USING SIMULATION TO INCREASE TRAINING SYSTEM EFFECTIVENESS
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ABSTRACT The design of training systems is a complex process which has traditionally relied on experienced SMEs to estimate the resources which are required to support the system. In undertaking the design of the Air 9000 Phase 7, Helicopter Aircrew Training System (HATS), in support of the RotorSim Australia RFT response, CAE Professional Services has developed a generic training system model which can be used to support the design of training systems. This paper describes the model and how it can be used to support analysis of complex training systems.

The outcome of the application of the model to the design of the HATS has been:

1. A solution which optimises the course syllabi, business rules for operation of the school and resources required to operate the school to reduce overall cost of operation.
2. Quantitative data which supports verification by the Commonwealth and Rotorsim Australia team members that CAE has provided a compliant solution.

While the model has been developed to support the design of the training system it could also be used to support: capability acquisition and management of existing training systems.

1. INTRODUCTION
As part of establishing CAE Australia’s Training Systems Integration capability, a decision was made to develop the capability to undertake analysis of complex training systems. The technology to support analysis builds on the work previously undertaken for Hospital Surge Modelling [1] while the concepts for modelling of training systems extended those outlined by Robert Brownie [2]. In developing the capability CAE Australia was seeking to:

- Provide support to the improvement of existing training systems. The operation of existing training systems is frequently not well understood and the most effective approach to reacting to changes in operational requirements (requests for additional graduates or decreases instructor hours) is not well understood.
- Increase the analytical rigor applied in undertaking the design of new training systems.

Work was initially undertaken to support Air Lift Group in understanding how to most effectively increase the throughput for C130J operational conversion students. In undertaking the development of a model to support analysis, the goal was that it would be generic and could read in course information to represent any training system.

It is important to note that the model provides a measure of the effectiveness of resource utilisation not the effectiveness of the training outcomes delivered by the system.

2. SUPPORT TO THE TRAINING SYSTEM DESIGN PROCESS
CAE has teamed with AgustaWestland and BAE Systems to propose a solution for the Commonwealth’s Air 9000 Phase 7 requirement. In developing the solution for HATS, CAE is undertaking design of the curriculum and definition of the training resource requirements to support the school. As illustrated in Figure 1, the process for designing the curriculum is being undertaken in accordance with the Defence Training Model (ADFP 7.0.2) [3], Systems Approach to Training. The inputs to the design process are: the Commonwealth provided Training Needs Analysis, the design constraints in the Functional Performance Specification (FPS), the operational constraints in the Operational Concept Document (OCD) and knowledge provided by helicopter training Subject Matter Experts (SMEs).
CAE is designing the training system to meet the Commonwealth defined requirements identified in the FPS and OCD while minimising the cost of establishing and operating the HATS. Because of the complexity of operating the HATS, the optimal solution cannot be established through spreadsheet analysis but must be undertaken using a dynamic analysis of the school in operation. CAE has developed a training systems analysis model which facilitates the conduct of dynamic analysis resulting in an optimal balance of: school resources, the syllabus being executed for each of the courses, and the business rules for how the school will operate.

In undertaking analysis and design of the model the operational question which needs to be addressed is first defined. In the case of the HATS the question is:

“What are the resources which the HATS will require to reliably achieve the contracted Time To Training (TTT) and student throughput?”

In answering this question, a model is required which provides a representation of the operation of a school to a sufficient level of detail that the complexity of the interrelationship between the syllabus, business rules, resources and the different courses is captured. An example of a model which is frequently used is a spreadsheet which identifies the duration of events, the number of students and calculates the operating time required for each resource. This would not provide sufficient detail to capture the impact of business rules, such as limitations on student and instructor sortie numbers, on the TTT. In analysing this problem for a range of training systems, CAE has defined a representation training systems which allows operational questions to be addressed with confidence in the validity of the results.

The design of the syllabus, the business rules for operation of the HATS and the model used for analysis were refined over a number of iterations. The interaction between the analysis, syllabus design and analysis design is illustrated in Figure 44.

3. DESCRIPTION OF THE HATS
The HATS consists of the Undergraduate Training School and Holding Flight, to which some Naval pilots graduate prior to undertaking a type conversion. The courses which are provided by the HATS are:

- Army Pilot and Navy Pilot training
Army and Navy Aircrewman (including Navy SENSO) training
Navy Observer training

Instructor Training Wing (ITW) shares resources (aircraft and training devices) with the HATS and undertakes the training of pilot, aircrew and observer instructors. The relationship between the HATS and the organisations with which it shares resources is shown in Figure 45.

The FPS defines the students for each course and the intake interval which was entered into the training model as illustrated in Figure 46. The yearly course intake is:

- Three Army pilot training courses with 17, 16, and 16 students respectively
- Three Navy pilot training courses with 5 students.
- Three Navy observer training courses each with 5 students
- Three Army and Navy aircrew courses with 7 army and 4 navy, 8 army and 4 navy, and 7 army and 5 navy respectively

The analysis using the model is undertaken against three years of operation of the school (see Figure 47), with each year repeating the same schedule of courses and student loading.
4. DESCRIPTION OF THE MODEL

The representation of the HATS operation was developed using a discrete event simulation framework. The input to the model is the syllabus which captures all of the information for each training event, including: the duration of the event, the resources which are required to conduct the event and how long each resource is used for. The model executes the syllabus for each student scheduled on each course and records information on when the event occurred and the duration for which each resource is used. This data is then processed and analysed to understand the effectiveness of operation of the school.

The following paragraphs describe the operation of the models with reference the numbering in Figure 48.

1 Student Syllabus
The syllabus is the input for the model and contains information on the events and the order in which the events can be undertaken. The syllabus can either be executed sequentially, or events can have prerequisites. Prerequisites allow student to have a choice of events which can be undertaken, depending on whether the prerequisites have been met, and provide a more representative model of how the syllabus is likely to be executed by a student. The model captures both the HATS and ITW syllabi.

2 Current Event List
The current events list contains those events which can be executed, being the events for which the prerequisites have been completed. There is also a constraint on how far ahead of the most recently executed event the student can progress.

3 Prioritised Student Queue
Each of the students in the queue has a syllabus and list of Current Events which can be undertaken. The queue of students is ordered based on the relative progress which the students have made through their course, with the least advanced at the head of the queue and the most advanced at the rear. This is intended to stop students advancing too far ahead or falling too far behind their course mates, and reduces the delays when class room or other group events occur.

4 Event Checks
The student at the head of the queue undertakes checks to ascertain if he is able to undertake the next event in his current event list. The checks include self checks, availability of the required resources in the resource pool,
and whether there is sufficient time remaining in the day/night for the event to be completed. The checks include
daily and weekly limits on a range of simulator and live flying events as well as limits on hours worked,
simulator and live flying hours per week and per day. The are also minimum intervals between live flying events
and, simulator and live flying events. These checks are also applied to the instructors.

If the current event cannot be undertaken, the next event will be checked until either an event is undertaken or it
is found no event can be undertaken in which case the student returns to the queue. Priority is given to
undertaking group events to ensure that they are completed as soon as possible to ensure the student group is not
delayed.

While the impact of day-to-day weather effects on flying can be modelled, a simpler approach was taken to ease
analysis complexity.

5 Resource Pool
The resource pool includes all the resources which are being utilised by the school to execute training events,
excluding those which are not expected to impact operations, such as classrooms and debriefing rooms, although
these could easily be included. The resources for which analysis was undertaken are listed in Table 9 and there
were approximately 34 other resources which were either fixed or unconstrained modelled, examples of which
are listed in Table 10.

Table 1: Resources Analysed

<table>
<thead>
<tr>
<th>Resource Name</th>
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<tbody>
<tr>
<td>Simulator (FS)</td>
</tr>
<tr>
<td>Procedures Trainer (PT)</td>
</tr>
<tr>
<td>Aircraft (operational including ITW)</td>
</tr>
<tr>
<td>Pilot Instructor</td>
</tr>
<tr>
<td>Observer Instructor</td>
</tr>
<tr>
<td>Aircrewman Instructor</td>
</tr>
<tr>
<td>Ground Instructor</td>
</tr>
</tbody>
</table>

Table 2: Examples of Resources not Analysed

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aviation Training Vessel (ATV) Slots</td>
</tr>
<tr>
<td>Day Circuit Slots</td>
</tr>
<tr>
<td>Confined Area Slots</td>
</tr>
<tr>
<td>Low Flying Area Slots</td>
</tr>
<tr>
<td>HATS Hldg Flt - Pilot</td>
</tr>
<tr>
<td>NVG Set</td>
</tr>
</tbody>
</table>

Depending on the number of students from each course which are in the current shift, instructors are allocated
between night and day shift. This is reflected in the resource pool.
Many of the resources can support multiple aircraft at one time and are reflected in Table 10 as having “slots”. For example, the low flying area can support three aircraft, which could be one aircraft undertaking low flying, with two aircraft in the area.

6 Event Execution
The events are executed as specified in the syllabus. The types of events which can be specified include:

- Group events such as mass briefs and formation flights
- Events with multiple phases in which each phases uses a different resources, for example flying events which include briefing, flying and debriefing phases. For flying events the pre and post flight maintenance is modelled.
- Assessment events. With pass/failure and associated remedial activities.
- Self study, which requires no resources.

The time at which the event occurred and the duration for which each resource was utilised is recorded for further analysis.

At the completion of the event execution, the resources are released to the resource pool and the students are returned to the student queue and the process repeats itself until all the students have attempted to execute the current event list.

Once all students have attempted to execute their current event list, time is progressed and the students in the queue attempt to execute their current event list again.

1.1 ANALYSIS AND MODEL VALIDATION
The analysis of the operation of the HATS and development of the model was undertaken in seven iterations of increasing complexity, while the model validation was undertaken in conjunction with the analysis on the initial four iterations and subsequently when additional functionality was introduced. The model validation sought to answer the question as to whether the model was suitable for its intended use.

Analysis of operation of HATS and validation of the model were taken in three major steps:

1. Support to the design of single courses executing in isolation during which desktop review was undertaken to ensure:
   - The course as it was being designed could be expected to meet the TTT requirement.
   - The model provided an accurate representation of how the course would be executed within the school.
2. Support to the design of the business rules for the execution of multiple courses which would compete for resources. This included validation that the business rules as they were represented in the model resulted in an accurate representation of how the school would operate. The validation included walking through two weeks of operation of the school to ensure all events had occurred in an appropriate sequence and resources had been correctly employed.
3. Support to optimisation of overall system performance, primarily through harmonisation of the syllabus and resources to reduce the overall cost. This involved some modification of the business rules to improve the range of operational conditions which could be represented in the school.

5. DESCRIPTION OF THE ANALYSIS PRODUCTS
The primary Measure of Effectiveness (MOE) for operation of the HATS was Time-To-Time. Could the contracted TTT be achieved given the FPS specified student intakes, the CAE design syllabus, business rules for HATS operation and CAE proposed resourcing? In analysing the achievement of TTT a range of Measure of Performance (MOPs) were employed. The TTT was measured as an average and as a maximum across three years of operation of HATS, with the goal being that the average must be below the contracted TTT.

The MOPs were developed over the course of the analysis process to provide insight on how effectively resources were being employed. The MOPs included:

- Rate of progress of a course as captured in a student progress graph
- Utilisation in hours per day of all resources and students
- The causes of unproductive student time allocated to the resources or constraints which causes the poor productively.

The application of each of the MOPs in diagnosing a performance issue affecting the pilot course is discussed in the following paragraphs.
In a hypothetical situation the pilot training course is not achieving its overall TTT. Figure 49 illustrates pilot student progress over the course of three years. Each student has a separate coloured line while closely grouped lines represent courses of students. This is illustrated in the insert which magnifies the area highlighted area and shows the thick line is made up of individual lines.

The slope of a course line levelling off indicates resource contention which is a potential cause of the TTT not being achieved. In Figure 49 it can be seen that each course experiences a delay at approximately 150 hrs into the course. The insert shows that almost no progress is made by pilot intake 4 during that time. This is validated in Figure 50 which shows that there have been negligible hours worked by pilots on student intake 4 over the period 12 – 18/10.

The cause of this delay can then be analysed by looking at the causes of the students on pilot intake 4 being unproductive, which is shown in Figure 51. Unproductive time is measured by allocating time to the resources or constraints which are the causes of the student not being able to undertake an event. This is done for each student on the course, so for example; Figure 51 is shows that on 16/02 approximately 130 hrs were spent by students waiting for the PT to become available. Thus for pilot intake 4 over the period 12 – 18/10, all delays are attributable to the PT not being available.
The cause of the PT not being available to the students on pilot intake 4 can then be analysed by looking at how the PT was used for over the period, as illustrated in Figure 52. This shows that the primary reason that the PT was unavailable was that it was servicing the observer course. The reason that the observer course would be prioritised ahead of the pilot course is that they are behind in their course schedule and so are being prioritised ahead of other courses to enable them to meet their TTT goal.

Based on this analysis it would appear that improving that pilot intake 4 access to the PT is an option for improving the TTT. Figure 53 shows the causes of student unproductive time across the whole school and shows that the PT is the cause of 22% of student unproductive time across the operation of the school. This adds weight to the case that access to the PT should be addressed as it would be of benefit of operation of the whole school.

<table>
<thead>
<tr>
<th>Resource</th>
<th>Student unproductive hours</th>
<th>% of unproductive time</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS</td>
<td>19283</td>
<td>32.3</td>
</tr>
<tr>
<td>PT</td>
<td>13475</td>
<td>22.6</td>
</tr>
<tr>
<td>Work Day Limit</td>
<td>4902</td>
<td>8.2</td>
</tr>
<tr>
<td>Group</td>
<td>4673</td>
<td>7.8</td>
</tr>
<tr>
<td>Night Time</td>
<td>2255</td>
<td>3.7</td>
</tr>
<tr>
<td>Pilot Instr</td>
<td>2213</td>
<td>3.7</td>
</tr>
<tr>
<td>Aircrew Instr</td>
<td>1891</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Figure 11: Cause of Unproductive Student Time

The information on the causes of unproductive student time provides powerful insight on the bottlenecks in the training system. While the two most significant constraints are resources, the non resource causes include:

- **Group**: indicates that students had to wait for other students before they could form a group large enough for a particular event. For example, for a whole classroom activity, all the students in a course are required. Other examples are half classroom, four-ship formation and two-ship formation training events.
- **Night Time**: Because the night shift starts at 16:00, but it is not dark until 18:00, there are two hours when students cannot perform event which require darkness. If they do not have any other events (such as self study) to perform in those night modules, there will generally be delays.
- **Work day limit**: Indicates that the next event that the student was considering is too long to fit within the day and would take them over their word day hour limit. For example if they had completed 7 hours and their possible events were longer than one hour, they would exceed an 8 hour work day limit.

The Group cause of unproductive student time is of interest as pilot training in particular has traditionally used Mass Briefings to convey information to students. The initial syllabi which were developed resulted in 300% more unproductive time due to grouping than the final syllabus. To reduce the overhead of briefings, the number of briefings and their placement within the course was refined to reduce the delay which they caused.

Mass Briefings can result in a concertina effect as students are delayed while the group is being formed and then delayed following the mass briefing as they undertake events using a constrained resource. Using the model, the effect of Mass Briefings can be clearly understood.

6. **LESSONS LEARNT FROM DEVELOPMENT**

The development of a generic model of training school operation was a complex problem and the lessons learnt were predominantly in areas of analysis and process modelling. The two most interesting were:

- **It is important to plan the Data Analysis Requirements early in the process.** For each iteration of the analysis, the definition of the data required to undertake analysis was only undertaken once the model used to analysis was developed. This increased the complexity of the model development as the model was not designed to output the data, necessitating complex post processing to generate the required data.

- **A pipeline-Agent hybrid system may be more effective to model a complex training system than just a pipeline system alone.** The process modelling framework within which this model was implemented predominantly supports manufacturing and activities associated with manufacturing. Much of the complexity in developing the model was in implementing the business rules which ended up impacting many components. Implementing the model within a framework which supports agent based modelling would increase cohesion and reduce coupling, improving the overall supportability and maintainability. For example, all of the constraints for a student would exist within a student model rather than being spread across the components which “use” the student resulting in improved cohesion and reduced coupling.

7. **M ODES OF USE OF THE MODEL**

While the model was initially developed to support the design of a new training system, and ensure cost effective compliance it’s with contractual requirements, the model could also be applied to a range of other uses within the training system lifecycle. The other uses include:

- Support to defining capability requirements by allowing the Commonwealth to develop an appreciation for how requirements will impact cost and efficiency of the solution.

- Support to management of in-service operation of a school by providing the capability for medium – long term planning and the development of a clear appreciation of how where the bottlenecks are in operation and how they can be most effectively managed.

8. **C O NCLUSION**

CAE Australia has successfully demonstrated the application of process modelling to improving the design of an operational system. The modelling has provided the capability to “run” the system prior to it being implemented and allowed its performance to be optimized to meet particular requirements. In undertaking this process a deep appreciation of the operation of the system has been developed which allows the development of innovative solutions to operational challenges in the system.
REFERENCES

1. ADFP 7.0.2 "Defence Training Model"