Simulating R&D decision for critical subsystems in defence R&D projects

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Abstract

Purpose – The purpose of this paper is to study the effect of a critical subsystem development indigenously on the outcome of an Indian defence R&D project. Indigenous development of the critical subsystem requires the development of a number of technologies; hence the study is taken up for indigenously development of critical subsystem.

Design/methodology/approach – A simulation-based approach is used in this paper for studying the effect of indigenization decisions. A defence R&D project with the critical subsystems is modeled in Graphical Evolution and Review Technique (GERT) networks, and simulated in Arena simulation software using discrete event simulation model. The simulation model is thereafter experimented with decision options for the critical subsystem. Data were collected from the project management office (PMO) of short range homing guided missile (SRHGM) for this simulation study.

Findings – It has been found in this case that timely development of technology plays a key role in the Indian defence R&D projects. While indigenization of critical components reduces cost of development, the trade-off lies in much increased project development time. It is imperative that project teams should identify critical components early and work out appropriate strategies of indigenous development to avoid time overrun of the projects.

Research limitations/implications – The accuracy of results of the study could perhaps be affected on account of the extent of data forthcoming from the PMO. However, GERT framework presented in this paper is realistically derived from the practices used in the SRHGM project.

Originality/value – The study would help the project teams to identify critical subsystems early and work out appropriate strategies of indigenous development to avoid time overrun of the projects. This study would also make the project as well as the R&D teams aware of the causes for delays and cost overruns, and assist to deliver a product meeting end-user requirements.

Keywords Discrete event simulation, Make or buy, Defence project management, Graphical Evaluation and Review Technique (GERT), Indigenization

Paper type Research paper

1. Introduction

In India, defence R&D projects involve a complex network of activities due to the need of multiple technologies to be developed and the integration of these to get the desired system/product. For such an R&D project to succeed, multiple teams are employed within a matrix organizational structure by a defence R&D organization. The project is assigned to a project head and to relevant subsystem development teams, each having a technology head, who work together for carrying out the defined tasks. Meeting the requisite time and cost requirements within a limited budget allotted to the project, apart from fulfilling other

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performance requirements, is of very high importance for the successful delivery of the project to the end user.

Several past projects reveal that time and cost overruns in defence R&D projects occur due to some specific subsystems only. These subsystems are termed as critical subsystems and it is important to evaluate the indigenization decision options for such critical subsystems with respect to time and cost considerations.

A simulation-based approach is presented in this paper for making such indigenization decisions. The defence R&D project with the critical subsystems is modeled in Graphical Evolution and Review Technique (GERT) networks. The GERT model is converted to an Arena discrete event simulation model. The simulation model is thereafter experimented with indigenous decision options for the critical subsystem. The simulation results help in evaluating the indigenous decision options for the critical subsystem.

The rest of the paper is organized as follows – Section 2 gives the characteristics of defence R&D projects, Section 3 focuses on the indigenization decision options, Section 4 discusses on GERT modeling and discrete event simulation using ARENA, Section 5 illustrates the GERT model, Data analysis and results are given in Section 6, and Section 7 gives the conclusion and future scope of work.

2. Characteristics of defence R&D projects

Defence R&D projects are complex systems since they include a large amount of interrelated research activities with both simple and complex precedence relationships. The complexity in such projects is often due to the high part count (order of hundreds to thousands), an inherent characteristic of the defence projects. Within the defence R&D projects, as most of the research activities are carried out for the first time, it is not possible to estimate a specific time span and cost for their completion. Delays and lack of achieving breakthroughs in the research activities also adds to the uncertainty. Due to such inherent uncertainties, the estimation of the time and cost parameters becomes difficult in the defence R&D projects (Pal and Selvamurthy, 2008).

Early estimates of important parameters are usually quite inaccurate in two respects. First, such estimates are often based on over optimism. Second, apart from the bias, the errors in estimates show a substantial variation. That is, even if estimates are multiplied by an appropriate standard factor to eliminate the bias, a significant source of error may still remain. The accuracy of the estimates is a function of the stage of development, i.e., estimates improve as development of the item progresses. This also means that estimates for development projects representing only "modest advances" tend to be better than those for more ambitious projects.

Apart from the above encountered challenges, defence R&D organizations in India also has to face issues such as constant public scrutiny of such projects, strong competition from international suppliers, stiff acceptability benchmarks set by the users, natural tendency of the user to buy off-the-shelf products rather than support indigenous R&D, recent trend towards entering into transfer of technology arrangements with overseas R&D and production establishments, and manpower attrition. In addition, there are R&D project challenges such as complexity in technology transfer, lack of testing and other infrastructure facilities, compulsion to achieve best of broachers claims, lack of interaction among university-R&D laboratory-production agency, and non-assured order quality discouraging the vendor participation in R&D.

There are also traditional project management problems, such as lack of realistic estimates of activity times, tendency of not starting the task until it becomes critical (Student's syndrome), delaying (or pacing) completion of the task (Parkinson's Law), and cherry picking of tasks. Technology heads working on a particular component research project naturally resist reporting any early completion. Since if an early completion is reported, the estimate for the task is recognized as too long and increased pressure will be placed on the technology head to accept a shorter estimate next time. The risk is that a shorter estimate will not offer sufficient buffer to the project should a problem occur. Hence, the technology heads often ensure that sufficient buffer is always embedded in each task estimate and the entire buffer is usually in execution of the task. Hence, there is little incentive to complete the activity earlier than the projected time.

While assigning the subsystem development to technical teams, the following considerations apply:

(1) the research capabilities of different subsystems development teams within the organization like those for aerodynamics, structures, control and guidance, propulsion, electronics and system integration;

(2) previous performance of the development teams;

(3) the precedence relationship of a particular research activity since it will define the time when to carry out the subsequent research;

(4) alternate strategies for obtaining the subsystem/component or technology like buying out, subcontracting, transfer of technology and in-house R&D;

(5) preoccupation of some teams with any other project requirements; and

(6) project deadline, exceeding which the project group may incur heavy penalty.

If goals of the project head and the subsystem development technology heads are not aligned, additional difficulty of managing research projects arises in this multi-project environment.

3. Indigenization decisions in defence R&D Projects

Integrated Guided Missile Development Program (IGMDP) of India started in mid-1980s. Under IGMDP, several key critical technologies like seeker technology, phase shifters technology, servo valves gyroscopes and accelerators technology, magnesium alloy, gyroscopes and accelerators for various IGMDP projects were not part of the technology transfer (Wikipedia, 2015). These technologies, subsystems, components and materials were developed indigenously through well-coordinated collaboration among academic institutions, R&D organizations, public, private sector industries and user services (Pillai *et al.*, 1997, 2002; Pillai and Rao, 2000).

Mission critical and technologically complex subsystems in defence R&D projects have been studied in respect of indigenization and decision options thereof. In this paper, we have focused on the electro-optical target tracking system (EOTTS). It was learnt that sizable amount of time, funds and resources were used up towards deciding on which of the three options namely R-F based, day-version electro-optical and day-night version electro-optical of target tracking system (TTS) will be adopted. EOTTS was best viable in terms of ensuring project timelines, availability of relevant resources and technologies and finally acceptability from end user.

For all three types of TTS, the decision option in favor of indigenization *vis-à-vis* collaborative development or direct buyout was made easy since these systems or related technologies were outright denied to India in the early part of the project. It was only after the development of successful R&D in EOTTS, offers for collaboration and sales started getting received from established overseas design houses. Similarly, offers came in for performance improvement sales for another mission-critical subsystem that is tandem warhead (part of which was required to be located in the EOTTS section of the short range homing guided missile (SRHGM)) after its successful development indigenously.

With regard to indigenization of EOTTS itself it was observed that a decision option could perhaps have been taken for at least one more alternate of R&D within the country, e.g. at an academic institute or a R&D capable agency in the public or private sector. This might have saved precious R&D time, increased the possibilities of better performance and ensured easier and faster graduation to productionization from R&D. Of course enhanced funding and empowerment to the R&D laboratory and the Project lead would also be needed for this. This is also a factor in simulating indigenization decision.

Another issue in this regard is the necessity of earnest involvement of all stakeholders, specifically the end user and the production partners throughout the R&D exercise. One should also be aware of to what extent can the end user accept the performance parameters of the product developed, and what support can the identified production agency extend during initial small-scale production.

4. GERT modeling and discrete event simulation using ARENA

GERT is one of the network analysis techniques used in project management. It allows probabilistic treatment of both network logic and estimation of activity duration which other network analysis techniques do not have capability (Pritsker, 1966; Pritsker, 1966; Pritsker and Whitehouse, 1966). GERT is used in complex network systems as compared to other techniques such as PERT and CPM. GERT can take up "Inclusive-OR" logic (substitution relationships), "AND" logic, probability of R&D success and R&D time for a target technology. Hence, GERT is better suited for evaluating R&D projects having uncertainties in time, cost and technology maturity.

GERT allows looping between tasks. GERT addresses the majority of the limitations associated with PERT and CPM techniques. The only fundamental drawback associated with the GERT technique is the complex simulation required to model the GERT network system (Elmaghraby, 1968, 1977). GERT network modeling with its capability to include probabilistic branching and network looping, provides an ideal framework for modeling real-world research and development projects since they generally do involve false-starts, redoing many activities, and multiple outcomes, i.e., success or failure (Taylor and Moore, 1980). GERT has been revised and considerably extended. Its most recent version is GERT III Z and specialized versions include Q-GERT, for analyzing queuing and logistic problems, and P-GERT, for project planning using precedence networks (Wiest and Levy, 1979). Hence, GERT is the right project network analysis technique for R&D projects where events are probabilistic and lot of reworks of events exists.

The GERT method has been used in various fields due to its applicability and adaptability to a gamut of complex systems. Taylor and Moore (1977) conducted a simulation study on multi-team, multi-project Research and Development Planning with GERT and also in a paper (Taylor and Moore, 1980) studied two cases of R&D project planning using Q-GERT Network modeling and simulation. The first case considers a series of R&D projects analyzed sequentially by a single R&D team, while the second case involves a series of R&D projects analyzed sequentially and concurrently by two teams. Their focus is the individual component development projects as compared to this paper which focuses on the overall defence R&D project and component development projects are just parts of it. Dawson and Dawson (1998) proposed project management tools for managing uncertainty and risk in project planning.

Discrete event simulation describes a process with a set of distinctive and explicit events in time. Discrete event simulation allows to quickly analyze a process or system's behavior over time, inquire "why" or "what if" questions, and design or change processes or systems without any resource implications. These flexible, activity-based models can be successfully used to simulate almost any process. Discrete event modeling is the process of representing the behavior of an intricate system as a series of well-defined and ordered events and works well in practically any process where there is variability, constrained or limited resources or complex system interactions.

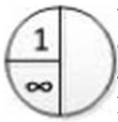
Arena simulation software professional edition 14.50.0 version is used for GERT modeling of SRHGM project. Arena is user-friendly windows based commercially available discrete event simulation software from Rockwell Automation, USA. Arena simulation software has also got capability of 2D and 3D animation to visualize results. Arena simulation software uses simulation language SIMAN (SIMulation ANalysis) to execute the model. Users need not to interact directly with the SIMAN code, but Arena translates the user's actions into SIMAN code. It uses stochastic systems to generate random-number. The output of the simulation is an estimate of the true system behavior. simulation software uses Flowchart modeling methodology which includes a large library of pre-defined building blocks to model your process without the need for custom programming Arena simulation software has complete range of statistical distribution options to accurately model process variability. Multiple simulation runs are required to determine a sample of system behavior, so a confidence interval is used to describe the output results Kelton *et al.* (2014).

5. Description of the model

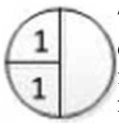
Product breakdown structure of SRHGM is given in Figure 1. The activities of SRHGM are tabulated in Table I. A detailed GERT Network diagram of "SRHGM" is constructed from Table I. All data are gathered from project management office (PMO) of "SRHGM." The complete SRHGM is broken down into six sections. The R&D of these six sections was carried out by six different technology teams concurrently.

After the completion of design, development and successful testing of each section; all the sections are assembled, tested and launch to know whether all the specified objectives are met or not. Once, all the objectives are met, the project is called complete and ready for production.

The following GERT node types are used in network model:



The first nodal release will occur when there have been 1 incident activity completions. Subsequent releases require ∞ completions, i.e., the node is activated only once in its life. This node is used for the activities which are performed only once during the project lifecycle.



The first nodal release will occur when there have been 1 incident activity completions. Subsequent releases require 1completion, i.e., activated for every incident activity completion. This node is used in the cases where an activity may be repeated a number of times

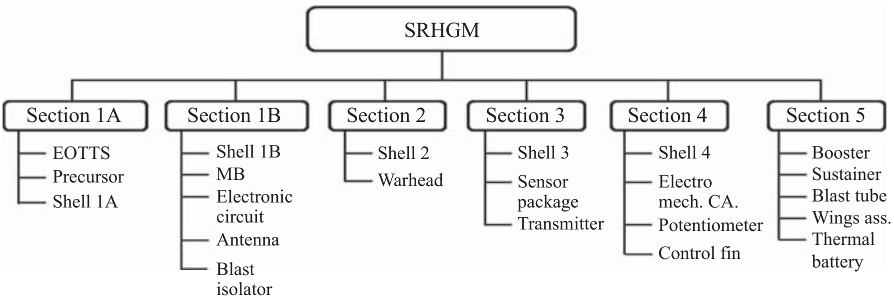


Figure 1.
Product breakdown structure of SRHGM

Table I. Defence R&D project activity times

Subsystem	Preliminary design time in days Before PDR O-M-P* (success rate %)	Preliminary design time in days After PDR O-M-P (success rate %)	Detailed design time in days Before CDR O-M-P (success rate %)	Detailed design time in days After CDR O-M-P (success rate %)	Development time in days O-M-P (success rate %)	Assembly time in days O-M-P	Testing time in days O-M-P (success rate %)	Redevelopment time in days O-M-P (success rate %)
Section 1A								
Subsystem 1A.1 (EOTTS)	170-175-185 (30)	25-27-30 (100)	710-715-720 (70)	40-42-45 (100)	1070-1075-1080 (80)	20-22-25	3-4-5 (85)	80-85-90 (100)
Subsystem 1A.2 (precursor warhead PDR)	25-27-30 (75)	3-4-5 (100)	325-328-330 (90)	12-15-20 (100)	710-715-720 (95)	3-4-5	0.5-1-1.5 (100)	50-55-60 (100)
Subsystem 1A.3 (shell section 1A)	25-28-30 (75)	3-4-5 (100)	55-58-60 (90)	10-12.5-15 (100)	175-178-180 (98)		3-4-5 (100)	25-27-30 (100)
Section 1B								
Section 1B.1 (shell 1B)	25-28-30 (70)	3-4-5 (100)	55-58-60 (85)	5-7-10 (100)	175-178-180 (90)		3-4-5 (95)	25-27-30 (100)
Section 1B.2 (MB)	85-87-90 (60)	3-4-5 (100)	205-207-210 (85)	5-8-10 (100)	535-538-540 (90)	3-4-5	1-2-3 (90)	30-32-35 (100)
Section 1B.3 (electronic circuit)	25-28-30 (75)	5-6-7 (100)	325-328-330 (90)	5-7-10 (100)	710-715-720 (95)	4-5-6	1-2-3 (100)	30-32-35 (100)
Section 1B.4 (antenna)	28-29-30 (75)	3-4-5 (100)	55-58-60 (90)	5-6-7 (100)	178-179-180 (95)	0.5-1.0-1.5	1.5-2-3 (100)	10-12.5-15 (100)
Section 1B.5 (blast Isolator)	5-6-7 (70)	0.5-1.0-1.5 (100)	13-14-15 (90)	3-4-5 (100)	85-88-90 (95)		3-4-5 (100)	7-8-9 (100)
Section 2								
Section 2.1 (shell 2)	25-27.5-30 (75)	3-4-5 (100)	55-57.5-60 (90)	5-6-7 (100)	170-175-180 (98)	25-27.5-30	2-3-4 (100)	20-25-30 (100)
Section 2.2 (warhead)	88-90-92 (60)	3-5-7 (100)	448-450-452 (70)	14-15-16 (100)	535-540-545 (95)		3-5-7 (100)	25-30-35 (100)
Section 3								
Section 3.1 (shell 3)	25-30-35 (70)	4-5-6 (100)	40-45-50 (85)	7-10-12 (100)	175-180-185 (90)		1-2-3 (100)	30-35-40 (100)
Section 3.2 (sensor package)	28-30-32 (60)	5-7-10 (100)	145-150-155 (75)	8-10-12 (100)	175-180-185 (90)	3-4-5	1-1.5-2 (100)	25-27.5-30 (100)
Section 3.3 (transmitter)	25-27.5-30 (65)	3-5-7 (100)	55-60-65 (85)	10-8-12 (100)	235-240-245 (95)	5-6-7	1.5-3-4.5 (100)	30-35-40 (100)
Section 4								
Section 4.1 (shell 4)	25-30-35 (75)	3-5-7 (100)	38-40-42(85) (85)	8-10-12 (100)	175-180-85 (98)		3-4-5 (100)	23-25-27 (100)
Section 4.2 (electro mechanical control actuation)	88-90-92 (60)	4-5-6 (100)	265-270-75 (75)	20-25-30 (100)	535-540-545 (90)	3-5-7	1.5-2-2.5 (100)	55-60-65 (100)

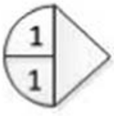
(*continued*)

Table I.

Subsystem	Preliminary design time in days Before PDR O-M-P* (success rate %)	Preliminary design time in days After PDR O-M-P (success rate %)	Detailed design time in days Before CDR O-M-P (success rate %)	Detailed design time in days After CDR O-M-P (success rate %)	Development time in days O-M-P (success rate %)	Assembly time in days O-M-P	Testing time in days O-M-P (success rate %)	Redevelopment time in days O-M-P (success rate %)
Section 4.3 (potentiometer assembly)	30-35-40 (75)	3-5-7 (100)	328-330-332 (90)	25-27.5-30 (100)	505-510-515 (98)	3-4-5	2-3-4 (100)	35-40-45 (100)
Section 4.4 (control Fin assembly)	43-45-47 (50)	3-4-5 (100)	175-180-185 (70)	8-10-12 (100)	410-415-420 (90)	3-4-5	1.5-2-2.5 (100)	20-25-30 (100)
Section 5								
Section 5.1 (booster motor)	22-25-28 (60)	3-5-7 (100)	145-150-155 (75)	20-25-30 (100)	345-350-355 (80)	3-4-5	2-3-4 (100)	28-30-32 (100)
Section 5.2 (sustainer)	20-25-30 (65)	3-5-7 (100)	85-90-95 (75)	19-20-21 (100)	235-240-245 (85)	3-4-5	1.5-2-2.5 (100)	23-25-27 (100)
Section 5.3 (blast tube)	14-15-16 (75)	1.5-2-3 (100)	38-40-42 (90)	4-5-6 (100)	85-90-95 (90)	1.5-2-2.5	0.5-1-1.5 (100)	10-12.5-15 (100)
Section 5.3 (wings assembly)	28-30-32 (50)	4-5-6 (100)	118-120-122 (75)	28-30-32 (100)	255-260-265 (90)	3-5-7	1.5-2-2.5 (100)	23-25-27 (100)
Section 5.4 (thermal battery)	22-25-28 (60)	3-4-5 (100)	50-55-60 (80)	4-6-5 (100)	175-180-185 (98)	3-4-5	1.5-2-2.5 (100)	10-12.5-15 (100)
	Preliminary design time				Development time		Assembly and testing time	Procurement time
EOTTS (abroad)	175-180-185	–	–	–	360-365-370	–	90-95-100	180-185-190

Notes: O, optimistic; M, most likely; P, pessimistic

The first nodal release will occur when there have been 2 different incident activity completions. Subsequent releases require ∞ such completions. This node is used to represent the Assembly Activities.



The first nodal release will occur when there have been 1 incident activity completions. Subsequent releases require 1 completions but the output in this case is probabilistic. This node is used to denote the testing activities which can either fail or pass.

In Figure 2, the node S0 represent the start of the project and similarly nodes S1A, S1B, S2, S3, S4 and S5 represent the start of the development of Section 1A, Section 1B, Section 2, Section 3, Section 4 and Section 5, respectively. The nodes 1A.1, 1A.2 and 1A.3 constitutes the research and development of parts within the Section 1A of the product. Same holds for the other nodes 1B.1 – 1B.5, 2.1 – 2.2, 3.1 – 3.3, 4.1 – 4.4 and 5.1 – 5.5 which constitute the Section 1B, Section 2, Section 3, Section 4 and Section 5, respectively. The nodes A0, R0, T0 and F0 represent the Assembly, Rework and Testing of the Complete Product Prototype.

Following assumptions are made in the GERT model:

- only the decision in respect of a single critical component is considered;
- there is no delay in the starting of the activity (activities may start at the same time);
- working hours is 8 hours per day with average 245 days of working in a year; and
- triangular distribution is considered for time and cost estimation.

Models are simulated in professional software edition of Arena simulation software. Project activity duration time and subsystems costs are used for simulation are given in Tables I and II, respectively. The development process as shown above is followed for each of the component which is to be developed in-house. However, only a single critical component Part 1.1, i.e. EOTTS and study its effect on the defence R&D project is considered.

6. Data analysis and results

The Arena models for the defence R&D project with indigenous and overseas EOTTS are simulated individually to gather the data which are compared. The simulation is run both

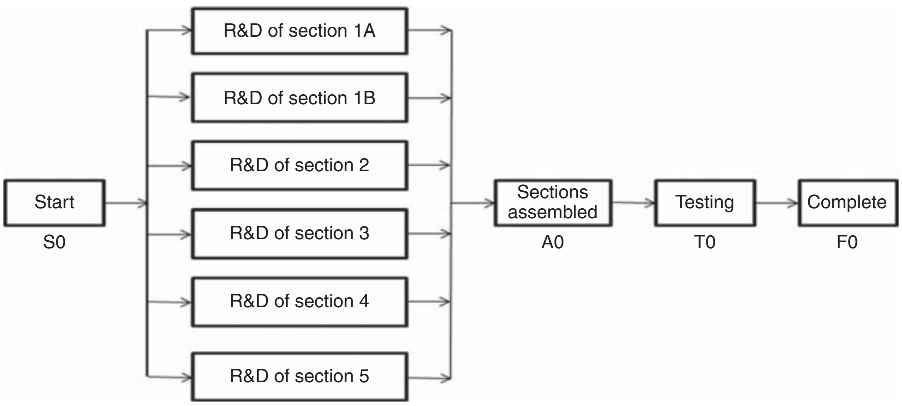


Figure 2.
GERT Network model of defence R&D project

Table II.
Defence R&D project cost estimates (in Lacs rupees)

Sections	Subsystems	Optimistic cost	Most likely cost	Pessimistic cost
Section 1A	EOTTS	33.4	33.5	33.6
	Precursor	0.45	0.5	0.55
	Shell 1A	0.19	0.2	0.21
Section 1B	Shell 1B	0.24	0.25	0.26
	MB assembly	0.49	0.5	0.51
	Electronics assembly	0.34	0.35	0.36
	Antenna	0.19	0.2	0.21
	Blast isolator	0.39	0.4	0.41
Section 2	Shell 2	0.19	0.2	0.21
	Warhead	1.2	1.3	1.4
Section 3	Shell 3	0.19	0.2	0.21
	Sensor package	13.5	14.0	14.5
	Transmitter	0.9	1.0	1.1
Section 4	Shell 4	0.24	0.25	0.26
	Electro mech control actuator	2.4	2.5	2.6
	Potentiometer assembly	0.19	0.2	0.21
	Control fin assembly	0.95	1.0	1.05
Section 5	Booster motor	2.0	2.5	3.0
	Sustainer	2.0	2.25	2.50
	Blast tube	0.45	0.5	0.55
	Wings assembly	0.95	1.0	1.05
	Thermal battery	0.45	0.5	0.55
Section 1A	EOTTS (overseas)	39.5	40.0	40.5

for time and cost separately. Figure 3 also shows GERT network diagram of the Section 1A with critical path in dark line. Arena model of Section 1A is also given in Figure A2 of Appendix 1.

It can be seen that the critical component considered, i.e., node 1.1 is a part of the critical path. After the components 1.1, 1.2 and 1.3 are developed, Section 1A assembly is carried out and comprehensive testing done. It is seen that in this replication the testing fails and some rework has to be performed. If test results are satisfactory Section 1A is assembled with other sections such as Section 1B, Section 2, Section 3, Section 4 and Section 5. It was seen that the redefinition for the problem was carried out as per Table I in this replication due to multiple rework. After the research activity is successfully completed, subsequent activities are carried out. The prototype development again was carried out because of rework. Once, the prototype is made; the integrated subsystem comprehensively evaluated. Critical path was found after simulation run is S0→S1A→1A.1A→1A.1B→1A.1C→1A.1D→1A.1E→1A.1F→1A.1G→ A1A→T1A→A0→T0→F0 that is R&D of EOTTS. Critical path was constructed using Figures 2 and 3, respectively.

The results of the simulation run are presented in the below figures and tables. Table III shows the minimum, average and maximum values for the defence R&D project completion time and cost as well as the time and cost for the critical component EOTTS development project. Hundred replications run are performed for simulation of each case to get consistent results. The results for the below simulation runs are presented in Figure 4 and Tables III and IV, respectively. SRHGM development time with indigenous and overseas EOTTS is shown in Figure 4.

The average time taken with project with indigenous EOTTS takes 2,045.39 days as compare to 1,105.39 days for project with overseas EOTTS, respectively. The development of SRHGM project with indigenous EOTTS is very much required because of indigenous development of EOTTS is crucial for SRHGM as this technology is denied by overseas design houses.

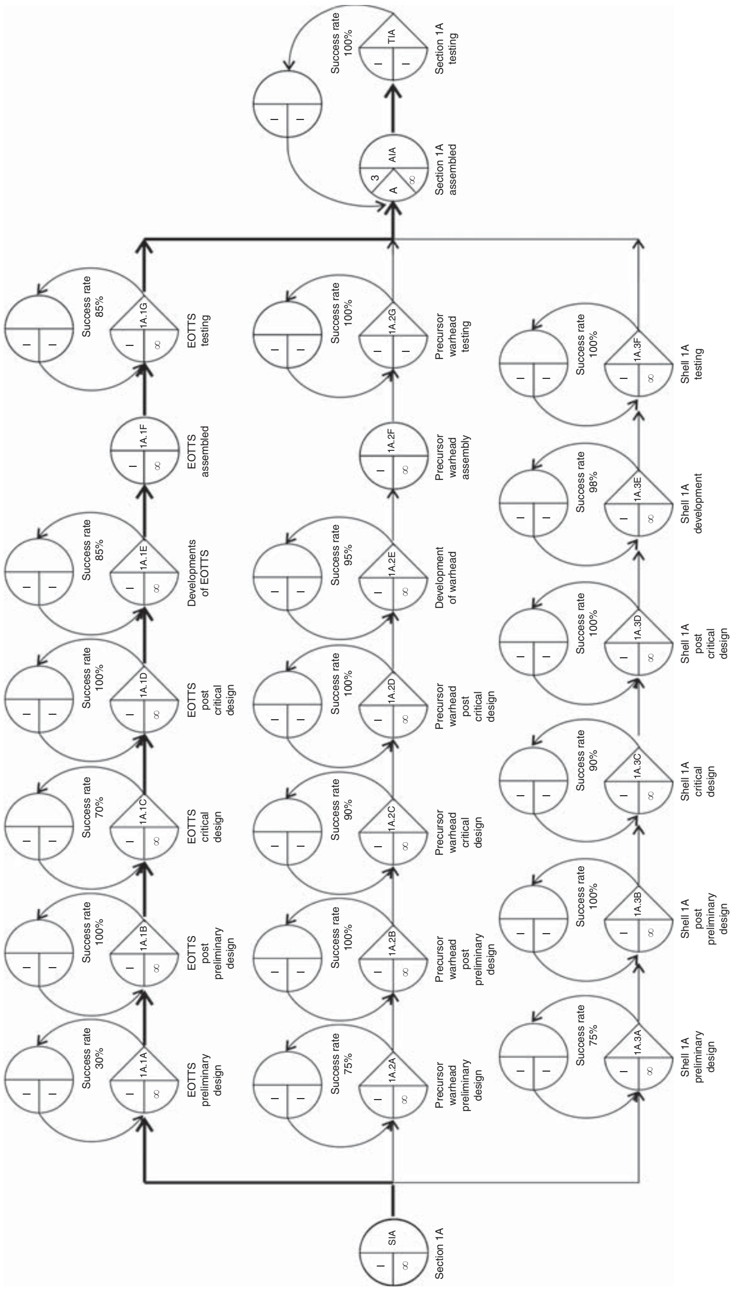


Figure 3.
GERT Network model of Section 1A

Figure 5 shows the Replication Results of Cost of SRHGM development. SRHGM requires developing for not compromising with national security.

Average cost of project with indigenous EOTTS takes 68.90 Lacs rupees as compare to 75.42 Lacs rupees for project with overseas EOTTS, respectively as given in Table IV.

Development of indigenous EOTTS is beneficial as compared to overseas EOTTS because of less cost but as seen earlier technology was denied for EOTTS. Project has to take hit of huge delay.

Table III.
Replication results of timings (in days) of project SRHGM development

Cases	Minimum time	Average time	Maximum time
Project with indigenous EOTTS	1,989.50	2,045.39	2,153.33
Project with overseas EOTTS	1079.44	1,105.39	1146.4

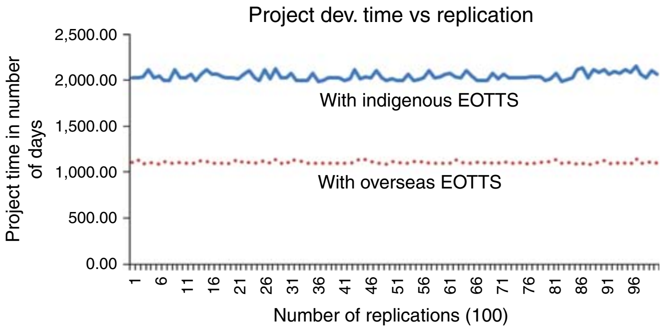


Figure 4.
SRHGM development time with indigenous and overseas EOTTS

Table IV.
Replication results of cost (in lacs rupees) of project SRHGM development

Cases	Minimum cost	Average cost	Maximum cost
Project with indigenous EOTTS	66.41	68.90	74.94
Project with overseas EOTTS	72.96	75.42	81.49

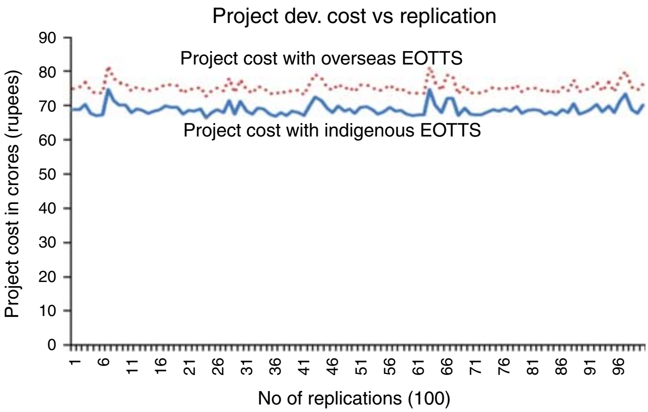


Figure 5.
Replication results of cost of SRHGM development

The Arena models for the development of indigenous and overseas EOTTS are simulated for time individually to gather the data which then used to compare. The simulation is run both for time and cost separately are given in Figure 6 and Table V, respectively.

Although, average time taken for indigenous EOTTS development takes 2,037.99 days as compare to 661.79 days with overseas EOTTS, respectively as given in Table V. Still the development of indigenous EOTTS is very much required because of indigenous development of EOTTS is crucial for mastering this technology is denied by overseas companies.

Figure 7 shows the Replication Results of Cost of EOTTS development. EOTTS requires to be developed indigenously for project SRHGM. Average cost of indigenous EOTTS takes 35.51 Lacs rupees as compare to 42.02 Lacs rupees with overseas EOTTS, respectively as given in Table VI.

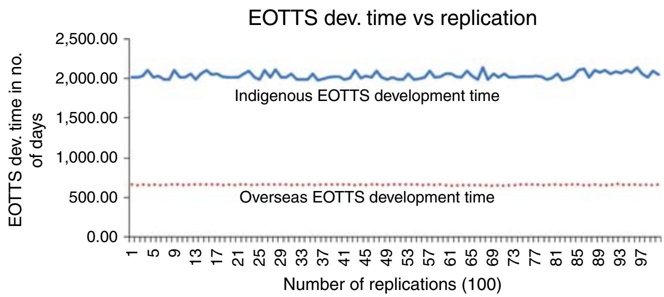


Figure 6.
Replication results of average development time of indigenous and overseas EOTTS

Cases	Minimum time	Average time	Maximum time
Indigenous EOTTS	1,980.26	2,037.99	2,145.33
Overseas EOTTS	652.18	661.79	670.75

Table V.
Replication results of timings (in days) of EOTTS development

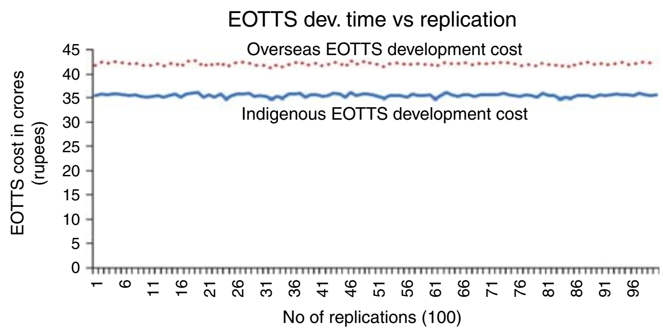


Figure 7.
Replication results of average development cost of indigenous and overseas EOTTS

Cases	Minimum cost	Average cost	Maximum cost
Indigenous EOTTS	34.77	35.51	36.15
Overseas EOTTS	40.99	42.02	42.84

Table VI.
Replication results of cost (in lacs rupees) of EOTTS development

Hence, the above stated factors are note worthy because the know-how, technology availability, resources availability, and the high cost of critical components (required to be procured ex-import) and the time required for their procurement all contributed to the overall time and cost of the Project.

7. Conclusions

An attempt is made in this paper to study the effects of indigenously development of a critical subsystem such as the EOTTS on the outcome of a defence R&D project. The defence R&D project is modeled with the help of GERT network. The GERT model is converted to an Arena Discrete Event Simulation model. Such a model provides flexibility of precedence relationship, capability to model activity failures and ability to reiterate activities as many times as necessary. It also provides the ability for simulation-based decision making for the subsequent activities based on the current state of the project.

The Arena models for the defence R&D project with indigenous and overseas EOTTS are simulated individually to gather the data for the purpose of comparison. The simulation is run separately for time and cost. All the EOTTS related activities such as preliminary design, post preliminary design, critical design, post critical design, development, assembly, and testing are found to be in the critical path.

It is found from the simulation runs that the average time taken for the project with indigenous EOTTS to complete in 2,045.39 days compared to 1,105.39 days for the project with overseas EOTTS. Average cost of the project with indigenous EOTTS is 68.90 Lacs rupees compared to 77.42 Lacs rupees for the project with overseas EOTTS. The development of SRHGM project with indigenous EOTTS is very much required because of indigenous development of EOTTS is crucial for SRHGM as this technology is denied by overseas design houses.

It is also found that timely development of technology plays a key role in the Indian defence R&D projects. While indigenization of critical components reduces cost of development, the trade-off lies in much increased project development time. It is imperative that project teams should identify critical subsystems early and work out appropriate strategies of indigenous development to avoid time overrun of the projects.

Future work lies in considering the interaction of multiple critical subsystems in a defence R&D project and also in considering the dynamics of decision making by the project head and the technology heads in the context of India. It can also use fuzzy based GERT simulation analysis.

Glossary

EOTTS	Electro-optical Target Tracking System
GERT	Graphical Evolution and Review Technique
IGMDP	Integrated Guided Missile Development Program
PBS	Product Breakdown Structure
PMO	Project Management Office
SIMAN	SIMulation ANalysis
SRHGM	Short Range Homing Guided Missile
TTS	Target Tracking System

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Further reading

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Appendix 1

The Arena models both for the defence R&D project and the critical component development project are presented in Appendix 1. The simulation runs on these models are performed for time and cost.

A.1 R&D project model

The Figure A1 shows the Arena model for the defence R&D project. The project contains six distinct Sections (1A, 1B, 2, 3, 4 and 5) which constitute the desired product. After each of the individual sections is successfully developed, integrated and tested, the sections are assembled together as a product. Only after comprehensive testing of the integrated subsystem, in the laboratory and in field conditions, can this be led to production.

The model as shown above includes six sections modeled as the sub-models in the Arena Simulation Package. The sub-models for the Section 1A, Section 1B, Section 2, Section 3, Section 4 and Section 5 are shown in the Figures A2-A7.

The Section 1A sub-model as shown in the Figure A2 which includes the critical component development project with indigenous and overseas EOTTS, respectively. The critical subsystem which is being developed is then assembled along with subsystem 1.2 and subsystem 1.3 for testing if the testing is successful it proceeds towards the assembly of the product otherwise some rework is done on the assembly, it is retested and proceed for final assembly.

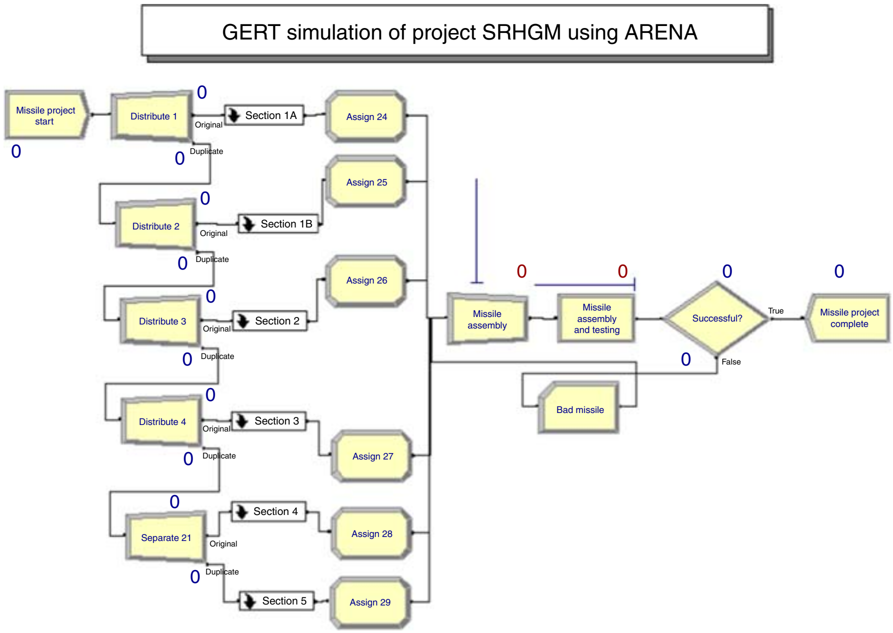

Figure A1.
Arena model for the SRHGM R&D project

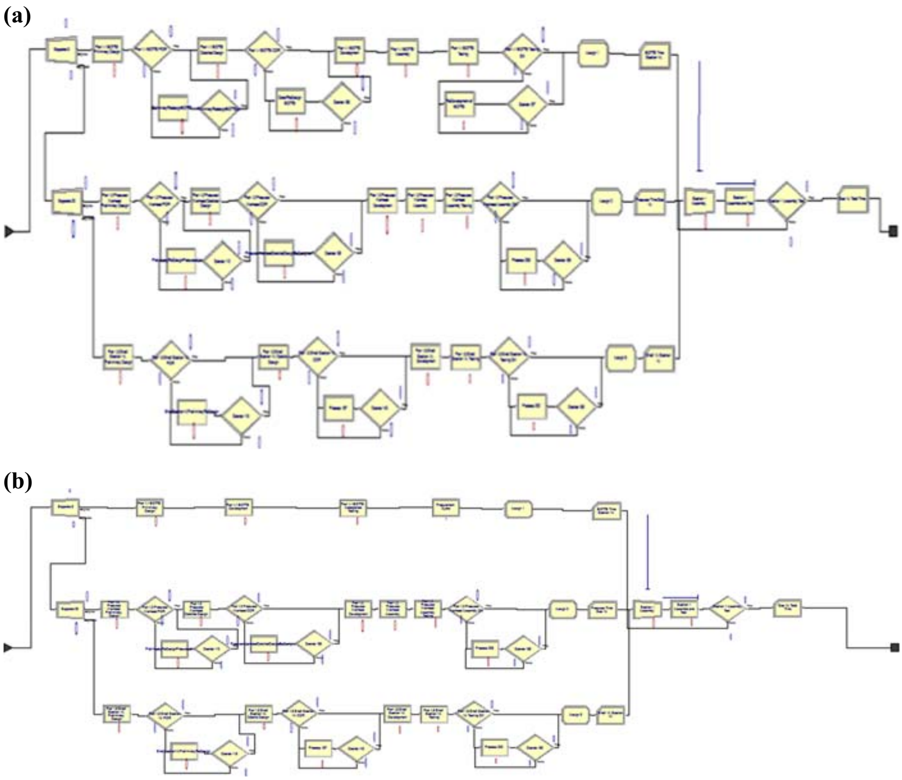

Figure A2.
(a) Arena model for Section 1A with indigenous EOTTS (b) Arena model for Section 1A with overseas EOTTS

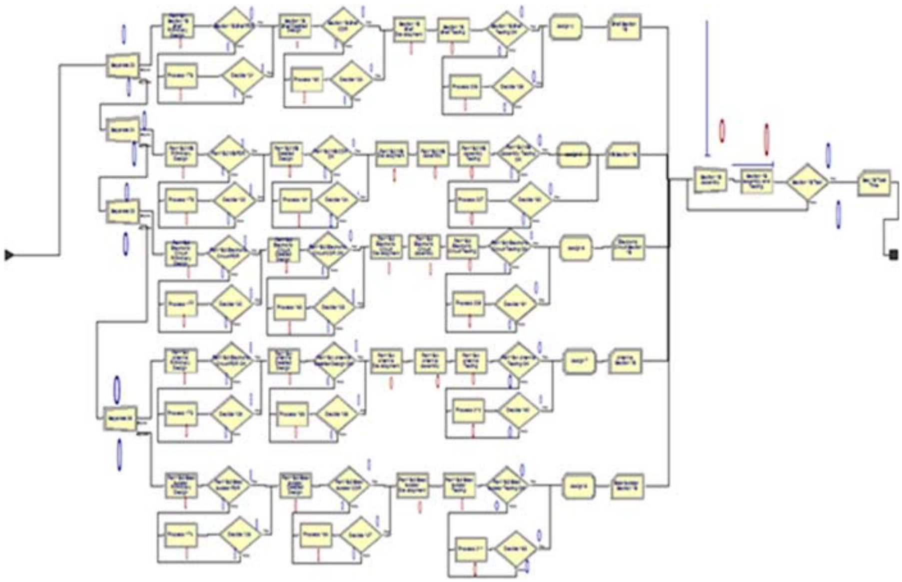

Figure A3.
Arena model
for Section 1B

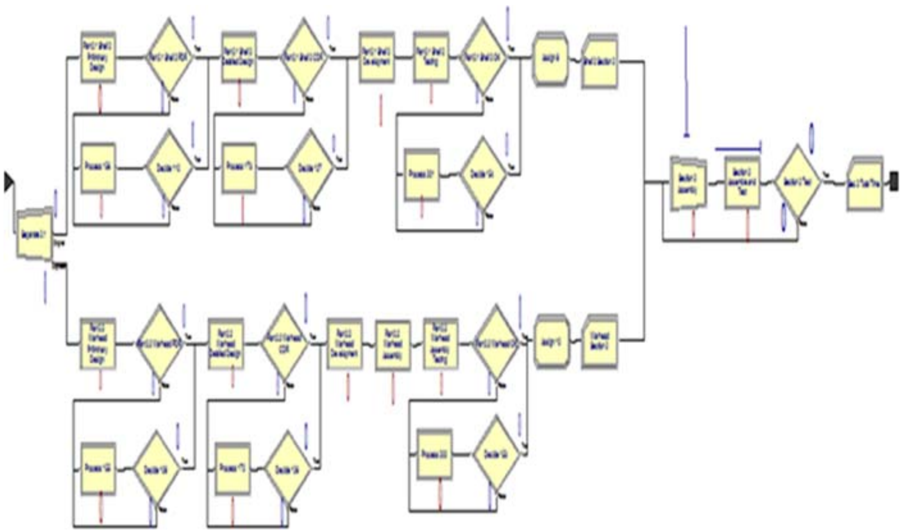

Figure A4.
Arena model
for Section 2

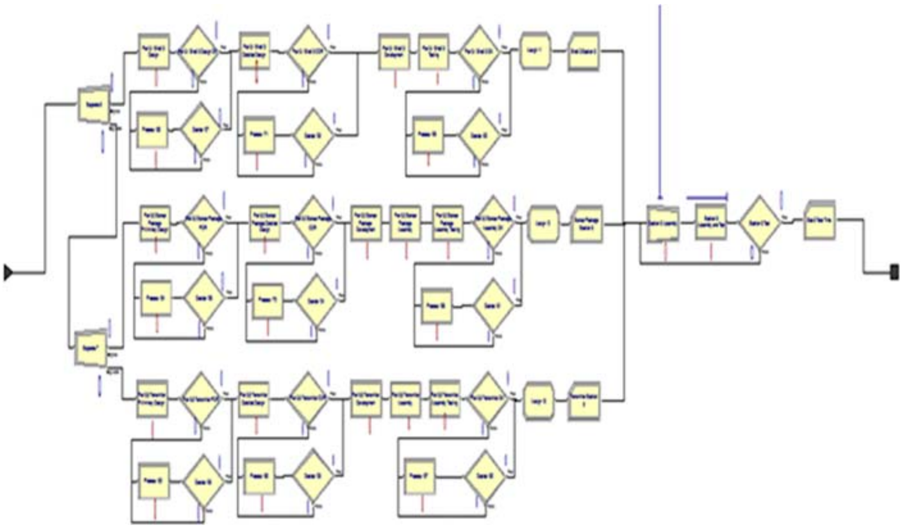

Figure A5.
Arena model
for Section 3

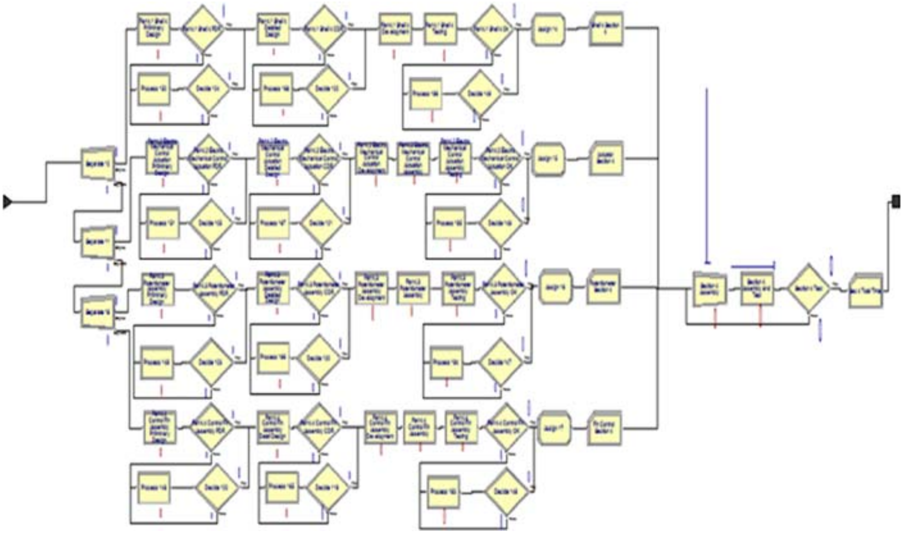

Figure A6.
Arena model
for Section 4

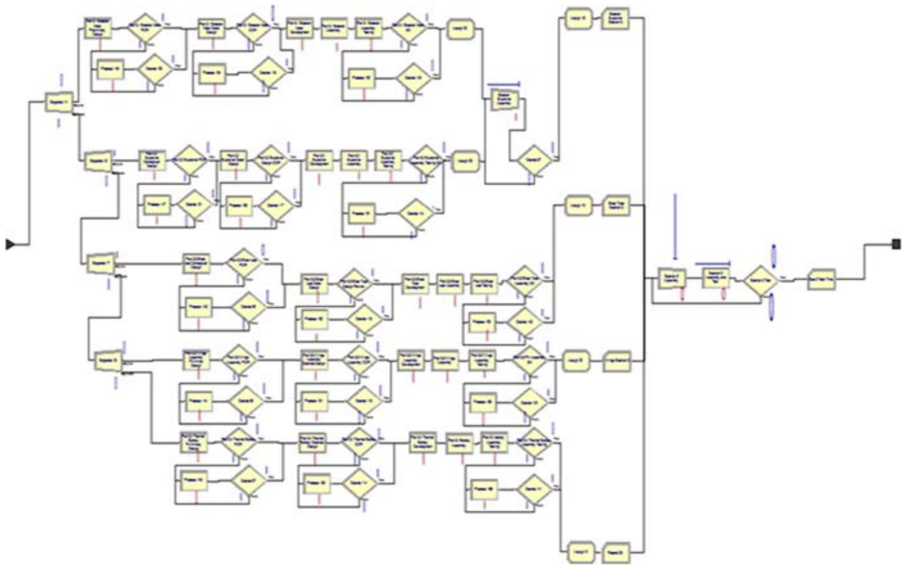

Figure A7.
Arena model
for Section 5

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