Abstract—This paper illustrates the event-oriented Behavioral Pattern Analysis (BPA) modeling approach in developing an Air Traffic Control System (ATC). The Event defined in BPA is a real-life conceptual entity that is unrelated to any implementation. The major contributions of this research are developing the Behavioral Pattern Analysis (BPA) modeling methodology. And the development of an interactive software tool (DECISION), which is based on a combination of the Analytic Hierarchy Process (AHP) and the ELECTRE Multi-Criteria Decision Making (MCDM) methods.

Index Terms—Analysis, air traffic control, modeling methodology, software modeling, event-oriented, behavioral pattern, use cases.

I. INTRODUCTION
Experience reports problems with Use Cases such as [1] lack of a formal specification, lack of atomicity which has made the measurement of a project’s task complicated, and a problem with the phrase use case itself.

A major problem in the use case approach is its tendency to focus on the solution rather than the problem. Jacobson defined use case as “a behaviorally related sequence of transactions in a dialogue with the system” [2]. The processing of transactions, or operations, or use cases is what the machine does. It is part of the solution, not part of the problem [3].

The concluding statement of the “Question Time! About Use Cases” Panel of the OOPSLA’98 Conference by Ian Graham [4] was “There is a need for another modeling methodology with a sound theoretical basis and a precise definition.” This need is what this research problem area is about.

In addition to the problems with the use cases [3], [4] that were described briefly above, several additional problems were identified during this research [5], [6]. The following is a discussion of these problems:

1) The types of interactions are: interactions among users, interactions between users and the system, and interactions among the different components of the system. Yet, use cases describe only the users’ interaction with the system.

2) Using natural language in use cases description, with the absence of any semantic structure such as alternation or repetition, increases the risks of ambiguity, incompleteness, and inconsistency.

In conclusion, if the analyst misinterpreted or neglected some structural or behavioral aspects, the resulting conceptual model will not be a good representation or understanding of the real world. The resulting software solution system built from the model may not demonstrate the correct behavior or may ungracefully terminate. The end result might be the loss of opportunities in using business systems, serious damages in embedded systems, or the loss of lives in using a safety-critical system.

In the BPA modeling methodology, the BPA Behavioral Pattern, which is the template that one uses to model and describe an event, takes the place of the Use Case in the UML Use Case View. The BPA Behavioral Patterns are temporally ordered according to the sequence of the real world events.

II. ILLUSTRATING BPA THROUGH THE AIR TRAFFIC CONTROL SYSTEM (ATCS)
One of the primary duties of air traffic controllers (ATC) [7] is to control the flow of air traffic so that it is most efficient and safe as can be. More specifically, air traffic controllers engage in a number of tasks relative to this objective such as direct pilots to the runway, alert the pilots as to additional air traffic in the area, issue instructions for takeoff and landing, direct airplane pilots while en route to their destinations and maintain contact with the pilots during the travel. The air traffic controllers are responsible for aiding the pilots in reaching their destination.

The air traffic controllers are also responsible for doing preparation work before the flights take off. They will be responsible for checking weather statistics at both the current airport and future destination to ensure the safest route of travel and issue any possible weather delays. It has to contact Meteorological Stations (METs) to update the weather info. These individuals will also need to prepare specific flight information prior to the flight taking off.

The job of the air traffic controller does not always entail pilot contact alone. There are many clerical duties which go along with being an air traffic controller. There are many documents needed to be filled out and paperwork which must be completed each day by the air traffic controller. Certain clerical tasks may include analyzing weather reports and fuel requirements, compile pilots reports and flight plan documentation, complete daily logs, keep messages from the aircraft and review all reports for clarity and completeness.

The pilots are not the only ones who receive instruction from air traffic controllers. Also part of an air traffic controller’s duties is to instruct ground workers at the airport and/or airline in certain duties. This is necessary to ensure...
that the airplanes receive baggage workers and maintenance workers at the right place at the right time.

Air traffic controllers are also vital in the case of an emergency. Should an airplane encounter problems, the air traffic controller’s role is extremely important. The air traffic controllers will maintain contact with the pilots, aid in overcoming any flight problems, provide flight path changes for bad weather and in extreme circumstances, direct pilots to a specific area for emergency landings.

The air traffic controller must also efficiently hand over control to the airplane’s destination traffic control tower. Therefore, it is imperative that air traffic controllers maintain contact with one another so that they can let the destination tower know which airline is coming into their vicinity and let them know the approximate time of arrival. Lastly, air traffic controllers must ensure that they are doing their jobs in strict compliance with federal regulations.

The following describe the operation:
1) ATC direct pilots to the runway, taxiway, or apron
2) It controls the flow of runway traffic so that it is most efficient and safe (fast clearance, no hold or delay)
3) It is also vital in the case of an emergency:
   • ATCs will maintain contact with the pilots, aid in overcoming any flight problems, provide flight path changes or ad weather, and direct pilots to specific area for emergency landing
   • As an example, the air craft crash, bomb threats
4) Also part of the ATC’s duties is to instruct ground workers at the airport to execute certain duties. As example, snow removal, ice control, airport lighting etc.
5) This system will be spread across three facilities:
   • Terminal Area Radar (TAR)
   • Surface Movement Radar (SMR)
   • Automatic Terminal Information Service (ATIS).
6) TAR is comprised of two major components:
   • Primary Surveillance Radar
   • Secondary Surveillance Radar.
7) PSR detects and provides both range and bearing information of an aircraft within its coverage by radio wave reflection as follows
8) SSR radar provides, after processing, the range, earing, altitude and identity (callsign) of an aircraft
9) SMR radar mounted on top of the Aerodrome Control Tower for surveillance of the movement of aircraft and vehicles on the runway and taxiways.
10) The accurate information provided enables the tower controller to maintain a smooth flow of traffic during low visibility or darkness.
11) Flight Data Processing System (FDPS) processes the flight plan data from aeronautical messages and prints out flight progress strips automatically for use by air traffic controllers to assist in updating/monitoring of the aircraft flight profile, such as flight route, estimated time of departure/arrival, flight level, expected times at reporting points, cruising speed, etc.
12) Automatic Terminal Information System (ATIS) is a VHF broadcasting system for continuous distribution of vital information (such as updated airdside, meteorological and navigational aids serviceability information, etc.) to pilots.
13) Flight Profile:
   • Every aircraft that flies follows a similar flight pattern that begins before takeoff and ends after landing.
   • This pattern is called a flight profile.
   • Each phase of a typical flight profile is monitored by an ATC facility with its own group of controllers.
   • They monitor the flight using special equipment and decision support tools that ensure a safe and efficient flight.

![Fig. 1. Air traffic profile.](image)

III. THE BPA REQUIREMENTS DEVELOPMENT PROCEDURE

The following is an outline of the BPA functional requirements development procedure (Fig. 2 and Fig. 3):
1) Identify the problem at the highest level of abstraction (e.g. The Mission Statement and Operating Requirements).
2) Identify the scope of the requirements (problem) from the Originating Requirements.
3) Analyze the Originating Requirements to identify the Critical Constraints (e.g. Safety) and/or the Utility Requirements.
4) Decompose the scoped problem (from step2) into Main Events based on the Mission and Operating Requirements (Step 1).
5) Using the identified Main Events, draw the High Level Event Hierarchy Diagram which is constructed in several levels whose top level includes the highest main event (Fig. 3).
6) Decompose these identified Main Events into smaller and simpler events represented as Episodes (Composite Events) with clear boundaries.
   - An Episode Boundary at this stage may be marked with Location / Loci of Control and Effect.

7) Add additional levels to the Event Hierarchy Diagram (Event Hierarchy Sub-Diagrams). For complex problems, it is often helpful to extract these sub-diagrams and analyze them. Detailed level event hierarchy diagrams are drawn as necessary.
   - Decomposition Heuristics at this stage is ‘One Agent and One Location’

8) For each identified main event (from step 4) draw an Event Thread Diagram which represents the events’ sequence (Fig. 4)
   - Starting with the Main Events, as initial composite events, recursively decompose the composite events into Basic Events
   - The Event Decomposition Heuristics at this stage is ‘One Agent, One Location, One Motion Direction, and One Time Interval’.
   - Group Basic Events by their Location / Loci of Control and Effect. Draw a frame box around these Basic Events

9) Refine and transform the above Basic Events into their corresponding BPA Behavioral Patterns which describes the which, who, when, and where of each of the basic events (Fig. 5)

10) Using the Event Thread Diagrams from step 8, draw the Temporal/Causal Constraint Diagrams by adding the temporal constraints (time order as illustrated in Fig. 6 and Fig. 7) alongside the associations and identifying the enable/causal relationships (Enable is what makes it ready, and Causal means making something happen) in each corresponding Event Thread Diagram (Fig. 8).

11) Using the Critical Constraints (e.g. Safety), identify the critical events, identify all possible ways of each critical event’s failure, and draw the Critical Event Analysis Diagram (Fig. 9).

12) Using the BPA Event Patterns and the Critical Event Analysis Diagrams, identify any missing requirements that are necessary to satisfy the critical constraints. One develops a Derived Requirements document and get users approval on this document.

13) Using the Missing Requirements (from step 12), refine the Event Hierarchy Diagram (from step 6), the Thread Diagrams (from step 8), and the Temporal Constraint Diagram (from step 10) as necessary. Draw additional Event Thread Diagrams for identified critical events as necessary.

Fig. 2 illustrates the BPA iterative and incremental development process. The figure shows the start with the Originating Requirement and Steps 1 to 3, then Steps 4 to 7, then Step 8, then Refine and come-up with the Derived Requirements which covers any Missing Requirements as explained in Steps 9 and 10. After that we re-iterate as explained in Steps 11 and 12.

14) Using the BPA Behavioral Patterns (from Step 9), identify the candidate Classes from the Event Roles (Participants) and Instrument. Draw the Class Diagram (Fig. 10).

15) To illustrate the relationship between Events and States, optionally, using the BPA Behavioral Patterns, draw the Event/State History Chart (Optional – not shown) that includes the States before and after each Event for each identified Class whose instance is a participant in that Event.

The above procedure illustrates the BPA functional requirements development procedure. Fig. 2 depicts the flow of the modeling activities (Steps 1 to 14) for the BPA procedure.

A. Event Hierarchy Diagram (EHD)
Documentation. The third level includes sub-events of the second level’s event which are Check Weather Statistics at Current and Destination Airports, Issue Flight Delays and Prepare Specific Flight Information (sub-events of Preparation Work before Flights Take Off), Direct Pilots to Runway, Alert Pilots to Additional Traffic in the Area, Issue Instructions for Takeoff and Landing, and Direct Pilots while En Route to their Destination, (sub-event of Maintain Pilot Contact), and Analyze Weather Reports, Analyze Fuel Requirements, and Compile Pilots Reports (sub-events of Maintain Documentation).

Fig. 4. Event hierarchy-air traffic control.

In order to model the sequence of events (and show the location / loci of control and effect view, or the temporal / causal constraints), one uses the event thread diagrams as shown in the next subsections.

B. Event Thread Diagram (ETD)

In BPA, as per step 8, an Event Thread Diagram (ETD – Fig. 5) is drawn for each main event, and optionally drawn for any other event, subordinate to main event, depending on its complexity or its critical nature.

A Basic Event is defined as an event that cannot be decomposed into another set of events (atomic event). The heuristic used in decomposing is one agent, one location, one time interval, and one motion direction if the event involves any motion. The ETD, which one draws for an event, shows the sequence of the basic events of that event.

C. Behavioral Patterns

As explained in step 8, the research goal is to develop a requirements definition mechanism (BPA Pattern – Fig. 6) that describes the What, Who, How, When, Where and Why.

**BPA BEHAVIORAL PATTERN - EXAMPLE**

**Event (WHAT?)** Direct Pilots While En Route To Their Destinations

1. 2. 3. 4. 5. 6.

**Agent:** Radar PSR and SSR
- Initial State: Identify Range, Bearing, and Altitude of Aircraft
- Final State: Provide Information to Pilot

**Affected:** p: ATC Tower, Pilot
- Initial State: Uninformed
- Final State: Informed with Range, Bearing, and Altitude of Aircraft

**Modality (HOW?)**
- Instrument: Radar Processor
- Circumstances: Critical Condition
- Manner: Released c2:
- Effect: Flying
- Date/Time (WHEN?): Before Issue Instruction for Takeoff or Landing
- Place (WHERE?): Radar Path
- Motion: Flying
- Direction: Calculated Trajectory

**Rationale (WHY?)**
- Goal: Provide Range, Bearing, and Altitude
- Mental State: bd;
- Caused-By: e`: Radar Processor

End;

Fig. 6. BPA pattern – ATC direct pilot.

D. Introducing Time

The key intuitions motivating the introduction of time are:
1) Events take time. Yet, in most of the popular Object-Oriented Modeling methodologies such as OMT and UML, time is neglected in the event definition.
2) Multiple events may occur at the same time, and could be unrelated, cooperating, or interfering with each other.
3) Events may have temporal constraints. They may overlap, start or finish together, occur together, or disable (disjoint) each other. BPA uses the time intervals’ relations that are described in the Interval Algebra framework [8] to model the temporal relationships between events. In this Interval Algebra framework, seven basic relations can hold between time intervals. Fig. 7 and Fig. 8 illustrate these basic relations for arbitrary events x and y.
4) Fig. 7 illustrates the Interval Algebra Relations.

![Fig. 7. Time interval algebra-temporal relations.](image)

**E. Introducing Enable / Cause Relationships**

The introduction of the Enable \(^1\) / Cause relationships between events will enable the analyst to do cause effect analysis and reason about any possible failure of the system.

![Fig. 8. Time interval algebra-temporal relations notation.](image)

In the Temporal Constraint Diagram, as described in Steps 9, and 10, the temporal relations that are displayed in Fig. 9 are written alongside the sequence relationships to represent the possible timing at which these events can occur.

**F. Failure Issues**

The following is a list of reasons of possible failures in responding to events:

- Occurrence of a relevant event which the system does not handle
- Event rate exceeding the system’s capacity
- Unsuccessful detection and acquisition of all events including manually captured events
- Non-capturing of all information triggered by event
- Failure across man-machine interface
- Failure of Software, Hardware, or Human.

![Fig. 9. Temporal constraint diagram-air traffic control.](image)

The ability to provide requirements specification for safe behavior is very limited using the current modeling methodologies. Neither a safety analysis (anterior analysis) nor accident analysis (posterior analysis) can be achieved efficiently without event analysis. As will be explained below, the BPA modeling methodology provides the Critical Event Analysis (defined below) as an efficient solution to this problem.

1) **Critical events analysis**

The requirements should correctly reflect the critical properties of the environment in which software is to work. In order to gain as much confidence as possible in the software for a critical system, the analyst should perform a ‘Critical Event Analysis’. The Critical Event Analysis procedure includes the following steps:

- Identify Critical Events
- For each critical event, identify all possible ways in which it may fail
- Capture these possible failure modes using the undesired event notation
- Study each undesired related state to find out how to achieve protection against such possible failure.

In the Critical Analysis Diagram, the rectangles represent the states of the critical events. The dashed rounded ended rectangles represent the failure that occurs due to these states.

IV. **MISSING REQUIREMENTS**

There were no missing requirements that required generating a Derived Requirement Document.
V. ATC CLASS DIAGRAM

The resulting Class Diagram is shown in Fig. 11.

VI. EVALUATION OF THE EFFECTIVENESS OF THE BPA MODELING METHODOLOGY AND THE UCA MODELING METHODOLOGY

The UCA and the BPA modeling methodologies were used to define the requirements and model the following safety-critical real-time-systems:
1) The Therac-25 Medical Device System [9]
2) The Production Cell System [10]

The first application was used, as a proof of concept, in a pilot case study. The last two applications were distributed as part of the case studies material to compare the UCA versus the BPA modeling methodologies using the pre-mentioned effectiveness criteria.

VII. THE EFFECTIVENESS METRICS

The effectiveness metrics categories used in this research include:
1) System Effectiveness represented by safety
2) Requirements Engineering Process Effectiveness represented by the CMM [12] and CMMI repeatability
3) Definition of Requirements Effectiveness represented by the ANSI (NIST) / IEEE Std 830-1984 [13] for systems specifications:
   • Unambiguous
   • Complete
   • Consistent
   • Modifiable
   • Traceable

VIII. THE PAIRWISE COMPARISON METHOD

A Multi-Criteria Decision Making (MCDM) Tool, named as DECISION, was developed by this researcher to evaluate the assessment results. The Decision tool uses a combination of the Analytic Hierarchy Process (AHP) and the ELECTRE Pairwise Comparison approaches. Pairwise Comparisons is the process in which experts rate a set of objects, events, or criteria, by comparing only two at a time. Most people are reliable estimators using pairwise comparisons because they only have to consider two things at a time [14]. The selected approaches, AHP and ELECTRE, are popular and have strong theoretical basis [15], [16].

IX. THE CASE STUDY MATERIAL

Each SME was provided with a case study kit that contains the instructions, an application, an overview and a step by step procedure describing how to analyze and model requirements using the UCA and BPA modeling methodologies, two analyses of the given application; one using the UCA modeling methodology and the other using the BPA modeling methodology, explanation of the evaluation method (Pairwise Comparison) and the effectiveness criteria. The set of questions presented clearly in a table format (Evaluation Forms).
X. THE SUBJECT MATTER EXPERTS

The number of SMEs depends on the number of the controlled variables. The controlled variables are:
1) The applications.
2) The set of the SMEs.
3) The SMEs’ software engineering experience:
   • Structured Analysis
   • Use Case Analysis / UML.

XI. CASE STUDIES’ RESULTS

A. Case Studies Results

1) AHP results

The summary of the assessment results using AHP is illustrated in Fig. 12 in a column chart format.

![Evaluation of the BPA versus UCA](image)

The above results give an indication of about 93.8 % approval rate for the thesis hypothesis with about three times overall effectiveness for BPA over UCA.

2) ELECTRE results

Fig. 13 shows that there is 87% approval rate for the thesis hypothesis.

![Evaluation results’ summary by SMEs](image)

XII. CONCLUSION - WHY THIS WORK IS IMPORTANT

A. Real-Time Systems

In most of the popular object-oriented development modeling methodologies state diagrams are used to model the behavior. By using state diagrams, one is focusing on an individual object’s response to specific events rather than objects interaction. Hence, objects interaction must be reconstructed from the analysis of groups of diagrams. Such a task is at least complex and error-prone. By describing the requirements in terms of events, represented by the behavioral patterns, this perceived problem is reduced.

B. Multi-Agent Systems

There is a need for a multi-agent systems analysis and design method that is powerful enough to model interaction patterns involving autonomous agents.

C. Safety-Critical Systems

In these systems, analysts should perform a ‘Safety Analysis’. Using BPA, one identifies and documents the critical events during the requirements definition stage.

GOD says [KORAN] [TORAH], “… Whoever rescues a single life earns as much merit as though he had rescued the entire world.” If the use of the BPA Modeling methodology may save one life, the significance of this modeling methodology is immeasurable.

REFERENCES


Assem El-Ansary was born on September 2, 1944, in Elfashn, Egypt, and he is an American Citizen. He earned his BSc in 1969 in electrical engineering from Cairo University. He earned his masters degree in MIS in 1979 from The American University. He earned his PhD in IT in 2005 from George Mason University (GMU) in Fairfax, USA.

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Assem El-Ansary Assem developed a software system (Decision) to elicit and analyze experts’ judgment using multi-criteria decision making (MCDM) techniques. He is a Member in ACM, and IEEE. He worked as Technical Committee Member in CIMCA 2004, 2005, 2006, and Icem 2014. He received the “Developing Courses around the Clock” Award in 1990 from Intersolv, and the “Year 2000” Award in 2000 from ATS.