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Logistics and Supply Chain: An Overview of Business Jet Aircraft Manufacturing

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Abstract
The paper highlights key points of aircraft manufacturing and supply chain, which includes key supply chain stages of macro processes and logistics of material flow through a network of stages, organization and workstations. Supply chain refers to a series of facilities, with sequence of activities involved in producing and delivering of a product and service. The study was done through personal work experience in an aircraft factory, watching video documentary on National Geography Chanel, literature review of Federal Aviation Administration manuals, books, newspaper articles, aircraft manufacturing websites, and other internet survey. The network of stages starts from ultimate supplier, in the form of raw material, ends up to the final customer, in the form of finished goods. Logistics involve movement of materials, funds, and information between these stages of a supply chain, in a coordinated way. In some large manufacturing facility, such as an aircraft manufacturing factory, multiple stages of supply chain are found within the factory premise itself. Within a specific stage, production lines are found, such that workers and machines are grouped together with a sequence of assigned activities to produce customized, handcrafted, yet standardized outputs. Zooming from supply chain macro level process to micro level manufacturing processes, together with transportation and logistics of material between the stages are highlighted.
Keywords: Aircraft Manufacturing, Logistics, Transporation, Supply Chain and Opertions Management.

1. Introduction

There have been a lot of thoughts, ideas, presentations, literatures books, certification programs, publications and seminars for a couple of decades, making the supply chain management concept and philosophy very popular around the world. Most of the literatures mainly cover inventory management, sourcing, logistics, distribution, and transportation as their primary thoughts of supply chain management. These thoughts are mostly related to moderate to fast moving products and there manufacturing and distribution of inventories. However, there has not been any substantial literature published on the aircraft supply chain management. Therefore, it is worth of study to explore the overview of supply chain management regarding aircraft manufacturing from macro to micro level processes.

Supply chain management theories, concepts and formulas are being widely accepted and practiced in many industries. However, there are little indication or readily available evidence that such practices are well known or being practiced in aviation industry. Practitioners in aviation industry is using manufacturing, industrial engineering and operations management theories, concepts, and formulae in a limited scope from an organizational (single stage) prospective, without showing any sign of being practiced from end to end supply chain point of view. The statement of the problem of this research is: What are the relationships between the well known concepts of supply chain management and aircraft manufacturing macro to micro level precesses? How are the aircraft manufacturing processes related to the types of inventory, mode of transportations, logistcs within the organization and facility layout of aircraft assembly line, zooming in from macro to micro level processes?

The key concepts of supply chain management, operations management, inventory, logistics and transporation are reviewed and relationship with the aircraft manufacturing are highlighted by an exploratory research. The definitions for above concepts were extracted from two prominent books. Most of the information were gathered through video documentary, aircraft manufacturers website and other relevent internet survey, for connecting the relationship with the denitions and practices are the novilty of current research.

Thorough involvement by aviators, academicians, researchers in supply chain management studies, practices and optimization modeling in aircraft manufacturing processes would bring about substantial benefits to aircraft industry. Hence, this research tries to give an overview of supply chain management in relationship with aircraft manufacturing, specifically high level inventory, logistics, and material flow.

2. Liturature review

Definitions of Supply Chain Management, Inventory, Logistices, Movement of Materials across the supply chain and within the facilities were taken from the highly revered Operations Management book (Stevenson, 2011). Concepts of Supply Chain Stages, definitions of Distribution, Transporation were taken from the highly publicized Supply Chain Management book (Chopra and Meindl, 2012).

The author Abdinnour (2003) wrote an article on "Hawker Beechcraft Uses a New Solution Approach to Balance Assembly Lines" where the author proposed a new customized line balancing solution on Hawker Beechcraftassembly-line setting. The company reported savings of over $30 million, applying these solutions to multiple aircraft model assembly-lines. However, the highly beneficial solution is applied within a single factory, rather than looking into the whole, end to end global supply chain (Abdinnour, 2011). Another article, published by Krishnan & Almaktoom (2016) titled "Optimisation of stochastic assembly line forbalancing under high variability", focuses on optimizing the aircraft assembly line in more detailed, micro level. Even though both the approaches are very benificial and profitable for aircraft manufacturers, there is no indication that the single or plant stage optimization is interconnected with the remaining stages in the whole global supply chain. All other readily available articles and publications on supply chain are not necessarily based on aircaft manufacturing.

3. Material and methods

An exploratory research based on secondary datas are collected mainly from video documentary, aircraft manufacturers website and other relevent internet survey. Graphics were taken from different published websites. Snap shots were taken from video documentaries by studying them frame by frame, to get the appropriate picture aligned with the theme of this article. Newspaper articles were used to gather relevent information and pictures. Secondary data were collected from various sources as mentioned above. Personal work experience of five years in an aircraft company provided comprehensive understanding and knowledge. The following materials cover:

- Supply chain stages
- Types of Inventory
- Logistics, distributions, transportations
- Mode of transportations
- Movement within the facility
- Facility layout and assembly line

Supply chain management is the strategic coordination of business functions within a business organization and throughout its supply chain for integrating supply and demand management. Supply chain managers are people at various levels of the organization who are responsible for managing supply and demand both within and across business organizations. They are involved with planning and coordinating activities that include sourcing and procurement of materials and services, transformation activities, and logistics (Fig. 1).

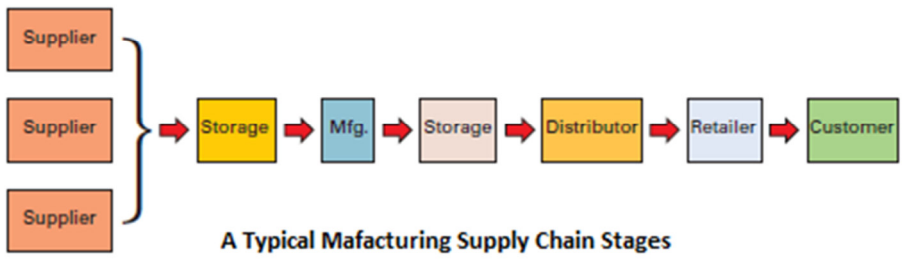


Fig. 1: Manufacturing supply chain stages (Stevenson, 2011).

Most commonly taught books, published literatures, and professional certification programs relate their supply chain management body of knowledge to moderate to fast moving products or finished goods. However, very little thoughts were presented or published regarding the supply chain for aviation industry, especially manufacturing of high performance business jets.

A typical manufacturing supply chain consists of series of stages for producing and delivering of product or goods, starting from supplier to manufacturer to distributor to retailer and to final customer (Chopra, 2012). Stages are usually referred to as separate business organizations, and they may be located close to each other or across the world. Supply chain management strategically coordinates different business functions within a business organization, such a manufacturing plant, and throughout its supply chain, such as a series of buying and selling organizations (Stevenson, 2011). It is observed that, in an aircraft mega factory, many of the production stages are situated within the premises of the manufacturing plant itself, while maintaining its links

outside the premises with remaining of supply chain stages, near or across the globe. It is commonly observed that even if a mega factory can perform the functions of multiple stages, a few or many of the production stages may also be outsourced to partnering companies.

A typical series of stages for a high-performance business jet include component manufacturing, wing assembly, fuselage assembly, electronic installation, engine attachment, final assembly, production flight, painting, completion, and customer delivery. Most of the manufacturing stages may be utilized within the mega factory for an aircraft model, such as for Bombardier Learjet 60XR, in Wichita, Kansas facility (National Geographic Channel, 2011). However, for Bombardier Learjet 45, only a few of the stages are within the mega factory, such as final assembly, fitting, flight test and certification, while other stages are outsourced to global family and partners, such Shorts Bothers of Belfast for fuselage, De Havilland of Canada of wings and Honeywell for Engine.

A320 Family jetliners are produced at four Airbus final assembly lines: Toulouse, France; Hamburg, Germany; Tianjin, China; and Mobile, Alabama in the USA (Airbus, 2017).

An inventory is a stock or store of goods. Manufacturing firms carry supplies of raw materials, purchased parts, partially finished items, and finished goods, as well as spare parts for machines, tools, and other supplies (Stevenson, 2011). A Bombardier Learjet 60XR requires 48,000 components (National Geographic Channel, 2011).

The different kinds of inventories include the following:

Major Components and Systems of an Aircraft (FAA, 2008 & 2012)

- Fuselage:
  - Nose, Flightdeck, Flight Deck, Cabin, Aft Sections
  - Frame, Formers, Bulkheads, Skin, Longeron, Stringers
- Wings:
  - Ribs, Spar, Stringers, Skin, Fuel Tank, Fairings, Wingtips, Winglets
- Empennage:
  - Horizonal Stabalizer, Vertical Stabilizer, Radder, Elevetor, Trim Tabs
- Flight Controls Systems:
  - Ailerons,Elevator, Rudder
  - Flaps, Trim Tabs, Spoilers, Slats, Slots, Leading edge flap
- Powerplant
- Landing Gear
- Other Systems:

Electrical systems, Instruments systems, Communication and Navigation systems, Hydraulic and Pneumatic Power systems, systems, Fueling Systems, Cabin Environment Control Systems, Fire Protections systems.

3.1 Aircraft Tools and Supplies

Aircraft Jacks, Blind Riveters, Bucking Bars, Cable & Wire, Cleaning & Polishing Equipment, Composite Tools, Composite Tools, Cutters, Dimpling Tools, Drills, Drill Bits, Drilling Aids, Electrical Equipment, Fabric Tools, Die Grinders & Sanders, Engine Equipment, Hand Tools, Power Riveters, Precision Measuring tools, Reamers, Rivenut Equipment, Rivet Guns, Rivet Sets, Rivet Squeezers, Rivets, Sheet Metal Fasteners, Sheet Metal Tools, Shop Equipment, Surface Prep Tools, Test & Inspection, Time-Rite, Tool Videos, Audio & Software (Fig. 2).

					
Fuselage jack	Air power riveter	Engine specialist kit	Air impact wrench	Rivets	Floor brakes

Fig. 2: Aircraft tools and supplies (ATS, 2017).

3.2 Ground Support Equipments

Air Start Service, Deicing & Anti-Icing Service, Eagle Tugs Tow Tractors, Fluid Service, Fuel Service, Ground Power Supply Headsets & Intercom Systems, Hydraulic Fluid Service, Nitrogen Service, Oxygen Service, Parts, Spares and Supplies, Passenger Access, Potable Water Service, Pre-Conditioned Air Service, Safety Equipment, TLD Ground Support Equipment, Tow Tugs/Pushback Tractors, Towbar & Head Equipment, Unitron Frequency

Converters/Rectifiers (Fig. 3).






Tow bar	Flat tire dolly	Nitrogen cart	Cleaning cart	Tow tugs	Tow tractor

Fig. 3: Ground support equipments of aircrafts (AERO Specialties, 2017).

3.3 Aerospace Material Handling Equipment

Jet Engine Lifts, Pre-Dress Bay Lifts, Personnel Lifts, Traversing Paint Booth Lifts, Wing Assembly Platforms, Ground Plane Simulators, Vertical Fixturing Systems, Pit Mounted Engine Assembly Lifts, Cowling Transport Carts, Wing removal and maintenance lifts, Portable personnel and material lifts (Fig. 4).





Fig. 4: Aerospace material handling equipments (Handling Specialty, 2017).

Distribution refers to the steps taken to move and store a product from the supplier stage to a customer stage in the supply chain. Distribution occurs between every pair of stages in the supply chain (Chopra & Meindl, 2012). Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer. Transportation is an important supply chain driver because products are rarely produced and consumed in the same location. Supply chains use a combination of the following modes of transportation: Air, Package carriers, Truck, Rail, Water, Pipeline, and Intermodal (Chopra & Meindl, 2012).

Aircraft industry uses most mode of transprotation (Air, package carriers, lorry, rail, water, intermodal). Boeing 787 Dreamliner forward fuselage sections are transported on board of Boeing's Large Cargo Freighter, the Dreamlifter, a specially modified Boeing 747, for delivery from Spirit AeroSystems, Wichita production plant to Everett, Washington, for final assembly (McMillin, 2014). Bombarbier used an aircraft carrier to transport the the Learjet 45 fusalege from manufacturing plant in Belfast to Wichita, Kansas for final assembly (Flying, 1995). Airbus' fleet of A300-600ST Super Transporters provides the rapid transport for major sections of its single-aisle and widebody aircraft using airtransport (Airbus, 2017; Fig. 5).


(Source: McMillin, 2014).	(Source: Flying, 1995).	(Source: Airbus.com, 2017)

Fig. 5: Air Transportation of Boeing, Learjey and Airbus.

Boeing 737 fuselage are transported from Wichita, Kansas production facility to Renton, Washington Assembly line, using 89-foot BNSF railway cars (Fig. 6).

Fig. 6: Rail Transportation of Boeing 737 (Bizjournal, 2013).

Boeing 747 jumbo jet, an aircraft, weighing 60-tonnes and measuring 22 feet wide, 16ft 3ins high and 137ft long, were obsorved to be carring on road using widebody lorries, taking front section and cockpit, from Cotswold Airport in Gloucestershire to Staffordshire, Britain (Fig. 7).

Fig. 7: Road Transportation of Boeing 747 (Burrows, 2015).

The A380's size means its fuselage and wing sections are shipped via a surface transportation network that includes specially-commissioned roll-on roll-off ships to carry these sections from production sites in France, Germany, Spain and the United Kingdom to the French city of Bordeaux. From there, sections are transported by barge along the Garonne River to the Toulouse final assembly line.

As for other Airbus aircraft programmes, production of the A380 takes place in different sites across Europe. Each site produces completely equipped sections, which are transported to the final assembly line. Most A380 sections are transported to Toulouse by sea, river and road. A number of smaller components, such as the vertical fin produced in Stade or the nose section produced in Meaulte, France, are carried in Airbus' Beluga fleet (Fig. 8).

Fig. 8: Multimodal transportation of A380 (Airbus.com, 2017).

Logistics refers to the movement of materials, services, cash, and information in a supply chain. Logistics includes movement within a facility, overseeing incoming and outgoing shipments of goods and materials, and information flow throughout the supply chain (Stevenson, 2011).

Movement within a Facility: Movement of goods within a manufacturing facility is part of production control. The following table and figure shows the many steps where materials move within a manufacturing facility (Fig. 9).

Movement within a Facility:
1. From incoming vehicles to receiving.
2. From receiving to storage.

From storage to the point of use (e.g., a work center).
4. From one work center to the next or to temporary storage.

From the last operation to final storage.
6. From storage to packaging/shipping.
7. From shipping to outgoing vehicles.

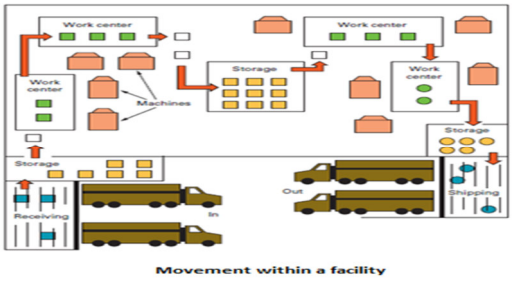


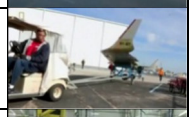
Fig. 9: Step by step movement of the materials within a facility (Stevenson, 2011).

The following table illustrates Movement within a Facility. These video snapshots were taken from "Learjet Documentary on Mega factories" (Table 1).

Table 1: Movement within a Facility (National Geographic Channel, 2011).

SL	Inventory	From	To	Equipment	Method	Thumbnail
1	purchase parts	supplier	warehouse	dolly	driving	
2	Components	components hanger	warehouse	cover vans	driving	
3	Kitted parts	warehouse	shop floor	bag	walking	
4	Wing skin panel	work center (jig)	work center (jig)	overhead crane	carrying, guiding	
5	Wing structure	work center (jig)	work center (jig)	overhead crane	carrying, guiding	
6	Fuselage, aft section	work center (jig)	work center (jig)	overhead crane	carrying, guiding	
7	Windshield	shop floor	work center (subassembly)	hand carrying	walking	
8	Fuselage flight deck	work center (jig)	work center (subassembly line)	movable jig, overhead crane	rolling, carrying, guiding	
9	Fuselage, passenger cabin, skin	work center (jig/shelf)	work center (subassembly line)	hand carrying	Carrying	
10	Fuselage, forward section	work center (subassembly line)	work center (subassembly line)	dolly, carrying	rolling, carrying, guiding	
11	Empennage, horizontal plane	work center (subassembly line)	work center (subassembly line)	overhead crane	carrying, guiding	
12	Fuselage assembly	work center (assembly line)	work center (penultimate jig)	overhead crane	lifting, carrying, guiding	

Table 1: Movement within a Facility (National Geographic Channel, 2011).

SL	Inventory	From	To	Equipment	Method	Thumbnail
15	Empennage, vertical fin	work center (subassembly line)	work center (penultimate jig)	overhead crane	carrying, guiding,	
16	Wiring bundle (electronics)	Hanger / testing form board	Hanger / installation site	small tractor enclosed cage	driving, rolling table	
17	Fuselage Assembly	Hanger	Hanger/ mating	Tugs bar, dolly	Pulling	
18	Wing Assembly	Hanger	Hanger	small tractor, tug bar, dolly	Pulling	
19	Engine	Work center	Aircraft installation area	Forklift / overhead crane	Driving	
20	Aircraft	Final assembly	Fight test	Tow Tugs, manual	Pulling	
21	Aircraft	Ground	Sky	Plane	Flying	
21	Interior furnishing	Shop floor	Inside plane	Manual	Hand Carry	
22	Aircraft	Shop floor	Delivery point	Tugs Tow Tractors	Driving	
23	Aircraft	Delivery Center	Sky	Plane	Customer delivery flight	

Layout refers to the configuration of departments, work centers, and equipment, with emphasis on movement of work through the system. Assembly line: Standardized layout arranged per a fixed sequence of assembly tasks (Fig. 10).

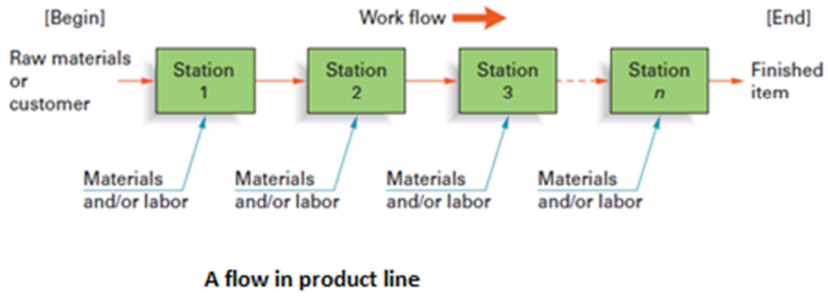


Fig. 10: Process Flow Diagram of a Product Line (Source: Stevenson, 2011).

The following diagrams illustrate a facility in a mega factory with assembly line for manufacturing fuselage for a high-performance business jet. These video snapshots were taken from "Learjet Documentary on Mega factories" (National Geographic Channel, 2011; Figs. 11 & 12).

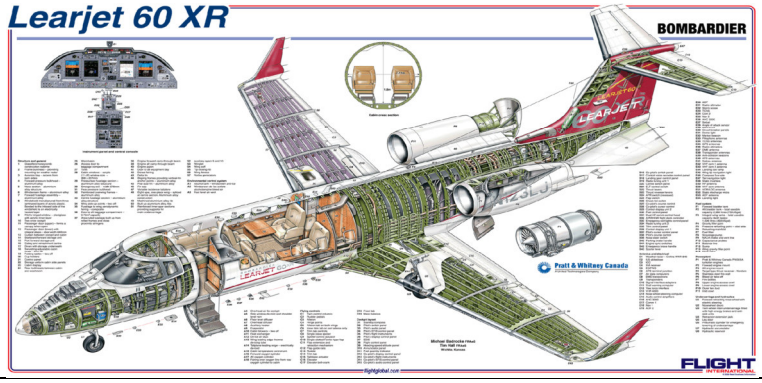
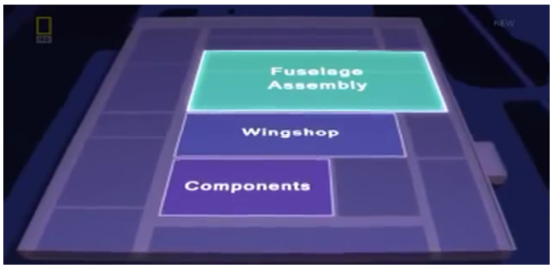


Fig. 11: Cross Section View of Learjet 60XR Aircraft (Flight International, 2004).



Fuselage Assembly Site

Fuselage Assembly Line

Nose and Flight Deck

Cabin

Empennage

Forward Section

Fuselage

Aft Section

Fig. 12: Production of Deferent Sections in Fuselage Assembly (National Geographic Channel, 2011).

4. Results and discussions

It is found that there are strong relationship between the well known concepts of supply chain management and aircraft manufacturing, macro to micro level precesses. It is found that supply chain management is the strategic coordination of business functions within an organization and throughout its supply chain for interacting supply and demand management. The specific major findings after the analysis and interpretation of the datas are:

- Supply Chain Stages: Manufacturing supply chain consists of series of stages for producing and delivering the aircraft. The stages starts from supplier of parts to manufacturer to final customer. In an aircraft factory, many of the production sages are situated within the premesis, while links are maintaind with plant stages outside the premesis through implementing global supply chain strategies. These stages include component manufacturing, wing assembly, production flight, painting, completion and customer delivery.
- Types of Inventory: Aircraft mega factory carry supplies which includes raw materials, purchased parts,

partially finished items and goods. They also has to carry spare parts for machines and tools. Different inventories include major components and systems of an aircraft such as fuselage, wings, powerplant, landing gear, and other systems.

- Loistics, Distributions and Transportations: Logistics, distributions and tranportations are different aspescts of the supply chain which mainly deals with the movement of goods. Logistics includes movement of materials, cash and information within the facility, incoming and outgoing of materials. In a supply chain distribution refers to the steps taken to move and store a product from the supplier stage to a customer stage. Transportation on the other hand refers to the movement of goods from one location to another within a supply chain. However, it is clear that logistics, distribution and transportations are intregal part of aircraft industry supply chain.
- Mode of Transportations: Aircraft industry uses various mode of transportations for transporting different materials. For example Boeing 787 Dreamliner forward fuselage sections are transported on board of Boeing's Large Cargo Freighter, the Dreamlifter, a specially modified Boeing 747. Bombarbier used an aircraft carrier to transport the the Learjet 45 fusalege from manufacturing plant in Belfast to Wichita.
- Movement within the Facility: Movement of raw materials and other goods within a manufactuing plant is a part of production control. These can be moving goods from storage to point of work to temporary storage etc.
- Facility Layout and Assembly Line: Layout refers to the configuration of departments, work centers, and equipment, with emphasis on movement of work through the system. A typical layout of an aircraft manufacturing plant is aimed towards increasing the efficiency of the manufacturing. Assembly line that standardize layout arranged per a fixed sequence of assembly tasks.

The different types of specialized inventory includes major components and systems of an aircraft, airacrft tools and supplies, aircraft ground support equipments, aerospace material handling equipments. Aircraft supply chain uses specialized and taliored forms and modes of transportation, to carry very small to very large components from one point to another. Movement of goods within an aircraft manufacturing facilities are also very specialized for the industry, handling a wide varity of equipments and methods. The aircraft manufacturing facilities and assembly lines are highly customized to handle large varity of jobs in an standardized sequence.

5. Conclusion

Even though there are a lot published documents relating supply chain management studies and practices in the many industries, however, very little such documents were found for the aviation industry. The current findings explores the relationship between well known concepts and practices of supply chin managent, types of inventory, logistics, transportation relating to aircraft industry, zooming in from macro to micro level processes. It has found that aviation industry is very speciallized and customized industry, with relationship to supply chain stages, logistcs, transporation, and manufacturing processes. Optimization of aviation supply chain from a macro level can have a huge industry benefits, as it is evident in micro level, is a new thought.

Researchers, academicians, practitioners can extend this work in many ways. First, they take a specific aircraft model as a case study and define the end to end supply chain model from a holistic view. Then zoom into each specific stage to do further detailed analysis, while keeping in mind the impact on whole supply chain. Secondly, while optimal solutions are found in an assembly line for a stage in supply chain, the rest of the stages need to be collaborated and synchronized for a given cycle time of production. Finally, the whole supply chain must be optimized first, and then looked into optimizing each single stage and their logistics in the supply chain of aircraft manufacturing process.

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