Report on Phase 5 Causal Modeling for Schiphol Airport

Oswaldo Morales, Dorota Kurowicka, Roger Cooke
EWI, TU Delft,
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1. Introduction.

This document reports on the activities of EWI during the fourth phase of the CATS project; that is, the time period between the end of October 2006 and the end of February 2007. The project kicked of in July 2005, although preparatory work was initiated in the spring of the same year.

The previous report [10] described a first quantification of the Flight Crew Error Model and the development of software implementation for Distribution-Free Continuous /Discrete Bayesian Belief Nets (DFCDBBNs); in particular regarding the ability to update the BBN from UniNet.

In this report we present:

- An overview of the progress in the work being done to translate ESDs & FTs into BBNs
- A preliminary suggestion on how to connect continuous BBNs to each ESD & FT once they have been written as BBNs

This report is largely based on the report mentioned previously [10]. Some concepts are repeated for consistency.

2. Representing Fault Trees as Bayesian Belief Nets.

Previous studies have proposed representing FTs as BBNs [7]. Ways to deal with the dependence amongst base events have also been presented. In this section we summarize the main results on this issue, as well as a way to represent a node from the DFCDBBN as a two state node from the FT. All examples will be presented in NETICA®. Later versions will include the corresponding models in UniNet.

2.1 Base Events Independent.

The first case to be discussed is when the basic events are independent. Figure 1 shows independent events A and B determining event T. In NETICA one can specify equations and they will be translated (Relation → Equation to Table) to the corresponding probability table. For the AND and OR gate one would write respectively:

- T (A, B) = if(and (equal(A, Failed),equal(B, Failed)), Failed, Works)
- T (A, B) = if(or(equal(A, Failed),equal(B, Failed)), Failed, Works)

Extension to more than two base events all being independent of each other follow the same line of reasoning.

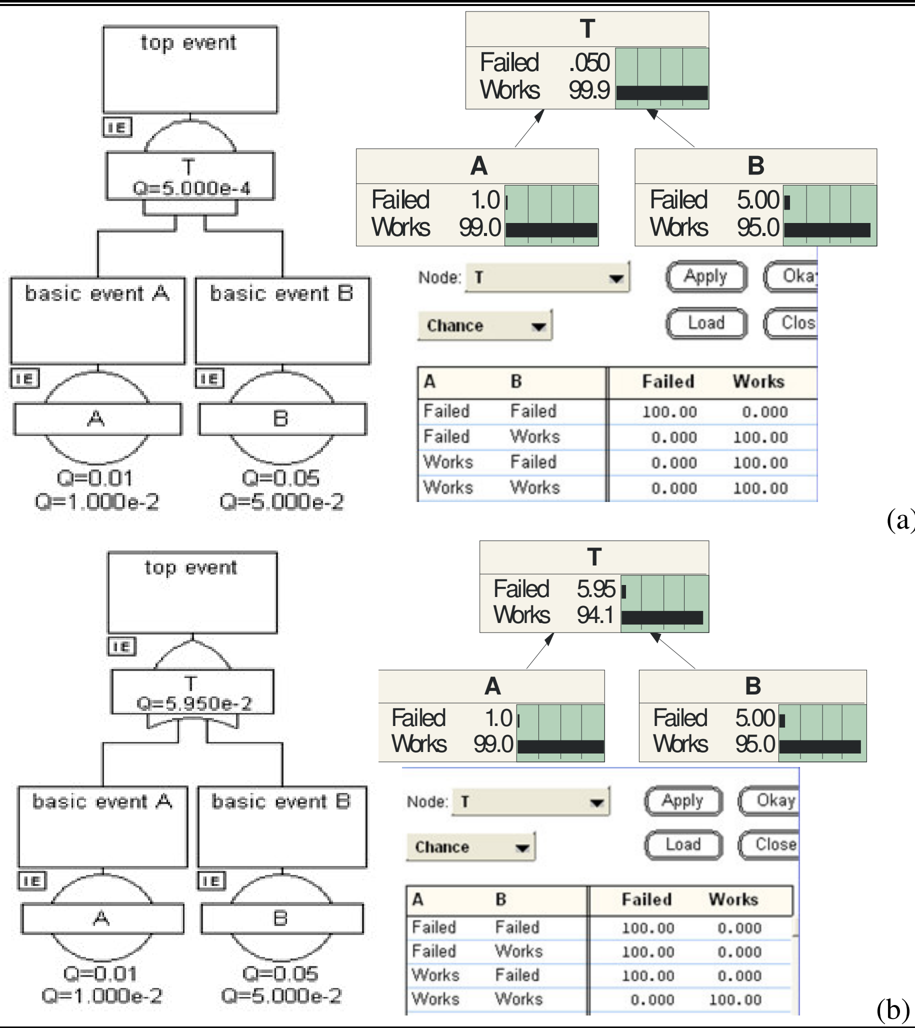

Figure 1. The AND (a) and OR (b) gate in FT and BBN Representation.

It may be slightly cumbersome to rewrite a fault tree to the corresponding Bayesian belief net. Moreover one cannot see from the BBN graph to which gate a given influence corresponds. This information must be retrieved from a conditional probability table. On the other hand we can easily see an influence of each gate on the top event as all intermediate failure probabilities of each gate are calculated.

The main difference between the FT and BBN approaches is that a FT represents a binary function with basic events as inputs and the top event as the output. BBNs however represent a joint distribution between binary random variables (basic, intermediate events and the top event). Hence BBN is a much richer model then FT and will allow existence of repeated events as well as dependencies between the events.

2.2 Repeated Events.

Let us consider the FT in Figure 2 (a). If event A and A2 were in fact the same event one could easily model it in the BBN by simply connecting them with an arc (Figure 2 (b)) and indicating in the conditional probability table that A2 is just equal to A. Another option is to introduce the relation as an equation: A2 (A) = A. NETICA would build the appropriate probability table after one pass of Relation → Equation to Table.

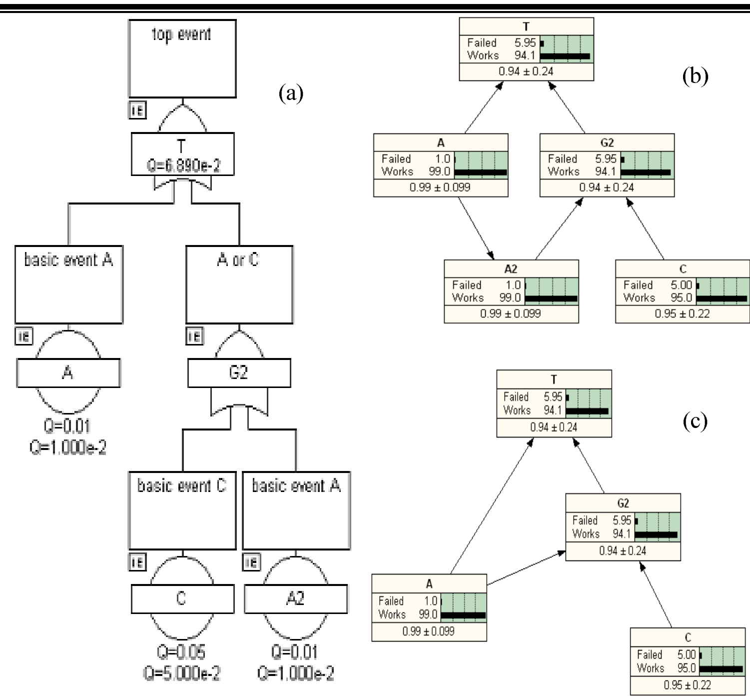

Figure 2. Fault Tree where events A & A2 are different (a) and BBN representation assuming A = A2 (b) & (c).

Alternatively, we could use only one version of event A and then the BBN would look like the one in Figure 2 (c). Observe that when A and A2 are considered the same event then P(T) is different than the one retrieved by the fault tree assuming A and A2 are different events.

An example of an ESD together with its corresponding FT translated into a BBN may be observed in Appendix 1. The ideas discussed in section 2 have been applied to a number of ESDs the progress on this respect is presented in table 1 and a graphical representation of the model as it stands now is presented in Appendix 2.

ESD & FT	STATUS	ESD & FT	STATUS	ESD & FT	STATUS	ESD & FT	STATUS	ESD & FT	STATUS
1	OK	8	-	15	-	25	OK	32	-
2	-	9	OK	16	-	26	OK	33	-
3	OK	10	OK	17	-	27	OK	35	-
4	OK	11	-	18	-	28	OK		
5	OK	12	OK	19	-	29	OK		
6	OK	13	-	21	-	30	-		
7	OK	14	-	23	-	31	-		

Table 1. Overview of progress on the representation of the CATS model as a Single BBN.

OK: Ready to be checked by other members of the consortium.
- : Not available.

3. Connecting Fault Trees and Continuous Bayesian Belief Nets.

Once the FT has been expressed as a BBN, the next task is to couple the continuous BBN with the corresponding node (or nodes) in the FT. Part of the Tasks of EWI-TU Delft for this period was to propose a way to connect BBNs and FTs such that dependencies could be handled. Through this section a discretized version of the BBN for Flight Crew Error Probability[1] and ESDs 1, 12, 26 and 29 will be used.

3.1 The Expectation of A continuous Variable as an Estimate of the Probability of an Event.

Recall that in the DFCDBBNs, nodes represent continuous random variables and edges unconditional and conditional rank correlations[2]. The expectation of node L12B3121 may be regarded as the probability of no ADI cross-check by pilot per ADI failure. Central estimates for this probability are provided by DNV together with confidence bands and distribution is fit to these estimates assuming the estimates provided by DNV are the 5th, 50th and 95th percentiles of the number of Human errors of a particular kind per million flights.

In order to ensemble the three models together (ESDs, FTs and BBNs) a discretized version of the model is built (Appendix 3). And the expectation of the continuous distribution is represented as a two state node.

[1] We refer to the first quantified version of the flight crew error model presented in [9] Appendix 5.
[2] See [3], [4], [6] and [10] to see how the quantification of the model was done

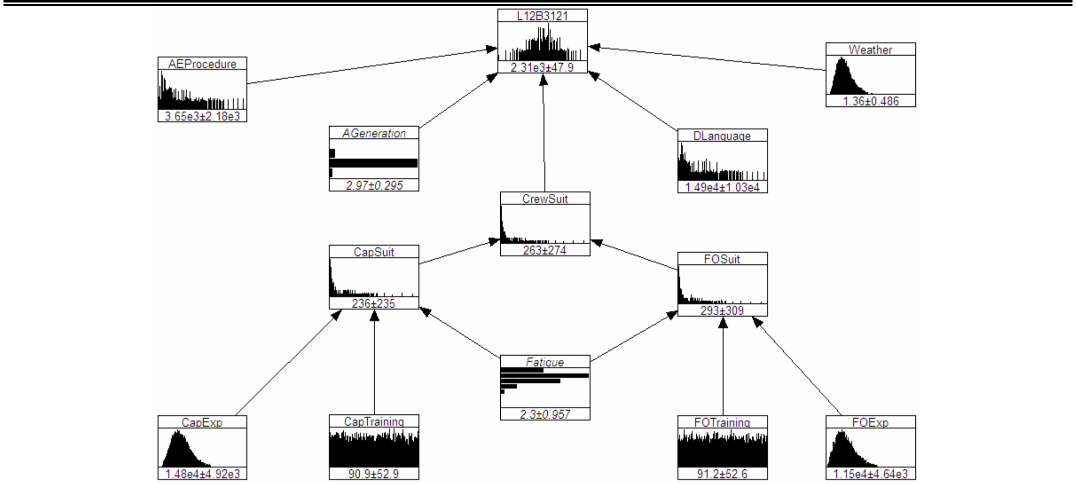

Figure 3. Flight Crew Error Probability Model representing a Single Error
(No ADI cross-check by pilot per ADI failure).

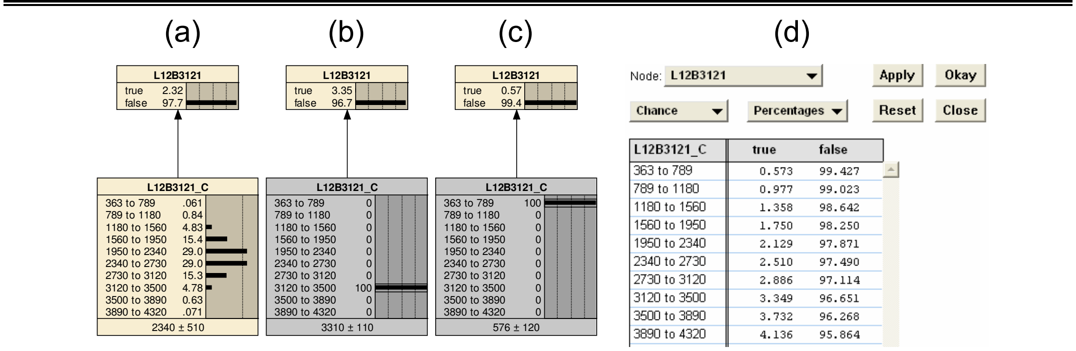

Figure 4. Discrete version of node L12B3121 in Figure 4 represented as a binary node.

The reader may see in Figure 4 that the CPT presented there (d) is able to represent the expectation of the continuous node L12B3121 as the probability of occurrence (or not occurrence) of a Flight Crew Error. The unconditional probability of observing an error of the type L12B3121 (a) is 2.32% changes in this probability according to different beliefs about the distribution of the number of errors per million flights are presented in (b) and (c). This procedure may be applied when other continuous BBNs become available in the project. Next section presents an example of a model connecting ESDs, FTs and the BBN for Flight Crew Error.

3.2 Example

Once a continuous node has been represented as a binary variable, it can be coupled with an FT by first representing the last as a BBN and connecting its node (or nodes) to the corresponding binary node representing the expectation of a continuous variable. This case is illustrated in Figure 5.

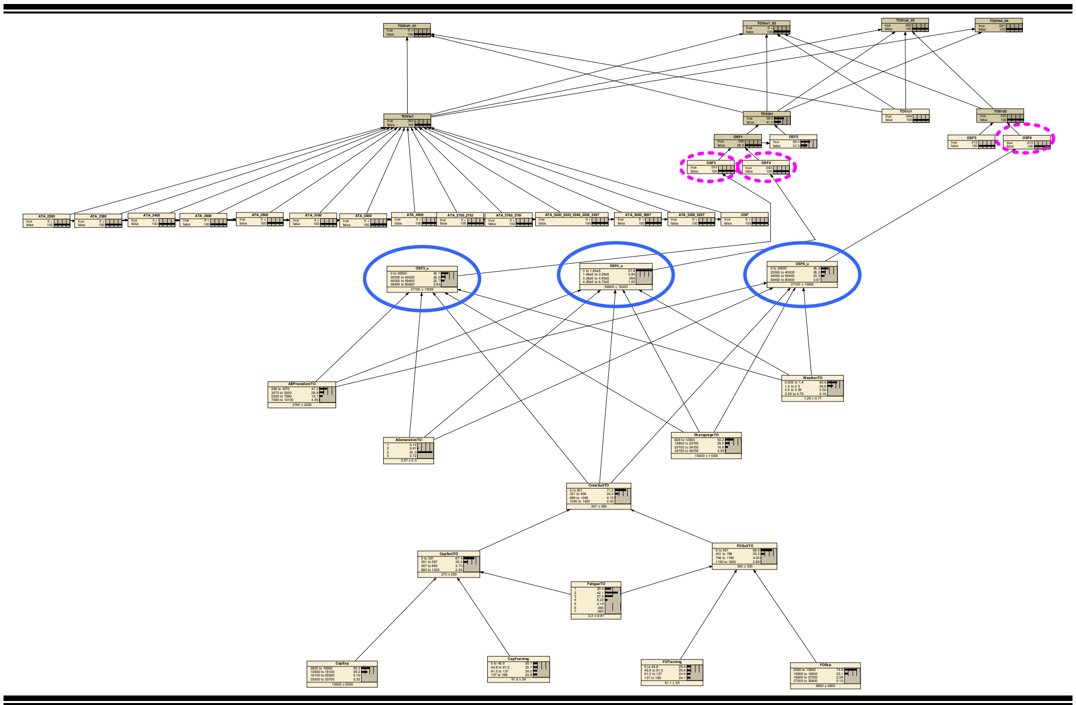

Figure 5. Representation of ESD 1 together with its Fault Tree and the Discretized Version of the Continuous BBN for Flight Crew Error Probability.

Continuous Node

Expectation as an estimate of the base event probability

Three nodes in ESD 1 represent Human failures:

TO01B2.1.1	Pilot Misdiagnoses (TO incorrectly rejected above V1)
TO01B2.1.2	Pilot Misjudgement (TO incorrectly rejected above V1)
TO01B3.3	Brakes not applied correctly

These events are circled in Figure 5. Since the probabilities of these human errors are present in the Take Off (TO) phase, one single instance of the flight crew error model is necessary to compute each base event in the FT[3]. Each one of the circled nodes in ESD 1 is a representation similar to the one presented in figure 4. In order to extend the model to each ESD in Figure A3, different instances of the Flight Crew Error Probability model are required for each flight phase.

[3] Recall that the base event in the FT is the Expectation of the continuous

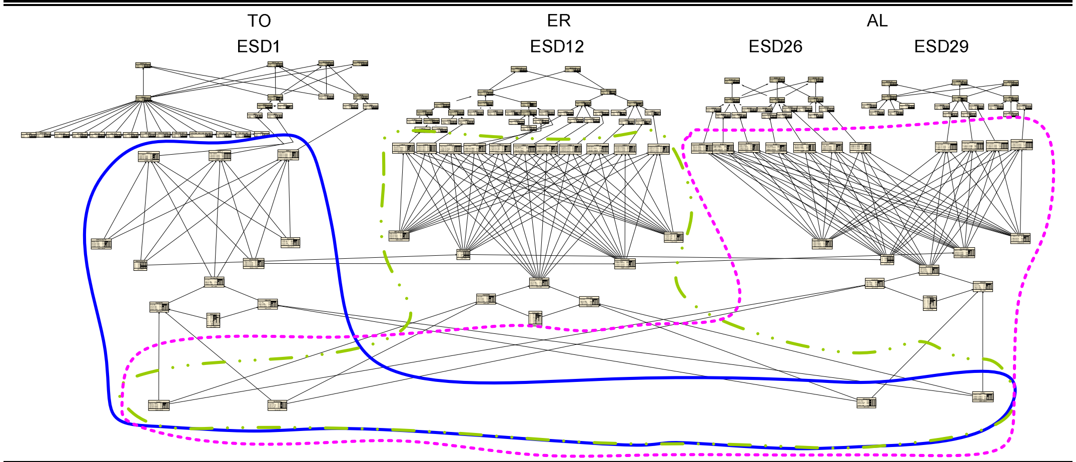

Figure 6. Representation of ESDs 1, 12, 26 and 29 Connected Through the Flight Crew Error Probability Model.

Flight Crew Error Probability during Take Off
Flight Crew Error Probability during en-route
Flight Crew Error Probability during Approach-Landing

4. Future work.

Future work from the EWI-TU Delft group includes:

1. Finalize the quantification of the BBN for flight crew error probability. This will be done in combination with NLR and with the cooperation of experts.
2. Support the construction of new models for other parts of the CATS 'back bone' model. The construction of a model for Air Traffic Controller human error has been initiated together with NLR and TBM-TU Delft and the quantification phase will start shortly.
3. Continue assembling the models in figure A3 as in Figure 6 to build a single Bayesian Network.
4. Continue enhancing the software tools for elicitation and construction of BBNs.

Further work to be performed as agreed on the technical meetings

Basic bibliography.

[1] Hanea A.M. et al., "*Hybrid Methods for Quantifying and Analyzing Bayesian Belief Nets*", Proceedings of the 2005 ENBIS5 Conference, 2005.

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[3] Cooke R.M. et. al, "*Report on Phase 1 Causal Modeling for Schiphol Airport*", in Causal Model for Air Transport Safety (CATS). Third Interim report. 4 February 2006. Risk Centre TU Delft.

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[7] Bobbio A. et. al, "*Improving the Analysis of Dependable Systems by Mapping fault trees into Bayesian Networks*", Reliability Engineering & System Safety 71 (2001), 249-260.

[8] Bedford T. & Cooke R.M. "*Mathematical Tools for Probabilistic Risk Analysis*" Cambridge University Press, 2001.

[9] Ale B.J.M. "*Causal Model for Air Transport Safety: Fifth Interim Report*" August 1 2006. Risk Centre TU Delft.

[10] Morales O. et. al, "*Report on Phase 4 Causal Modeling for Schiphol Airport*", in Causal Model for Air Transport Safety (CATS).

[11] Roelen A.L.C. et al., "*Quantification of Event Sequence Diagrams for Causal risk Model of Commercial Air Transport"* National Aerospace Laboratory, NLR-CR-2006-520.

Appendix 1. ESD1, its Fault Tree and its Corresponding BBN

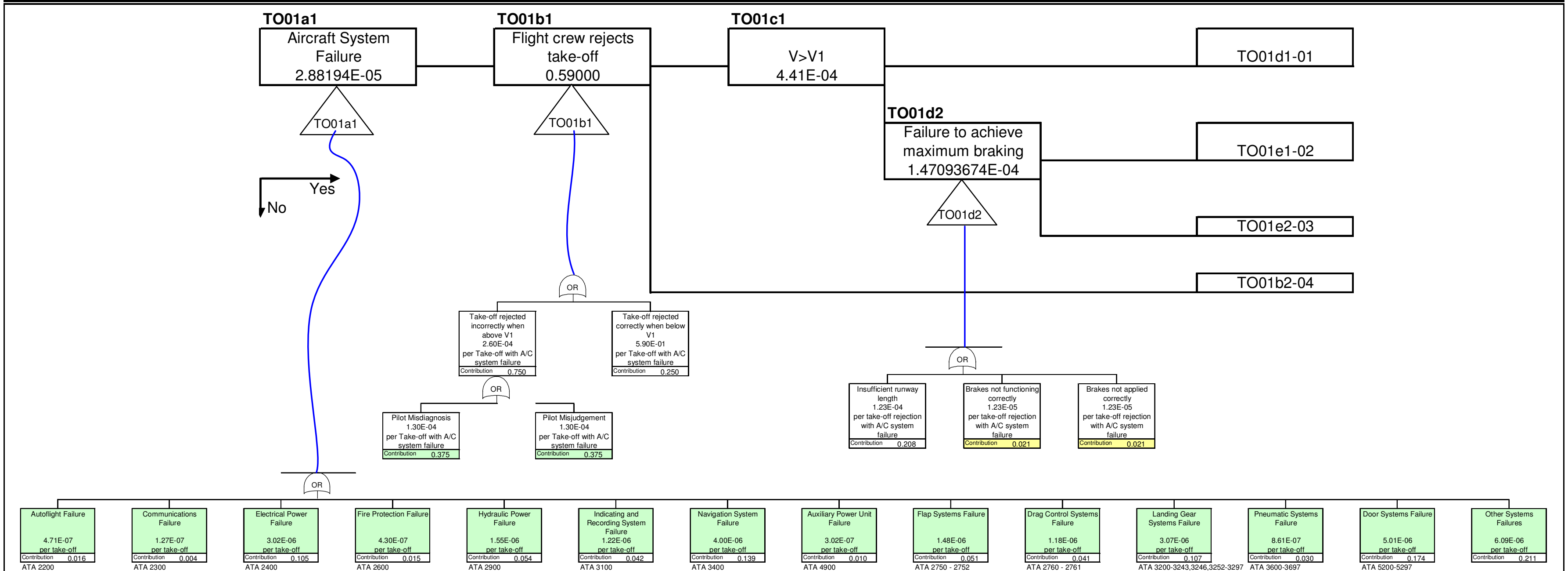

Figure A1. ESD1 and its Corresponding Fault Tree Representation.

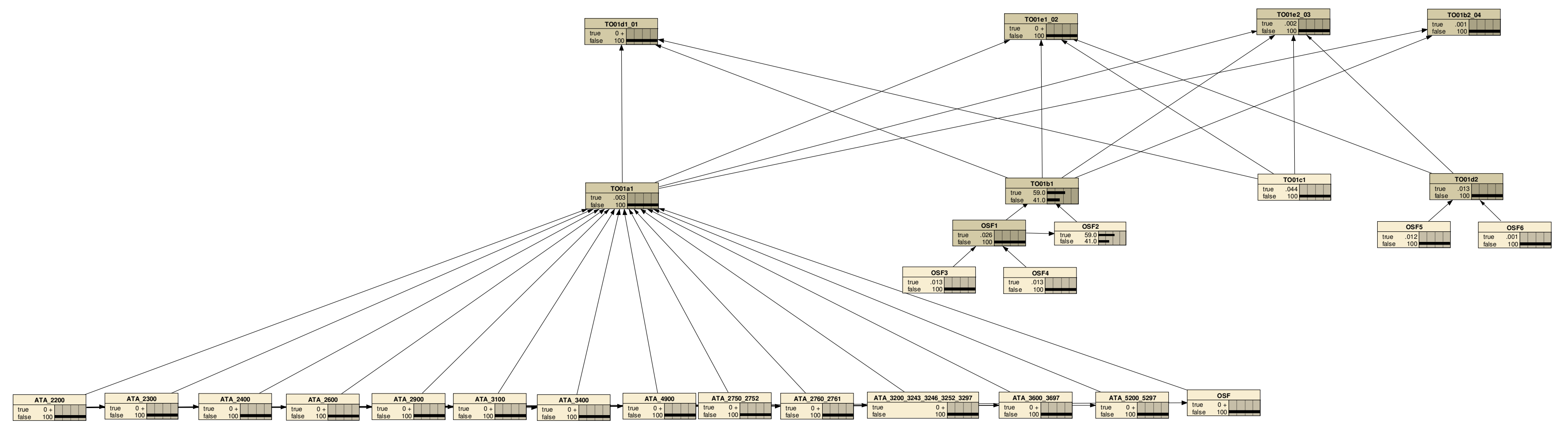

Figure A2. BBN representation of ESD1 (Figure A1).

Appendix 2. First Graphical Representation of the CATS Model as a Single BBN.

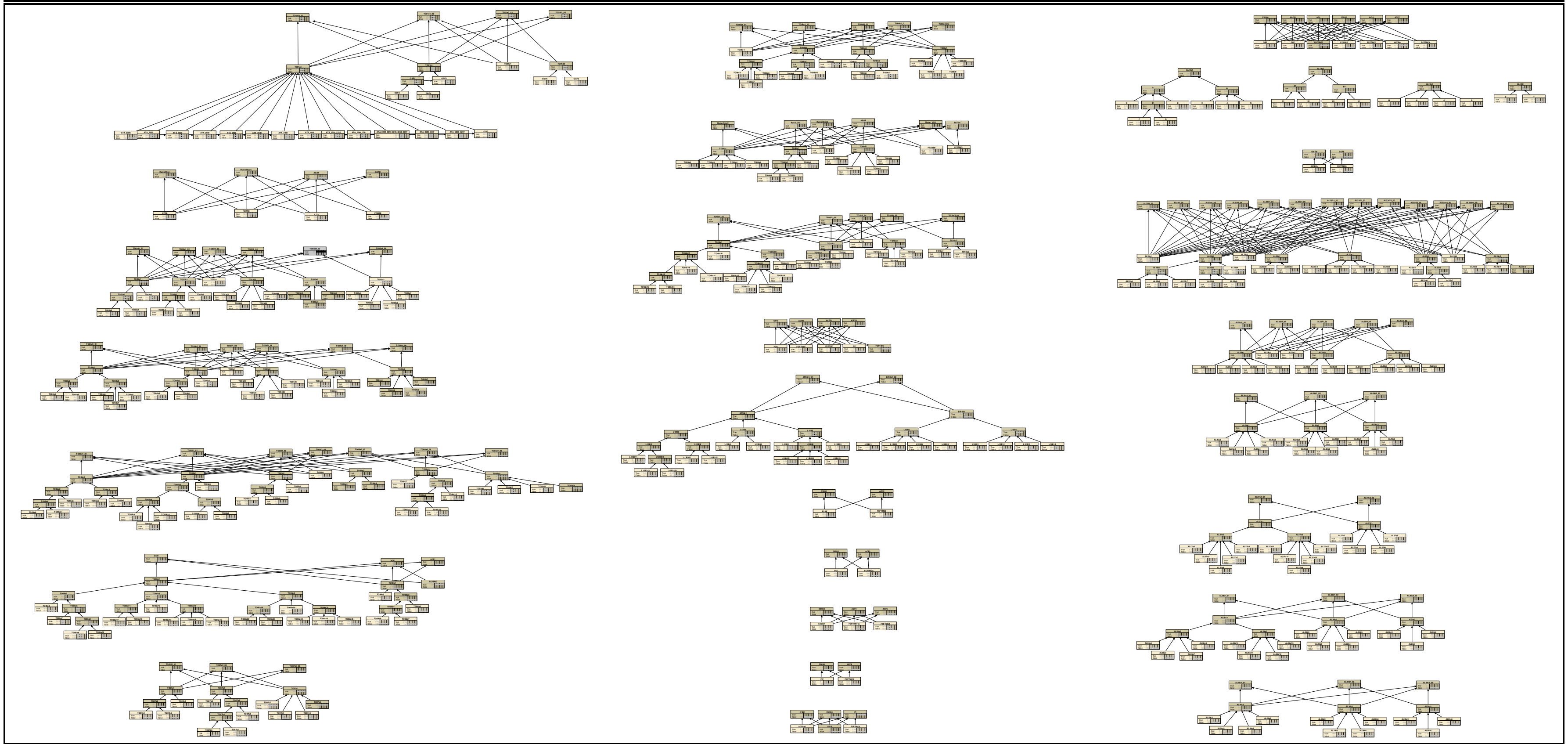

Figure A3. The CATS model represented as a Single BBN.

Appendix 3. Discrete Version of the Flight Crew Error Probability Model.

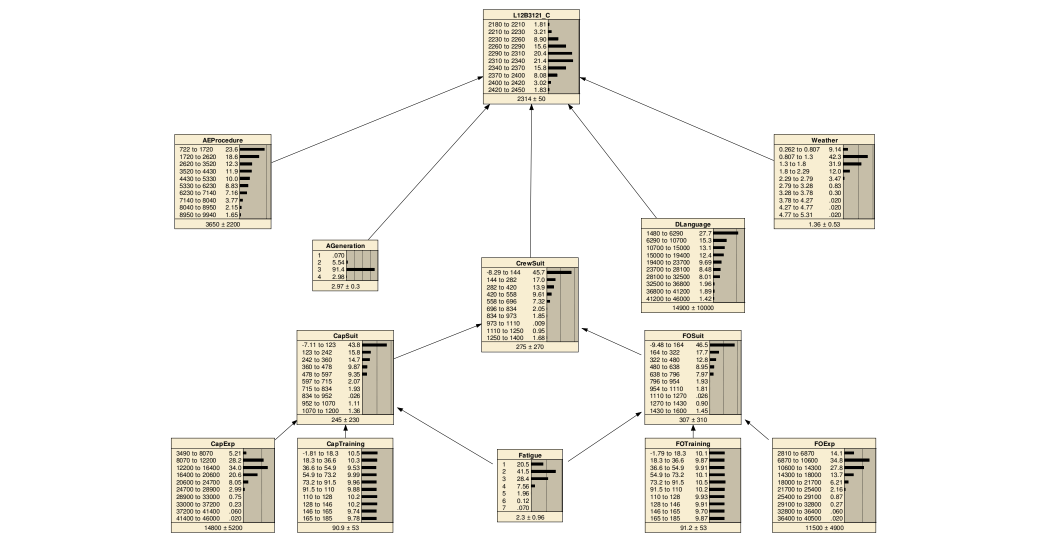

Figure A3. Discrete version of the Flight Crew Error Probability Model.