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Opportunities and Risks in a large Process and Computing System Project

Semester Presentation

Juristisches IT-Project Management

Wintersemester 2017/2018

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Abstract

Using public resources the paper discusses goals and complexities of introducing new processes and computing systems on a large scale across the overall supply chain for a significant technical product. Emphasis will be placed on legal risks and opportunities with respect to the software and the requirements placed by the product on the software.

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1. The Product and supporting processes and systems: Boeing 787

We will base the discussion in this paper on the Boeing 787 product development. The product was introduced to the public in 2002 as the 7E7 airplane. Many of the technical components of the 7E7 were based on a product development study known as the Sonic Cruiser. The product development timeline spans more than 10 years. (Seattle Times, December 15, 2009,). The major development phases are shown in Figure 1.

Figure 1: 787 Timeline (Boeing 787 - Realizing The Dream, July 14, 2014)

The unique development plan of the 787 and innovative product design had significant impact on the required processes and systems to support the design and production of the airplane.

a) Product Development Plan

The airplane was developed with several innovative design ideas and significantly different supply chain plan than prior airplane development programs. These approaches formed the core of the requirements for the development of the supporting processes and computing systems.

i. Supply Chain.

Boeing was interested in reducing the development costs of the program and its development time compared with other programs such as the 777 airplane. The idea was "spreading the financial risks of development to Boeing's suppliers. Unlike the 737's supply chain, which requires Boeing to play the traditional role of a key manufacturer who assembles different parts and subsystems produced by thousands of suppliers, the 787's supply chain is based on a tiered structure that would allow Boeing to foster partnerships with approximately 50 tier-1 strategic partners. These strategic partners serve as "integrators" who assemble different parts and subsystems produced by tier-2 suppliers." (C. S. Tang, 2009) A picture of the partners producing the integrating the airplane structure is shown in figure 2. (Tinseth, 2013)

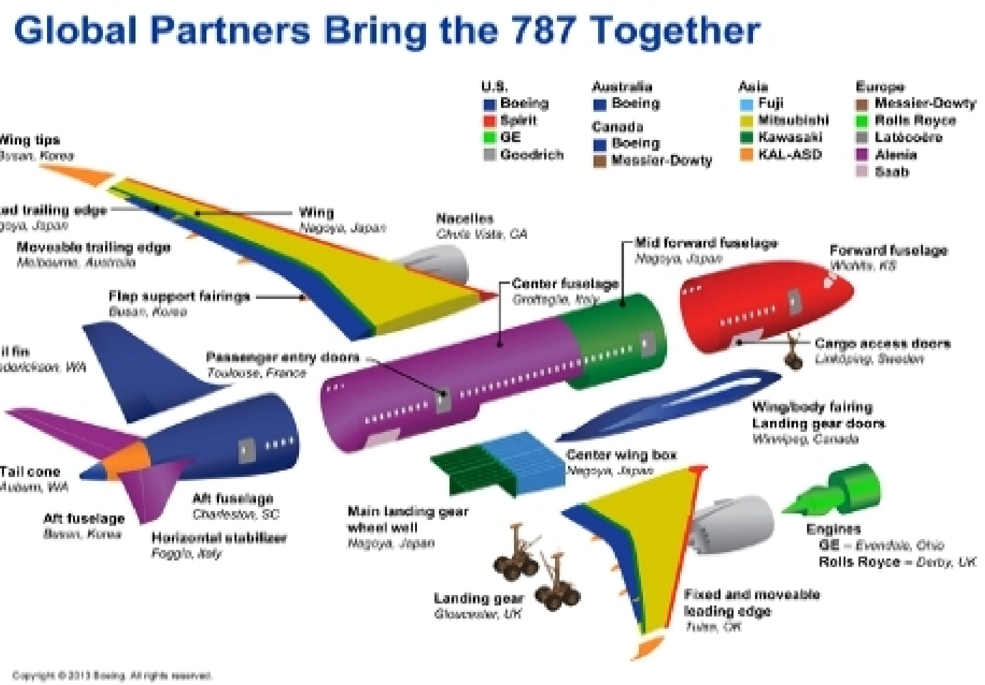

Figure 2: 787 Supply Chain Structures

Electrical System.

A significant innovation on the airplane is significant increase in the usage of electrical power. "The 787 Dreamliner uses more electricity, instead of pneumatics, to power airplane systems such as hydraulics, engine start and wing ice protection. … Because the 787 uses more electricity than do other Boeing airplanes, the 787 generates more electricity, via six generators: two on each engine and two on the auxiliary power unit (APU, a small turbine engine in the tail)… As with every Boeing airplane, the 787 includes many layers of redundancy for continued safe operation, and the electrical system is no exception." (Boeing, 787 Electrical System, 2013)

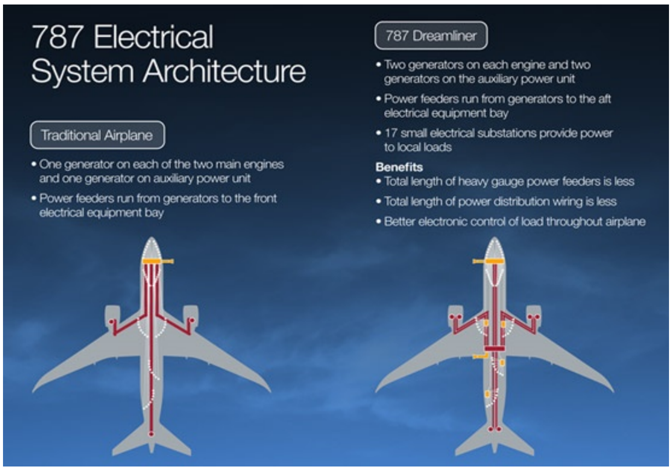

Figure 3: 787 Electrical System Architecture

ii. Composites.

“The chief breakthrough material technology on the 787 is the increased use of composites. The 787 is 50 percent composite by weight. A majority of the primary structure is made of composite materials, most notably the fuselage.

Composite materials have many advantages. They allow a lighter, simpler structure, which increases airplane efficiency, reduces fuel consumption and reduces weight-based maintenance and fees. They do not fatigue or corrode, which reduces scheduled maintenance and increases productive time. Composites resist impacts better and are designed for easy visual inspection. Minor damage can be repaired at the gate in less than an hour. Larger damaged sections can be repaired exactly like today's aircraft, through bolted repairs, or using a bonded repair.” (Boeing, 787 Dreamliner by Design, 2018). Much of the innovation occurred in collaboration between Boeing and suppliers. (Boeing, Wings around the world, 2006) Examples are shown for the wing box Figure 4 (Hashish, 2013) and the main structural barrels Figure 5 (Carey, 2016).

Figure 4: Wing Box

Figure 5: Composite Barrel

b) Technical Requirements

I want to highlight some of the technical requirements which result from experiences over the years on other airplanes. These requirements have significant consequences on the process and computing system development.

i. Experiences from the Past: Engine Failure

"What happened: On 4 November 2010, while climbing through 7,000 ft after departing from Changi Airport, Singapore, the Airbus A380 registered VH-OQA, sustained an uncontained engine rotor failure (UERF) of the No. 2 engine, a Rolls-Royce Trent 900. Debris from the UERF impacted the aircraft, resulting in significant structural and systems damage." (Australian Transport Safety Bureau, 2013). The initial failure was in a small oil tube, which was not quite manufactured to specifications. (See Figure 6). (Australian Transport Safety Bureau, 2013)

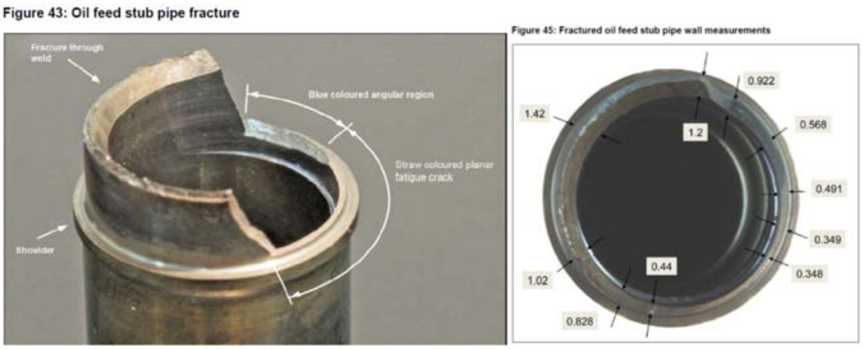

Figure 6: Fractured oil feed stub pipe

In the root cause analysis by the Australian Transport Safety Bureau several process failures, loss of inspection data, und not understanding inspection data were identified:

- "In 2007, the manufacturer identified that a number of components had left the facility with unreported non-conformances and carried out a major quality investigation. After that investigation, a number of newly manufactured non-conforming oil feed stub pipe counter bores were identified and reported by manufacturing personnel. However, due to a difference between the reference datum used by the manufacturer's automated measuring machines and the datum specified on the drawings, the engineers assessing the effect of the non-conformance misunderstood how the non-conformance would affect the wall thickness of the oil feed stub pipe. ..

- In March 2009, a manufacturing engineer identified that oil feed stub pipe counter bores were misaligned in previously manufactured and released HP/IP bearing support assemblies. The engineer was the first to identify the effect that misalignment of the counter bore had on the wall thickness of the pipe." (Australian Transport Safety Bureau, 2013)

A primary principle of aviation safety is learning from mistakes of the past. The advent of Big Data, Internet of Things and the ability to connect many sources of data for analytics reasons should make these types of mistakes a problem of the past. Requirements to prevent such failures not to be incorporated into future system designs.

ii. Experiences from the Past: Wiring A380

The meet the challenging timeline of developing the Airbus A380 airplane, a significant usage of computer-assisted design technology was needed. "Since the early 1990s, Airbus sites in France, where the A380's nose and central fuselage sections are built, have used a package of two powerful three dimensional computer modeling programs called Catia and Circe. Developed by the French software maker Dassault Systèmes, they were used successfully on the A340 and, according to Williams, the Airbus programs chief, "were constantly being improved." … German engineers preferred to work with an older design software made by a U.S. company, Computervision. The program had been the gold standard of industrial design tools in the 1980s but was only capable of producing two dimensional blueprints." (Clark, 2006)

As a result, Airbus discovered during the installation of wire bundles into the first airplanes, that the wires were too short at the section breaks between the products provided by the different countries in the consortium: ""The wiring wasn't following the expected routing through the fuselage, so when we got to the end they weren't long enough to meet up with the connectors on the next section," said one German mechanic, who said he arrived in Toulouse in early 2005. He asked not to be identified out of fear that he might lose his job. "The calculations were wrong," he said. "Everything had to be ripped out and replaced from scratch."" (Clark, 2006)

These experiences from non-integrated computing systems and the underlying lack of data integration focused the 787 program on Global Collaboration Tools to enable remote work on one set of data. (Seil, 2006)

iii. Experiences from the Present: Separation Requirement

The Federal Aviation Administration issues Airworthiness Directives (AD) to address safety issues on all in-service airplanes in the USA. An example is the AD 2017-15-04 for the 787 (FAA, Docket No. FAA-2016-9516; Directorate Identifier 2016-NM-053-AD; Amendment 39-18964; AD 2017-15-04], 2017). "This AD was prompted by wire harness chafing on the electro-mechanical actuators (EMAs) for certain spoilers due to insufficient separation with adjacent structure." (see Figure 8).

The issue here is that the specific placement of brackets to locate the wires in the airplane is of utmost importance. New technologies with augmented reality can help to perform the installation and inspection of these locations more reliably.

Figure 7: Primary Flight Control Systems

2. Legal Requirements

In the prior sections we have been introduced to the airplane and some of the particular product requirements which drive process and system requirements. In this section we will discuss some of the requirements imposed by laws, rules and regulations which need to be met by the process and system development projects for the airplane.

a) Federal Aviation Administration and other countries counter parts

The Federal Aviation Administration (FAA) mission is "to provide the safest, most efficient aerospace system in the world." (FAA, FAA Mission, 2018). The European Aviation Safety Administration (EASA) mission is more detailed, but similar: "Ensure the highest common level of safety protection for EU citizens. Ensure the highest common level of environmental protection. Single regulatory and certification process among Member States. Facilitate the internal aviation single market & create a level playing field. Work with other international aviation organisations & regulators." (EASA, 2018). We will provide some examples of regulations

i. Code of Federal Regulations, Title 14,Part 21

CERTIFICATION PROCEDURES FOR PRODUCTS AND PARTS

I will provide some examples of these regulations: (CFR, 2018)

§ 21.31 Type design. "The type design consists of— (a) The drawings and specifications, and a listing of those drawings and specifications, necessary to define the configuration and the design features of the product shown to comply with the requirements of that part of this subchapter applicable to the product; (b) Information on … (c) The Airworthiness Limitations … (d) For primary category aircraft, if desired, a special inspection and preventive maintenance program … (e) Any other data … ".

This regulation provides for the detailed requirements what constitutes are complete design for an airplane. Notice that it is a lot more than pure drawings. New processes and computing systems need to fully manage all this design information.

§ 21.137 Quality system. "Each applicant for or holder of a production certificate must establish and describe in writing a quality system that ensures that each product and article conforms to its approved design and is in a condition for safe operation.."

The applicant here is the company (Boeing) which wans to produce and sell the airplane. This requirement specifies that a explicit quality system must established to ensure, that the airplane is produced conforming to the design. This has significant configuration management requirements to the processes and systems.

ii. Advisory Circular

Advisory Circulars are further detailed requirements which provide for interpretations of the government agency on the rules and regulations. They nearly the power of law and are generally followed by the aerospace companies. An example is the following Advisory Circular (AC). (FAA, Advisory Circular AC 21-43, Production Under 14 CFR Part 21, Subparts F, G, K, and O. , 2009): "This AC guides PAHs in developing and maintaining quality systems for the products and articles they produce. …

5. Design Data and Configuration Control.

a. Identify the design data package provided by the PAH, including all pertinent data required for the supplied article(s) to be identified, manufactured, inspected, used, and maintained.

b. Establish procedures for managing design changes. "

Again here, an explicit definition of procedures is required. These need to be maintained and followed by the implanted processes and computing system for the airplane program.

b) Export Control

Many states control the export of any products which could be used for military purposes. Examples are:

- Germany: "The Federal Office for Economic Affairs and Export Control as a central licensing authority is responsible for the administrative implementation of the Federal Government's export control policy. Together with the monitoring and investigating authorities, especially the different customs offices, it is involved in a complex export control system." (BAFA, 2018)
- European Union: "The trade in dual-use items – goods, software and technology that can be used for both civilian and military applications and/or can contribute to the proliferation of Weapons of Mass Destruction (WMD) – is subject to controls to prevent the risks that these items may pose for international security. The controls derive from international obligations (in particular UN Security Council Resolution 1540, the Chemical Weapons Convention and the Biological Weapons Convention)

and are in line with commitments agreed upon in multilateral export control regimes." (European Union, 2018)

- India: India's System of Controls over Exports of Strategic Goods and Technology (Government of India, 2004)
- USA: The International Traffic in Arms Regulations (ITAR) (USA Department of State, 2018)
    - §120.16 Foreign person.Foreign person means any natural person who is not a lawful permanent resident as defined by 8 U.S.C. 1101(a)(20) or who is not a protected individual as defined by 8 U.S.C. 1324b(a)(3). It also means any foreign corporation, business association, partnership, trust, society or any other entity or group that is not incorporated or organized to do business in the United States, as well as international organizations, foreign governments and any agency or subdivision of foreign governments (e.g., diplomatic missions)..
    - §120.17 Export (a) Except as set forth in §126.16 or §126.17, export means: … (2) Releasing or otherwise transferring technical data to a foreign person in the United States (a "deemed export"); …(b) Any release in the United States of technical data to a foreign person is deemed to be an export to all countries in which the foreign person has held or holds citizenship or holds permanent residency.

c) Other Legal Requirement

Other significant requirements for processes and computing systems are certainly in the areas of data privacy, taxation, customs, corruption to name just a few.

3. Risk and Opportunities within each phase of the traditional waterfall model

We will now discuss specific examples of risks and opportunities due to the unique nature of the 787 airplane product, the aerospace requirements and the international nature of the development due to the large supply chain for the airplane program. We will provide these risks and opportunities for each stage of the waterfall model provided in the lecture (Sarre, 2017):

a) Study

- Opportunities

Enable Profitability of new product by reducing cost structure. The large benefit of creating a new and optimized process and system infrastructure for a very different product is very enticing.

- Risks

Development of new processes and systems while applying it to a new product creates the potential of a significant negative impact on the new product if the timeline or specific requirements are not met and the product cannot be delivered to contracted customers.

b) Requirements Analysis

- Opportunities

A new product has quite often significant new requirements. As an example, the 787 had an innovative electrical design which required new design and analysis methods not used on prior airplane. Another aspect are strength analysis techniques to support the extensive use of composites on the new airplane, absolutely required.
Computing systems of a new generation offer significant new capabilities enabling better on-board system and weight saving composite on the airplane. The technical progress the Computer Aided Design from the 1980's/90's to a few years ago where significant. By upgrading the system capabilities for a new product at the beginning f the design cycle, benefits are being accrued.
Computing system suppliers, both software and hardware suppliers can be incentivized in contracts by sharing in the risks and profits of the new product itself, instead of just receiving revenue through licensing.

- Risks

Newly acquired systems are not understood in their impact on business processes. Delays in the implementation can actually delay the product. As often on large and complicated processes, significant requirements are overlooked in contracts with system suppliers.
This includes in particular impact on the supply chain when the new processes and systems are required to be used by the suppliers. Special emphasis shall be made on the legal requirements such as export controls which need to be embedded into the data design of the new solutions.

c) System Design

System Design includes here not only the design of the computing system, but also the design of the business processes forming the business process architecture of the main product company as well as the integration with the supply chain. As discussed above, a formal process design will be required prior to implementation due to the FAA quality requirents.

- Opportunities

The process and system architecture to supplier the new product can be specifically tailored to such product to be unencumbered by prior legacy decisions. Processes can be built taking care of specific capabilities of newly purchased systems. In contracts with product suppliers the new processes and system require different integrations with the supplier system, causing the need for collaboration requirements to be included in contracts.

- Risks

The intricacies of purchased systems are mostly not understood at the beginning of the project. Specific risks are the integration of such system with other existing system in both the main company and in the supply chain. When the actual product is being designed and built in conjunction with the processes and systems, decisions on such must be made under significant time constraints, yielding to late and wrong requirements with the corresponding impacts on incorrect supplier contracts. This is the case both for product and system suppliers.
Many of the legal requirements cited above are be incorporated into the new processes and systems. Due to the sheer volume of these requirements, the likelihood of significant misses is real

d) Implementation

- Opportunities

Phased process and system development allows early use of new capabilities often needed during the early phases of the product. Examples for the electrical system and composite designs were cited above. These early implementations require a continuous update to detailed agreements with software suppliers and production supply chain.
As discussed above, linking production and quality equipment into the overall computing system infrastructure using industry 4 generation technologies should help prevent the root causes of accidents.

- Risks

While the phased development provides for early use of new capabilities, the corresponding risk is the late delivery of the software when it was already needed for the design of the product. From legal risk, we have the typical risks as in any contract such as the German “Werkvertrag”

Specifically are also risks of the main product company with respect to providing new capabilities to the supply chain which are then delivered incorrectly or late. This might lead to assertions from the supply chain.

e) Integration

Opportunities and risk during the integration phase are essentially the same as during the implantation phase. A particular emphasis will be the integration with the supply chain where surprises might be happening due to the myriad of processes and system at the 100+ suppliers.

f) Acceptance Test

- Opportunities

Besides the usual acceptance tests by the main product company, the inclusion of overall Supply Chain into acceptance testing is critical. Acceptance by the supply chain supports the contractual accountability of the supply chain to the main product.

- Risks

Besides software bugs, testing reveals misunderstood process requirements across all product organizations. For the computing system suppliers their risks are as in any typical Werksvertrag. For the main product company and the product suppliers risks are the problems found themselves, in particular the ability for fast resolution or finding an appropriate mitigation to not impact the schedule of development delivery of the product.

g) Production Implementation

Congratulations, we proper follow through on the prior steps, there should be no surprises.

4. Summary

Supporting the design and introduction of a new complex product with newly designed business processes and computing systems requires a significant investments in due diligence focusing on the requirements of the product itself, regulatory and legal requirements, integration with the supply chain and understanding the new computing capabilities. Design of the systems and it’s production implementation pose the usual challenges, scaled up.

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