INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

DESIGN 2014

AN INTEGRATED PRODUCT DEVELOPMENT MODEL FOR AIRCRAFT FOOD DISPENSING MACHINES

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Keywords: product development strategies, concurrent engineering, IDEF0 modelling, design for product life-phases

1. Problem Background

Due to increasing competition, airlines are striving to reduce their operating costs. One of the airline's indirect operating cost as classified by the *International Civil Aviation Organisation* (ICAO) is related to passenger services [Horder 2003]. Although this cost is highly subjective to the airline itself, its major contributors include costs associated with cabin crew and in-flight catering service. Considering the in-flight catering service, the current cost-cutting focus of airline operators has given a boost to buy-on-board practices. The in-flight catering process is very time consuming, involving vast handling tasks, transportation and post-flight services. A long chain of activities, involving a vast number of stakeholders, take place before the actual serving of meals. Coupled with this, airlines are faced with extensive in-flight catering equipment maintenance. The extent of maintenance is mainly attributed to wear and tear, and corrosion. The latter is mainly a consequence of spillages from beverages and food stuff during preparation phase, and also from fluids migrating to the flooring substructure. Other challenges include the amount of leftovers after each revenue flight. With the traditional in-flight catering system there is no adequate control on wastage of on-board meals. An in-flight catering system which optimizes on holding stock and reduction in meal wastage contributes to reduced cost of operations.

The in-flight catering service has always been an important driver in customer relationship management in order to meet passenger needs and expectations. Currently the majority of passengers are being served with pre-packaged food at scheduled time during the flight by the cabin attendant. Furthermore, the majority of airlines do not provide special meals for those passengers who suffer from a metabolic disorder such as; gluten intolerance, diabetes and lactose intolerance. This implies that there is a lack of flexibility and diversity in the way in-flight catering serivce is being offered to passengers. Another concern is that during meal service the aircraft aisle is blocked by the service trolleys which can inhibit the passenger from going to the lavatory or simply walking by the aisle. Furthermore, trolleys can be of a safety issue as there is a risk for the passenger to be hit by a trolley during meal service, especially in case of turbulence.

From studies carried out by Airbus industry [Airbus 2008] it has been shown that over 60% of occupational injuries among flight attendants occur in the galley. Apart from the high risk of getting burnt during food preparation, these injuries are mostly due to galley equipment or objects that are not secured, such as trolleys that remain in the galleys without the brakes being applied and galley compartments that are not correctly latched and closed, falling from their stowage, and spilling their contents.

Flight attendants report on high physical load and complaints particularly focussing on the lower back. These findings are mainly ascribed to pushing and pulling of trolleys during the ascent and descent flight phases. Within an interdisciplinary experimental study conducted by Jager et. al [2007], the load on the lumbar spine of flight attendants during trolley handling aboard aircraft was analysed based on laboratory measurements regarding posture and exerted forces as well as on subsequent biomechanical model calculations. In this study a criterion of 2.5 kN load was set for evaluating disc compression during trolley manoeuvres. Jager et al. [2007] show that the mechanical load on the lumbar spine of flight attendants when moving a full size trolley having a weight of 65 kg and on a 5 degree-inclined floor, the compression-related peak values ranged from 1.7 kN to 2.7 kN.

Many different aircraft operators with diverse needs are a big challenge to the aircraft cabin design interior sector. For example, while low cost carriers are reducing galley equipment to the bare minimum, airlines which want to reach clients with extraordinary service offerings are looking for new galley design solutions. Beside these differences, there also exist common needs among various aircraft operators, such as developing lightweight galley equipment which consumes minimal space and energy. All of this shows that understanding and identifying the customer needs and demands at an early stage of aircraft interior design is critical for its success. The *integrated product development* (IPD) model [Andreasen and Hein 2000] is one proposal for the implementation of concurrent engineering in the product development process. As illustrated schematically in Figure 1, it follows the idea of parallelising tasks which are carried out by various streams within the product development process to allow for concurrent consideration of problems.

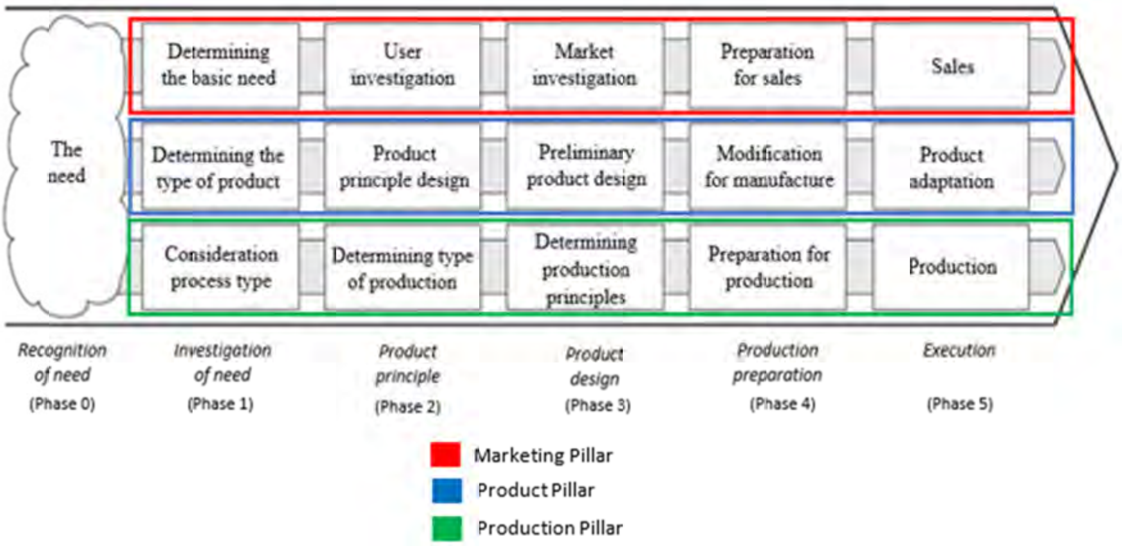

Figure 1. IPD Model – adopted from [Andreasen and Hein 2000]

Within this context, the overall aim of this research is to generate an IPD model (referred to as *AFDM_IPD*) aimed specifically at developing an *aircraft food dispensing machine* (AFDM) to be retrofitted into the galley of a commercial aircraft. One of the purposes of such machine is to transform the current in-flight catering service into a self-service system. Although the model is based on the three pillars of the IPD model, the major emphasis of this research was placed on the product design pillar. In addition, it must be mentioned that due to a pending patent application, this paper considers only the *AFDM_IPD* model, and will not disclose the design solution of the actual AFDM, which also form part of the research objectives. The main research boundaries include the following:

1. only the *Airbus A320* family (A319, A320, and A321) type of commercial aircraft is considered;
2. the AFDM has been designed in a way to be retrofitted into the galley. Since the galley configuration of any aircraft is aircraft operator specific, a G1 type of galley, commonly found on the A320 family is considered;
3. during the development process, reference is made to aviation regulations effective within the European jurisdiction only. This means that the AFDM design is compliant to the *European*

Aviation Safety Agency (EASA) *Part 21 subpart J* [EASA 2013] and not to the *Federal Aviation Administration* (FAA) [2013].

Based upon this introduction, the rest of this paper is organised as follows. Section 2 reviews existing product development models, and attempts made to develop AFDMs. Section 3 discloses the *AFDM_IPD* model developed. Qualitative evaluation results of this model with relevant stakeholders are presented in the subsequent section. Section 5 discusses the results obtained and draws key conclusions from this work.

2. Related Work

2.1 Product Development Models

Besides the IPD model illustrated in Figure 1, other models were found in literature. The model described in [Clark and Wheelwright 1993] is aimed at achieving cross-functional cooperation among product development, marketing and manufacturing. It is characterized by five phases, namely concept development, product planning, detailed design and development, commercial preparation and market introduction. As remarked by Schätz [2005], this model "achieves a cross-functional integration by describing what the product development core functions do, when they do it and how they get their work done." The model proposed by Ulrich and Eppinger [2011] starts by the planning phase followed by concept development, system level design, detail design, testing and refinement and production ramp-up. At each phase marketing, design and production activities are identified. Similar to Andreasen and Hein [2000] model, these two models are characterized by a matrix showing chronologically the different development phases in relation to the functional core disciplines Schätz [2005]. The model described in [Ullman 2010] is more fosuced on the *mechanical design process* and consists of product discovery, project planning, product definition, conceptual design, product development and product support. Relevant manufacturing and business related activities are then included in the corresponding phases of this model. These models are compared with repsect to Andreasen and Hein's model in Table 1.

Table 1. – Comparison of IPD Models

Author	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Andreasen and Hein [2000]	Recognition of the need	Investigation of need	Product Principle	Product Design	Production Preparation	Execution	
Clark and Wheelwright [1993]		Concept Development	Product Planning	Detailed Design & Development	Commercial Preparation	Market Introduction	
Ullman [2010]		Product Discovery	Project Planning	Product Definition	Conceptual Design	Product Develop-ment	Product Support
Ulrich and Eppinger [2011]		Planning	Concept Development	System Level Design	Detail Design	Testing & Refinement	Production Ramp-up

The model being proposed in this research for developing aircraft food dispensing machines is based on that proposed by Andreasen and Hein [2000]. The main reason is that this model considers the product adaptation as part of the design pillar in the *execution phase*. Given the various manufacturers of G1 galley type such as, *Driessen, Diehl* and *Sell Gmbh*, modifications of a vending machine for retrofitting requirements would be necessary in order to retrofit the galley during the execution phase.

Common to all the aforementioned models is that fact that the information flow between the different phases is not modelled formally using the *Integration DEFinition (IDEF) modelling language* [Integrated Definition Methods 2013] but rather by means of block diagrams and flowcharts. IDEF0 was chosen to model the IPD in this research as it is specifically designed to model the activities, actions and decisions of a 'system'. Furthermore, apart from its simplicity, the major benefit of using IDEF0 is that it applies dynamic information into the model to handle problems involving parallel activities. Kima et al. [2003] studied the use of IDEF and the *Unified Modelling Language* (UML) in the modelling of the product development process in the electronics industry. Kima C.H. et al. did not resort to one of the IPD models listed in Table 1. The model they used is specific to the electronics industry, though they considered relevant business and marketing activities in the IDEF modelling of different phases of product development. A product development model specific to aviation industry was found in [Bailey et al. 1999]. This six phase model illustrated in Figure 2, was employed by *McDonnell Douglas (MD) Aerospace*, in order to develop its Navy's F/A-18E/F tactical aircraft [Bailey et al. 1999]. The first four phases of the model perform configuration synthesis whilst the last two conduct product and process development. The need at MD was to develop an innovative aircraft which could fly longer distances without the need to refuel, had more carriage capability and the cost could not exceed more than 25 % of its previous version [Bailey et al. 1999]. This case study includes several examples of the concurrent product development. By tailoring the design of the E/F to take maximum advantage of improved manufacturing processes, the E/F consists of 42 % fewer parts than its predecessor even though it is 25 % larger [Bailey et al. 1999]. Reducing the number of parts reduced costs. Moreover, by creating production processes and hardware designs simultaneously and carefully analysing the sources of variation in the process, the F/A 18E/F program was able to reduce production costs and create production processes that reduced defects and rework. As an example, concurrent design trade-offs (phase 2) resulted in E/F wing spars of higher quality and costing 30% less than the wing spars of its predecessor. Numerous iterations and early trade-offs made while designing the flight control computer system resulted in fewer requirements changes. As reflected in Figure 2, this model does not incorporate business and marketing activities. In addition, it does not employ IDEF to model the information flow.

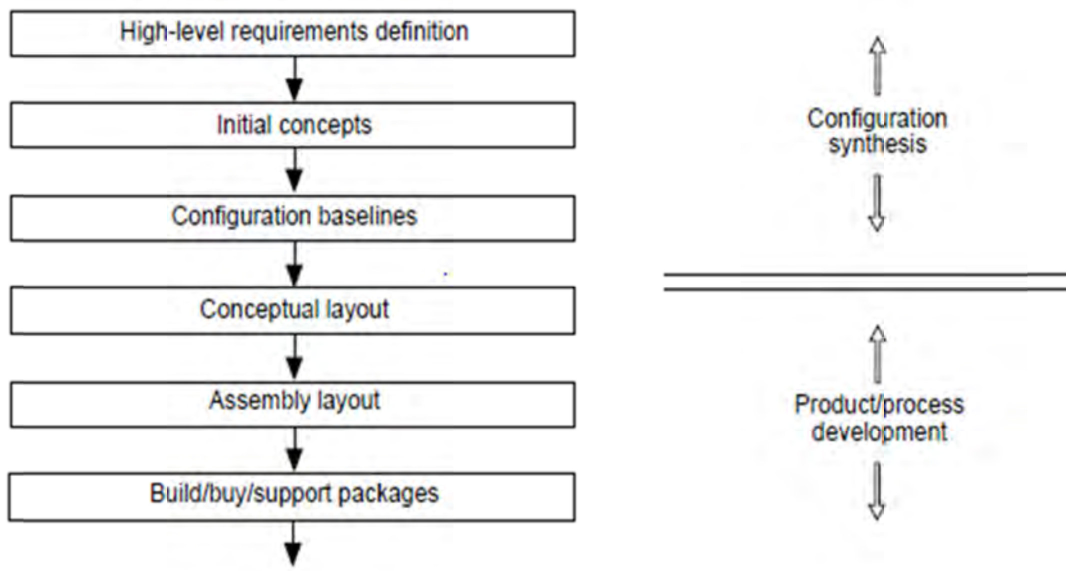

Figure 2. Product development strategy [Bailey et al. 1999]

2.2 Review of Similar Machines

During the research review for existing aircraft dispensing machines, very limited material was found. The conceptual design of the aircraft dispensing machine proposed by *Airbus Deutschland* [Bauch et al. 2009] includes a number of magazines to be loaded with products, a selector, the actuation of which triggers the dispensing of a selected product, a dispensing area and a mechanical product transport container that can be moved along guide rails. The delivery of the products to the dispensing area can be done independently of the products respective positions and any vibrations. This advantageously ensures a reliable operation independently of the altitude and turbulences that might be experienced during flight. Another advantage of this design is that the magazines are fixed using the customary sliding and locking system used in modern galleys, so that they can be exchanged without any special tools. This ensures that the products can be continuously replenished by the cabin crew and that even unusually high passenger demands can be met. One of the major concern of installing vending machines on commercial aircraft is the extra weight added to the overall aircraft structural weight. Further drawbacks of installing vending machines is the risk that a product gets stuck in the magazine during operation, the need to monitor and replenish the machine with food items in order to meet the passenger demand. The *Sky Tender* [SkyMax GmbH 2012] is a fully-automated beverage trolley and a prime example of a future-oriented development. It can prepare up to thirty different drinks including; tea and coffee, fruit juices, and soft drinks. Depending on the flight profile and aircraft type, it was found that overall aircraft weight can be reduced by 20 to 60 kilograms per flight [SkyMax GmbH 2012] which implies less fuel consumption and as a result less carbon dioxide emissions. By using the *Sky Tender*, coffee makers and hot water boiler are no longer required. This also implies that dry ice for cooling, which is very complex in the handling and is expensive, is no longer needed. Another benefit of *Sky Tender* is that its design ensures its compatibility to aircraft galleys. Although the *Sky Tender* is a fully automated system it is still a trolley which means that it needs to be carried by a cabin attendant. Another limitation of the *Sky Tender* is that it can only serve beverages and not food items.

3. An IPD Model to develop AFDM

Andreasen and Hein [2000] do not elaborate on Phase 0 and do not consider this phase as one requiring the three IPD pillars. However, they stress its importance as the necessary starting point for development; without it, the risks of starting off wasteful development work are high. As Phase 0 of the AFDM_IPD model does not require the participation of the three IPD pillars, it indicates that the flow of activities taking place in this phase are primarily sequential in nature. Due to this, the activities in this phase are represented by means of a flowchart available in [Fenech 2013]. The rest of the phases require the concurrent participation and integration of the three IPD pillars. As a consequence, a different representation means was needed due to the fact that flowchart representation is more appropriate to illustrate sequential activities. As mentioned earlier, *IDEF0* was chosen to represent the integrity of the activities occurring in each of these five phases. Figure 3 represents a simple syntax of the IDEF0 modelling.

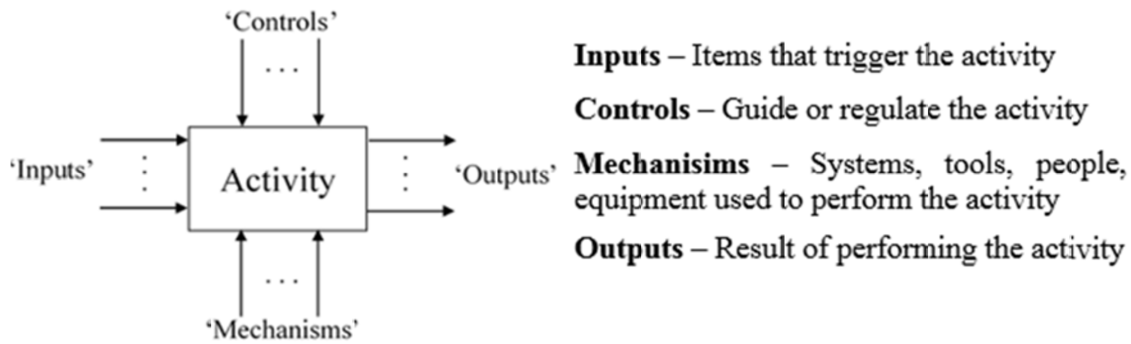

Figure 3. The basic *IDEF0* construct

The *AFDM_IPD* model, illustrates an ideal case scenario where a multidisciplinary team of people, referred to as the project team, are involved in the development process of aircraft food dispensing machines. The aim of the model is to help the team take a concurrent approach and to perform the necessary trade-off studies in order to come out with a reliable design for AFDM. The model consists of six phases (Phase 0 – Phase 5), whereby development passes through these phases sequentially whilst, in each of these phases, development activity will be taking place both sequentially and concurrently, involving the three IPD pillars. Figure 4 depicts a general overview of how the phases are linked together with inputs and outputs. As a case study, this paper focuses on phase 3 (see Figure 5). Further details on the other phases are available in [Fenech 2013]. With reference to Figure 5, the prime activity, 'product design' has been decomposed into three lower-level activities. As defined in the case study of *McDonnell Douglas* [Bailey et al. 1999], the primary goal of this phase is to define further design details and ensure that the final detailed design solution would suit a technology that meets the expected market size. The technical library personnel are responsible to identify the required *Part21J* [EASA 2013] approved documentation and the manuals which need to be updated due to the galley modification. Based on the machine internal component selection, the marketing stream is responsible to compute an estimate of the cost of the individual machine components, thereby proceeding with the economic aspect of the dispensing machine. The major focus of the product stream is on the actual detailed design of the machine and the definition of its 'expected' behaviour and properties, in the form of conditional predictions. Applicable design tools highlighted by the model include DFX tools and detailed design using *CAD* software package. The AFDM_IPD model prescribes that designers together with load-analysis engineers identify proper means of affixing the dispensing machine with the galley. This requires engineers to compute a number of calculations including the machine maximum gross mass and calculations related to dispensing machine loading, experienced during different flight phases (e.g. landing phase and take-off phase). Other relevant calculations include, finding the approximate location of where the centre of mass of the dispensing machine is concentrated, when fully loaded. This is a very important parameter in order to control the stability of the machine. The model prescribes that the project team should determine the production principles. Information regarding design tolerances is of utmost importance, since to a certain extent the design tolerances will control the production processes. The model prescribes the need to identify the requirements in terms of production resources, such as special tooling, specialised maintenance staff, machines and ground support equipment. This will help the marketing department in the subsequent phase of the model (see Figure 6), to determine the capital investment required for the embodiment of this modification.

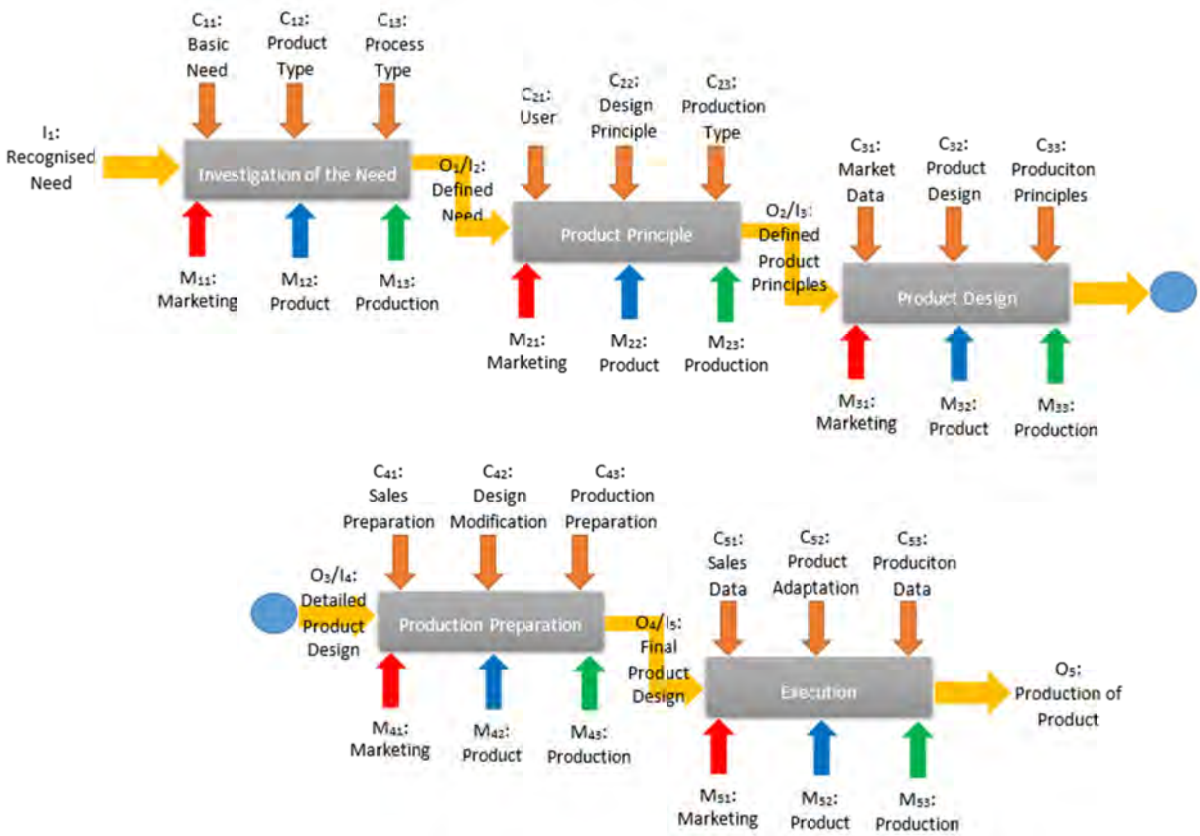

Figure 4. General overview of the developed *AFDM_IPD* model

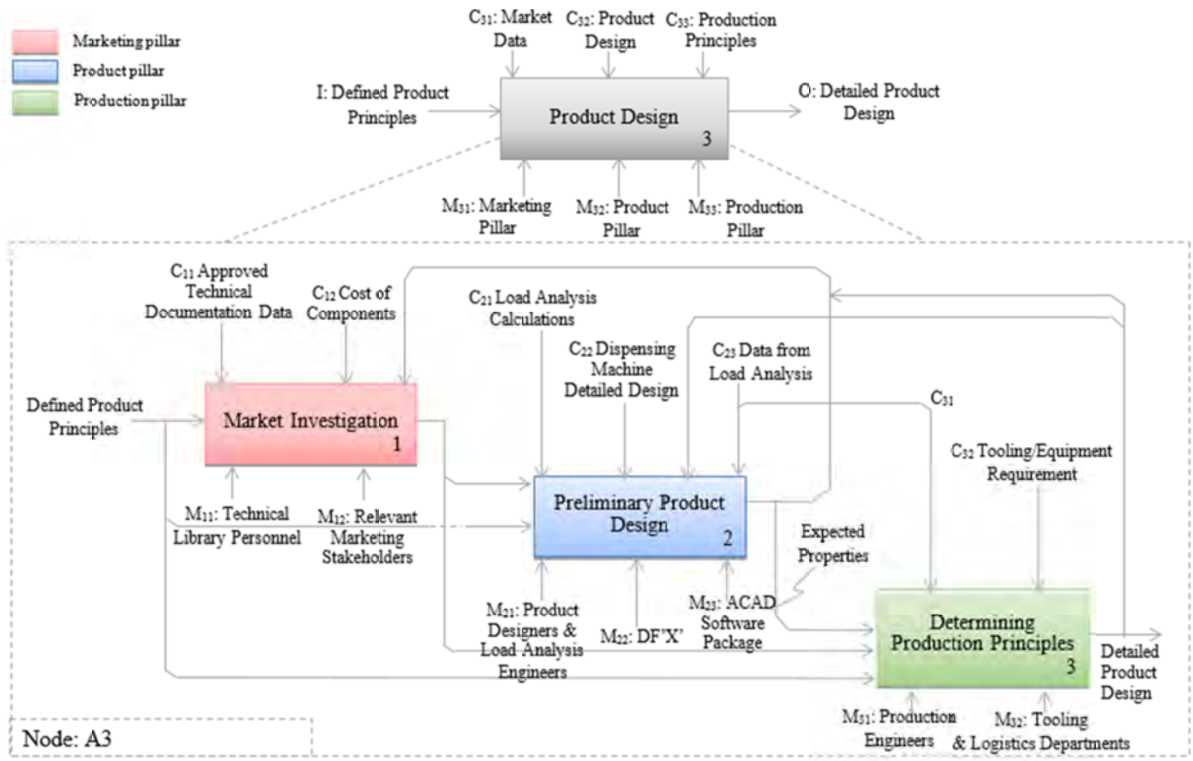

Figure 5. – Phase 3 of the *AFDM_IPD* model: product design

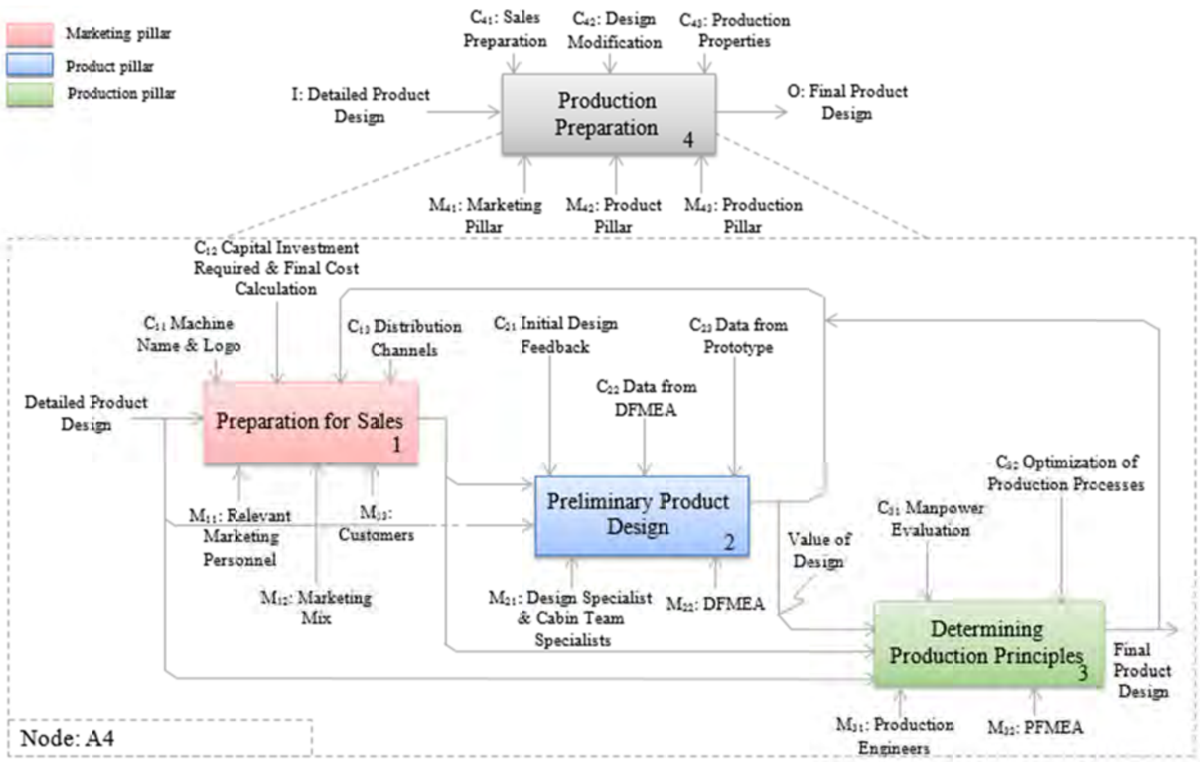

Figure 6. Phase 4 of the *AFDM_IPD* model: production preparation

4. Evaluation of the AFDM_IPD Model

The scope of the evaluation exercise was to collect initial qualitative results on the developed model. A sample of seven evaluators was selected, four from managerial positions and three from specialist position. The range of experience varies between 5 to 20 years and the companies consulted include

Lufthansa Technik Malta, *Medavia* and *Air Malta*. The participants were first provided background to this research and also a phase-by-phase explanation of the *AFDM_IPD* model. Each participant was then involved in a one-to-one semi-structured interview. A five point Lickert scale was employed to measure the participant's attitude. Participants were encouraged to comment on the ratings given. Following are the key evaluation results.

The majority of the interviewees (4 of 7) confirmed their awareness on the IPD principles. Some of the mentioned IPD principles include establishing cross-functional teams, give responsibility and authority to the team to make decisions related to product development, encourage upfront planning and promote continuous improvement. Overall, the feedback on the developed *AFDM_IPD* model was very promising. Almost all respondents have argued that there is a need for such product development models in aircraft related product development projects. Such models would allow them to speed up the development process, hence enable them to put the product faster on the market. All of the participants exhibited a positive attitude towards the use of the IDEF0 modelling language as the syntax employed is simple, easy to follow and to understand. Three managers have stated that they make use regularly of IDEF0 modelling language at work, to model a variety of business, manufacturing and other types of organisation operations. The participants were also asked to give their feedback on the level of vertical integration of the three IPD pillars highlighted in the *AFDM_IPD* model. Five of the participants stated that the *AFDM_IPD* model was very clear in representing the concurrent activities taking place among the three IPD pillars. A design engineer remarked that during phase 3 of the model the product pillar personnel will be carrying out the detailed design, the marketing pillar stakeholders can start calculating the cost of the identified standard components, whilst in the meantime the production pillar personnel identify the tooling and equipment required to produce the machine. Another key result concerned the use of various product development tools prescribed in the model. All participants agreed that the extent to which such tools are prescribed in different phases of the model is exhaustive. On the other hand, it resulted that only three participants (design engineer, development engineer and senior interior cabin specialist) make practical use of such tools.

5. Discussion and Conclusion

AFDMs can potentially provide a new way of providing in-flight catering service, especially in low cost airlines, whereby the number of seats offered by low-cost carriers in Europe has increased by an average of 14 % per year over the last decade, compared to a 1 % average annual rise in capacity among legacy carriers [Air Traffic Management 2013].Yet, this is subject to a detailed cost-benefit analysis. In addition, a time-study would be required to assess the viability of applying this type of catering service during a flight.

Although the proposed model is based on already established design and IPD principles, it is being represented in a completely unique way, through a simple IDEF0 modeling language syntax, as also reflected in the evaluation results. One of the major benefits of the developed model is that each IPD phase, is sub-divided into three activities, each representing an IPD pillar. This will guide the relevant IPD stakeholder to consider all IPD pillars during the development process. Furthermore, the model is designed in such a way that the information collected in one phase is used by the subsequent phases. This will help the IPD stakeholder to accumulate information incrementally and hence provide the stakeholder with comprehensive knowledge-base. Another benefit of the developed model is that each IPD activity is providing the IPD stakeholder with a set of guidelines to follow, which as a consequence will make the development process faster and more efficient.

The qualitative results collectively indicate that the participants found the model useful as a roadmap to develop AFDMs from an IPD perspective. The strong point of the evaluation is that the participants were selected from three different local aviation companies, with different level of knowledge and expertise. This enriched the evaluation because each participant viewed the model from a different perspective. However, it is also true that the participants were mainly from a design and maintenance environment, which indicate that they are good representatives of the product and production pillars but not to the same extent in the marketing pillar. Coupled with the small sample, future research work is required to test the validity of the results presented in this paper.

In conclusion, this paper contributes an integrated product development-based model for developing aircraft food dispensing machines, represented by the IDEF0 modelling language syntax.

Acknowledgements

Special thanks go also to the *Strategic Educational Pathways Scholarship* (STEPS, Malta) for funding this research, conducted as part of the M.Sc. IPD thesis. This scholarship is part-financed by *the EU- European Social Fund* (ESF) under Operational Programme II – Cohesion Policy 2007 – 2013. The authors are also grateful for the input of all the participants who contributed in the evaluation.

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