A Framework Model through Data Flow Diagrams to Model an Air Traffic Control System

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Abstract: Air Traffic Control (ATC) is a service provided by ground-based controller who directs aircraft on the ground and in the air. A controller's primary task is to keep aircraft at a safe distance from each other horizontally or vertically. Secondary tasks include ensuring orderly and expeditious flow of traffic and providing information to pilots, such as radar traffic advisories, weather advisories, flight following and navigation information. In this paper we first provide brief historic background about ATC systems. Later we design and model an ATC using data flow diagrams (DFD) thus providing a framework for such complex control problem. The complete system after the realization of the model is being implemented using MATLAB for the verification of the proposed framework model.

Keywords: ATC, Framework, Data Flow Diagram, Design, Model.

1. Introduction

Air Traffic Control services can be divided into two major subspecialties, Terminal or airport control and en-route or area control. Terminal or airport control includes the control of airborne aircrafts traffic and vehicles on the airport ground within the immediate airport environment. Generally, this is approximately a 30 to 50 nautical mile (56 to 93 km) radius of the airport, from the surface (ground) to about 10,000 ft (about 3,050 m). Terminal controllers work in facilities called control towers and terminal control centers called Terminal Radar Approach Control (TRACON). At some locations, controllers are shared between tower control and the terminal control center, while at others the tower and the terminal control center are completely separate entities [1].

En-route controllers, also called Center or Area controllers control the traffic between the terminals. They can also control traffic in and out of airports where the traffic volume does not warrant the establishment of a terminal ATC operation or during periods when a terminal operation is closed at some airports e.g., midnight to 06:00 A.M. En-route controller works at facilities called Area control centers or Air Route Traffic Control Centers (ARTCC). Section 2 and 3 provides a detailed and elaborated conceptual view from inception to modern day ATC through a literature survey including internet and renowned pioneering articles of reputed journals/conferences. Section 4 provides the details of our ATC model based on DFDs and its implementation. Last section 5 is conclusion.

2. History of Air Traffic Control System

In the early days of aviation few aircraft were in the skies so there was a little need for ground-based control of aircrafts. However, the use of aircraft for traveling, transportation and other purposes became popular very soon and aircrafts were often flown in different countries, and it soon became apparent that some kind of standard rules are required to control the air traffic. In 1919, the International Commission for Air Navigation (ICAN) was created to develop “General Rules for Air Traffic.” Its rules and procedures were applied in most countries where aircraft were operating. As traffic increased some airport operators realized that such general rules were not enough to run the air traffic smoothly [2]. They began to provide a form of ATC based on visual signals. The early controllers stood on the field, waving flags to communicate with pilots. Archie League was one of the system's first flagman beginning in the late 1920s at the airfield in St. Louis, Missouri USA. When radio communication equipment was introduced in aircrafts and most of the aircrafts were fitted with radio communication, radio-equipped airport traffic control towers began to replace the flagmen. In 1930, the first radio-equipped control tower in the United States began operating at the Cleveland Municipal Airport. By 1932, almost all aircrafts were being equipped with radio-telephone communication and approximately 20 radio control towers were operating by 1935 in US only. The early en-route controllers (1936) tracked the position of planes using maps and blackboards and little boat-shaped weights called “shrimp boats” [3]. In 1942 racks of paper strips replaced blackboards as a way to note flight data [4]. The postwar years saw the beginning of a revolutionary development in ATC the introduction of radar; a system that uses radio waves to detect distant objects. Originally Radar was developed by the British for military defense, this new technology allowed controllers to “see” the position of aircraft tracked on video displays. In 1946, the Civil Aviation Authority (CAA) unveiled an experimental radar-equipped tower for the control of civil flights. By 1952, the agency had begun its first routine use of radar for approach and departure control. As the antenna illuminate its sector controllers watch radar scopes for “blips” which indicate the position of aircraft [5].

Although experimental use of computers in ATC had begun as early as 1956, a determined drive to apply this technology began in the 1960s. In 1967, IBM delivered a prototype computer to the Jacksonville Air Route Traffic Control Center USA. Improvement to such systems continued and the National Airspace System project used more instructions than any previous computer program in the early 1970s to provide automatic distribution of flight-plan data. In the same decade controllers were able to determine an aircraft's identity, altitude and other data through alphanumeric codes on their radar scopes. Air Traffic Control system achieved higher levels of automation in 1988 when IBM decided to build multi-billion dollar Advanced Automation System (AAS) [2][6]. Modern Air Traffic Management system today relies on the most advanced aircraft transponders, global navigation satellite systems and ultra-precise radars for Communication, Navigation and Surveillance [7][8][9][10][11]. Design of a new cockpit display which will allow pilots to better control their aircraft by combining as many as 32 types of information about traffic, weather, and hazards is under testing [12][13].

3. Elements of ATC System

Air Traffic Control comprises of various aircraft navigation and communication systems that use computers, radars, radios and other instruments and devices to provide guidance to flying aircraft [1]. Trained personnel working as air traffic controllers at stations on the ground constantly monitor these systems and obtain the location and speed of individual aircraft. Controllers can warn aircraft should they come too close to each other horizontally or vertically. Air Traffic Control is also used for the safe coordination of landings and takeoffs at airports. The goal of Air Traffic Control is to minimize the risk of aircraft collisions while maximizing the number of aircrafts that can fly safely in airspace at the same time. Aircraft pilots and their onboard flight crews work closely with controllers to manage air traffic. Air Traffic Control systems also provide updated weather information to airports around the country so aircraft can take off and land safely. This information is important not only to airline passengers but also to industries that rely on aviation for the timely transport of goods, materials and personnel. Air Traffic Control is a combination of four general elements:

a. The first element is the basic set of flying rules that pilots follow in the air.
b. The second element is the multitude of electronic navigation systems, landing system and instruments that pilots use.
c. The third element is the division of airport surface and air space in different type of control areas. Air traffic controllers operating in each of these areas and the computer systems they use to track aircraft during takeoff, landing and in flight are also part of this element.
d. The fourth element is the communication between pilots-controllers, controllers-controllers and the equipment used for this communication.

3.1 Air Route Traffic Control Center (ARTCC)

ARTCC usually referred to as "Center," is established primarily to provide Air Traffic Service to aircraft operating under Instrument Flight Rules (IFR) within the controlled airspace and principally during the en route phase of flight. Any aircraft operating under IFR within the confines of an ARTCC's airspace is controlled by air traffic controllers at the Center. This includes all types of aircrafts: privately owned single engine aircrafts, commuter airlines, military jets and commercial airlines. The largest component of the airspace system is the Air Route Traffic Control Center (ARTCC). Each ARTCC covers thousands of square miles. ARTCCs are built to ensure safe and expeditious air travel. All Centers operate 7 days a week, 24 hours a day and employ a combination of several hundred Air Traffic Control Specialists, Electronic Technicians, Computer System Specialists, Environmental Support Specialists and administrative staff. En-Route control is handled by pinpointing aircraft positions through the use of flight progress strips. These strips are pieces of printed paper containing pertinent information extracted from the pilot's flight plan. These strips are printed 20 minutes prior to an aircraft reaching each Center's sector. A flight progress strip tells the controller everything needed to direct that aircraft. If the flight progress strips of each aircraft approaching a sector are arranged properly, it is possible to determine potential conflicts long before the aircraft are even visible on the Center controller's display. In areas where radar coverage is not available, this is the sole mean of separating aircraft.

The strips, one for each en-route are posted on a slotted board in front of the air traffic controller. At a glance, he/she is able to see certain vital data: the type of airplane, who is flying it (airline, business, private, or military pilot), aircraft registration number or flight number, route, speed, altitude, airway designation and the estimated time of arrival at destination. As the pilot calls in the aircraft's position and time at a predetermined location, the strips are removed from their slots and filed. Any change from the original flight plan is noted on the strips as the flight continues. Thus from a quick study of the flight progress board, a controller can assess the overall traffic situation and can avoid possible conflicts. The Fort Worth Air Route Traffic Control Center (ZFW) is a typical ARTCC in US [14]. The Center has approximately 350 controllers. The geographical coverage area of Fort Worth ARTCC is shown in figure 1. Each sector has a unique radio frequency which the controller uses to communicate with the pilots. So when aircraft transition from one sector to another they are instructed to change to the radio frequency used by the next sector. In general there are three basic controller positions working together to monitor and direct traffic within the Center's airspace to maintain a smooth and efficient flow of air traffic [15][16][17].

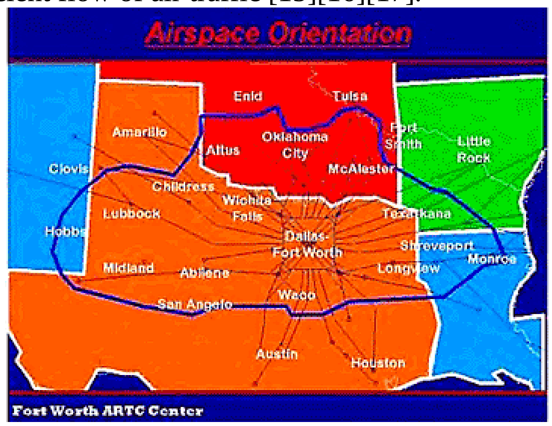

Figure 1: ARTCC Geographical Coverage [14].

The Center controllers have many decision support tools (computer software programs) that provide vital information to assist the controllers in maintaining safe separation distances for all aircraft flying through their sector. One such predictive tool allows the controller to display the extended route of any aircraft on the radar screen. It is called a "vector line", this line projects where the aircraft will be within a specified number of minutes, assuming the aircraft does not change its course. This is a helpful tool to determine if the flying aircraft routes will pass safely within the standard separation, or if they will conflict with each other. In addition to vector lines, the controller can also display a "route line" for any given aircraft on his/her radar screen. This will show to the controller where a particular aircraft will be in specified number of minutes as well as the path the aircraft will fly to get there. Such decision support tools help each controller to look ahead and avoid conflicts [18][19].

4. ATC Data Flow Diagram

Data flow diagrams (DFD) reveal the relationships between various components of the system. DFD is an important technique for modeling a system's high-level detail by showing how input data is transformed to output through a sequence of functional transformations [20][21][22]. Systems analysts prefer working with DFDs particularly when they require a clear understanding of the boundaries between existing systems and postulated systems. DFD represents the following:

1. External devices sending and receiving data

2. Processes that changes the data
3. Data flow itself
4. Data storage location

The hierarchical DFD typically consists of a top-level diagram (0 Level) underlie by cascading lower level diagrams (I Level, II Level…) representing different parts of the system with more elaborating detail description. In our study Microsoft Visio standard symbolic representation is used to show the data flows and sequence of operations in our model.

4.1. Design of Software

A structured software design process provides guidance on how to develop software successfully. Such guidance may cover the entire spectrum of activities associated with software development which are requirements, design and development, implementation and validation. Air Traffic Control System design requires similar structured approach. There are many design techniques for example just-develop-it, water fall, and interactive. However, statistics after reviewing and surveying many systems water fall technique seems to be the most likely approach for an ATC. In reality all software projects have iterations. DFD is an important technique for modeling a system's high-level design detail and additionally incorporating it with hierarchical levels more descriptive model can be build. We have shown here by first developing these high level abstraction diagrams and later with implementation that a larger system like ATC can be modeled through DFD efficiently.

4.2. ATC 0 - Level DFD

The ATC 0 - Level DFD shows only in broad terms tasks the system can perform. However, most systems are complex and therefore require more details to describe them completely. The ATC 0 - Level DFD of Air Traffic Control System is shown in figure 2 representing one entity the pilot. Pilot of the aircraft normally fills the information of the flight which is then handed over to the AT Controller to store in the system. This includes the names of departing and destination airports and the flight plans. A controller will activate the flight plan and a track will be created which is correlated with the flight plan. The track information will be stored in the track file. A weather file is also maintained in the system, the controller will get the information from this file and relayed to the pilot because pilot should know the weather updates before or during flying. The ATC system will create the transponder code based upon the track number. So in case of emergency pilot can request to the near TRACON (Terminal Radar Approach Control) in order to change the track which will be updated or changed in order to ensure safety. Alternative flight plan information is then relayed to the pilot by controller.

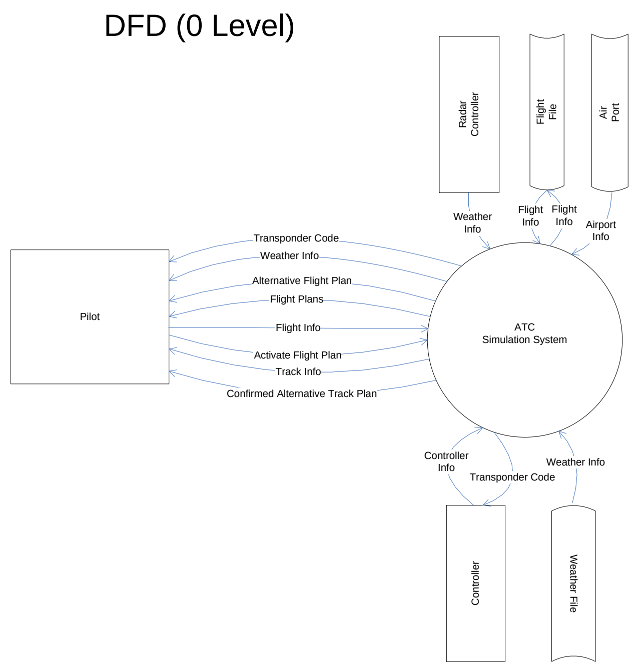

Figure 2: ATC 0 - Level DFD

4.3. ATC I - Level DFD

The ATC I - Level DFD shows in detailed all the processes that comprise a single process on the 0-level diagram and it also shows how information moves from one process to another. However, ATC I - level diagram may not be needed for all ATC 0 - level processes. The ATC I - level DFD of the ATC system is shown in figure 3. For example this ATC System will generate the flight plans list including aircraft data such as aircraft ID, reported altitude, assigned altitude, ground speed (depending upon the flight information) as shown by dotted line on figure 3. Typically, flight plan includes the departure and destination airport. If there are some transit airports then that city airport is included in the flight plan. Similarly we can see from this diagram that one can create new tracks and each newly created track will have a unique identity with other attributes like latitude, longitude, speed, heading etc.

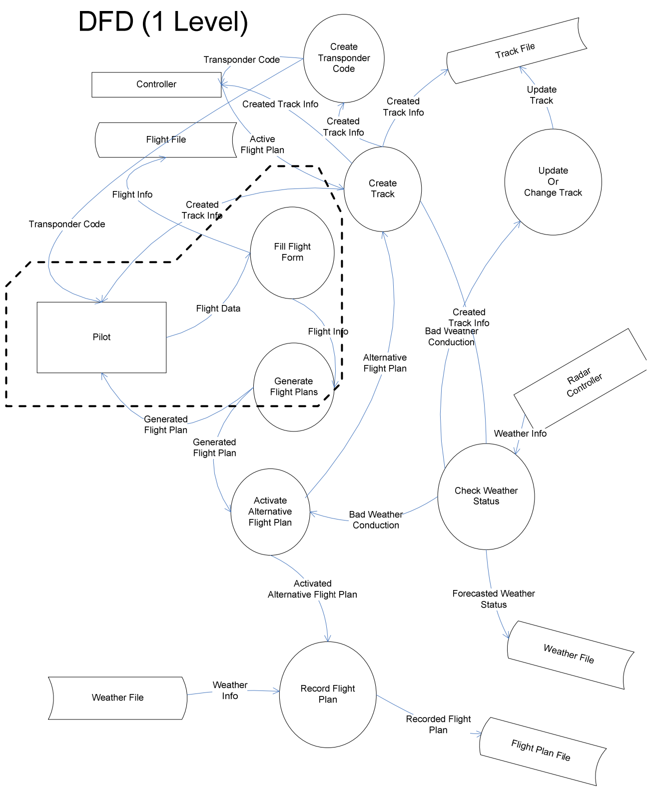

Figure 3: ATC 1 - Level DFD.

4.4. ATC II - Level DFD

ATC II - Level DFD is a detailed level diagram of the system which is shown in figure 4. This level of DFD has extra processes which are incorporated at this stage to the ATC system. For example Alarm process, which will generate alarm when the two aircrafts are on the same track or there separation is small (less than 5 nautical miles). The system has also included a process for Predicted Area or Track. The track can be predicted by getting the track information from the file. In our implementation we encircled (white) the predicted track and prediction shown as by red dotted line on figure 5. A modern ATC must have a range filter, so at this level a range filter with various ranges to give greater inside look to the controller to monitor traffic efficiently is included shown as Square dotted line on the level II figure 4.

5. Conclusions

This study has two parts first part is appreciating the achievement in ATC by providing historical survey background and second part is about the design and modeling of ATC system through data flow diagrams (DFD). DFD is a simple but efficient technique to represent complex systems like ATC. History describes how the Air Traffic Control evolved, from simple guiding the airplanes by flag signals, to complex Air Traffic Control system the ones we have today.

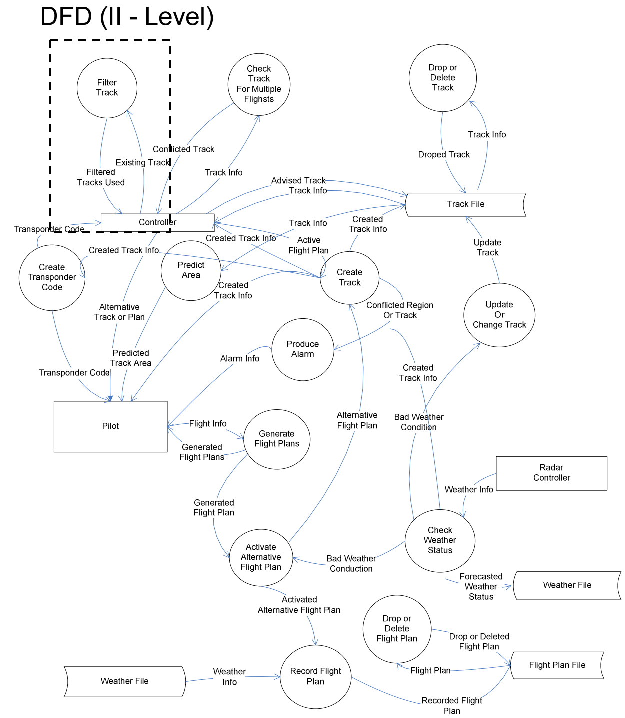

Figure 4: ATC II - Level DFD.

There are various ways to model complex systems; Data processing model, Compositional model, Architectural model, Behavioral model, Classification model and Stimulus model. For data processing application like ATC, DFD is an appropriate choice for implementation. It shows simple, intuitive notation, end to end processing and a functional perspective. We believe that these components of the ATC system has inherit tendency to be described through a model which is not only simple but has hierarchical levels. Therefore, we selected DFDs as our modeling tool for designing and implementation. We have shown through the construction of various levels of DFDs that a complex system such as ATC can be more convenient for design, development and consequently for implementation. The system concept of various levels after its conceptual model design was implemented for validation using MATLAB. In future we would like to perform rigorous test and analysis procedures on our framework model implementation to improve the design and implementation strategy.

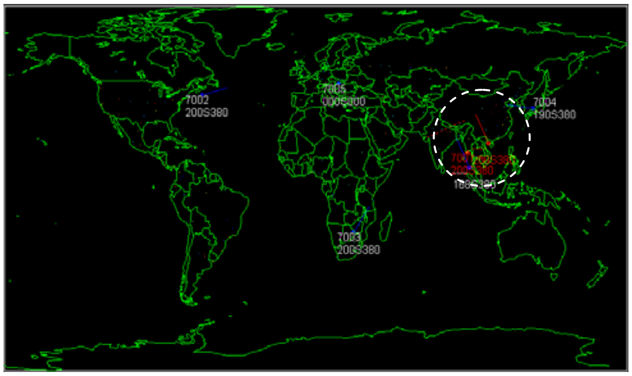

Figure 5: Track Prediction.

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