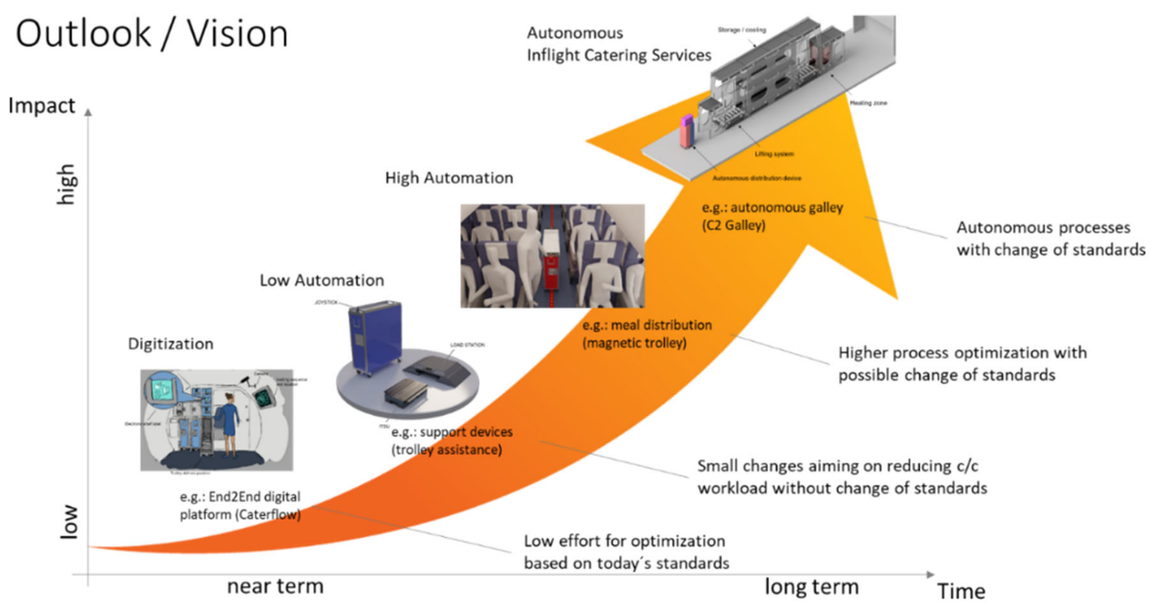



Figure 86 - Outlook for the further development of concepts for inflight catering services automation.

Also a visualisation of further evolution of the Caterflow concept has been developed, in this example, based on a cyber-physical system approach shown in the Figure 87 based on Frank (Frank,. *et al.* 2018).

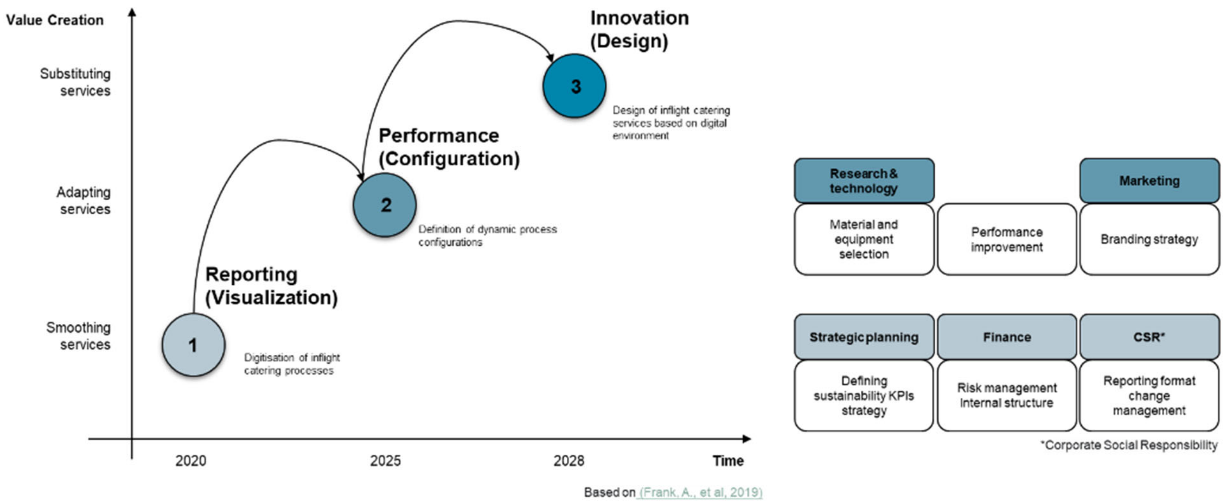



Figure 87 - Caterflow value creation of digitial services (Frank,. *et al.* 2018).

Table 27 - Applied TRL Review for the automation of inflight catering services.

| **TRL** | **Definitions** | Performance | Engineering | Manufacturing & Industrialisation | Operations | Value & Risk |
|---|---|---|---|---|---|---|
| 1 | Basic principles observed and reported | 0. ICS Demand PI-PSO : Requirements | 1. ICS Process analysis: Process interfaces | 0. ICS Demand PI-PSO : Processes | 2. ICS Automation concepts: To_be process | 4. ICS Concept choice: Key benefits |
| 2 | Technology concept and/or application formulated | 2. ICS Automation concepts: To_be process | 3. Modelling and analytics: Indexes, LoA, Functional mock-up | 6. Validation: Specification | 5. Process integration: Scenario choice | 7. TRL review: Impact on internal processes |
| 3 | Analytical and experimental critical function and/or characteristic proof of concept | 6. Validation: Level of process optimisation | 4. ICS Concept choice: Concept ranking & choice | 8. Development loop: Concept refinement | 5. Process integration: Stakeholder integration | 5. Process integration: Business case |
| 4 | Component and/or breadboard validation in laboratory environment | 6. Validation: Level of impact | 2. ICS Automation concepts: Technology assessment | 8. Development loop: Concept refinement | 8. Development loop: Concept of operation | 7. TRL Review: Definition of evolution strategy |

*8_Development loop*

During the development loop, continually assessing and improving the concept is essential. One improvement that could be made is to address the issue of the product coming out of the tablet support holding system. This involved redesigning the mount support and implementing additional measures to secure the tablet in place. Additionally, improvements in software were continuously implemented, exploring options for a barcode reader, e.g., with QR code, and further developing the app or GUI, helping streamline the use of the concept. Also, the pilot tests with caterers and airlines to gather feedback and make any necessary adjustments were performed, during the CET- customer experience team, a meeting with major airlines to demonstrate the technology. For further improvement, standardising procedures and implementing certification at caterers can possibly help improve the concept. Besides, implementing a beverage inventory system and including artificial intelligence methods for analysis can help improve the overall efficiency of the concept. Finally, adding a feature for trolley set-up visualisation can support flight attendants for better commissioning, as well as for supporting catering loading.

The documentation regarding concepts of operation should be organised in the following chapters:

- Context
- System of interest
- Scenarios and use cases
- Top-level performance objectives
- Fundamental principles
- Normal operating procedures
- Exception handling

*9_Technology transfer*

IP Protection & Management

The following patent generated from the concept Caterflow has been published:

EP3552962A1—System for inventory management of on-board refreshments for a vehicle

In conclusion, the execution of the overall-system's prototypical implementation, addressing the demand for individualized meals within the aircraft cabin, was successfully carried out. The feasibility of the proposed framework was demonstrated, facilitating the subsequent comparison of concepts and enabling the selection of the most suitable concept through the proposed methodology. The integration of the chosen concept, Caterflow, and its associated validation within the framework was achieved, with the results being disseminated. Furthermore, the chapter highlighted the integration of this process within the Technology Readiness Level (TRL) Review, emphasizing the meticulous documentation and protection of intellectual property throughout the entire endeavor. Overall, this chapter not only showcased the practical application of the proposed framework but also underscored its adaptability and effectiveness in addressing complex challenges within the aircraft galley development domain.

# 6 Evaluation and application

The evaluation and application of the multicriteria decision-making framework for selecting automation concepts for inflight catering services is applied in the current technologies and concepts.

## 6.1 Evaluation of the subcomponents

A survey was performed to evaluate the levels of automation. The survey has been done online by the use of a presentation and "Google Forms", with three experts, each possessing at least three years of experience in Airbus engineering division within galley development. In the presentation, the galley was defined as the monuments, trolleys, storage spaces and electronical components, like ovens or beverage makers, that are used to prepare and serve meals to the passenger. The goal of the survey was to test the developed levels of automation (LoA) scale and to find potential for improvement.

A baseline process was chosen for exemplifying the use of a specific level of automation for galley concepts or galley inserts. The process is a simple heating process of meals and placing them on top of a trolley. However, the process slightly varies for each concept. The baseline process follows the following process steps:

1. 'pick' casserole/box
2. 'move' casserole/box
3. 'place' casserole/box inside oven
4. 'insert data' e.g. temperature and time into oven
5. 'start' heating process
6. 'transform' casserole from cold to hot
7. 'pick' casserole/box from inside the oven
8. 'move' casserole/box
9. 'place' casserole/box on top of trolley.

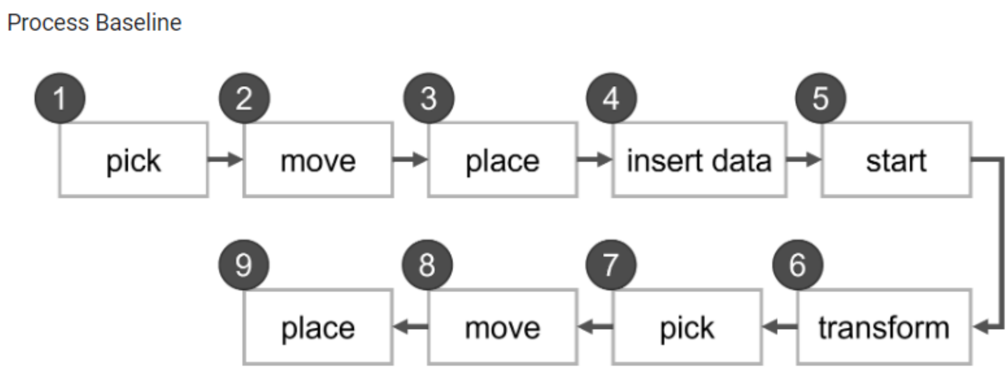



Figure 88 - LoA preliminary study - survey process baseline.

After each concept, a table with automation levels and their description is shown. You must sort the level that you think matches best to each concept.

| | LoA | Description |
|---|---|---|
| 1 | manual | The process/system/concept is manual. There is only little automated support regarding physical movement or data processing. |
| 2 | manual with automated support | The process/system/concept is mainly manual, with automated support regarding physical movement or data processing. |
| 3 | automated with manual support | The process/system/concept is mainly automated with manual support regarding physical movement or data processing. |
| 4 | automated | The process/system/concept is completely automated. There is only little manual support regarding physical movement or data processing. |
| (5) | (autonomous) | (The process/system/concept is nearly completely automated and capable of reacting to environmental changes by making own decisions, without human interaction. Therefore it's autonomous.) |

Figure 89 - LoA preliminary study - Levels of Automation for inflight catering services.

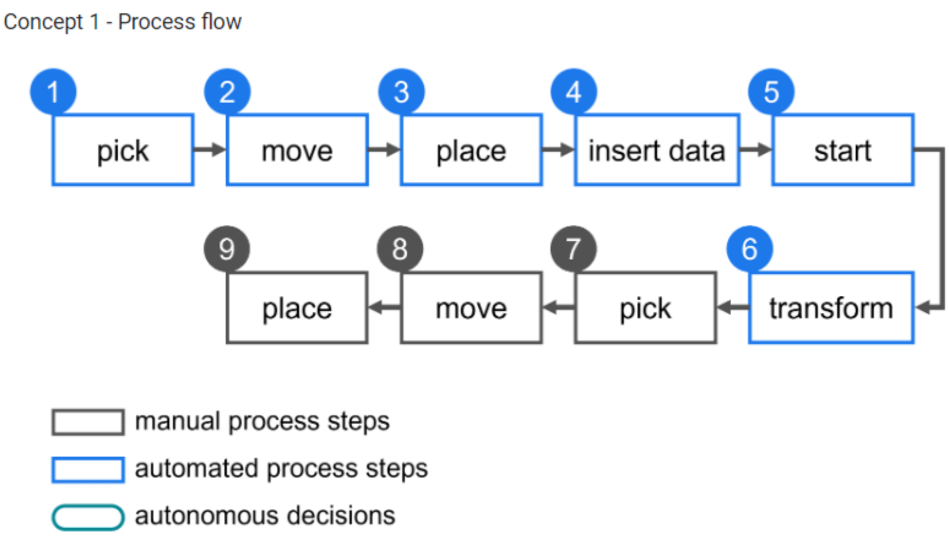



Figure 90 - LoA preliminary study - process flow for concept 1.

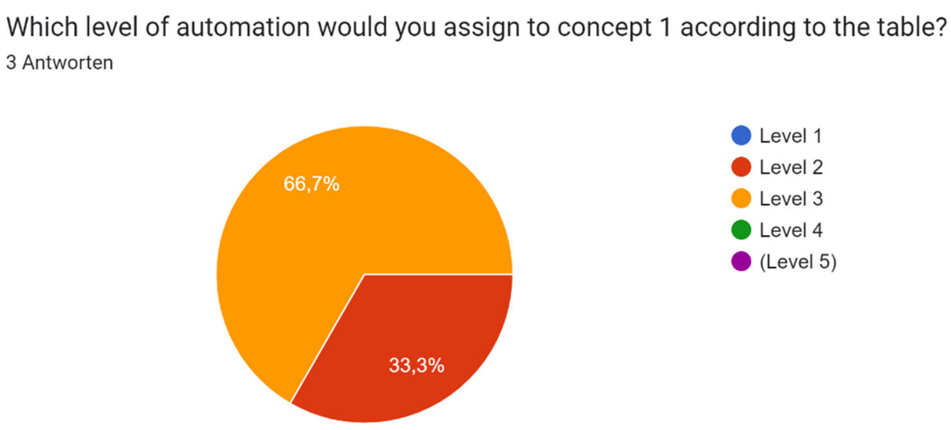



Figure 91 - LoA preliminary study - expert assessment LoA assessment for concept 1.

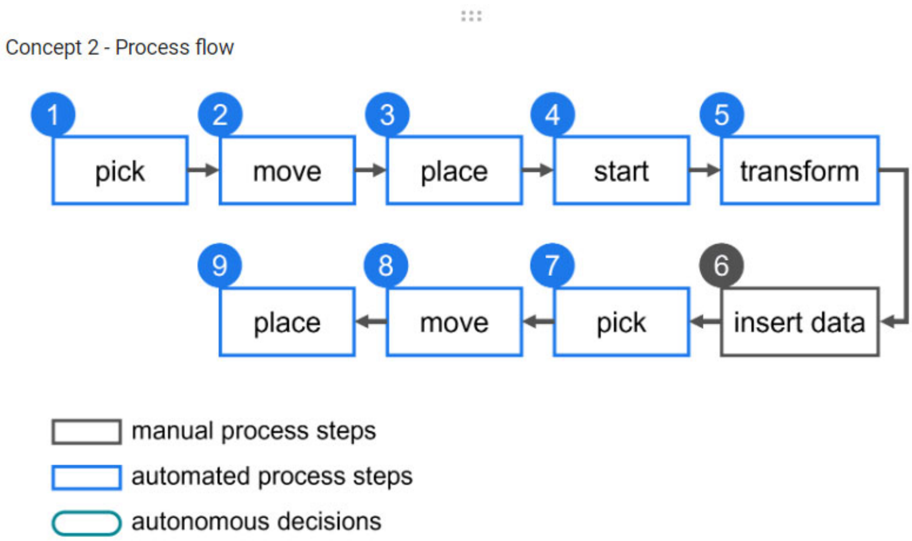



Figure 92 - LoA preliminary study - process flow for concept 2.

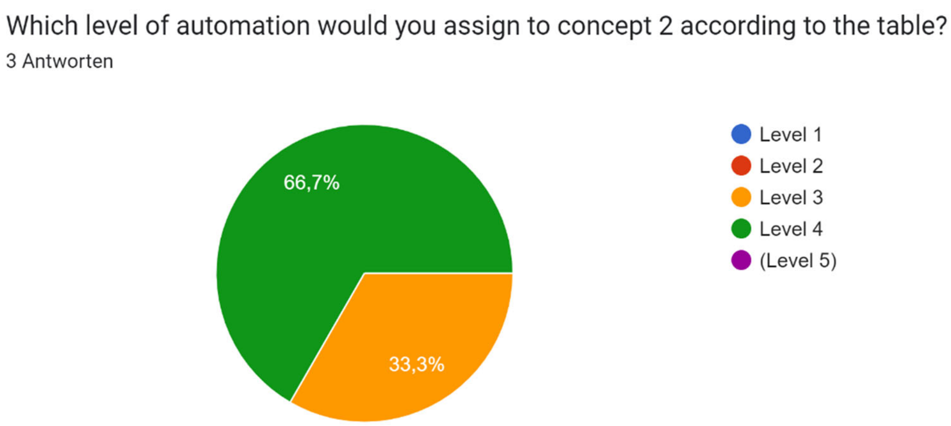



Figure 93 - LoA preliminary study - expert assessment LoA assessment for concept 2.

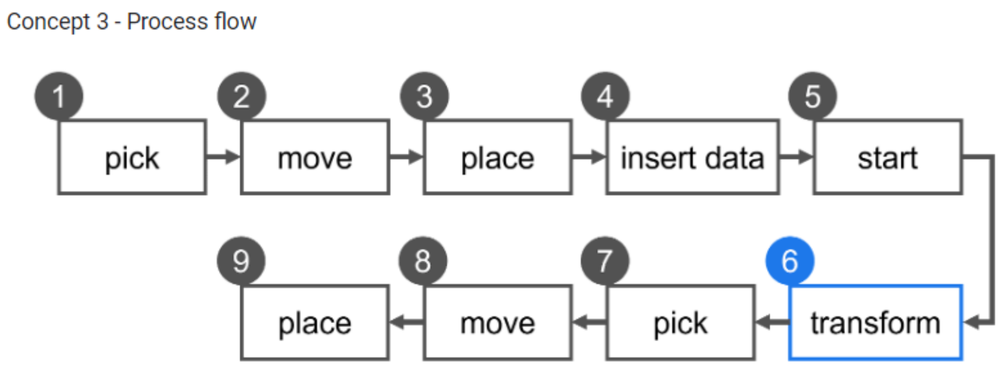



Figure 94 - LoA preliminary study - process flow for concept 3.

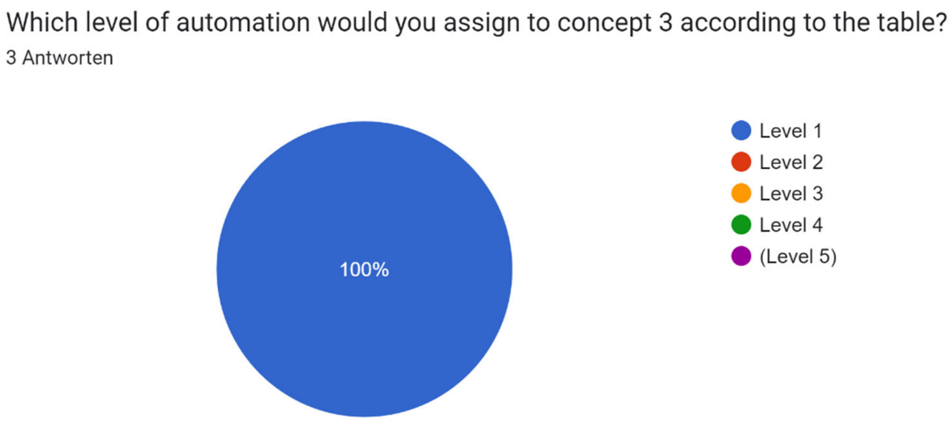



Figure 95 - LoA preliminary study - expert assessment LoA assessment for concept 3.

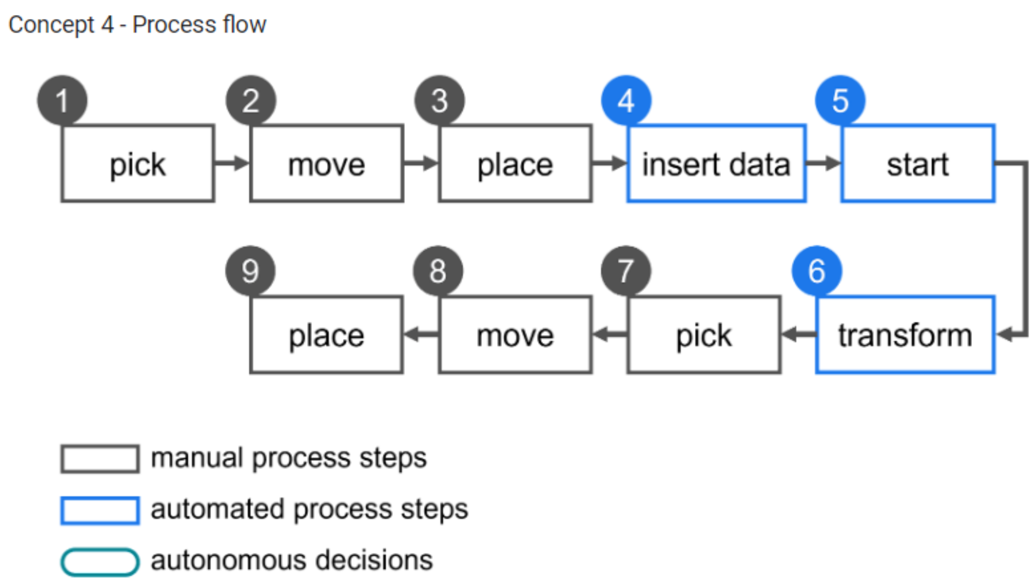



Figure 96- LoA preliminary study - process flow for concept 4.

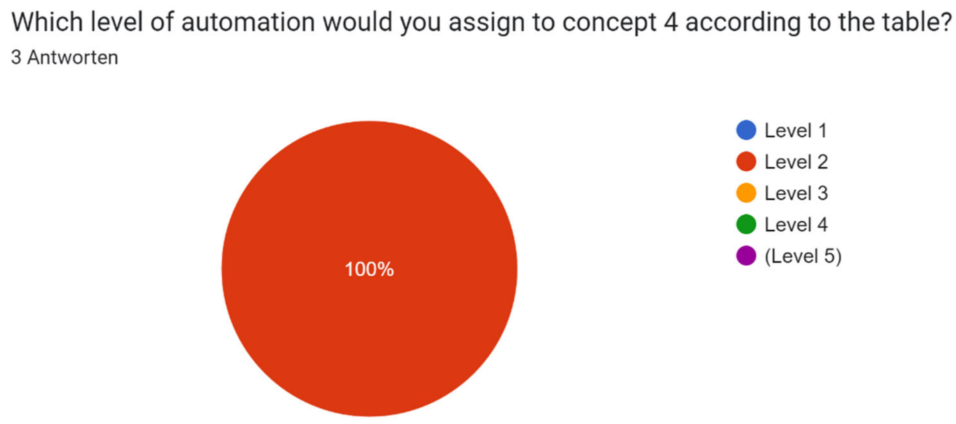



Figure 97 - LoA preliminary study - expert assessment LoA assessment for concept 4.

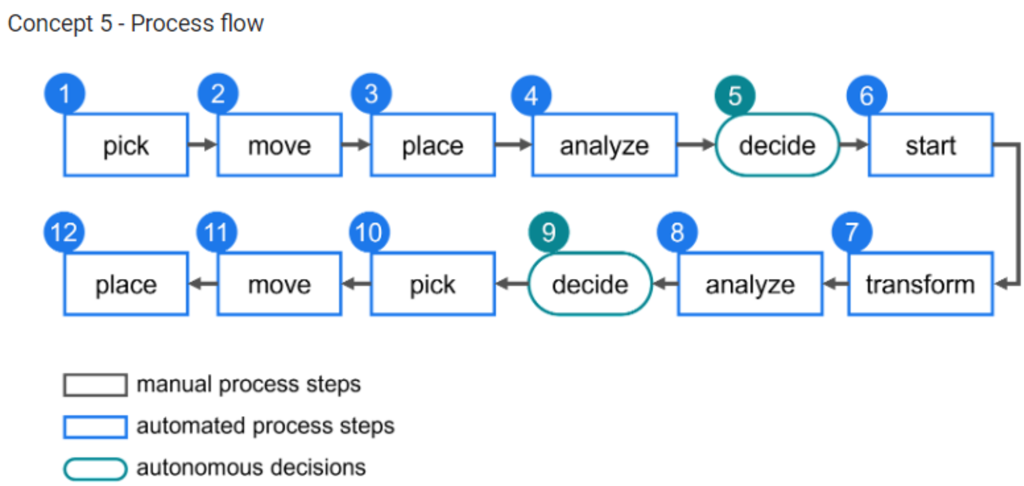



Figure 98 - LoA preliminary study - process flow for concept 5.

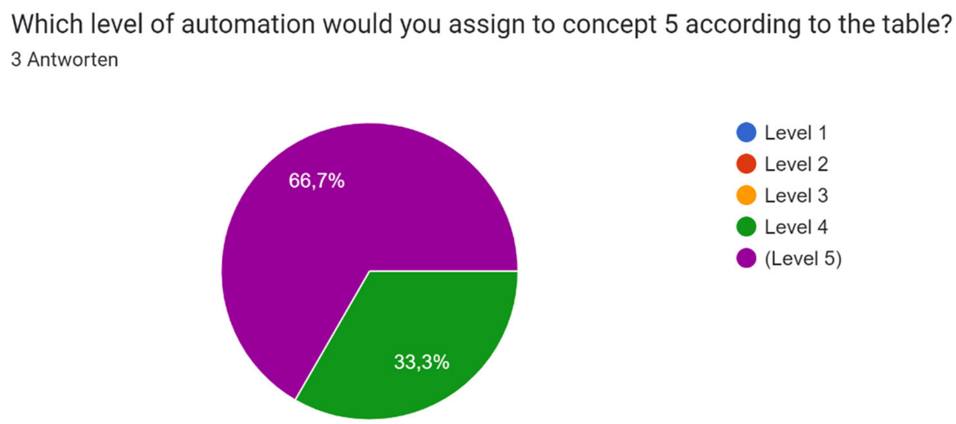



Figure 99 - LoA preliminary study - expert assessment LoA assessment for concept 5.

Which level of automation would you assign to each concept according to the table? *

| | LoA | Condition |
|---|---|---|
| 1 | manual | **manual > 85 %;** automated < 15 % |
| 2 | manual with automated support | **manual > 50 %;** automated < 50 % |
| 3 | automated with manual support | manual < 50 %; **automated > 50 %** |
| 4 | automated | manual < 15 %; **automated > 85 %** |
| (5) | (autonomous) | (manual < 15 %; automated > 85 %; **≥ 50 % of decisions autonomous**) |

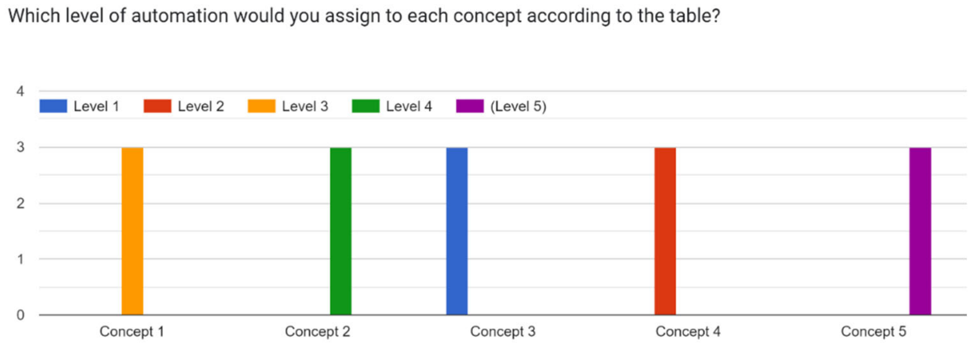



Figure 100 - LoA preliminary study - expert assessment LoA assessment for all concepts according to LoA table.

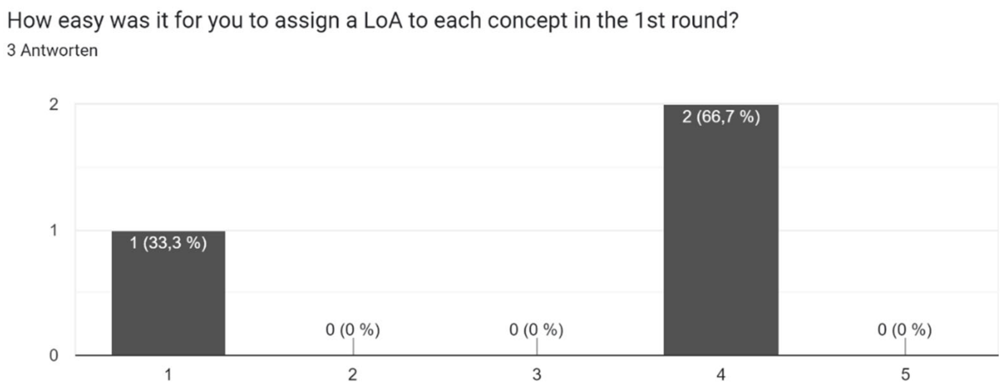



Figure 101 - LoA preliminary study - expert usability assessment first round.

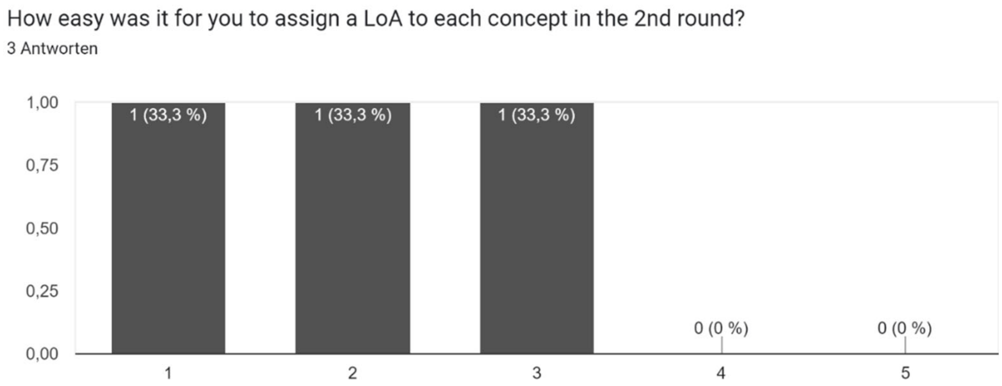



Figure 102 - LoA preliminary study - expert usability assessment second round.

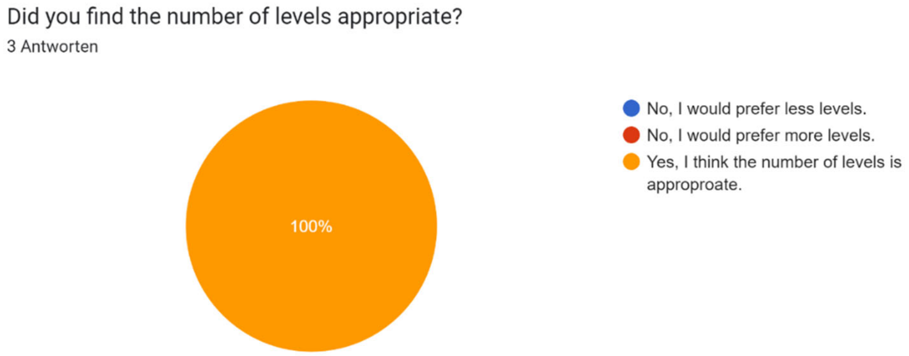



Figure 103 - LoA preliminary study - expert assessment on number of levels.

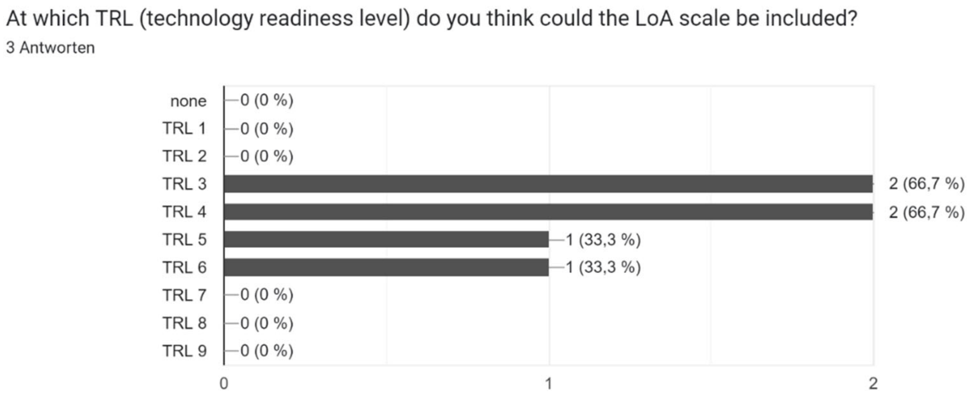



Figure 104 - LoA preliminary study - expert assessment on use of LoA in TRL process.

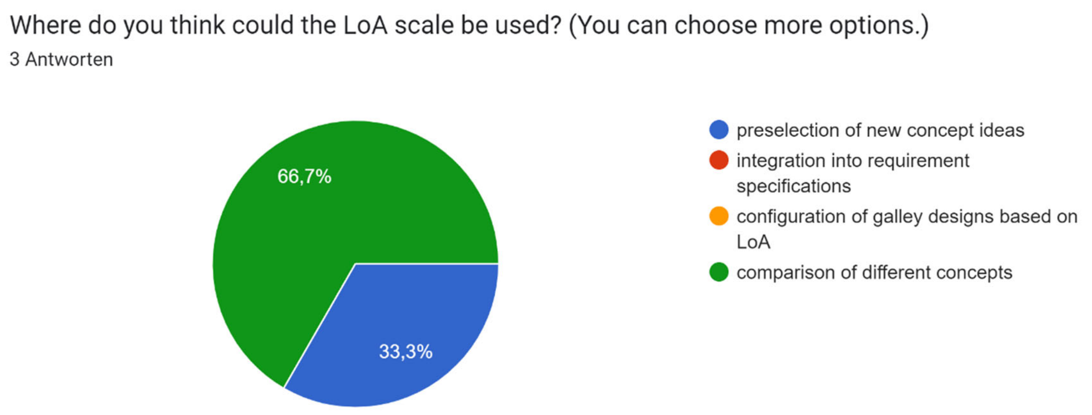



Figure 105 - LoA preliminary study - expert assessment on use cases.

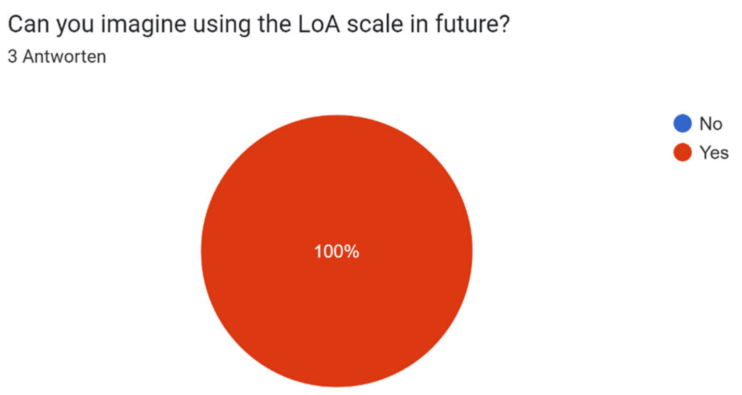



Figure 106 - LoA preliminary study - expert assessment on willingness of using the proposed scale.

Expert comment: "LoA should be linked with operational (or other) benefits (such as crew effort, avoiding failures, better process traceability, operation in non accessible areas), maybe to be combined with system complexity (automation could be an enabler but not necessarily a target itself)".

The survey results that aimed to define the levels of automation for the aircraft galley were insightful, drawing from the expertise of consulted engineering experts. However, upon critical reflection, a more representative viewpoint would be beneficial. Incorporating input from other departments, such as marketing and human factors, would enrich the understanding of the situation. Obtaining feedback from end-users such as flight attendants, airlines, and caterers would enhance the definition process.

## 6.2 Evaluation of the overall-system

Another evaluation was performed to compare the current TRL Review process with the new developed multicriteria decision making method framework for developing automation concepts for inflight catering services. The evaluation has been done online by the use of a presentation and "Google Forms", with five experts, each possessing at least three years of experience in Airbus engineering division within galley development. In the presentation, the pre-evaluation was structured as follows:

A – Screening

B – Experience with concept development

C – Pre-evaluation of a Framework with a MCDM for ICS - Automation

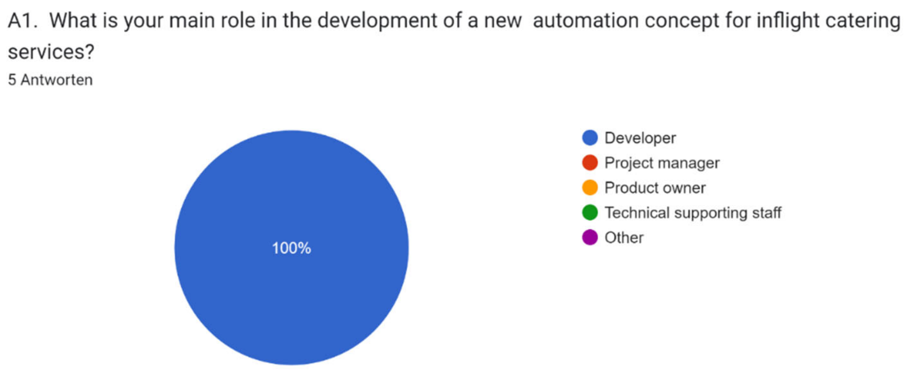



Figure 107 - Screening of survey participants, roles.

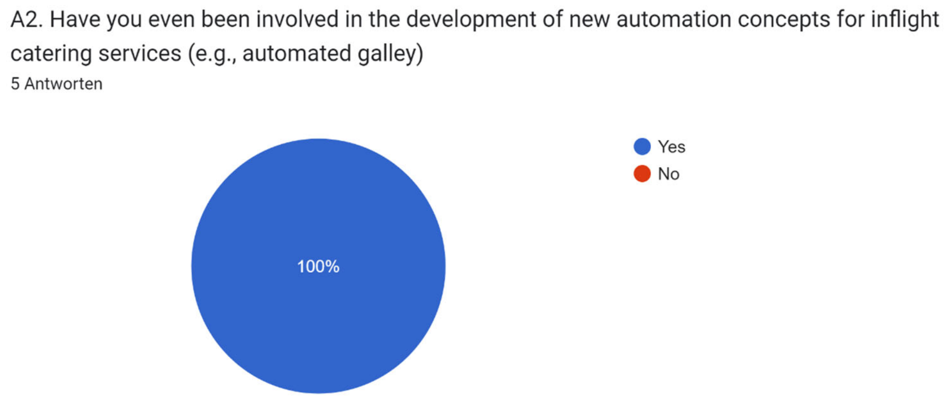



Figure 108 - Screening of survey participants, involvement in development.

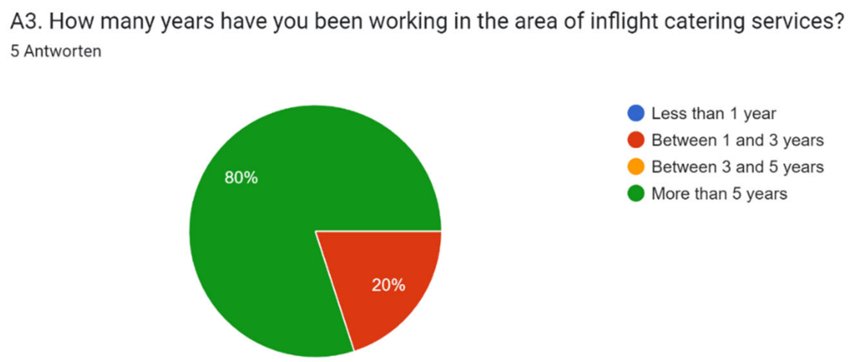



Figure 109 - Screening of survey participants, experience.

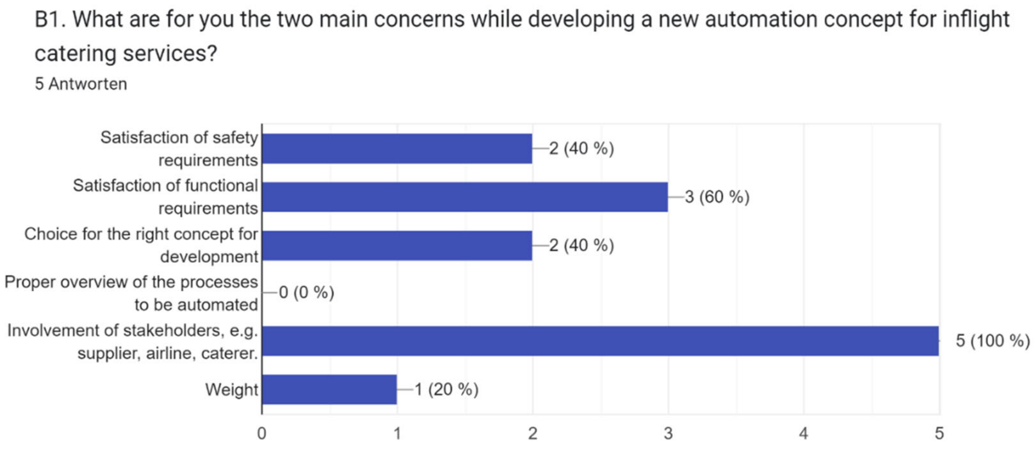



Figure 110 - Experience with concept development, concerns about development.

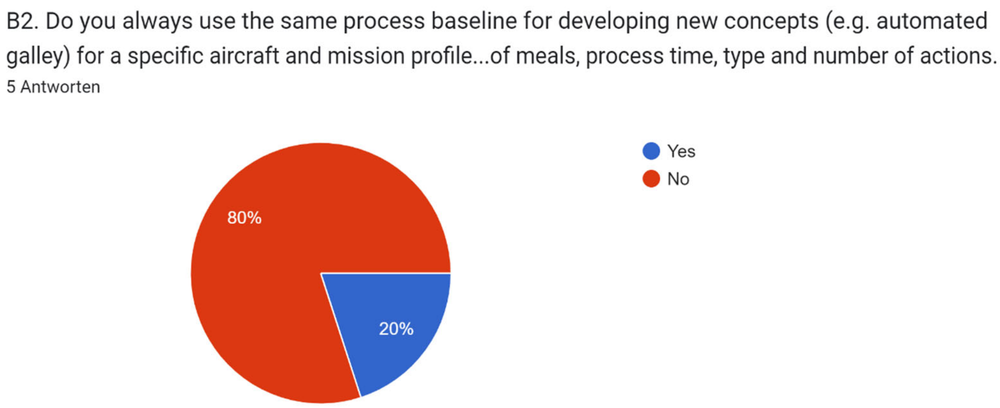



Figure 111 - Experience with concept development, use of baseline.

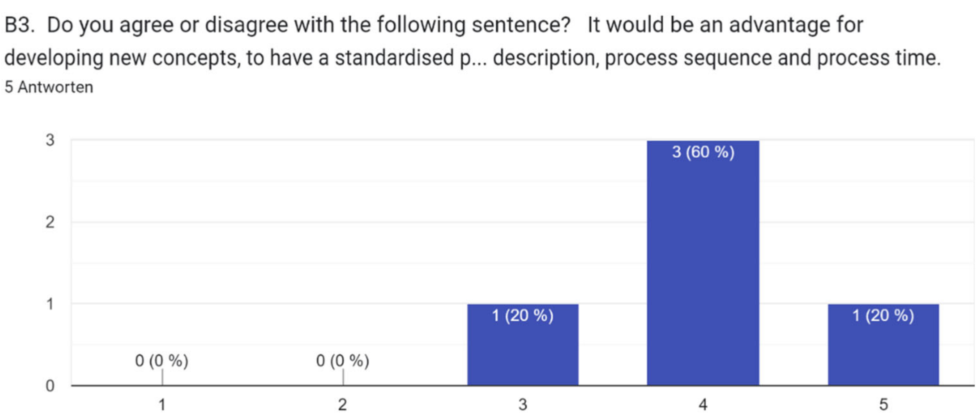



Figure 112 - Experience with concept development, interest in using standardised process analysis for concept development.

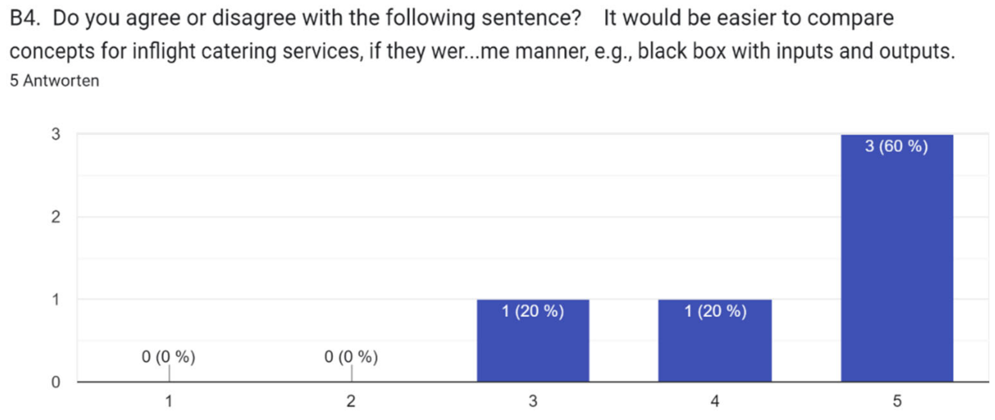



Figure 113 - Experience with concept development, comparison properties.

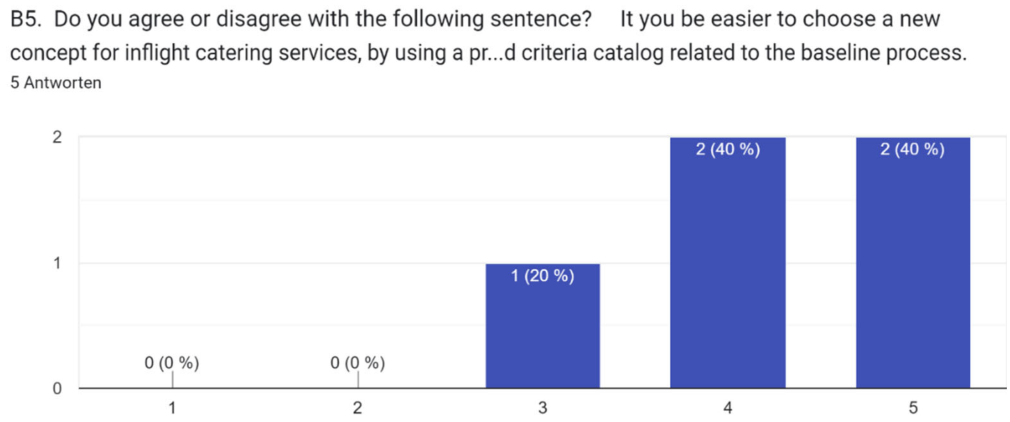



Figure 114 - Experience with concept development, choice of concepts.

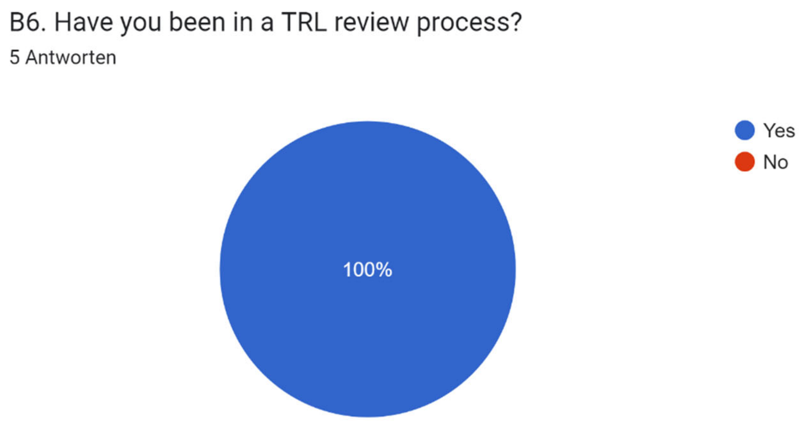



Figure 115 - Experience with concept development, experience with TRL review process.

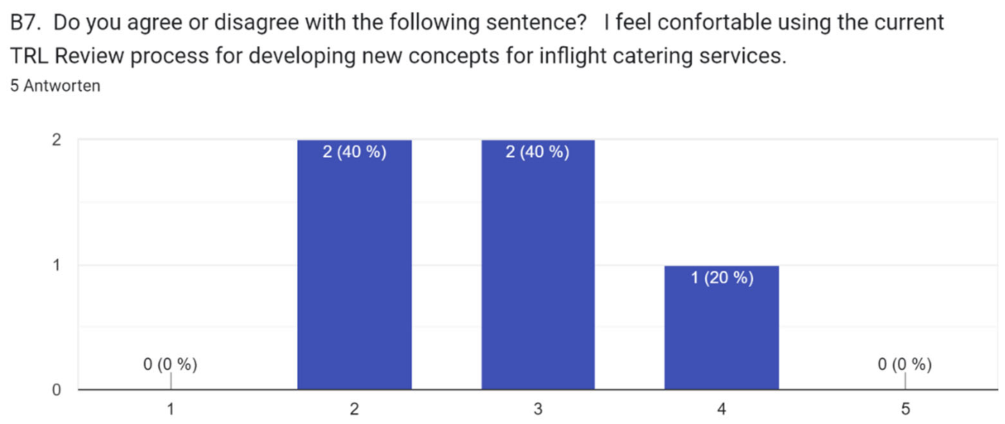



Figure 116 - Experience with concept development, confidence with TRL review process.

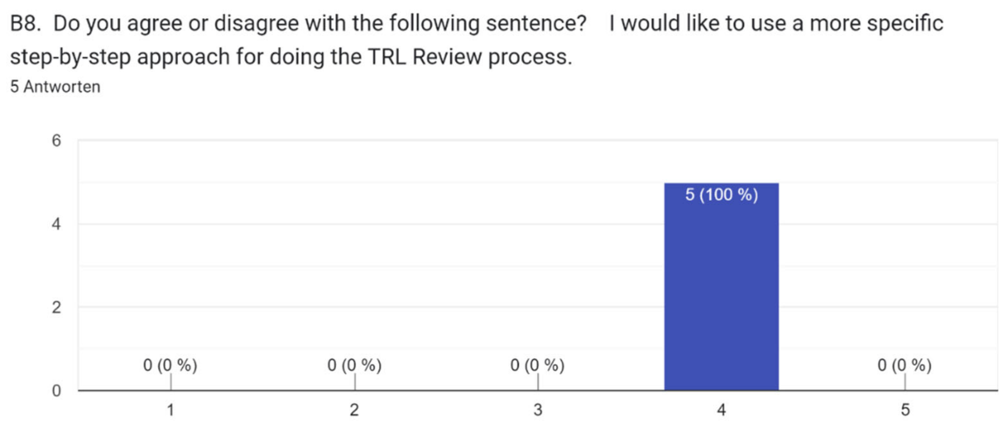



Figure 117 - Experience with concept development, support demand for TRL review.

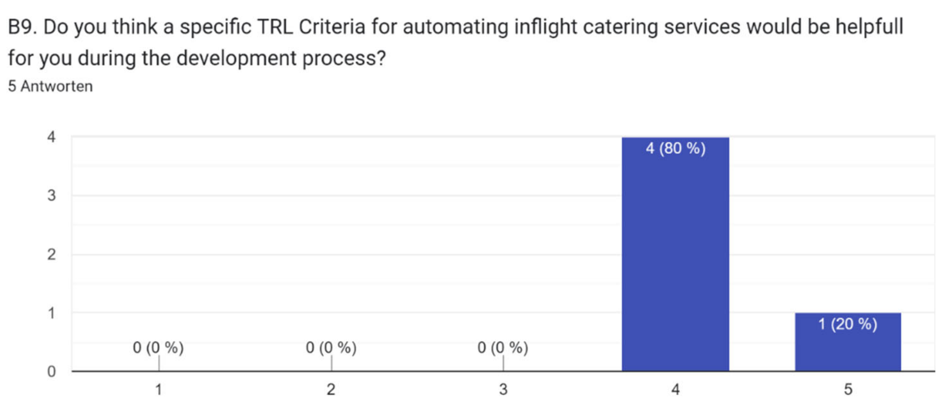



Figure 118 - Experience with concept development, demand for specific TRL criteria.

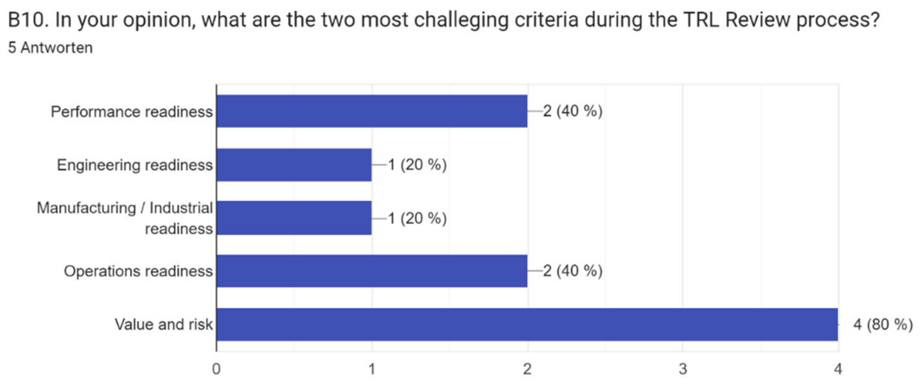



Figure 119 - Experience with concept development, most challeging criteria of TRL review.

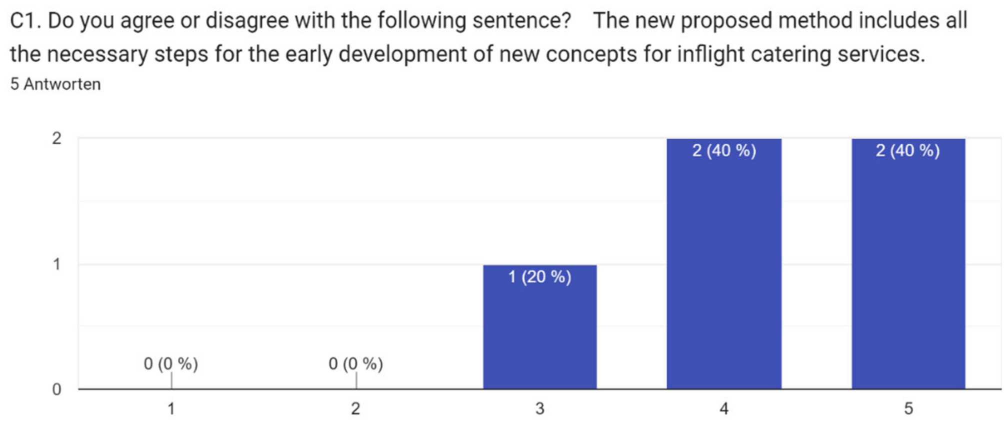



Figure 120 - Pre-evaluation of the framework for ICS - automation, view on support capabilities.

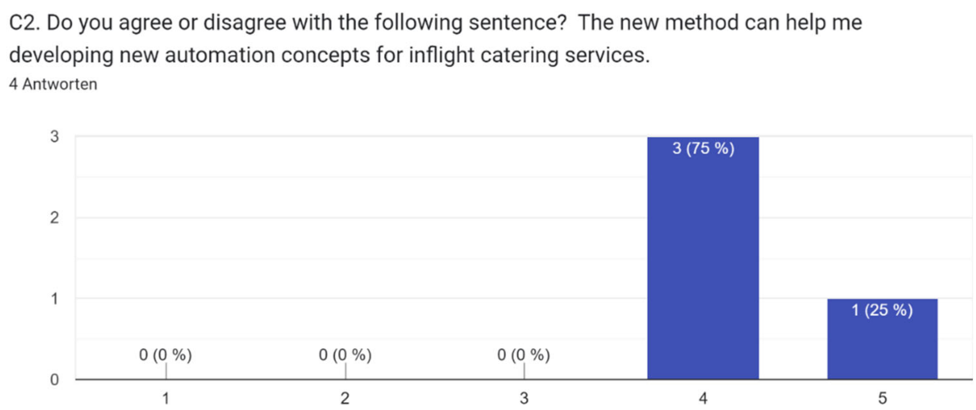



Figure 121 - Pre-evaluation of the framework for ICS - automation, possible support for development.

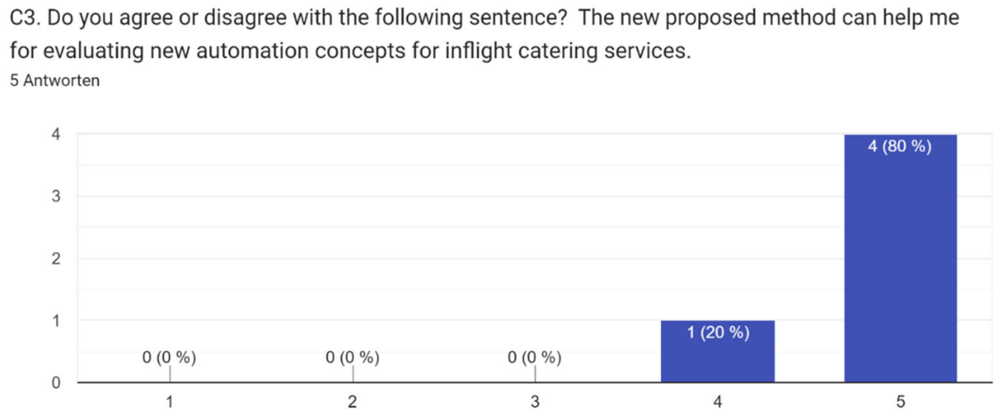



Figure 122 - Pre-evaluation of the framework for ICS - automation, possible support for evaluation.

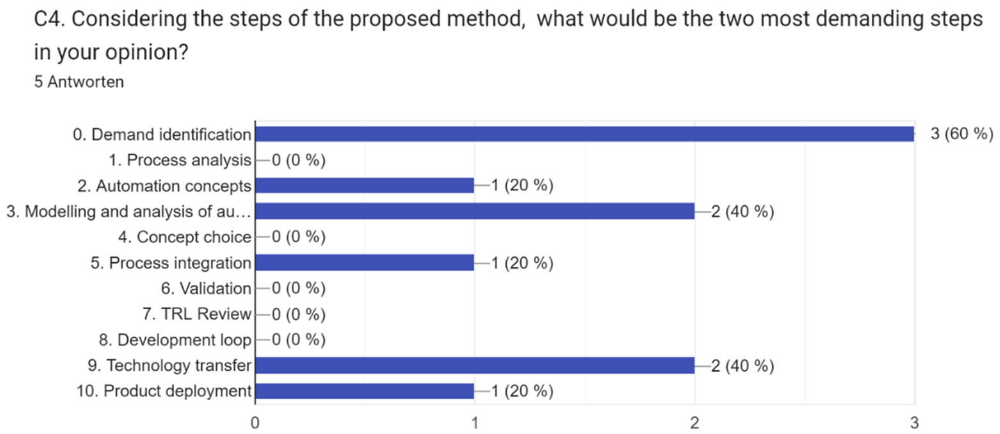



Figure 123 - Pre-evaluation of the framework for ICS - automation, estimation of effort.

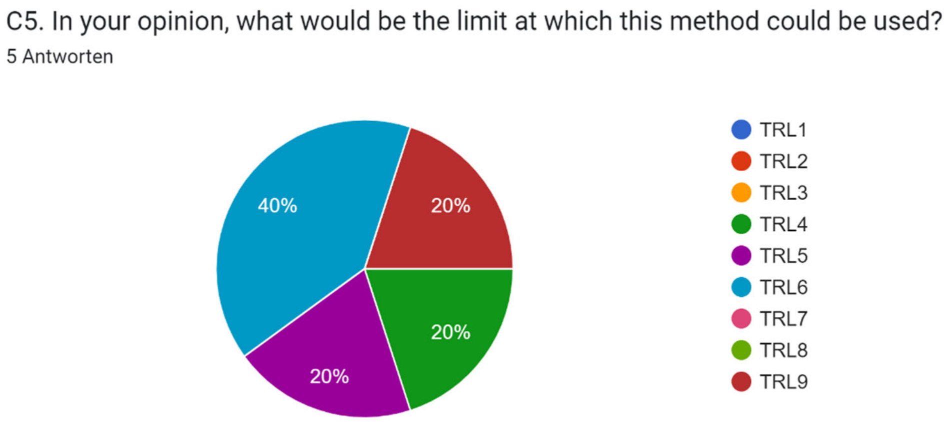



Figure 124 - Pre-evaluation of the framework for ICS - automation, utilisation in TRL development process.

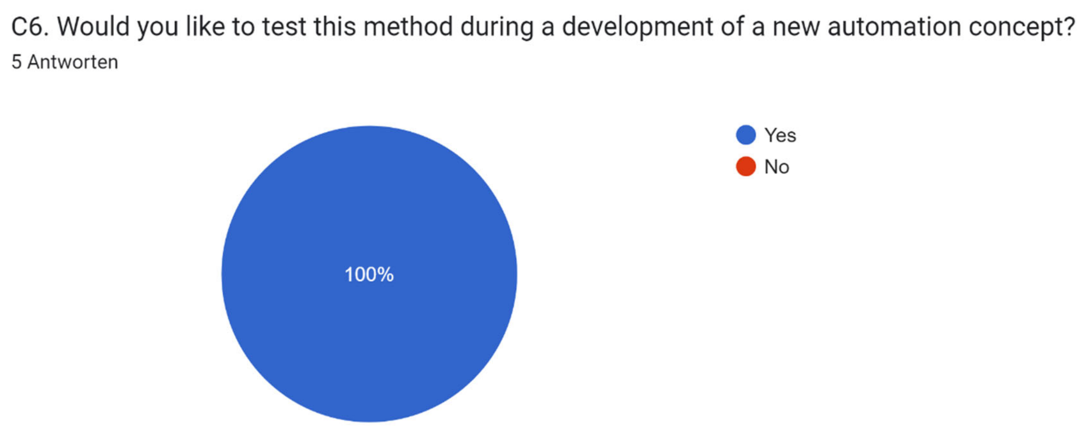



Figure 125 - Pre-evaluation of the framework for ICS - automation, intention of use.


C7. Are there any points that you would like to add in the method for the early development of automation concepts for inflight catering services?
2 Antworten

link between automation potential and value / KPI very important

would be good to have some real pilot cases

C8. What would be important for you for using this method?
3 Antworten

Align to DE.PA processes

Applying it with first real cases / pilots

pragmatic approach, good balance between possible extra effort and benefits

C9. Is there a particular reason that you would not use the method?
2 Antworten

no, but workload to be kept in mind (pragmatic approach important)

no

Figure 126 - Pre-evaluation of the framework for ICS - automation, further comments.

Looking after the process integration step, with the involvement of stakeholders. The feedback from the CET – Customer Experience Team at Airbus, showed that 81% of airlines rated the product as "absolutely interested." The feedback indicated that there is room for improvement in the product design, particularly regarding size and usability.

## 6.3 Interpretation and discussion of the results

The evaluation results indicate a promising direction and a recognized benefit by surveyed experts.

The evaluation of the automation scale showed a hands-on approach, allowing the experts to use the scale and afterwards compare the decided levels. There are possibly some adjustments to be done, but the procedure seems to be valid for the intended objective of specific evaluating the automation level of processes in inflight catering services.

The prototypical implementation of the developed framework has been presented in Section 5. Possibly, full use of the framework may generate more insights about the usability of the methods and also give more details about reducing the development time. Nevertheless, a more broad survey with more experts would enhance and give the approach more consistency. There are also internal processes that still must be considered in order to fully implement the developed framework, e.g., the aircraft modification process. It has been particularly interesting to see the different views, on the limit of implementation of the method considering the TRL development process.

However, incorporating the more views from the developing community would provide a more comprehensive perspective.

# 7 Summary and outlook

In this dissertation, a comprehensive overview of the available literature on cabin operations regarding inflight catering services, automation and multicriteria decision-making methods has been provided. The approach includes a holistic view of the processes involving all stakeholders: aircraft manufacturer, airline and flight attendant, caterer and passenger. It was possible to identify a gap in the early development of new automation concepts for inflight catering in the aircraft cabin. This gap is the lack of support in the development and selection of a new automation concept. The consequences of pursuing unpromising concepts lead not only to delays in the innovation process, but also to inadequate investments. Furthermore, it could be shown that the available methods for early development, e.g. Technology Readiness Level, are not specific to the development of automation concepts for inflight catering services, which can lead to a different baseline being used for each new development and affect the comparison between different concepts. Another important finding is the lack of history of concept development. Most new developments are in-house, and the level and type of documentation may vary over the years, so concepts developed 10 years earlier are hardly comparable to new concepts as the baseline may vary even though most processes remain the same.

The developed multicriteria decision-making method framework for the incremental introduction of automation in inflight catering addresses the above issues and proposes a new approach for early development. The method is based on the essential characteristics of early development: comparability, simplicity and feasibility. The developed method streamlines the development process from needs assessment, e.g. process optimisation, through process analysis, concept modelling and selection, development of the selected concepts, validation and final transfer to product deployment.

The framework as a whole can be understood as a black box system consisting of different input-output modules. The integration of the modules with core features such as a standard process analysis, the modelling of the concepts, the use of a multicriteria decision-making method for concept selection and the validation and verification through the technological readiness review were essential for the proposed holistic approach.

The purpose is to enable a fair comparison among different concepts, which may be developed in different maturity levels and to allow a classification, not only regarding the level of automation but also possible constraints that exceed the technology, e.g. process integration or interaction with flight attendant. Reducing the time for an innovation to get market-ready holds high potential for lowering costs or getting major competitive advantages and leads companies to rethink their innovation strategies.

The illustration of the method follows the determination of the need for individualised meals on board. Based on the needs assessment, a simplified process analysis is carried out to show the processes that can or will be influenced by new concepts. After modelling the concepts created, a decision-making method was applied to select the most promising concept. The concept was developed up to TRL4, in this example with a validation in a cabin mock-up together with a flight attendant. The topics for further development are listed and documented.

An evaluation of the framework was conducted with the cabin module development department of an aircraft manufacturer. The evaluation was based on an online survey that showed the core features of the framework compared to the current way of development. The survey results show promising results for the use of the proposed framework, although further developments are needed, especially regarding the integration into a simulation environment.

In summary, the potential of a new approach for the early development of new automation concepts for inflight catering services could be demonstrated. The disclosure of inflight catering service processes has not been the subject of public research. This work aims to initiate a discussion on the integration of automation in the aircraft cabin, highlighting the processes and challenges related to the intrinsic requirements of an aircraft.

## 7.1 Critical consideration

Although much thought has been given to the normal operation of flight attendants providing inflight catering services, abnormal operations have not been considered. Abnormal situations are instances where disruptions occur, such as emergencies or unruly passengers, where flight attendants need to act quickly and some situations may be unique. Looking at the proposed approach to automating the inflight catering service, it is reasonable to conclude that the number of flight attendants could be reduced or even eliminated by the possibility of fully autonomous inflight catering services; however, the safety aspects are very challenging. A cross-check with the reduction of flight attendants with the safety requirements would be necessary, in which case new safety concepts might be needed to close the requirement gaps while reducing the number of flight attendants. Nevertheless, the approach could be pursued if the number of cabin crew is reduced to a safety minimum.

The analysis of the system, the entities contained within it, the processes taking place and their throughput times and locations within the aircraft galley and involved processes lead to a deeper understanding of the overall system and the interrelationships. Nevertheless, there is a great variety of operations and enhancing the processes with different alternative steps would enhance the framework as a whole.

## 7.2 Outlook and further research needs

A further extension of the institutions with inflight catering services could be from advantage, particularly looking after public and state institutions, joining academics and state policies for achieving a counterpart and balance to industry institutions. A suggestion is given in Figure 127.

Besides, it could be interesting to look further at the topic of utilisation of the galley. Together with the throughput times, the resulting "heat maps" could be used for mission-specific loading optimisations or even new design approaches.

It could be particularly interesting to implement the framework within a simulation, allowing faster evaluation of different concepts and scenarios.

A further challenging topic would be to integrate the knowledge of the framework directly into the design approach.

The issues of sustainability are roughly highlighted; the extension of the framework with sustainability criteria would improve the approach.

It could be particularly interesting to seek standardisation in topics regarding levels of automation.

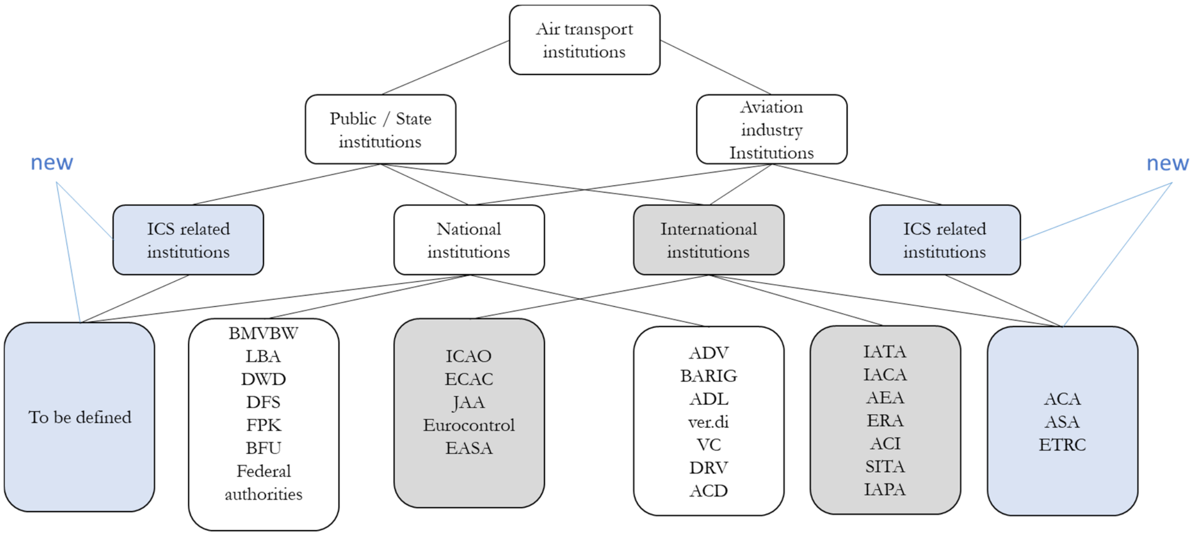



Figure 127 - Further extension of the institutions for further support and development of inflight catering services.

In conclusion, this dissertation presented a comprehensive framework for the gradual introduction of automation of inflight catering services through the use of a multicriteria decision-making method framework. This approach can support development projects and shorten development time, providing a competitive advantage in the industry. The importance of seeking synergy with all industry stakeholders and adopting standards and best practices must still be enhanced, as this can lead to more effective and efficient implementation of the framework. In addition, this dissertation has opened the research corridor for the scientific community to further explore challenges and opportunities inside the aircraft within inflight catering services. By unleashing the potential of this framework, it is hoped that it will contribute to the continued growth and improvement of aircraft and related processes.

## Declaration

I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

## References


Abdullah S. Karaman and Engin Akman (2018), "Taking-off corporate social responsibility programs: An AHP application in airline industry", *Journal of Air Transport Management*, Vol. 68, pp. 187–197.

Abele, T. (2006), *Verfahren für Das Technologie-Roadmapping Zur Unterstützung des Strategischen Technologiemanagements*.

Aeroexpo (2022), "Aircraft interiors, Inflight service, Galley", available at: https://www.aeroexpo.online/aeronautic-manufacturer/galley-109.html (accessed 28 December 2022).

Agampodi, S.B., Dharmaratne, S.D. and Agampodi, T.C. (2009), "Incidence and predictors of onboard injuries among Sri Lankan flight attendants", *BMC Public Health*, Vol. 9, p. 227.

Ai, D., Zuo, H. and Yang, J. (2013), "Personalized mobile catering recommender system based on context ontology model and rule inference", *Advanced Materials Research*, Vol. 717, pp. 708–713.

AIM Altitude (2020), "ARCA - meal-service innovation for sustainability and efficient use of space", available at: https://www.aimaltitude.com/arca/ (accessed 23 April 2022).

Air Baltic (2020), "Sustainability Report 2019", available at: https://www.airbaltic.com/sustainability/img/BT_SustainabilityReport2019_EN.pdf (accessed 25 April 2022).

Air Transport Association of America (2021), *iSpec 2200: Information Standards for Aviation Maintenance*, Harvard Dataverse.

Airbus Operations GmbH (2019), "An innovative solution to in-flight waste comes from the "Fly Your Ideas" student challenge", available at: https://www.airbus.com/en/newsroom/news/2019-04-an-innovative-solution-to-in-flight-waste-comes-from-the-fly-your-ideas (accessed 28 December 2022).

Airbus Operations GmbH (2021), "AIRCRAFT CHARACTERISTICS AIRPORT AND MAINTENANCE PLANNING", available at: https://www.airbus.com/sites/g/files/jlcbta136/files/2021-11/Airbus-Commercial-Aircraft-AC-A350-900-1000.pdf (accessed 28 June 2022).

Airbus Operations GmbH (2022), "A350-900", available at: https://aircraft.airbus.com/en/aircraft/a350/a350-900 (accessed 28 June 2022).

Airline Experience Association - APEX (2017), "Airbus' Award-Winning Concepts Address Aircraft Cabin Waste Problem", available at: https://apex.aero/articles/airbus-award-winning-concepts-address-aircraft-cabin-waste-problem/ (accessed 28 December 2022).

Akamavi, R.K., Mohamed, E., Pellmann, K. and Xu, Y. (2015), "Key determinants of passenger loyalty in the low-cost airline business", *Tourism Management*, Vol. 46, pp. 528–545.

Alexander Neb and Dominik Remling (2019), "Quantification and Evaluation of Automation Concepts based on a Multi-Criteria Decision Analysis", *Procedia CIRP*, Vol. 84, pp. 624–629.

Alonso Tabares, D. and Mora-Camino, F. (Eds.) (2017), *Aircraft ground handling: analysis for automation*.

Anderson, R.J. (1996), "Autonomous, teleoperated, and shared control of robot systems", in *Proceedings of IEEE International Conference on Robotics and Automation, Minneapolis, MN, USA, 22-28 April 1996*, IEEE, pp. 2025–2032.

APEX (2021a), "ACA/IFSA Announce Publication of In-Flight Service Guidelines - APEX", available at: https://apex.aero/articles/aca-ifsa-announce-publication-of-in-flight-service-guideline/ (accessed 1 March 2021).

APEX (2021b), "Omnevo is Aiming to Reboot the Ancillary Revenue Paradigm - APEX", available at: https://apex.aero/articles/omnevo-is-aiming-to-reboot-the-ancillary-revenue-paradigm/?utm_medium=email&utm_campaign=APEX%20February%2011%202021&utm_content=APEX%20February%2011%202021+CID_e2ce04500cd6fbe515f985c412e38484&utm_source=APEX%20Newsletter&utm_term=Omnevo%20Looks%20to%20Overhaul%20Aviation%20Catering%20and%20Retail (accessed 1 March 2021).

Arif, M., Gupta, A. and Williams, A. (2013), "Customer service in the aviation industry – An exploratory analysis of UAE airports", *Journal of Air Transport Management*, Vol. 32, pp. 1–7.

Armaghan, N., Costa, J., Renaud, J. and Martinez, M. (2006), "Industrial knowledge memory and multicriteria decision analysis", *IFAC Proceedings Volumes*, Vol. 9 PART 1.

Avers, K., Nei D., King, J., Thomas, S., Roberts, C., Banks, J. and Nesthus, T. (2011), "Flight Attendant Fatigue: A Quantitative Review of Flight Attendant Comments", *Federal Aviation Administration - Office of Aerospace Medicine* DOT/FAA/AM-11/16.

Azhar, S. (2011), "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry.", *Leadership and management in engineering No.* 11, 241-252.

Bachmann, J., Hidalgo, C. and Bricout, S. (2017), "Environmental analysis of innovative sustainable composites with potential use in aviation sector—A life cycle assessment review", *Science China Technological Sciences*, Vol. 60 No. 9, pp. 1301–1317.

Bahr, N.J. (2015), *System safety engineering and risk assessment: A practical approach,* Second edition, CRC Press, Boca Raton, FL.

Baines, T. and Lightfoot, H. (2013), *Made to serve: How manufacturers can compete through servitization and product service systems*, Wiley, Chichester, West Sussex.

Barabás, I., Todoruţ, A., Cordoş, N. and Molea, A. (2017), "Current challenges in autonomous driving", *IOP Conference Series: Materials Science and Engineering*, Vol. 252 No. 1, p. 12096.

Barke, A., Thies, C., Melo, S.P., Cerdas, F., Herrmann, C. and Spengler, T.S. (2022), "Comparison of conventional and electric passenger aircraft for short-haul flights – A life cycle sustainability assessment", *Procedia CIRP*, Vol. 105, pp. 464–469.

Bauer, M., Haas, K.-H., Hagg, H., Hartmann, L., Inden, U., Neubauer, F., Pietrek, D., Renner, T., Scheiding, F., Schirrmann, A., Sell, R., Tieck, S., Tönnies, F., Vidackovic, K. and Vogt, O. (2010), "Intelligentes Catering mit RFID: Prozesse, Logistik und Integration neuer Technologien im Luftfahrtcatering".

Becker, A. and Bruns, C. (2013), *LTC task "No Crew on Board": Phase 1 "Cross-Industry Analysis". Phase 2 "Market Research –qualitative & quantitative report"*, Internal presentation (Airbus), Hamburg.

Becker, H. (Ed.) (2007), *Catering-Management: Portrait einer Wachstumsbranche in Theorie und Praxis,* 1. Auflage, Behr, Hamburg.

Behzadian, M., Kazemzadeh, R.B., Albadvi, A. and Aghdasi, M. (2010), "PROMETHEE: A comprehensive literature review on methodologies and applications", *European Journal of Operational Research*, Vol. 200 No. 1, pp. 198–215.

Bellizzi, M.G., Eboli, L. and Mazzulla, G. (2020), "An online survey for the quality assessment of airlines' services", *Research in Transportation Business & Management*, Vol. 37, p. 100515.

Belton, V. and Stewart, T.J. (2003), *Multiple criteria decision analysis: An integrated approach,* 2. print, Kluwer Acad. Publ, Boston, Mass.

Berger, B. (2019), "Redesigning the Airplane Galley", available at: https://teague.com/insights/innovation/getting-rid-of-the-airplane-galley (accessed 23 April 2022).

Bernd Lorenz, Francesco Di Nocera, Stefan Röttger and Raja Parasuraman (2001), "The Effects of Level of Automation on the Out-of-the-Loop Unfamiliarity in a Complex Dynamic Fault-Management Task during Simulated Spaceflight Operations", *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 45 No. 2, pp. 44–48.

Beumer, R.R., Vrouwenvelder, T. and Brinkman, E. (1994), "Application of HACCP in airline catering", *Food Control*, Vol. 5 No. 3, pp. 205–209.

Billings, C.E. (2018), "Aviation automation: The search for a human-centered approach", *Aviation Automation: The Search for a Human-Centered Approach.*

Blanca-Alcubilla, G., Bala, A., Hermira, J.I., De-Castro, N., Chavarri, R., Perales, R., Barredo, I. and Fullana-I-Palmer, P. (2018), "Tackling international airline catering waste management: life zero cabin waste project. State of the art and first steps", *Detritus*, In Press No. 1, p. 1.

Boos, S.N., Köhler, A., Roth, I., SALVADOR, S. and Stoldt, A. (2016), *A cargo unit for an aircraft and a lower deck catering system: B64C1/22; B64D11/00; B64D11/04;* EP3034390A1.

Boucher, T.O., Luxhoj, J.T., Descovich, T. and Litman, N. (1993), "Multicriteria evaluation of automated filling systems: A case study", *Journal of Manufacturing Systems*, Vol. 12 No. 5, pp. 357–378.

Boye, Joyce I. and Arcand, Yves (Ed.) (2012), *Green Technologies in Food Production and Processing*, Springer US, Boston, MA.

Braud, A., Fromentoux, G., Radier, B. and Le Grand, O. (2021), "The road to European digital sovereignty with Gaia-X and IDSA", *IEEE Network No.* 35, pp. 4–5.

Briedenhann, J. (2018), "Book meals in advance and dine on demand with Turkish Airlines", available at: https://insidetravel.news/book-meals-in-advance-and-dine-on-demand-with-turkish-airlines/ (accessed 28 December 2022).

Bruce T. Clough (2002), "Metrics, Schmetrics! How The Heck Do You Determine A UAV's Autonomy Anyway".

Buhtz, C., Paulicke, D., Hirt, J., Schwarz, K., Stoevesandt, D., Meyer, G. and Jahn, P. (2018), "Robotische Systeme zur pflegerischen Versorgung im häuslichen Umfeld: ein Scoping Review", *Zeitschrift für Evidenz, Fortbildung und Qualität im Gesundheitswesen*, 137-138, pp. 1–8.

Bureau of Transportation Statistics (2022), "Average Domestic Air Fares", available at: https://www.bts.gov/ (accessed 17 June 2022).

Burghardt, D., Germer, T. and Sippel, S. (2002), "Flugzeugstandardisierung und Beschaffungsmanagement der Deutschen Lufthansa AG", in Hahn, Dietger and Kaufmann, Lutz (Ed.), *Handbuch Industrielles Beschaffungsmanagement: Internationale Konzepte -- Innovative Instrumente -- Aktuelle Praxisbeispiele*, Gabler Verlag, Wiesbaden, pp. 673–695.

Butterworth-Hayes, P. (2009), "Fuel efficiency improvements escalate", *Aerospace America*, Vol. 47 No. 7, pp. 4–6.

Capocchi, A., Vallone, C., Pierotti, M. and Amaduzzi, A. (2019), "Overtourism: A literature review to assess implications and future perspectives", *Sustainability (Switzerland)*, Vol. 11 No. 12.

Catalan, R.B., Pérez, E.I. and Pérez, B.Z. (2007), "Evaluation of 3D scanners to develop virtual reality applications", *Electronics, Robotics and Automotive Mechanics Conference, CERMA 2007 - Proceedings*.

Chang, Z.Y., Yeong, W.Y. and Loh, L. (1997), "Critical success factors for inflight catering services: Singapore Airport Terminal Services' practices as management benchmarks", *TQM Magazine*, Vol. 9 No. 4, pp. 255–259.

Charles E. Billings (1997), *Aviation automation the search for a human-centered approach, Human factors in transportation*, Lawrence Erlbaum Associates Publishers, Mahwah, N.J.

Chen, J. and Hao, Y. (2007), "Outsourcing for achieving mass customization in service operations: Lessons from the "smaller kitchen " strategy in Chinese catering services", *2007 International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2007*.

Chiambaretto, P. (2021), "Air passengers' willingness to pay for ancillary services on long-haul flights", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 147, p. 102234.

Chiaramonti, D., Prussi, M., Buffi, M. and Tacconi, D. (2014), "Sustainable bio kerosene: Process routes and industrial demonstration activities in aviation biofuels", *Applied Energy*, Vol. 136, pp. 767–774.

China Discovery (2018), "Food & Drinks on China High Speed Trains", available at: https://www.chinadiscovery.com/china-trains/food-drinks.html.

Chuck, C.J. and Donnelly, J. (2014), "The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene", *Applied Energy*, Vol. 118, pp. 83–91.

Clarke, M. and Smith, B. (2004), "Impact of Operations Research on the Evolution of the Airline Industry", *Journal of Aircraft*, Vol. 41 No. 1, pp. 62–72.

Colledani, M., Silipo, L., Yemane, A., Lanza, G., Bürgin, J., Hochdörffer, J., Georgoulias, K., Mourtzis, D., Bitte, F., Bernard, A., Belkadi, F. and Tolio T., Cavalieri S., Pezzotta G., Ceretti E. (2016), "Technology-based Product-services for Supporting Frugal Innovation", *Procedia CIRP*, Vol. 47.

Collins Aerospace (2019), "M-flex™ Duet monument adds new service possibilities without sacrificing seat count", available at: https://www.collinsaerospace.com/newsroom/News/2019/04/collins-new-m-flex-duet-monument-adds-new-service-possibilities-wo-sacrificing-seat-count (accessed 23 April 2022).

Conrady, R. (2019), *Luftverkehr: Betriebswirtschaftliches Lehr- und Handbuch, Lehr- und Handbücher Zu Tourismus, Verkehr und Freizeit Ser,* 6th ed., Walter de Gruyter GmbH, Berlin/München/Boston.

Costa, A. and Jongen, W. (2010), "Designing new meals for an ageing population", *Critical Reviews in Food Science and Nutrition*, Vol. 50 No. 6, pp. 489–502.

Costers, A., van Vaerenbergh, Y. and van den Broeck, A. (2019), "How to boost frontline employee service recovery performance: the role of cultural intelligence", *Service Business*, Vol. 22 No. 3, p. 227.

Crescenzio, F. de, Bagassi, S., Asfaux, S. and Lawson, N. (2019), "Human centred design and evaluation of cabin interiors for business jet aircraft in virtual reality", *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Vol. 13 No. 2, pp. 761–772.

D'Angelo, A., Gastaldi, M. and Levialdi, N. (1996), "Multicriteria evaluation model for flexible manufacturing system design", *Computer Integrated Manufacturing Systems*, Vol. 9 No. 3, pp. 171–178.

Damos, D.L., Boyett, K.S. and Gibbs, P. (2013), "Safety Versus Passenger Service: The Flight Attendants' Dilemma", *The International journal of aviation psychology*, Vol. 23 No. 2, pp. 91–112.

Danzer, K. (1987), *Analytik: Systematischer Überblick,* 2., überarbeitete und erweiterte Auflage, Reprint 2021, De Gruyter, Berlin, Boston.

Davood Sabaei, John Erkoyuncu and Rajkumar Roy (2015), "A Review of Multi-criteria Decision Making Methods for Enhanced Maintenance Delivery", *Procedia CIRP*, Vol. 37, pp. 30–35.

Dennis Keiser, Christoph Petzoldt, Max Münkner and Michael Freitag (2021), "Bestimmung des Automatisierungsgrades in der Montage. Methodisches Werkzeug für den Einsatz in der Montagegrobplanung", *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 116 No. 6, pp. 413–418.

Derossi, A., Husain, A., Caporizzi, R. and Severini, C. (2020a), "Manufacturing personalized food for people uniqueness. An overview from traditional to emerging technologies", *Critical Reviews in Food Science and Nutrition*, Vol. 60 No. 7, pp. 1141–1159.

Derossi, A., Husain, A., Caporizzi, R. and Severini, C. (2020b), "Manufacturing personalized food for people uniqueness. An overview from traditional to emerging technologies", *Critical Reviews in Food Science and Nutrition*, Vol. 60 No. 7, pp. 1141–1159.

Deutsche Lufthansa AG (2018), "A restaurant on the wing", available at: https://twitter.com/lufthansanews/status/1021750951210876928?lang=en (accessed 6 December 2022).

Diehl Aviation (2018), "Smart Galley", available at: https://www.diehl.com/aviation/de/innovation/innovative-loesungen/smart-galley/ (accessed 23 April 2022).

Dismukes, R.K., Kochan, J.A. and Goldsmith, T.E. (2018), "Flight Crew Errors in Challenging and Stressful Situations", available at: https://econtent.hogrefe.com/doi/10.1027/2192-0923/a000129 (accessed 29 July 2019).

Domschke, W. and Drexl, A. (2011), *Einführung in Operations Research, Springer-Lehrbuch,* 8. Aufl., Springer, Berlin, Heidelberg.

Dožić, S. (2019), "Multi-criteria decision making methods: Application in the aviation industry", *Journal of Air Transport Management*, Vol. 79, p. 101683.

Draper, J.V. (1995), "Teleoperators for advanced manufacturing: Applications and human factors challenges", *International Journal of Human Factors in Manufacturing*, Vol. 5 No. 1, pp. 53–85.

Dresel, K.M. and Boutros, R. (2001), "Extremely Long Flights: An In-Flight Survey of Passenger and Flight Attendant Comfort, Activities and Non-Stop Preferences", *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 45 No. 12, pp. 897–900.

EASA (2020), "Type Certificate - Datasheet - Airbus 330", available at: https://www.easa.europa.eu/sites/default/files/dfu/A330%20EASA%20TCDS%20A.004%20-%20Issue%2056.pdf (accessed 22 June 2022).

EASA (2022a), "Easy Access Rules for Air Operations — Revision 18, May 2022", available at: https://www.easa.europa.eu/downloads/20342/en (accessed 22 June 2022).

EASA (2022b), "Type Certificate - Data Sheet - Airbus A350", available at: https://www.easa.europa.eu/downloads/17736/en (accessed 27 June 2022).

El-Mobaidh, A.M., Razek Taha, M.A. and Lassheen, N.K. (2006), "Classification of in-flight catering wastes in Egypt air flights and its potential as energy source (chemical approach)", *Waste management (New York, N.Y.)*, Vol. 26 No. 6, pp. 587–591.

Endsley, M.R. and Kaber, D.B. (1999), "Level of automation effects on performance, situation awareness and workload in a dynamic control task", *Ergonomics*, Vol. 42 No. 3, pp. 462–492.

Engelmann, M., Drust, D. and Hornung, M. (2020), *Automated 3D cabin generation with PAXelerate and Blender using the CPACS file format*, Deutsche Gesellschaft für Luft- und Raumfahrt - Lilienthal-Oberth e.V.

Eriksson, E.M. and Nordgren, L. (2018), "From one-sized to over-individualized? Service logic's value creation", *Journal of health organization and management*, Vol. 32 No. 4, pp. 572–586.

EUROCONTROL (2018), "Delays – three questions and many answers", available at: https://www.eurocontrol.int/news/delays-three-questions-and-many-answers (accessed 27 June 2022).

European Environment Agency (2021), *Transport and environment report 2020: Train or plane?*, Luxembourg.

Fenech, G. and Farrugia, P. (2014), "AN INTEGRATED PRODUCT DEVELOPMENT MODEL FOR AIRCRAFT FOOD DISPENSING MACHINES", *DS 77: Proceedings of the DESIGN 2014 13th International Design Conference*, pp. 801–810.

Fiig, T., Le Guen, R. and Gauchet, M. (2018), "Dynamic pricing of airline offers", *Journal of Revenue and Pricing Management*, Vol. 17 No. 6, pp. 381–393.

Fjordline (2022), "Hirtshals to Bergen", available at: https://www.travelguide.de/en/ferries/hirtshals-bergen/ (accessed 27 December 2022).

Flixbus (2022), "Search for bus connections. Amsterdam to Paris", available at: https://shop.flixbus.de/ (accessed 27 December 2022).

Florio, F. de (2016), *Airworthiness: An Introduction to Aircraft Certification and Operations,* 3rd ed., Elsevier Science, Saint Louis.

Flynn, D. (2017), "Emirates rolls out smartphone-based meal ordering", available at: https://www.executivetraveller.com/emirates-rolls-out-smartphone-based-meal-ordering (accessed 28 December 2022).

Formation Design Group (2007), "Functional space innovation", available at: https://www.formationdesign.com/spice (accessed 28 December 2022).

Foskett, D., Paskins, P. and Pennington, A. (2016), *The theory of hospitality and catering,* Thirteenth edition, Dynamic Learning; Hodder Education, London, [England].

Fottner, J., Clauer, D., Hormes, F., Freitag, M., Beinke, T., Overmeyer, L., Gottwald, S.N., Elbert, R., Sarnow, T., Schmidt, T., Reith, K.B., Zedek, H. and Thomas, F. (2021), *Autonomous Systems in Intralogistics – State of the Art and Future Research Challenges,* 2nd ed., Bundesvereinigung Logistik (BVL) e.V.

Frank, C., Deveraux, M.N., Ausseil, R. and Mavris, D.N. (2016), "Design of an Automated On-Demand Meal Delivery System Under Emerging and Evolving Passenger Requirements", in *AIAA SciTech: 57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, San Diego, California, USA*, [publisher not identified], [Place of publication not identified], p. 36.

Freitag, M., Hoppe, N., Petzoldt, C., Wilhelm, J., Rolfs, L., Mortensen Ernits, R. and Beinke, T. (2020), "Digitaler Zwilling zur Mensch-Technik-Interaktion", in Freitag, M. (Ed.), *Mensch-Technik-Interaktion in der digitalisierten Arbeitswelt*, GITO Verlag, pp. 165–182.

Frohm, J., Lindström, V., Winroth, M. and Stahre, J. (2008), "Levels of automation in manufacturing", *Ergonomia.*

Fuchs, J. (2018), "Bahn-Bordbistro nimmt jetzt Onlinebestellungen entgegen", available at: https://t3n.de/news/deutsche-bahn-mobile-online-bestellung-bordbistro-restaurant-gastronomie-1131164/ (accessed 27 December 2022).

Fuchte, J.C. (2014), "Enhancement of aircraft cabin design guidelines with special consideration of aircraft turnaround and short range operations", *DLR Deutsches Zentrum fur Luft- und Raumfahrt e.V. - Forschungsberichte No.* 17, pp. 1–141.

Galand, L. (2006), "Interactive search for compromise solutions in multicriteria graph problems", *IFAC Proceedings Volumes*, Vol. 9 PART 1.

Garcia-Haro, J.M., Oña, E.D., Hernandez-Vicen, J., Martinez, S. and Balaguer, C. (2021), "Service robots in catering applications: A review and future challenges", *Electronics (Switzerland)*, Vol. 10 No. 1, pp. 1–22.

Gavine, A. (2021), "2020/2021 Crystal Cabin Awards: the winners!", *Aircraft Interiors International,* 30 March, available at: https://www.aircraftinteriorsinternational.com/features/2020-2021-crystal-cabin-awards-the-winners.html (accessed 31 March 2021).

Georgiou, P., Johan, N. and Jones, P. (2010), "Patterns of inflight alcohol consumption: A study of British holiday makers", *Tourism and Hospitality Research*, Vol. 10 No. 3, pp. 188–205.

Gershenson, J.K., Prasad, G.J. and Zhang, Y. (2003), "Product modularity: Definitions and benefits", *Journal of Engineering Design*, Vol. 14 No. 3, pp. 295–313.

Gibbs, L., Slevitch, L. and Washburn, I. (2017), "Competency-Based Training in Aviation: The Impact on Flight Attendant Performance and Passenger Satisfaction", *Journal of Aviation/Aerospace Education and Research*.

Glitsch, U., Ottersbach, H.J., Ellegast, R., Schaub, K., Franz, G. and Jäger, M. (2007), "Physical workload of flight attendants when pushing and pulling trolleys aboard aircraft", *International Journal of Industrial Ergonomics*, Vol. 37 No. 11, pp. 845–854.

Global Industry Analysts (2022), "Global In-Flight Catering Services Industry", Market Report, available at: https://www.reportlinker.com/p04838522/Global-In-Flight-Catering-Services-Services.html?utm_source=GNW (accessed 1 March 2022).

Goto, J.H., Lewis, M.E. and Puterman, M.L. (2004), "Coffee, Tea, or …?: A Markov Decision Process Model for Airline Meal Provisioning", *Transportation Science*, Vol. 38 No. 1, pp. 107–118.

Gou, J., Shen, G. and Chai, R. (2013), "Model of service-oriented catering supply chain performance evaluation", *Journal of Industrial Engineering and Management*, Vol. 6 1 LISS 2012, pp. 215–226.

Grimme, W. and Maertens, S. (2019), "Flightpath 2050 revisited – An analysis of the 4-hour-goal using flight schedules and origin-destination passenger demand data", *Transportation Research Procedia*, Vol. 43, pp. 147–155.

Groover, M.P. (2016), *Automation, production systems, and computer integrated manufacturing,* 4th ed., global ed., Pearson Education, Harlow, England.

Gudehus, T. (2010), *Logistik*, Springer Berlin Heidelberg.

Gudehus, T. (2011), *Logistik: Grundlagen - Strategien - Anwendungen,* 4., aktualisierte Aufl 2010, Springer Berlin Heidelberg, Berlin, Heidelberg.

Guinness World Records (2022), "First inflight meal", available at: https://www.guinnessworldrecords.com/world-records/498705-first-inflight-meal (accessed 17 June 2022).

Gumpinger, T., Jonas, H.P., Plaumann, B. and Krause, D. (2011), "A visualization concept for supporting module lightweight design".

Hagihara, A., Tarumi, K. and Nobutomo, K. (2001a), "The number of steps taken by flight attendants during international long-haul flights", *Aviation Space and Environmental Medicine*, Vol. 72 No. 10, pp. 937–939.

Hagihara, A., Tarumi, K. and Nobutomo, K. (2001b), "The number of steps taken by flight attendants during international long-haul flights", *Aviation Space and Environmental Medicine*, Vol. 72 No. 10, pp. 937–939.

Hagmann, C., Semeijn, J. and Vellenga, D.B. (2015), "Exploring the green image of airlines: Passenger perceptions and airline choice", *Journal of Air Transport Management*, Vol. 43, pp. 37–45.

Hamzeh Alabool, Ahmad Kamil, Noreen Arshad and Deemah Alarabiat (2018), "Cloud service evaluation method-based Multi-Criteria Decision-Making: A systematic literature review", *Journal of Systems and Software*, Vol. 139, pp. 161–188.

Han, H., Lee, K.-S., Chua, B.-L., Lee, S. and Kim, W. (2019), "Role of airline food quality, price reasonableness, image, satisfaction, and attachment in building re-flying intention", *International Journal of Hospitality Management*, Vol. 80, pp. 91–100.

Hankel, M. and Rexroth, B. (2015), "The reference architectural model industrie 4.0 (rami 4.0)", *Zvei No.* 2, pp. 4–9.

Heinemann, P., Schmidt, M., Will, F., Kaiser, S., Jeßberger, C. and Hornung, M. (2017), "Sizing implications of a regional aircraft for inner-city operations", *Aircraft Engineering and Aerospace Technology*, Vol. 89 No. 4, pp. 520–534.

Hevner, A., R, A., March, S., T, S., Park, Park, J., RAM and Sudha (2004), "Design Science in Information Systems Research", *Management Information Systems Quarterly*, Vol. 28, 75-.

Himanshu Gupta (2018), "Evaluating service quality of airline industry using hybrid best worst method and VIKOR", *Journal of Air Transport Management*, Vol. 68, pp. 35–47.

Hinnen, G., Hille, S.L. and Wittmer, A. (2017), "Willingness to Pay for Green Products in Air Travel: Ready for Take-Off?", *Business Strategy and the Environment*, Vol. 26 No. 2, pp. 197–208.

Hompel, M. (2009), *Materialflusssysteme: Förder- und Lagertechnik,* 3rd ed., Springer.

Hompel, M. ten, Sadowsky, V. and Beck, M. (2011), *Kommissionierung: Materialflusssysteme 2 - Planung und Berechnung der Kommissionierung in der Logistik, VDI-[Buch]*, Springer, Berlin.

Hompel, M. ten and Schmidt, T. (2005), *Warehouse Management: Automatisierung und Organisation von Lager- und Kommissioniersystemen,* 2., korr. Aufl., Springer, Berlin.

Hovora, J. (2001), "Logistics in Onboard Services (Inflight Services) of Airlines", *Tourism and Hospitality Research*, Vol. 3 No. 2, pp. 177–180.

Huang, M., Nie, H. and Zhang, M. (2019), "Analysis of ground handling characteristic of aircraft with electric taxi system", *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, Vol. 233 No. 6, pp. 1546–1561.

Hünecke, K. (2017), *Die Technik des modernen Verkehrsflugzeuges,* 1. Auflage, Motorbuch Verlag, Stuttgart.

Hunter, J.A. (2006), "A Correlational Study of How Airline Customer Service and Consumer Perception of Airline Customer Service Affect the Air Rage Phenomenon", *Journal of Air Transportation No.* 11.

IATA (2017), *Cabin Operations Safety Best Practices Guide*, Montreal—Geneva.

Inmarsat (2020), "Einfluss neuer Technologien in der Flugzeugkabine auf das Vertrauen der Passagiere (während der Corona-Pandemie)", available at: https://de.statista.com/statistik/daten/studie/1287060/umfrage/einfluss-neuer-technologien-in-der-flugzeugkabine-auf-das-passagiervertrauen/ (accessed 23 December 2022).

International Air Transport Association - IATA (2017), "Global Passenger Survey (GPS)", available at: https://www.iata.org/en/publications/store/global-passenger-survey/ (accessed 28 December 2022).

International Civil Aviation Organization - ICAO (2013), *Human Factors Digest No15: Human factors in cabin safety* Cir 300 AN/173, p. 218, available at: https://caisatech.net/uploads/XXI_1.1_OACI_H51_G251_Cir%20300_R0_2003.pdf (accessed 27 July 2022).

International Civil Aviation Organization - ICAO (2014), *Cabin Crew Safety Training Manual* DOC 10002 AN/502, First Edition, available at: http://www.aviationchief.com/uploads/9/2/0/9/92098238/icao_doc_10002_-_cabin_crew_safety_training_manual_1.pdf (accessed 27 July 2022).

International Civil Aviation Organization - ICAO (2017), *Minimum Number of Cabin Crew Members On Board* DOC-10072-001-01, available at: https://store.icao.int/en/manual-on-the-establishment-of-minimum-cabin-crew-requirements-doc-10072 (accessed 28 December 2022).

International Organization for Standardization - ISO (2021), *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles* ISO/SAE PAS 22736:2021, 1st ed., available at: https://www.iso.org/standard/73766.html (accessed 28 December 2022).

Ivanov, S. (2019), “Ultimate transformation: How will automation technologies disrupt the travel, tourism and hospitality industries?”, *Zeitschrift für Tourismuswissenschaft*, Vol. 11 No. 1, pp. 25–43.

Ivanov, S.H., Webster, C. and Berezina, K. (2017), *Adoption of Robots and Service Automation by Tourism and Hospitality Companies*.

Ivkov, M., Blesic, I., Simat, K., Demirović, D., Bozic, S. and Stefanovic, V. (2016), “Innovations in the restaurant industry: An exploratory study”, *Ekonomika poljoprivrede*, Vol. 63, pp. 1169–1186.

Jayanath, A. and Gamini, H. (2009), “A critical review of multi-criteria decision making methods with special reference to forest management and planning”, *Ecological Economics*, Vol. 68 No. 10, pp. 2535–2548.

Jiang, Y., Wu, X. and Chen, Y. (2020), “Designing a Flexible Catering System for High-Speed Railway Considering Departure Time Selection and Time Deadline Constraints”, *IEEE Access*, Vol. 8, pp. 44300–44317.

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-González, M.J. and Narayan, J. (2017), “Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges”, *Urban Planning*, Vol. 2 No. 2, pp. 13–25.

Jonas, H.P., Gumpinger, T. and Krause, D. (2009), “Flexgalley – innovative approach for a modular design of an aircraft-galley”.

Jones, P. (Ed.) (2011), *Flight catering,* Second edition 2004, this edition published 2011 by Routledge, Routledge, Abingdon, Oxon, New York, NY.

Kao, W.-K. and Huang, Y.-S. (2023), “Service robots in full- and limited-service restaurants: Extending technology acceptance model”, *Journal of Hospitality and Tourism Management*, Vol. 54, pp. 10–21.

Karaman, A.S. and Akman, E. (2018), “Taking-off corporate social responsibility programs: An AHP application in airline industry”, *Journal of Air Transport Management*, Vol. 68, pp. 187–197.

Kelleher, C. and McGilloway, S. (2005), “Survey Finds High Levels of Work-related Stress Among Flight Attendants”, *Cabin Crew Safety*, Vol. 40 No. 6, pp. 1–5.

Kern, H. and Schumann, M. (1985), “Das Ende der Arbeitsteilung?: Rationalisierung in der industriellen Produktion; Bestandsaufnahme, Trendbestimmung.”.

Keselova, M., Liptakova, D., Koscak, P. and Kolesar, J. (2019), “Air carrier training process specifications”, *ICETA 2019 - 17th IEEE International Conference on Emerging eLearning Technologies and Applications, Proceedings*.

KLM - Royal Dutch Airlines (2022), “Meals in Economy Class. Onboard experience and services”, available at: https://www.klm.com/information/travel-class-extra-options/economy-class-meals#intercontinental-flights (accessed 2 November 2022).

Kohl, N. and Karisch, S.E. (2004), “Airline Crew Rostering: Problem Types, Modeling, and Optimization”, *Annals of Operations Research*, Vol. 127 1-4, pp. 223–257.

Konold, P. and Reger, H. (2003), *Praxis der Montagetechnik: Produktdesign, Planung, Systemgestaltung, Vieweg Praxiswissen,* 2., überarbeitete und erweiterte Auflage, Vieweg+Teubner Verlag, Wiesbaden.

Korita Aviation (2019), “ALUFLITE ATLAS STANDARD OVEN RACK”, available at: https://www.directaviation.aero/korita/aviation/oven-racks/aluflite-atlas-standard-oven-rack (accessed 18 October 2019).

Kotha, S. and Orne, D. (1989), “Generic manufacturing strategies: A conceptual synthesis”, *Strategic Management Journal*, Vol. 10 No. 3, pp. 211–231.

Kovbasyuk, S.V. and Pisarchuk, A.A. (2007), “Application of methods of multicriteria analysis to decision making in automated control systems”, *Journal of Automation and Information Sciences*, Vol. 39 No. 9, pp. 26–39.

Kovynyov, I. and Mikut, R. (2019), “Digital technologies in airport ground operations”, *NETNOMICS: Economic Research and Electronic Networking*, Vol. 20 No. 1, pp. 1–30.

Krallmann, H., Bobrik, A. and Levina, O. (2013), *Systemanalyse im Unternehmen: Prozessorientierte Methoden der Wirtschaftsinformatik,* 6., überarb. und erw. Aufl., Oldenbourg-Verl., München.

Krause, D., Beckmann, G., Eilmus, S., Gebhardt, N., Jonas, H. and Rettberg, R. (2014), “Integrated Development of Modular Product Families: A Methods Toolkit”, in Simpson, T.W., Jiao, J.R., Siddique, Z. and Hölttä-Otto, K. (Eds.), *Advances in product family and product platform design: Methods & applications*, Vol. 18, Springer, New York, NY, pp. 245–269.

Krause, D., Gebhardt, N., Greve, E., Oltmann, J., Schwenke, J. and Spallek, J. (2017), “New Trends in the Design Methodology of Modularization”.

Krause, D., Plaumann, B., Gumpinger, T. and Jonas, H. (2011), “Flexible Positionierung von modularen Kabinenmonumenten durch innovative Anbindungen in Leichtbauweise”.

Krishnakumar, K. and Kavitha, S. (2020), “Passengers’ expectation and satisfaction on service performance in indian railway catering and tourism corporation”, *International Journal of Scientific and Technology Research*, Vol. 9 No. 3, pp. 6908–6916.

Krylov, E., Fedorova, N. and Kozlovtseva, N. (2018), “Development of multicriteria approach to cutting tools selection for automated manufacturing systems”, *2018 International Russian Automation Conference, RusAutoCon 2018*.

Kuen-Chang Lee, Wen-Hsien Tsai, Chih-Hao Yang and Ya-Zhi Lin (2018), “An MCDM approach for selecting green aviation fleet program management strategies under multi-resource limitations”, *Journal of Air Transport Management*, Vol. 68, pp. 76–85.

Kuhl, J. and Krause, D. (2019), “Strategies for Customer Satisfaction and Customer Requirement Fulfillment within the Trend of Individualization”, *Procedia CIRP*, Vol. 84, pp. 130–135.

Kyung-in, Y. and Mun-kyung K. (2018), “A Study on Minimum Cabin Crew Requirements for Korean Low Cost Air Carriers”, *Journal of the Korean Society for Aeronautical and Space Policy and Law*, Vol. 33 No. 2, pp. 291–314.

Landau, K., Rademacher, H., Meschke, H., Winter, G., Schaub, K., Grasmueck, M., Moelbert, I., Sommer, M. and Schulze, J. (2008), “Musculoskeletal disorders in assembly jobs in the automotive industry with special reference to age management aspects”, *International Journal of Industrial Ergonomics*, Vol. 38 No. 7, pp. 561–576.

Lapesa Barrera, D. (2022), “Human Factors”, in Lapesa Barrera, D. (Ed.), *Aircraft Maintenance Programs*, *Springer eBook Collection*, 1st ed. 2022, Springer International Publishing; Imprint Springer, Cham, pp. 265–281.

Law, K. (2011), “Airline catering service operation, schedule nervousness and collective efficacy on performance: Hong Kong evidence”, *Service Industries Journal*, Vol. 31 No. 6, pp. 959–973.

Laws, E. (2005), “Managing Passenger Satisfaction”, *Journal of Quality Assurance in Hospitality & Tourism*, Vol. 6 1-2, pp. 89–113.

Lee, H., Wilbur, J., Conrad, K.M. and Miller, A.M. (2006), “Risk factors associated with work-related musculoskeletal disorders among female flight attendants: Using a focus group to prepare a survey”, *Aaohn Journal*, Vol. 54 No. 4, pp. 154–164.

Leite, G.S., Albuquerque, A.B., Pinheiro, P.R. and Silhavy R., Silhavy P., Prokopova Z. (2020), “A Multi-criteria Model Application in the Prioritization of Processes for Automation in the Scenario of Intelligence and Investigation Units”, *Advances in Intelligent Systems and Computing*, Vol. 1294, pp. 947–965.

Levin, D.N., Ponomarenko, A.V. and Tsigin, Y.P. (2020), “Automation of ergonomic expertise of the information management and cockpit management of a promising aircraft”, *Mekhatronika, Avtomatizatsiya, Upravlenie*, Vol. 21 No. 8, pp. 489–496.

Lezoche, M., Hernandez, J.E., Díaz, Maria del Mar Eva Alemany, Panetto, H. and Kacprzyk, J. (2020), “Agri-food 4.0: a survey of the supply chains and technologies for the future agriculture”, *Computers in Industry*, Vol. 117, p. 103187.

Li, C., Liu, X., Zhang, Z., Bao, K. and Qi, Z.T. (2016), “Wheeled delivery robot control system”, *MESA 2016 - 12th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications - Conference Proceedings*.

Li, W. (2015), “A cabin crew fatigue risk comprehensive evaluation model”, in *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery: FSKD 2015 15-17 August, Zhangjiajie, China, Zhangjiajie, China, 8/15/2015 - 8/17/2015*, IEEE, [Piscataway, New Jersey], pp. 1596–1600.

Lihong Chen and Jingzheng Ren (2018), “Multi-attribute sustainability evaluation of alternative aviation fuels based on fuzzy ANP and fuzzy grey relational analysis”, *Journal of Air Transport Management*, Vol. 68, pp. 176–186.

Liou, F.W. (2019), *Rapid prototyping and engineering applications: A toolbox for prototype development,* Second edition, CRC Press, Boca Raton, FL.

Lotter, B. and Wiendahl, H. (2012), *Montage in der industriellen Produktion: Ein Handbuch für die Praxis, VDI-Buch,* 2nd ed., Springer, Dordrecht.

LSG (2018), “LSG Sky Chefs | Facts and Figures”, available at: https://www.lsgskychefs.com/ (accessed 17 July 2019).

Lück, M., Hünefeld, L., Brenscheidt, S., Bödefeld, M. and Hünefeld, A. (2019), *Grundauswertung der BIBB/BAuA-Erwerbstätigenbefragung 2018 (2. Auflage)*, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA).

Lufthansa Innovation Hub (2021), “Distribution of airline reviews on tripadvisor.com by main topic discussed”, available at: tnmt.com.

M. Nila, D.S. (2010), “From preliminary aircraft cabin design to cabin optimization”, *Deutscher Luft- und Raumfahrtkongress*.

Macuada, C.J., Oddershede, A.M., Quezada, L.E., Palominos, P.I. and Dzitac I., Manolescu M.-J., Dzitac S., Oros H., Filip F.G., Kacprzyk J. (2021), “Methodological proposal to define the degree of automation in the sanitary industry in chile to adapt to climate change”, *Advances in Intelligent Systems and Computing*, 1243 AISC, pp. 284–295.

Mahony, P.H., Griffiths, R.F., Larsen, P. and Powell, D. (2008), “Retention of knowledge and skills in first aid and resuscitation by airline cabin crew”, *Resuscitation*, Vol. 76 No. 3, pp. 413–418.

Mak, B. and Chan, W.W. (2007), “A study of environmental reporting: International Japanese Airlines”, *Asia Pacific Journal of Tourism Research*, Vol. 12 No. 4, pp. 303–312.

Mankins, J. (2004), “TECHNOLOGY READINESS LEVELS”, Advanced Concepts Office, *Office of Space Access and Technology - NASA.*

Marija Cubric (2020), “Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study”, *Technology in Society*, Vol. 62, p. 101257.

Maurer, P. (2007), *Luftverkehrsmanagement: Basiswissen,* 4., völlig überarbeitete und erweiterte Auflage, De Gruyter, München.

McKinsey (2017), “MGI-A-future-that-works_Full-report”.

McMullin, D.L., Jacobsen, A.R., Carvan, D.C., Gardner, R.J., Goegan, J.A. and Koehn, M.S. (2008), “The Boeing 787 Dreamliner – a Case Study in Large-Scale Design Integration”, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 52 No. 20, pp. 1670–1671.

Medard, C.P. and Sawhney, N. (2007), “Airline crew scheduling from planning to operations”, *European Journal of Operational Research*, Vol. 183 No. 3, pp. 1013–1027.

Meincke, P., Asmer, L., Geike, L. and Wiarda, H. (2018), “Concepts for Cargo Ground Handling of Unmanned Cargo Aircrafts and Their Influence on the Supply Chain”, *8th International Conference on Logistics, Informatics and Service Sciences, LISS 2018 - Proceeding.*

Mensen, H. (2013), *Handbuch der Luftfahrt, VDI-Buch,* 2., neu bearbeitete Auflage, Springer Berlin Heidelberg, Berlin, Heidelberg.

Merriam-Webster, “"Customize."”, available at: https://www.merriam-webster.com/dictionary/customize (accessed 3 November 2022).

Merriam-Webster, “"Individualize."”, available at: https://www.merriam-webster.com/dictionary/individualize (accessed 3 November 2022).

Merriam-Webster, ““Personalize.””, available at: https://www.merriam-webster.com/dictionary/personalize (accessed 3 November 2022).

Merriam-Webster (2022a), “Definition of CATERING”, available at: https://www.merriam-webster.com/dictionary/catering#other-words (accessed 1 March 2022).

Merriam-Webster (2022b), “"Framework"”, available at: https://www.merriam-webster.com/dictionary/framework (accessed 30 December 2022).

Mica R. Endsley and Esin O. Kiris (1995), “The Out-of-the-Loop Performance Problem and Level of Control in Automation”, *Human factors*, Vol. 37 No. 2, pp. 381–394.

Michaelis, M. (2013), *Co-Development of Products and Manufacturing Systems Using Integrated Platform Models*, Unpublished.

Milgram, P., Rastogi, A. and Grodski, J.J. (1995), "Telerobotic control using augmented reality".

Miriam F. Bongo, Kissy Mae S. Alimpangog, Jennifer F. Loar, Jason A. Montefalcon and Lanndon A. Ocampo (2018), "An application of DEMATEL-ANP and PROMETHEE II approach for air traffic controllers' workload stress problem: A case of Mactan Civil Aviation Authority of the Philippines", *Journal of Air Transport Management*, Vol. 68, pp. 198–213.

Mohamed Eshtaiwi, Ibrahim Badi, Ali Abdulshahed and Turan Erman Erkan (2018), "Determination of key performance indicators for measuring airport success: A case study in Libya", *Journal of Air Transport Management*, Vol. 68, pp. 28–34.

Moir, I. and Seabridge, A. (2012), *Design and development of aircraft systems/ Ian Moir; Allan Seabridge, Aerospace series,* 2. ed., [Elektronische Ressource].

Moray, N., Rodriguez, D. and Clegg, B. (2000), "Levels of Automation in Process Control", *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 44 No. 1, pp. 93–96.

Mortensen Ernits, R., Bauer, M., Kaufeld, N., Kiehne, O., Reiss, M. and Stock, S. (2019a), *Electrically driven transport trolley combination for an aircraft cabin* EP3459851A1, available at: https://worldwide.espacenet.com/patent/search/family/063678417/publication/EP3459851A1?q=pn%3DEP3459851A1 (accessed 31 July 2020).

Mortensen Ernits, R., Pupkes, B., Keiser, D., Reiß, M. and Freitag, M. (2022a), "Inflight catering services – A comparison of central and decentral galleys inside the aircraft cabin, a concept-based approach", *Transportation Research Procedia*, Vol. 65, pp. 34–43.

Mortensen Ernits, R., Reiß, M., Bauer, M., Becker, A. and Freitag, M. (2022b), "Concept for individualisation of inflight catering meals through integrated pre-ordering in usual distribution service inside the aircraft cabin", *Journal of Air Transport Management.*

Mortensen Ernits, R., Reiss, M., Bauer, M., Kaufeld, N., Dahms, T., Hoelscher, H. and Freitag, M. (2019b), *System for inventory management of on-board refreshments for a vehicle* EP3552962A1, available at:
https://worldwide.espacenet.com/patent/search/family/063678417/publication/EP3459851A1?q=pn%3DEP3459851A1 (accessed 31 July 2020).

Mumtaz, S.H. (2017), "Analysis of Mental Health Issues and its Implications On Cabin Crew at Emirates Airlines", Master Thesis, Middle Tennessee State University, Tennessee, 2017.

Murphy, A. (2001), "The flight attendant dilemma: an analysis of communication and sensemaking during in-flight emergencies", *Journal of Applied Communication Research*, Vol. 29 No. 1, pp. 30–53.

Mustafa Jahangoshai Rezaee and Samuel Yousefi (2018), "An intelligent decision making approach for identifying and analyzing airport risks", *Journal of Air Transport Management*, Vol. 68, pp. 14–27.

Narishkin, A. (2019), "How Emirates makes 225,000 region-specific meals a day for its passengers", available at: https://www.businessinsider.com/emirates-airline-airplane-food-how-makes-flight-meals-2019-5 (accessed 27 December 2022).

Niţă, M.F. (2012), *Contributions to aircraft preliminary design and optimization*, Zugl.: Hamburg, Hochschule für Angewandte Wiss., Diss., 2012 / Zugl.: Bucharest, Politehnica Univ., Diss., 2012, *Luftfahrt,* 1. Aufl., Verl. Dr. Hut, München.

Niţă, M.F. and Scholz, D. (2011), "Business opportunities in aircraft cabin conversion and refurbishing", *Journal of Aerospace Operations*, Vol. 1 1-2, pp. 129–153.

Norin, A., Granberg, T.A., Di Yuan and Värbrand, P. (2012), "Airport logistics – A case study of the turn-around process", *Journal of Air Transport Management*, Vol. 20, pp. 31–34.

O'Connell, J.F. and Williams, G. (2005), "Passengers' perceptions of low cost airlines and full service carriers: A case study involving Ryanair, Aer Lingus, Air Asia and Malaysia Airlines", *Journal of Air Transport Management*, Vol. 11 No. 4, pp. 259–272.

O'Leary, D.E. (2008), "Gartner's hype cycle and information system research issues", *International Journal of Accounting Information Systems*, Vol. 9 No. 4, pp. 240–252.

Okwir, S., Ulfvengren, P., Angelis, J., Ruiz, F. and Núñez Guerrero, Y.M. (2017), "Managing turnaround performance through Collaborative Decision Making", *Journal of Air Transport Management*, Vol. 58, pp. 183–196.

Olive, M.L., Oishi, R.T. and Arentz, S. (2006), "Commercial Aircraft Information Security-an Overview of ARINC Report 811", in *IEEE/AIAA 25th Digital Avionics Systems Conference, 2006: Oct. 2006, [Portland, OR, Portland, OR, 10/15/2006 - 10/19/2006*, IEEE Operations Center, Piscataway, NJ, pp. 1–12.

Orlady, H.W., Orlady, L.M. and Lauber, J.K. (2017), *Human Factors in Multi-Crew Flight Operations*, Routledge.

Pahl, G. (2013), *Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung, Springer-Lehrbuch,* 8., vollständig überarbeitete Auflage, Springer Berlin Heidelberg, Berlin, Heidelberg.

(2012), *Pahl/beitz konstruktionslehre: Methoden und anwendung erfolgreicher*, Springer, [Place of publication not identified].

Palmer, A. (2008), *Principles of services marketing,* 5. ed., McGraw-Hill, London.

Parasuraman, R., Sheridan, T.B. and Wickens, C.D. (2000), "A model for types and levels of human interaction with automation", *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, Vol. 30 No. 3, pp. 286–297.

Payam Shojaei, Seyed Amin Seyed Haeri and Sahar Mohammadi (2018), "Airports evaluation and ranking model using Taguchi loss function, best-worst method and VIKOR technique", *Journal of Air Transport Management*, Vol. 68, pp. 4–13.

Pedro Jose Gudiel Pineda, James J.H. Liou, Chao-Che Hsu and Yen-Ching Chuang (2018), "An integrated MCDM model for improving airline operational and financial performance", *Journal of Air Transport Management*, Vol. 68, pp. 103–117.

Peffers, K., Tuunanen, T., Rothenberger, M.A. and Chatterjee, S. (2007), "A Design Science Research Methodology for Information Systems Research", *Journal of Management Information Systems*, Vol. 24 No. 3, pp. 45–77.

Petrova, A. (2018), "How high-design interior structures can enhance beauty and utility - The Loose Galley", available at: https://runwaygirlnetwork.com/2018/10/11/how-high-design-interior-structures-can-enhance-beauty-and-utility/ (accessed 23 April 2022).

Pfeiffer, W., Asenkerschbaumer, S. and Weiss, E. (1990), "FuE-Projektanalyse ein Instrument zur Erhöhung der FuE-Effiziens", in *Technologie-Management / Werner Pfeiffer … (Hrsg.)*, pp. 127–160.

Pfohl, H.-C. (2022), *Logistics systems: Business fundamentals,* 9th ed., Springer, Berlin.

Ponn, J. (2011), *Konzeptentwicklung und Gestaltung technischer Produkte: Systematisch von Anforderungen zu Konzepten und Gestaltlösungen, VDI-Buch,* 2nd Aufl., Springer, Heidelberg [Germany].

R.M. Wilson (1987), "Patent analysis using online databases—I. Technological trend analysis", *World Patent Information*, Vol. 9 No. 1, pp. 18–26.

Rahman, N., Ahmad, M.F., Rahim, S.A. and Mayor-Vitoria, F. (2020), "Advancing theory on halal food supply chain in aviation: Current issues and future research", *Test Engineering and Management*, Vol. 83, pp. 1333–1337.

Raj, A., Kumar, J.A. and Bansal, P. (2020), "A multicriteria decision making approach to study barriers to the adoption of autonomous vehicles", *Transportation Research Part A: Policy and Practice*, Vol. 133, pp. 122–137.

Rebezova, M., Sulima, N. and Surinov, R. (2012), "Development trends of air passenger transport services and service distribution channels", *Transport and Telecommunication*, Vol. 13 No. 2, pp. 159–166.

Reitmann, J. (2004), *Neue Technologien und Trends in der Kabinenkommunikation, DGLR*, Hamburg.

Renaud, J., Levrat, E. and Fonteix, C. (2006), "Weights determination in industrial decision making aided by OWA operators", *IFAC Proceedings Volumes*, Vol. 9 PART 1.

Renehan, D. and Efthymiou, M. (2020), "Transatlantic market competition between hybrid carrier and long-Haul low-cost carrier business models", *Journal of Aerospace Technology and Management*, Vol. 12 No. 1, pp. 1–16.

Renold, M., Kuljanin, J. and Kalić, M. (2019), "The comparison of financial performance of airlines with different business model operated in long-haul market", *Transportation Research Procedia*, Vol. 43, pp. 178–187.

Retail inMotion (2022), "Food & Beverage and Boutique Products", available at: https://www.retailinmotion.com/boutique-products/ (accessed 28 December 2022).

Reznar, M.M., Brennecke, K., Eathorne, J. and Gittelsohn, J. (2019), "A cross-sectional description of mobile food vendors and the foods they serve: Potential partners in delivering healthier food-away-from-home choices", *BMC Public Health*, Vol. 19 No. 1.

Richter, A. (2013), *Gepäcklogistik auf Flughäfen: Grundlagen, Systeme, Konzepte und Perspektiven*, Springer Berlin Heidelberg, Berlin, Heidelberg.

Riley, M. (2005), "Food and beverage management: A review of change", *International Journal of Contemporary Hospitality Management*, Vol. 17 No. 1, pp. 88–93.

Rohde, A.-K., Pupkes, B., Mortensen Ernits, R., Keiser, D., Lütjen, M. and Freitag, M. (2022), "Challenges and Approaches of Non-pharmaceutical Interventions for Airport Operations During Pandemic Situations", in Freitag, Michael and Kinra, Aseem and Kotzab, Herbert and Megow, Nicole (Ed.), *Dynamics in Logistics*, Springer International Publishing, Cham, pp. 52–64.

Rojahn, J. (2007), "Flugzeugkonzept Streamliner", available at: https://rojahn-design.com/de/post_projects/streamliner/ (accessed 23 April 2022).

Rossow, C.-C., Wolf, K. and Horst, P. (2014), *Handbuch der Luftfahrzeugtechnik: Mit 34 Tabellen,* [Elektronische Ressource], Hanser, München.

Ruff, H., Narayanan, S. and Draper, M. (2002), "Human Interaction with Levels of Automation and Decision-Aid Fidelity in the Supervisory Control of Multiple Simulated Unmanned Air Vehicles", *Presence*, Vol. 11, pp. 335–351.

Ryan W. Proud, Jeremy J. Hart and Richard B. Mrozinski (2003), "Methods for Determining the Level of Autonomy to Design into a Human Spaceflight Vehicle: A Function Specific Approach".

Sadraey, M.H. (2013), *Aircraft design: A systems engineering approach, Aerospace series,* Online-Ausg, Wiley, Chichestet, West Sussex.

Salvador, F. (2007), "Toward a Product System Modularity Construct: Literature Review and Reconceptualization", *undefined.*

Sampath, V., Abrams, E.M., Adlou, B., Akdis, C., Akdis, M., Brough, H.A., Chan, S., Chatchatee, P., Chinthrajah, R.S., Cocco, R.R., Deschildre, A., Eigenmann, P., Galvan, C., Gupta, R., Hossny, E., Koplin, J.J., Lack, G., Levin, M., Shek, L.P., Makela, M., Mendoza-Hernandez, D., Muraro, A., Papadopoulous, N.G., Pawankar, R., Perrett, K.P., Roberts, G., Sackesen, C., Sampson, H., Tang, M.L.K., Togias, A., Venter, C., Warren, C.M., Wheatley, L.M., Wong, G.W.K., Beyer, K., Nadeau, K.C. and Renz, H. (2021), "Food allergy across the globe", *The Journal of allergy and clinical immunology*, Vol. 148 No. 6, pp. 1347–1364.

Santos, G.D., Koothal, A., Cardenas, I.S., Lovell, M., Collier, C. and Kim, J.-H. (2017), "FlightBot: Towards Improving In-Flight Customer Experience through the Use of Robotics", in Arabnia, H. (Ed.), *2017 International Conference on Computational Science and Computational Intelligence: CSCI 2017 proceedings Las Vegas, USA, 14-16 December 2017, Las Vegas, NV, USA, 12/14/2017 - 12/16/2017*, IEEE Computer Society, Conference Publishing Services, Los Alamitos, CA, pp. 1793–1796.

Schlegel, A. (2010), *Bodenabfertigungsprozesse im Luftverkehr: Eine statistische Analyse am Beispiel der Deutschen Lufthansa AG am Flughafen Frankfurt/Main, Gabler research,* 1. Aufl., Gabler, Wiesbaden.

Schmidt, M. (2017a), "A review of aircraft turnaround operations and simulations", *Progress in Aerospace Sciences*, Vol. 92, pp. 25–38.

Schmidt, M. (2017b), "A review of aircraft turnaround operations and simulations", *Progress in Aerospace Sciences*, Vol. 92, pp. 25–38.

Schnieder, E. (1999), *Methoden der Automatisierung: Beschreibungsmittel, Modellkonzepte und Werkzeuge für Automatisierungssysteme, Studium Technik*, Vieweg+Teubner Verlag, Wiesbaden.

Scholz, D. (2002), "Aircraft Systems - Reliability, Mass, Power and Costs", *European Workshop on Aircraft Design Education.*

Schönsleben, P. (2019), "Tangible services and intangible products in industrial product service systems", *Procedia CIRP*, Vol. 83, pp. 28–31.

Schultz, M. and Reitmann, S. (2019), "Machine learning approach to predict aircraft boarding", *Transportation Research Part C: Emerging Technologies*, Vol. 98, pp. 391–408.

Schulz, M. (2017), "Dynamic change of aircraft seat condition for fast boarding", *Transportation Research Part C: Emerging Technologies*, Vol. 85, pp. 131–147.

Selçuk Perçin (2018), "Evaluating airline service quality using a combined fuzzy decision-making approach", *Journal of Air Transport Management*, Vol. 68, pp. 48–60.

Sell, W. (1967), "Airlines Food Service Problems", *Cornell Hotel and Restaurant Administration Quarterly*, Vol. 8 No. 1, pp. 93–97.

Seren Bilge Yılmaz and Eda Yücel (2021), "Optimizing onboard catering loading locations and plans for airlines", *Omega*, Vol. 99, p. 102301.

Seth, R. (2013), "The Flying Cart", available at: https://www.yankodesign.com/2013/04/12/the-flying-cart/ (accessed 23 April 2022).

Shao, P.-C., Yen, J.-J. and Ye, K.-D. (2008), "Identifying fatigue of flight attendants in short-haul operations", *ICAS Secretariat - 26th Congress of International Council of the Aeronautical Sciences 2008, ICAS 2008*, Vol. 1.

Sheridan, T., Verplank, W. and Brooks, T. (1978), "Human and Computer Control of Undersea Teleoperators".

Skytender (2023), "SkyBarista | One", available at: https://skytendersolutions.com/products/ (accessed 25 March 2023).

Skytrax (2022), "Airline and Airport Customer Reviews", available at: https://www.airlinequality.com/ (accessed 28 December 2022).

Slavica Dožić, Tatjana Lutovac and Milica Kalić (2018), "Fuzzy AHP approach to passenger aircraft type selection", *Journal of Air Transport Management*, Vol. 68, pp. 165–175.

Snell, M. (2002), *Cost-benefit analysis for engineers and planners*, Thomas Telford, London.

Splaver, B.R. (1975), *Successful catering*, Cahners Books, Boston.

Statista (2022a), "Average passenger fare of selected airlines in Europe in 2020", available at: https://www.statista.com/statistics/1125265/average-ticket-price-selected-airlines-europe/ (accessed 17 June 2022).

Statista (2022b), "Average passenger fare of selected airlines in Europe in 2021 (in euros)", available at: https://www.statista.com/statistics/1125265/average-ticket-price-selected-airlines-europe/ (accessed 28 December 2022).

Stechert, C., Franke, H.-J. and Vietor, T. (2011), "Knowledge-Based Design Principles and Tools for Parallel Robots", in Siciliano, B., Khatib, O., Groen, F., Schütz, D. and Wahl, F.M. (Eds.), *Robotic Systems for Handling and Assembly*, *Springer Tracts in Advanced Robotics*, Vol. 67, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 59–75.

Stevens, R.E. and Sherwood, P.K. (1982), *How to prepare a feasibility study: A step-by-step guide including 3 model studies*, Prentice-Hall, Englewood Cliffs, N.J.

Straub, J. (2015), "In search of technology readiness level (TRL) 10", *Aerospace Science and Technology*, Vol. 46, pp. 312–320.

Sundarakani, B., Abdul Razzak, H. and Manikandan, S. (2018a), "Creating a competitive advantage in the global flight catering supply chain: a case study using SCOR model", *International Journal of Logistics Research and Applications*, Vol. 21 No. 5, pp. 481–501.

Sundarakani, B., Abdul Razzak, H. and Manikandan, S. (2018b), "Creating a competitive advantage in the global flight catering supply chain: a case study using SCOR model", *International Journal of Logistics Research and Applications*, Vol. 21 No. 5, pp. 481–501.

Sweet, N., Morris, E., Roberts, M. and Patterson, K. (2019), "Cabin Waste Handbook", *IATA*.

Sze, S.-N., Suk-Fong, A.N. and Chiew, K.-L. (2012), "An Insertion Heuristic Manpower Scheduling for In-Flight Catering Service Application", in Hutchison, D., Kanade, T., Kittler, J., Kleinberg, J.M., Mattern, F., Mitchell, J.C., Naor, M., Nierstrasz, O., Pandu Rangan, C., Steffen, B., Sudan, M., Terzopoulos, D., Tygar, D., Vardi, M.Y., Weikum, G., Hu, H., Shi, X., Stahlbock, R. and Voß, S. (Eds.), *Computational Logistics*, *Lecture Notes in Computer Science*, Vol. 7555, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 206–216.

Tabares, D.A. and Mora-Camino, F. (2019), "Aircraft ground operations: steps towards automation", *CEAS Aeronautical Journal*, pp. 1–10.

Tan Tan, Grant Mills, Eleni Papadonikolaki and Zhening Liu (2021), "Combining multi-criteria decision making (MCDM) methods with building information modelling (BIM): A review", *Automation in Construction*, Vol. 121, p. 103451.

Thakkar, J.J. (2021), *Multi-criteria decision making, Studies in systems, decision and control*, Vol. 336, Springer, Singapore.

Thamagasorn, M. and Pharino, C. (2019), "An analysis of food waste from a flight catering business for sustainable food waste management: A case study of halal food production process", *Journal of Cleaner Production*, Vol. 228, pp. 845–855.

TravelKhana (2022), "Food Delivery In Train", available at: https://www.travelkhana.com/ (accessed 27 December 2022).

Tuomi, A., Tussyadiah, I.P. and Stienmetz, J. (2021), "Applications and Implications of Service Robots in Hospitality", *Cornell Hospitality Quarterly*, Vol. 62 No. 2, pp. 232–247.

Vagia, M., Transeth, A.A. and Fjerdingen, S.A. (2016), "A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed?", *Applied Ergonomics*, 53 Pt A, pp. 190–202.

van den Berg, M.J., Signal, T.L. and Gander, P.H. (2019), "Perceived Workload Is Associated with Cabin Crew Fatigue on Ultra-Long Range Flights", *International Journal of Aerospace Psychology*.

van den Berg, M.J., Signal, T.L., Mulrine, H.M., Smith, A., Gander, P.H. and Serfontein, W. (2015), "Monitoring and managing cabin crew sleep and fatigue during an ultra-long range trip", *Aviation Space and Environmental Medicine*, Vol. 86 No. 8, pp. 705–713.

Vejvoda, M., Samel, A., Maaß, H., Luks, N., Linke-Hommes, A., Schulze, M., Mawet, L. and Hinninghofen, H. (2000), "Untersuchungen zur Beanspruchung des Kabinenpersonals auf transmeridianen Strecken".

Verpraet, I. (2019), "Safran reveals multiple galley advances at AIX 2019", available at: https://www.aircraftinteriorsinternational.com/news/galleys-monuments/safran-reveals-multiple-galley-advances-at-aix-2019.html (accessed 23 April 2022).

Vučijak, B., Pašić, M. and Zorlak, A. (2015), "Use of Multi-criteria Decision Aid Methods for Selection of the Best Alternative for the Highway Tunnel Doors", *Procedia Engineering*, Vol. 100, pp. 656–665.

Wang, J., Zhi, J.-Y., Xiang, Z.-R., Du, J., Chen, J.-P., He, S.-J. and Du, Y. (2021), "Enhancing aircraft cabin comfort to compete with high-speed trains: A survey in China", *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 31.

Whitelegg, D. (2007), *Working the skies: The fast-paced, disorienting world of the flight attendant*, New York University Press, New York.

Wilhelm, J., Beinke, T. and Freitag, M. (2020), “Improving Human-Machine Interaction with a Digital Twin”, in Freitag, M., Haasis, H.-D., Kotzab, H. and Pannek, J. (Eds.), *DYNAMICS IN LOGISTICS: Proceedings of the 7th international conference ldic, Cham, 2020*, Springer, [S.l.], pp. 527–540.

Wong, S., Singhal, S. and Neustaedter, C. (2017), *Smart Crew: A Smart Watch Design for Collaboration Amongst Flight Attendants*, ACM, available at: http://dl.acm.org/ft_gateway.cfm?id=3023274&type=pdf.

Wong, S., Singhal, S. and Neustaedter, C. (2018), “The Study and Design of Collaboration Tools for Flight Attendants”, *International Journal of Mobile Human Computer Interaction*, Vol. 10 No. 2, pp. 31–56.

Wu, C.-L. (2008), “Monitoring aircraft turnaround operations - Framework development, application and implications for airline operations”, *Transportation Planning and Technology*, Vol. 31 No. 2, pp. 215–228.

Wu, X., Nie, L., Xu, M. and Zhao, L. (2019), “Distribution planning problem for a high-speed rail catering service considering time-varying demands and pedestrian congestion: A lot-sizing-based model and decomposition algorithm”, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 123, pp. 61–89.

Xie, F., Wang, Q., Zheng, S., Li, L., Ling, L., Wei, Z., Wanyan, X. and Wu, X. (2018), “Optimization design and efficacy evaluation of crew cabin layout”, *Lecture Notes in Electrical Engineering*, Vol. 456, pp. 803–813.

Xu, S., Stienmetz, J. and Ashton, M. (2020), “How will service robots redefine leadership in hotel management? A Delphi approach”, *International Journal of Contemporary Hospitality Management*, Vol. 32 No. 6, pp. 2217–2237.

Yi-Chi Chang, Y. and Jones, P. (2007), “Flight Catering: An Investigation of the Adoption of Mass Customisation”, *Journal of Hospitality and Tourism Management*, Vol. 14 No. 1, pp. 47–56.

Yildiz, B., Förster, P., Feuerle, T., Hecker, P., Bugow, S. and Helber, S. (2018), “A Generic Approach to Analyze the Impact of a Future Aircraft Design on the Boarding Process”, *Energies*, Vol. 11 No. 2, p. 303.

Yılmaz, S.B. and Yücel, E. (2021), “Optimizing onboard catering loading locations and plans for airlines”, *Omega*, Vol. 99, p. 102301.

Yoo, K.-I. and Kim, M.-K. (2018), “A Study on Minimum Cabin Crew Requirements for Korean Low Cost Air Carriers”, *The Korean Journal of Air & Space Law and Policy*, Vol. 33 No. 2, pp. 291–314.

Yoon, B., Lee, K., Lee, S. and Yoon, J. (2015), “Development of an R&D process model for enhancing the quality of R&D: comparison with CMMI, ISO and EIRMA”, *Total Quality Management and Business Excellence*, Vol. 26 7-8, pp. 746–761.

You, F., Bhamra, T. and Lilley, D. (2019), “Design for the passengers’ sustainable behaviour in a scenario of the in-flight catering service”, *Proceedings of the International Conference on Engineering Design, ICED*, 2019-August.

Zacher, S. and Reuter, M. (2017), *Regelungstechnik für Ingenieure: Analyse, Simulation und Entwurf von Regelkreisen, Lehrbuch,* 15., korrigierte Auflage, Springer Vieweg, Wiesbaden.

Zafarzadeh, M., Wiktorsson, M. and Baalsrud Hauge, J. (2021), "A Systematic Review on Technologies for Data-Driven Production Logistics: Their Role from a Holistic and Value Creation Perspective", *Logistics*, Vol. 5 No. 2.

Zehender, M. (2018), "Bei welchen Airlines gibt es noch kostenloses Essen?", available at: https://www.airliners.de/bei-airlines-essen/44632 (accessed 28 December 2022).

Zheng, X., Xu, R., Peng, Y. and Wang, S. (2015), "Tourism Service Composition Based on Multi-objective Optimization", *Proceedings - 2015 IEEE 12th International Symposium on Autonomous Decentralized Systems, ISADS 2015*.

Zijm, H. and Klumpp, M. (2017), "Future Logistics: What to Expect, How to Adapt", in Freitag, M., Kotzab, H. and Pannek, J. (Eds.), *Dynamics in Logistics: Proceedings of the 5th International Conference LDIC, 2016 Bremen, Germany*, *Springer eBook Collection Engineering*, Springer, Cham, pp. 365–379.

# Appendix

*A1 - Student theses*

This dissertation contains the results of the supervision of the following student theses:

Beierle, T.
Konzepterstellung für die Optimerung des Cateringprozesses innerhalb der Flugzeugkabine
Universität Bremen
2019

Kämena, C.
Konzeptentwicklung zur Automatisierung von Gepäckabfertigungsprozessen auf Flughäfen
Universität Bremen
2020

Modersitzki, S.
Konzeptentwicklung einer neuartigen Bordküche für Verkehrsflugzeuge
Universität Bremen
2019

Pupkes, B.
Development of automation levels for aircraft galleys considering safety requirements
Universität Bremen
2019

Rosenberger, L.
Mehrdimensionale Bewertung einer neuen Bordküche für das Flugzeugcatering
Universität Bremen
2019

*A2 - Resulted invention disclosures and patents*

| # | Invention Disclosures | Decision | Automation | Digitisation | Sustainability |
|---|---|---|---|---|---|
| 1 | Aircraft Catering Information System | File | | X | |
| 2 | Automated Tray identification System | Drop | | X | |
| 3 | Automated identification system GAIN | File | | X | |
| 4 | Galley water treatment unit for beverage dispenser | File | | X | |
| 5 | Automatic Galley for Preparation, Storage and Assembly of Aircraft Meals | Scient.Publ. | X | | |
| 6 | Ergonomic trolley for top tray Output for inflight meals | Drop | X | | |
| 7 | Integrated movement and guidance support for aircraft trolley | Drop | X | | |
| 8 | Mission specific flexible plug and play mounted aircraft galley | Drop | X | | |
| 9 | Passenger conveying table for automatic handover of inflight meals | File | X | | |
| 10 | Smart tool for oven related handling | File | X | | |
| 11 | Mobile Seat Mounted inflight meal box | Scient.Publ. | X | | |
| 12 | System and process for life cycle assessment orientated Aircraft cabin optimization | File | | | X |
| 13 | System and process for supporting aircraft cabin dismantling and recycling | File | | | X |