Integration of Reliability, Availability and Maintainability Analysis and Operational Research Modelling – A Case Study

J. Bishop*, M. Niblett** and M. McCarthy***

*Sellafield Ltd., jacqueline.l.bishop@sellafieldsites.com
**ZUP Badura Ltd., External Consultants to Sellafield Ltd., mike.niblett@zupbadura.com
***Risk Based Decisions Ltd., External Consultants to Sellafield Ltd

Abstract. A facility on the Sellafield site is being designed which will receive waste from several of the site’s high hazard facilities during their decommissioning.

Sellafield Ltd. uses a process called T-RAM (Throughput – Reliability, Availability and Maintainability) to develop a reasoned auditable argument that a new plant, and its systems and subsystems, will meet its performance targets. T-RAM activity is focused on areas of the plant that represent the most T-RAM risk as determined through a top-down proactive approach to risk identification. Identified T-RAM risk is mitigated through improved design supported by the development of effective operations, maintenance and asset care strategies using techniques including Failure Mode Effects and Criticality Analysis (FMECA); Reliability Centered Maintenance (RCM) and Reliability Block Diagrams (RBD).

In order to underpin the “Throughput” capability of the facility, the Operational Research (OR) Group has developed a simulation model of the facility which has been used to feedback the expected throughput based on current best knowledge of plant configuration, equipment cycle times, reliability and maintainability data. This is an iterative process, with high risk bottleneck areas identified by the simulation model becoming the focus for T-RAM progressive risk reduction activities. The project is an excellent example of the OR and T-RAM teams working together to influence facility design.

1. Background

Sellafield Ltd is responsible for the safe and secure operation and clean-up of the Sellafield nuclear site. Focus is on the decommissioning of the two highest hazard facilities; the Magnox Swarf Storage Silo (MSSS) and First Generation Magnox Storage Pond (FGMSP).

MSSS is a 50 year old radioactive waste store on the Sellafield site, operational from 1964 until the final routine waste “tip” in 1992, Sellafield Ltd. (2015). The 22 compartment building now contains radioactive waste from the UK’s first generation Magnox power stations. FGMSP was operational for 26 years, processing around 27,000 tonnes of nuclear fuel, Sellafield Ltd. (2016). It now contains a mix of radioactive sludge waste and solid nuclear fuel.

A facility is being designed and built to receive and process waste from these, and other, high hazard legacy facilities to enable safe interim storage pending a final disposal route.

2. The T-RAM Process

T-RAM is a progressive and proactive process used within Sellafield Ltd. to identify and mitigate risks that would otherwise threaten the required performance of physical assets throughout their intended life. The focus of the analysis is to assure that asset(s) have sufficient capability (functional performance) and availability to contribute to the successful achievement of throughput requirements.

The asset being analysed could be something as small as a component or alternatively it could be a sub-system, a whole Plant Based System, a Facility or even a whole Value Stream – the question of whether assets are meeting their T-RAM requirements can effectively be asked at any level.

For example T-RAM can be applied to a major project to design and build a brand new processing facility to remediate waste from legacy ponds and silos, right through to a much more modest plant modification to replace the type of pump used on an existing plant. In the former case the T-RAM process will seek to progressively substantiate that the high level T-RAM requirements detailed in a Project Functional Specification can be achieved, whilst in the latter the T-RAM process may simply seek to verify that changing the pump will mean that local sub-system availability can be improved to meet performance targets. Of course, even in the case of the pump replacement the local piece of T-RAM analysis is effectively
carried out in the context of the bigger picture – i.e. how improving the T-RAM of the specific pump will contribute to improving the T-RAM of the facility in which the pump resides.

Regardless of the scope, the application of T-RAM can be considered through answering the following three basic questions:
1. What do the assets need to deliver?
2. What is the risk of them not delivering?
3. How can the risk of non-delivery be managed/mitigated to acceptable levels?

In the case of building a processing facility, question 1 starts with ensuring that all the high level requirements detailed within the Project Functional Specification (implicitly including T-RAM requirements) are suitably resolved and progressively disseminated down to areas/functions, systems and ultimately to sub-systems/components, where appropriate, as part of the project requirements management process.

The disseminated T-RAM requirements ensure that individual design teams are targeted on developing a design that will contribute to delivering overall facility throughput requirements (as well as meeting appropriate statutory or regulatory requirements). Verification that T-RAM requirements are being achieved is sought as early as possible within the project lifecycle i.e. commencing with design supported by further and progressive verification managed appropriately through purchasing (e.g. vendor requirements), manufacture (e.g. quality assurance), works testing/factory acceptance testing (e.g. functional performance, condition assessment/baselining, maintainability testing), construction and commissioning and into operations.

A range of methods and tools are deployed in a graded way to proactively identify T-RAM risks as early as possible and to provide insight into how they may be mitigated or eliminated in order to reduce performance risk to acceptable levels and progressively verify that project T-RAM requirements should be met. A fundamental and overarching tool that is used within Sellafield major projects to help achieve this is throughput modelling which may take the form of relatively simple spreadsheet based models early on in the project life cycle followed by the development of more complex discrete event simulation models as the design progresses.

In order to support timely completion of the processing facility, the various systems of design and associated procurement packages vary in terms of level of progression through the project lifecycle stages. For example, some packages of equipment have been procured and are undergoing construction whilst some systems are still in the latter stages of detailed design. Appropriate T-RAM analysis through the use of tools including FMECA, RBD, Support Options Analysis (SOA) and RCM are being employed in a timely manner on a system by system basis using a risk based graded approach taking account of Operational Experience from the use of similar assets both inside and outside of Sellafield. Where relevant the T-RAM analysis is now being augmented with Original Equipment Manufacturer (OEM) and vendor information through appropriate detailed design and procurement phases. As the maturity of equipment performance (e.g. cycle time), reliability and maintainability progresses the information is periodically updated within the project OR (Throughput) model to simulate and analyse the behavior of the plant both with equipment breakdowns disabled (to predict the demonstrable throughput) and with equipment breakdowns enabled (to predict the effective throughput). This includes the appropriate use of more specific bottleneck, sensitivity and scenario analysis to assist with the development of the remaining engineering design and associated support strategies - in support of the project T-RAM case.

3. The Processing Facility Operational Research Model

A discrete event simulation model of the processing facility has been developed by the Sellafield Operational Research (OR) Group. Its main function is to help prove or otherwise the ability of the facility to meet its design functional requirements and where gaps are identified to help target areas for improvement. The analysis includes an assessment of import, processing and export rates between the processing plant, its associated product store and its donor facilities. A schematic of the facility is shown in figure 1, and an illustration of the simulation in figure 2.
Figure 1. High Level Schematic of the Processing Facility

Figure 2. High Level View of the Processing Facility Simulation Model

The model inputs cover a wide range of data types, with over 500 parameters which can be adjusted to represent a vast range of scenarios. The data being used to drive the model is being progressively developed by the project T-RAM team using the methods described above. The model, together with simplified earlier model variants, has already been used to support project review milestones by providing progressive throughput analysis relating to the various waste streams that the facility is tasked with processing.

The following sections present specific (non-classified) examples of the type of analysis undertaken to help verify that the plant, as designed, should be capable of meeting its T-RAM requirements including specific scenario analysis to assess the impact of robot redundancy in one of the main processing areas and an improved means of recovery from a roadbay door failure.
3.1 FGMSP waste processing

The OR model has been used to predict whether the processing facility should be capable of supporting performance requirements for the import, processing and export to store of packages of waste received from the FGMSP waste stream. To achieve this, the model was run in a number of different modes and scenarios including:

- An unlimited number of waste packages made available to be imported to the model on demand
- A fixed and discrete daily schedule of waste packages presented to the model
- Scenarios both with equipment breakdowns enabled and breakdowns disabled
- Scenarios covering a credible range of process variations including effluent settling times and grout curing times (sensitivity analysis)

Key conclusions drawn from the analysis included:

- With baseline process cycle times the plant was not capable of consistently achieving the required daily throughput
- Despite this, a significant headroom in plant capacity was demonstrated against the foreseeable peak yearly processing requirements
- Sensitivity analysis demonstrated that a circa 30% reduction in grout curing times generated a 62-65% throughput performance increase
- By delivering waste packages to the model against a regular daily schedule and taking credit for reduced grout curing and effluent settling times allowed daily throughput requirements to be fully demonstrated

3.2 MSSS waste processing

A key requirement of the processing facility is to support the decommissioning of MSSS through timely receipt and processing of waste retrieved, packaged and dispatched from the MSSS facility. The inability of the facility to receive MSSS waste packages due to equipment unavailability, for example, can lead to the undesirable effect of constraining the MSSS retrievals process.

3.2.1 Robot Redundancy

The baseline design includes two robots to perform in-cell waste-processing duties, with a defined list of activities assigned to each robot. Due to the nature of the nuclear environment in which they reside, repair or replacement of either one of the robots in the event of failure requires significant recovery time (measured in days rather than hours) in order to remotely prepare, disconnect and remove the failed robot and then replace it with a spare one. Initial model analysis was performed assuming that upon failure of either robot all operations in the processing cell would stop until safe recovery and replacement could take place.

A change in MSSS waste processing requirements, to a simplified sequence of mainly automated processing steps, presented the opportunity for the robot sequences to be reconsidered in such a way that each robot, whilst configured slightly differently, could perform the required MSSS processing tasks single handedly. This presents the opportunity of leaving a failed robot in-situ whilst continuing MSSS processing with the other robot until a suitable planned or forced outage occurs to enable the failed robot to be replaced without directly impacting throughput. The potential benefits of adopting this pseudo duty/standby robot arrangement for processing the MSSS waste stream was configured and tested using the OR model by adjusting the baseline robot recovery and reinstatement time down to only 2 hours – to instead represent the anticipated time it would take to manipulate the failed robot into a safe (retracted) position and configure the second robot to take up the failed robot’s duties.
3.2.2 Roadbay Door Failure Mitigation

Vehicular (transporter) access to the plant is gained via two roadbay doors in the Waste Package Import Area (Figure 1) with one door designated for entry and the other for exit. Similar to the robots the baseline T-RAM analysis indicated potentially significant repair times in the event of roadbay door failure and baseline model analysis shows the doors failing during operation and therefore blocking a waiting transporter from either entering or leaving the facility.

Subsequent T-RAM analysis of the door design indicated that, in the event of the majority of failures, the doors could be manually operated or, for more significant failures, that vehicle entry/exit might still be possible via controlled use of the remaining operational door. To test the potential impact of these proposed operational workarounds using the model each of the two roadbay door repair times was adjusted down to 2 hours to represent the time it would take to implement a change in operational practice to enable continued transporter entry and exit from the facility. The intent being that repair of the failed door could be managed in an opportune and timely manner with little or no direct impact on throughput.

3.2.3 Model results

Table 1 below summarises the model output covering the two scenarios described in 3.2.1 and 3.2.2 above in terms of percentage improvement against baseline. Package rejection rate (i.e. percentage of package arrivals from MSSS which could not enter the processing facility in a timely fashion) was used as a measure of facility unavailability and associated extension impact on the MSSS retrievals programme.

<table>
<thead>
<tr>
<th>Scenario description</th>
<th>Percentage improvement against baseline package rejection rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline except with 2 hour repair times against each of the two robots (to represent changeover of duty rather than repair)</td>
<td>6.7%</td>
</tr>
<tr>
<td>Baseline except with 2 hour repair times on both robots (as above) plus 2 hour repair times on each of the two roadbay doors (to represent a change in operational practice rather than repair)</td>
<td>20%</td>
</tr>
</tbody>
</table>

The model results show that improvements to the operations and maintenance strategy of the robots and the roadbay doors combined could have a significant impact on plant availability and throughput (measured in terms of a 20% reduction in the percentage of packages rejected over baseline). The results also indicate that the roadbay door improvements contribute more than the robot changes. This is not unexpected as delays in transporter access to the plant because of erstwhile roadbay door unavailability would very quickly impact import rates. In contrast, the robots are located further along within the process enabling buffer positions and work in progress to act to reduce the impact of robot unavailability on facility import rates.

3.4 Distributed Simulation

The OR model was initially developed to provide an assessment of stand-alone facility performance across a number of waste feeds including but not limited to the MSSS waste stream. More recently the model has been further enhanced and dynamically linked to the MSSS facility discrete event simulation model using an innovative technique called Distributed Simulation. This allows the OR team to not only understand the
performance of individual facilities, but also how they interact with each other to provide the business with a Value Stream throughput assessment.

4. Conclusions and Next Steps

The OR model for the processing facility contributes an essential element of the developing T-RAM case in that it allows progressive assessment of throughput capability and scenario/sensitivity analysis as the project moves through its lifecycle stages from concept design, through preliminary and detailed design to procurement, installation and commissioning.

In addition to updating the model to more accurately reflect current design and agreed operational strategy the next phase of work using the OR model is to further improve understanding of the impact of key equipment repair times on package import rates (e.g. to identify the maximum repair times for key equipment which, if achieved, would have little or no impact on throughput). This will allow the T-RAM team to focus attention on key areas of the plant and optimise spares and maintenance strategy development activities to maximise package import availability in support of high hazard reduction within donor facilities such as MSSS and FGMSP.

References
Sellafield Ltd (2015) Sellafield Magazine: Issue 1. In Focus: Magnox Swarf Storage Silo,