Proceedings of the 2000 Winter Simulation Conference
J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, eds.

SIMULATION BASED OPERATIONAL ANALYSIS OF FUTURE SPACE TRANSPORTATION SYSTEMS

Alex J. Ruiz-Torres

Information and Decision Sciences Department
College of Business Administration
University of Texas at El Paso
El Paso, TX 79968, U.S.A

Edgar Zapata

Shuttle Engineering
NASA John F. Kennedy Space Center
KSC, FL 32899, U.S.A.

ABSTRACT

This paper presents an approach to the operational analysis of future space transportation systems. The approach combines knowledge from government and industry space operation and design experts, with system analysis methodologies to predict operational characteristics of a future space transportation system. The model proposed under this approach utilizes expert knowledge to predict the operational requirements of a vehicle concept, including the ground activities, flows, resources, and costs; all the components of the *spaceport*. The model incorporates simulation in order to include spaceport characteristics as alternative flows, processing variability, and other random events. This model will provide vehicle designers with useful understanding of the spaceport operations related to the investigated vehicle design. A stand-alone application is being developed where the model will be implemented and validated.

1 INTRODUCTION

As the twenty-first century begins, the human race continues to look at the skies and dream of someday establishing a human presence beyond Earth, routinely traveling to the moon, mars, or beyond. While the day where some of these dreams are a reality may be decades away, space transportation systems provide our civilization critical capabilities including the ability to place satellites in orbit, conduct experiments in space, and repair/ service satellites already in orbit. Satellites in both Geo-synchronous Earth orbit (GEO) and Low Earth orbit (LEO) provide the information backbone that is fueling a new economic revolution.

Satellites are by no means the end point of the commercialization of space. Companies like Hilton Hotels, Lockheed Martin, Boeing and multiple entrepreneurs are interested in other commercial uses of space, including tourism, manufacturing, health care, and passenger transportation. Tourism and space based passenger transportation are the two areas that have the most promise with the growing number of *adventure travel* enthusiasts and the dramatic increase in airline travel between the Americas, Europe, and Asia.

The major obstacle to the commercialization of space is the cost of space transportation in conjunction with low reliability and operability (Scott 1998). The cost of moving one pound of material (payload) from the earth's surface to low earth orbit (100 miles above earth) is estimated at 6 to 10 thousand dollars, which translates into more than a million dollars per passenger. This cost is made of several components including those related to the vehicle(s): design, manufacture, and operation, and to the infrastructure required to operate the vehicle: facility/equipment design, construction, and operation.

Research in the area of space transportation systems has focused primarily in the design and manufacture of the vehicle components: propulsion, materials, thermal protection, and controls to mention a few. In most cases, the operation of the vehicle and all phases of the facility/equipment component were ignored early on in design or had very little consideration. However, experience with previous systems has shown NASA and industry, that operations has the most significant effect in the life cycle cost and performance of a space transportation system. To reduce costs for future space transportation systems, the assessment of vehicle concepts/architectures must consider all life cycle costs; design and development, manufacturing, and production. Design decisions drive to a large extent development, manufacturing, support, and operations functions, thus models based on design decision can be used to predict all of these areas. However, the complexity of this assessment process requires the development of multiple models, capable of estimating the different cost elements, for example a program development assessment model, a manufacturing assessment model, and an operations assessment model. All of these models should then be integrated to provide true-life cycle costs for a space transportation system.

Operations models (ground operations or spaceport operations) are an important part of the assessment of new vehicle architectures as they reflect a large portion of the system's recurring costs and will determine the vehicle flight rate capability. The recurring costs and the flight rate are the result of tasks or activities that are required during ground operation, for example the preparation of a payload for integration with the vehicle. Typically the cost and task duration time assessment of these processes is performed by experienced engineers who employ their knowledge of production and operations technology, methods analysis, and engineering economics to predict the probable cost and production time of a product (Aderoba 1997) in this case a ground operation activity.

This paper presents research addressing issues related to the operational analysis of space transportation systems. The paper describes a methodology based on simulation modeling that estimates critical operational characteristics of a new vehicle concept. The research presented in this paper only addresses the modeling of the spaceport operations; other models have been proposed to estimate manufacturing costs and production times for launch vehicle systems (Marx et al. 1998). This paper also (1) presents an overview of the components of a space transportation system, (2) describes the proposed modeling approach for operations analysis, (3) describes the implementation of the model and (4) presents conclusions and future research directions.

2 SPACE TRANSPORTATION SYSTEMS

A space transportation system is in principle not very different from the civilian aviation system. In both cases, there is a need for a takeoff facility (runway for airplanes), a landing facility (if the vehicle is reusable - RLV), a facility to process cargo, passengers, and crew (terminal), and a location to inspect and maintain the vehicle among others. However, the similarities end there. While there are a variety of aircraft types, they share many common features including the type of landing and takeoff process (horizontal – runway), the types of fuels used, the type of maintenance, and the cargo they carry. More importantly, aircraft share a common baseline technology maturity which is highly evolved. On the other hand, space transportation systems of the future could be based on vehicles that may have very different characteristics than the existing shuttle or expendable launch system (rockets). The next generation vehicles may be launched from an magnetic launch assist track, from a platform at sea, or from a larger vehicle that never leaves the earth's atmosphere.

From a conceptual view, a space transportation system can be divided into twelve major components (HRST Synergy Team 1997); seven related directly to the flow of hardware at a spaceport and five that are indirect functions such as logistics, support, or planning. Each of the twelve spaceport components is controlled to some extent by the vehicle design and the expected use of the system. Given several of these operations play a support role, they are not included in this model. The seven included functions are:

- *Passenger/Cargo Processing (Terminal)*: Facilities and systems required for the handling of passengers and cargo after landing, and prior to launch. Could be separated into two facilities.
- *Traffic/Flight Control*: Oversight of landing, launch, and flight operations.
- *Launch*: Vehicle departure facilities and systems.
- *Landing*: Vehicle arrival facilities and systems.
- *Vehicle Maintenance and turnaround*: Facilities and systems required to repair, inspect, and prepare the vehicle for the next launch. One such facility may be needed for each reusable stage of the vehicle.
- *Vehicle Assembly/Integration*: Facilities and systems required to combine multiple stages. Could be part of the Maintenance and Turnaround facility.
- *Expendable Elements*: Facilities required to inspect and prepare expendable items for launch.

A Space Transportation System (STS) is defined as the combination of the vehicle (s) that physically moves people and objects to space with the supporting ground operating systems. In both cases, vehicle designers develop and specify the scheme by which the elements of the vehicle will be arranged into a single integrated system; the form and shapes, the propulsion systems, the number of major systems, the production processes for manufacturing and integration, and the detailed technologies of parts and subassemblies. This activity will specify manufacturing and other costs related to acquiring the first component of the STS: the vehicle (s). The vehicle design will also specify the operational systems required to test, process, maintain, and repair the vehicle systems. For example, a single stage to orbit system does not require a mating process (union of the stages i.e. the shuttle system where the orbiter is attached to an external fuel tank and two semi-reusable solid rockets).

However, a substantial portion of these operational requirements will not become defined and refined until actual hardware is built and enters operations. For example, during the shuttle design, the planned time for ground operations was less than a month, while in reality it requires an average of four months. This is partially due to differences in operational performance and part reliability, for example a higher number of repairs and replacements per flight.

Based on the vehicle design and the requirements for repair/replacement operations, several ground operation flows are proposed and presented in Figure 1. For airplane like vehicles with a single stage to orbit and periodic maintenance requirements, the typical flow will be to move from landing, to the terminal for unloading/loading, and then to launch (takeoff). For vehicles with multiple stages, an integration step must be included. Finally, for vehicles that require repair/replace operations after each flight, an additional step, called turnaround, is included after unloading the passengers/cargo as it is typically required before integration to other stages is performed. The vehicle design specifies (planned or unplanned) which of these flows will be required between landing and launch and the time required in each of these processes.

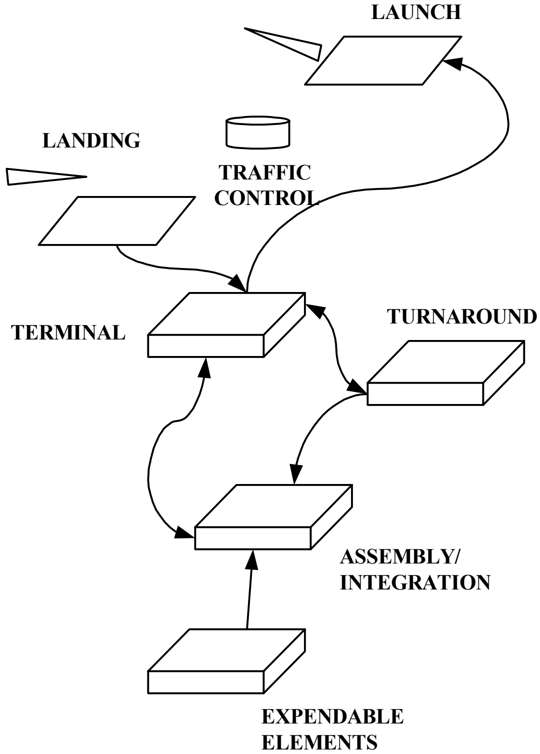

Figure 1: Spaceport Functions and Flows

The combination of different processing times and flows is an issue that takes us to the first fundamental relationship between the vehicle and the ground operations systems: *cycle time*. The *cycle time* of a vehicle can be defined as the expected interval of time between a vehicle's landing and launch. While a typical airplane *cycle time* can be measured in hours, as mentioned before the *cycle time* for our current reusable STS (the Space Shuttle) is measured in months. Finally, the expected time in orbit must be established in order to determine the true vehicle utilization - the expected number of flights per vehicle per year.

From the estimated processes and types of ground operations systems required, facility investment costs, operating costs, and the flight rate for a single vehicle are estimated. The costs of a STS can then be divided as follows:

- *Fixed Operational Costs*: These are the baseline operational costs required for a single flight per year. For example management, engineering, and technical staff.
- *Variable Costs*: These are flight dependent operational costs. For example fuel, replacement parts, additional staff and insurance.
- *Development Costs*: Initial costs required to develop the STS technologies required. This may include flight and ground systems development.
- *Facilities and Infrastructure Costs*: Initial costs required to build and equip the ground systems that will support the STS.
- *Vehicle Acquisition Costs*: Purchase of the vehicles.

A total cost assessment can be made for a vehicle concept by rolling up investment and operational costs, the expected life of the vehicle, and a demand for service. The demand for service (pounds per year) will determine the number of flights needed per year, and therefore the number of vehicles. As the size of the fleet grows so does the fixed operating costs (need more base staff). As the number of flights increase, the variable cost per flight may be reduced as a result of economies of scale, or increase as a result of increased complexity. The total facilities and infrastructure costs increase with fleet size and the number of flights (i.e. number of launch pads, number of maintenance hangars), but the per flight cost will eventually decrease with an increase in the number of flights given economies of scale.

However, the prediction of costs and other operations related parameters for a launch vehicle architecture/ concept is a complex problem. This is because launch vehicles are inherently very complex systems (Ryan and Townsend 1998), design architectures are based on new technologies where limited cost/operations knowledge exists, and the "true" reliability, maintainability, and operability of a concept vehicle are difficult to predict. In addition, at the architectural/concept design level a limited set of design characteristics has been defined, limiting the input side of the equation. In spite of these limitations, the development of cost assessment - operation focused models are required to truly understand the affordability of new launch systems. Ground operations account for a large portion of the cost of shuttle and ELV's operations. In addition, models that assess early at the concept level are essential as decisions made at this stage of design typically have the most significant effect on life cycle costs and other operation parameters.

The need for operation assessment models has prompted NASA, industry, and academia to form a partnership (Vision Spaceport) to address these issues (Vision Spaceport 1998). The efforts of the vision spaceport team have resulted in a model toolkit that assesses the spaceport requirements driven by a launch vehicle architecture. The tools developed by this team provide a broad capability for estimating a comparative sense of direction on Life Cycle Costs (LCC) based on baselines of the Shuttle program and other existing launch/transportation systems. The tools are founded on knowledge functions that map vehicle characteristics to operational functions of a spaceport (Zapata and Ruiz-Torres 1999), for example the launch function. The tools developed by this team have been used in two NASA studies; The Space Solar Power Study and The Space Transportation Architecture Study 99.

3 SIMULATION BASED OPERATIONAL ANALYSIS

An alternative approach to the knowledge based functions used in the Vision Spaceport toolkit is the development of knowledge driven activity/process models. These models will translate vehicle design parameters into an activity set/process map, where these activities have a stochastic characterization, therefore the need for simulation. While simulation is not typically part of it, Activity Based Cost models use a similar procedure. ABC has been used to develop cost estimation models for manufacturing; jobs shops environment (Aderoba 1997), CIM (Computer Integrated Manufacturing) environments (Dhavale 1990), and electronics manufacturing (Ong et al. 1993), and supply chain modeling. Christenson and Komar (1998) have proposed an ABC type model for the space vehicle operations environment for the modeling and analysis of reusable rocket engines. Their approach focused on detailed modeling of the activities required to turnaround reusable rocket engines, including the development of design specific schedules, resource sets, and stochastic characterizations.

In general, all of these models work by first estimating the activities required to produce/operate a product/device, and then based on these, estimate the time and labor/other costs associated with these activities. These models addressed "well defined" environments where technology is at a mature state and the effect of design choices is well understood. The problem addressed by this research is the estimation of activities on an environment were there is limited knowledge of the activities required by a vehicle architecture, given these architectures are typically based on new and experimental technologies. This research proposes the use of expert's knowledge to estimate the activities, and their cost and time characterizations.

3.1 Design Driven Characteristics

This model characterizes a RLV architecture/concept by I design variables and J vehicle characteristics/ operational drivers. Each of the design variables I represents a particular option of the vehicle, for example, engines of the staged combustion type, engines of the RBCC type, use of ceramic tile thermal protection system, etc. The binary variable d_i is used to represent the inclusion of a design option, $d_i = 1$ if the design option is included in the design and $d_i = 0$ if not. The vehicle characteristics J represents measures that will drive operational cost or time, for example the number of fuel cells or the area covered by a type of thermal protection. The variable q_j is used to represent the quantify of an operational driver, $q_j > 0$ if that operational driver exists in the design and $q_j = 0$ if not. Finally, there are A spaceport activities, where these activities are related to one or more design variables. The binary variable s_a is used to represent the inclusion of that activity in the activity set for that design, $s_a = 1$ if that activity is part of the activity set and $s_a = 0$ if it is not.

The determination of the activity set required will be based on a list of knowledge based equations. Two general examples of these equations are presented next:

$$s_3 = \{1 \text{, if } d_1 + d_{12} = 2;\ 0 \text{ otherwise}\}$$
$$s_7 = \{1 \text{, if } d_{11} = 0 \text{ and } d_{123} = 1;\ 1, \text{if } q_{56} > 100;\ 0 \text{ otherwise}\}.$$

For a vehicle design that does not include d_1 but includes d_{12}, activity 3 will not be a part of the spaceport operation, while for a design that includes both, activity 3 will be part of the process. There are two drivers for activity 7, either d_{11} is not part of the design and d_{123} is part of the design, or that q_{56} is greater than 100. Clearly, the process of generating the activity set cannot start until an initial design has been completed.

3.2 Activity Characterization

Each activity A of the spaceport will be defined by several factors; process time distribution and parameters, cost, and expected need; a percentage. Each activity A will have a knowledge based process time distribution and parameter estimate. The process time for an activity a; p_a, is determined by a knowledge based equation. Examples:

$$p_1 = \text{UNIF}\ (35, 100) \times q_{13} \text{ hours}$$
$$p_5 = \text{EXPO}\ (3 \times q_{38}) \text{ minutes}$$
$$p_{42} = 50 \times q_{38} \text{ minutes.}$$

The cost per activity a; c_a, will be characterized in a similar fashion. In some cases the cost will be based on the process time for that activity, on other, based on an operational driver, and in some cases, it would be a "flat" fee. Examples:

$$c_1 = p_1 \text{ x } \$14{,}000$$
$$c_{81} = \$10{,}000 + \$120 \text{ x } q_{39}$$
$$c_{22} = \$75{,}000.$$

The last characterization of an activity is the expected need of an activity a; n_a. This characterization will be based on several factors including the expected reliability of the design option, the maturity of the technology, or the typical need for the operation, for example each 10 flights a part must be replaced, therefore 10%. These will also be related to design options and operational drivers. Examples:

$$n_{19} = \{10\% \text{, if } e_{45} = 1;\ 30\% \text{, if } e_{46} = 1;\ 100\% \text{ otherwise}\}$$
$$n_7 = \{50\% \text{, if } q_{92} < 2{,}000;\ 100\% \text{ otherwise}\}$$
$$n_7 = \{100\% \text{, if } e_{92} = 1;\ 0 \text{ otherwise}\}.$$

By combining the process time and need variables, we can determine the adjusted expected process time of an activity (note that $E(p_a)$ is the expected process time given the time distribution and parameters):

$$E'(p_a) = n_a \text{ x } E(p_a).$$

For example, if it takes between 10 to 30 minutes (uniform distribution) per square feet to repair a particular protective tile surface, and it fails at an average of 1.5% of the surface per flight. The proposed vehicle prototype has 450 square feet, therefore $E(p_a) = 20*450 = 9000$ minutes (time to repair the complete surface). The adjusted expected process time is 135 minutes.

3.3 Process Modeling

The model characterizes the spaceport as a network of activities (a process model), where expert's knowledge is used to determine precedence constraints of all activities. The spaceport has R resources, where each resource has a capacity x_r. Further, each resource has a set Ω_r of activities assigned to it, and the resources can only process one activity at a time per unit of capacity. This approach allows activities to require more than one resource to be completed. While additional resource characteristic could be modeled, for example, typical failure or downtime rate, it was the researchers choice to assume facilities/resources are operational for 100% of the spaceport operation time. To determine the capacity of a resource x_r, the total annual flight requirement estimate F must be calculated – as this estimates the expected use of a resource. The capacity per resource is then calculated based on the number of flights and the expected time on each activity.

$$F = \text{Roundup}(D/Vc)$$
$$x_r = \text{Roundup}(F \text{ x } \Sigma \text{ for all } a \in \Omega_r\, [E'(p_a)] \,/\, T.$$

where

D = Annual demand for service per year in pounds.
Vc = Vehicle capacity in pounds.
T = Time of spaceport operation.

As mentioned before, a vehicle's ground cycle time is an important measure of operational performance. The critical path of activities will govern the lower bound vehicle cycle time. Based on the spaceport process model and the expected processing times of activities, a critical path can be determined –critical activity set Φ. The expected cycle time (critical path time), Vct, flight rate, Vfr, and number of vehicles, Vn, are calculated by:

$$Vct = \Sigma \text{ for all } a \in \Phi\, [E'(p_a)]$$
$$Vfr = T \,/\, (Vct + Vot)$$
$$Vn = Roundup\ (F/Vfr).$$

Two additional resource characteristics relate to the cost modeling part. Each resource will have a per unit of capacity fixed operational cost, fc_r, and an acquisition cost, ac_r. Resource capacity and cost are based on estimates of the facilities and personnel required to perform the activities assigned to that resource. Increases in the capacity for a resource will increase the fixed operational cost and acquisition cost for that set. Given the capacity will be determined without consideration to possible bottlenecks, the model will utilize some simple heuristics to modify the capacity of resources, increasing the cost of operations for that resource set, but allowing for a more efficient use of the spaceport.

For example, design *SpaceVan* has a proposed capacity of 20,000 pounds. The demand for service is estimated at 2 million pounds per year, therefore the expected total number of flights per year is 100. The expected time in orbit is 3 days and the expected cycle time given the process model for the vehicle is 20 days. This results in a per vehicle flight rate of 15.87 flights per year. The minimum number of vehicles required to satisfy the demand is 7. Further, lets visit one activity, surface repair. The model estimated the expected time for this activity to be 100 hours with a capacity of one. The total requirement given 100 flights is 10,000 hours. Assuming a 365 days/24 hour operation, at least a capacity of two is required.

3.4 Model Architecture

The objective of the model is to provide designers with a tool that allows the evaluation of designs, not only to provide a picture of cost and cycle time, but also of the processes. With this information designers can then identify the processes that drive costs or cycle time and work on their designs to improve the vehicle parameters that affect those processes, therefore improving operational performance. In addition, the model allows designers to modify the capacity of resources to eliminate bottlenecks for example. The architecture for the model is presented in Figure 2.

The model generates an average cost per flight, cycle time, resource utilization, queues, and total cost per flight. In addition to the variable costs generated by the activities, fixed operational costs and acquisition costs are distributed through the flights. Cost inputs from the designer include the expected per vehicle acquisition cost, development cost, and the cost of money. While a total cost picture will be provided, operations related costs would be provided separate from vehicle acquisition and development.

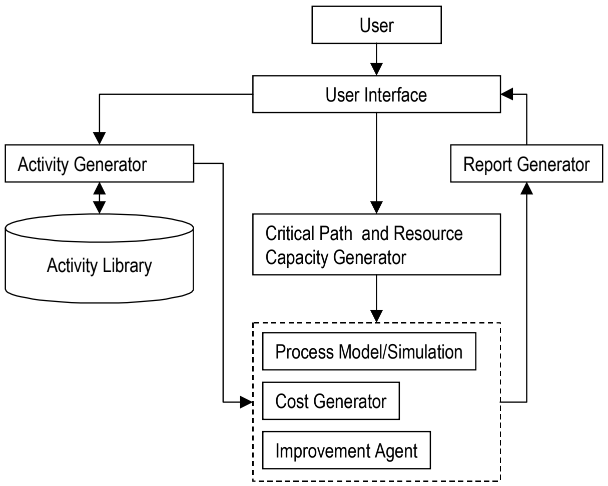

Figure 2: Model Architecture

3.5 Knowledge Requirements

The implementation of the described model requires an extensive knowledge base. The generation of this knowledge base will require the development and validation of a knowledge capture process which allows experts from launch and design centers to participate on its development. First, a set of vehicle design options, focusing on the operational drivers, must be developed. From these design options and operational drivers, a set of activities must be defined as in section 3.1. The next step is to define the cost and time of each activity based on one or more vehicle characteristics/operations drivers as described in section 3.2. The model development also requires the organization of the activities into a network, the determination of resource requirements, and the cost/capacity of these resources. Finally, an area of additional research is in the development of environment scenarios, where the activities, times, and costs, required by a design choice change with improvement in reliability, vehicle life, and technology, and reductions in complexity, similar in operations to an airplane.

4 TOOL DEVELOPMENT

The implementation of the described model is currently in progress. All the components of the model are in the process of being implemented in a Visual Basic ® / ARENA ® application. At this time, the application uses close to 40 inputs from the designer and selects from over 35 activities based on the inputs. The model includes 8 resources, primarily facilities and complex machinery as a launch platform. The model considers a preset demand scenarios to establish resource capacity and fleet size. The model has a set warm up period and has a simple heuristic to modify resource capacity.

Figures 3-6 present snapshots of two of the input forms, and of the simulation model. However, at the current time, the process time, cost, and need characterizations are not complete, therefore the model cannot be validated as a representation of expert's knowledge. The development team is in the process of capturing the required knowledge so that it is integrated into the model.

5 CONCLUSIONS AND FUTURE WORK

The use of a simulation based model to assess the operational requirements and impacts of new products is not a new concept. With the addition of the proper knowledge base, complementing the partial information available, it could be applied to the assessment of even very complex systems of systems such as space transportation architectures. By using the knowledge of experts in the areas of spaceport operations and vehicle/technology designers, design driven activities can be determined, and from there, the time and cost of the activity. The approach allows vehicle designers to better understand (by looking at the process model and output) the cost and cycle time drivers as they can easily observe which design driven activities have the highest costs and task times. In addition, this approach fosters the development of additional operations knowledge as it "forces" operations experts to predict the activities (and their cost and time characteristics) that new technologies will require in the context of the spaceport. There is still a great amount of work to complete, primarily in the knowledge acquisition part. In addition to that, the inclusion of an optimization routine that will find the best resource allocation will eliminate the need to play what if games with the capacity of resources.

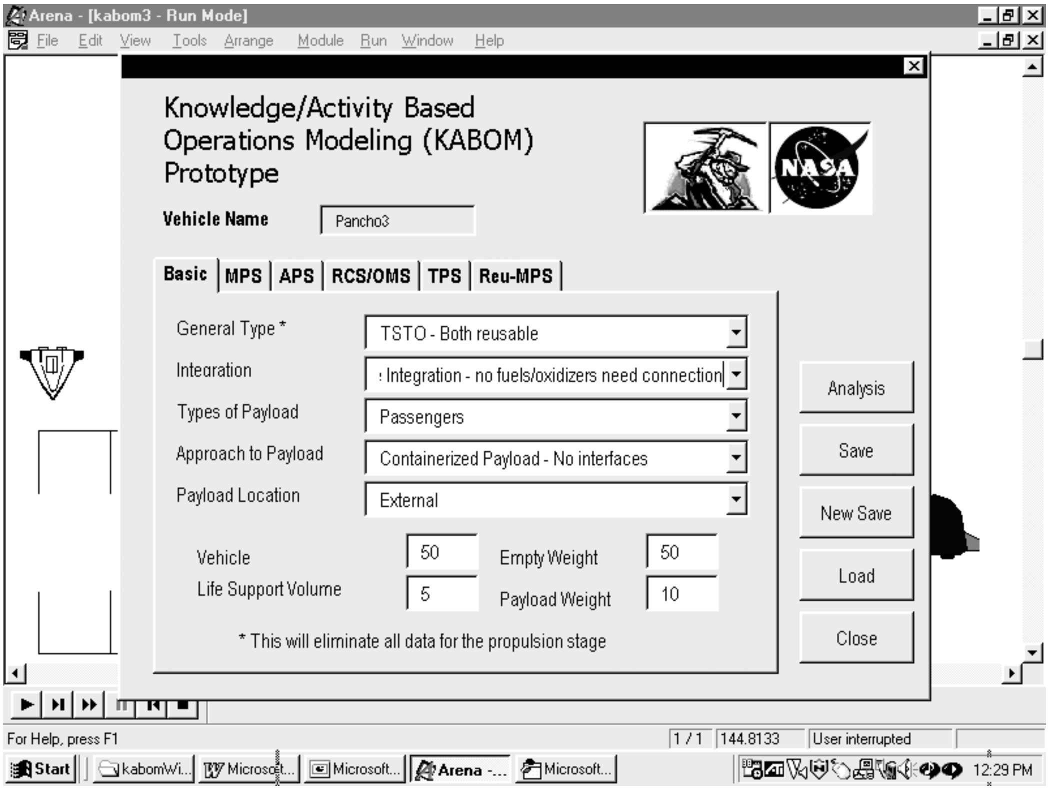

Figure 3: Snapshot of Vehicle Inputs – General Architecture

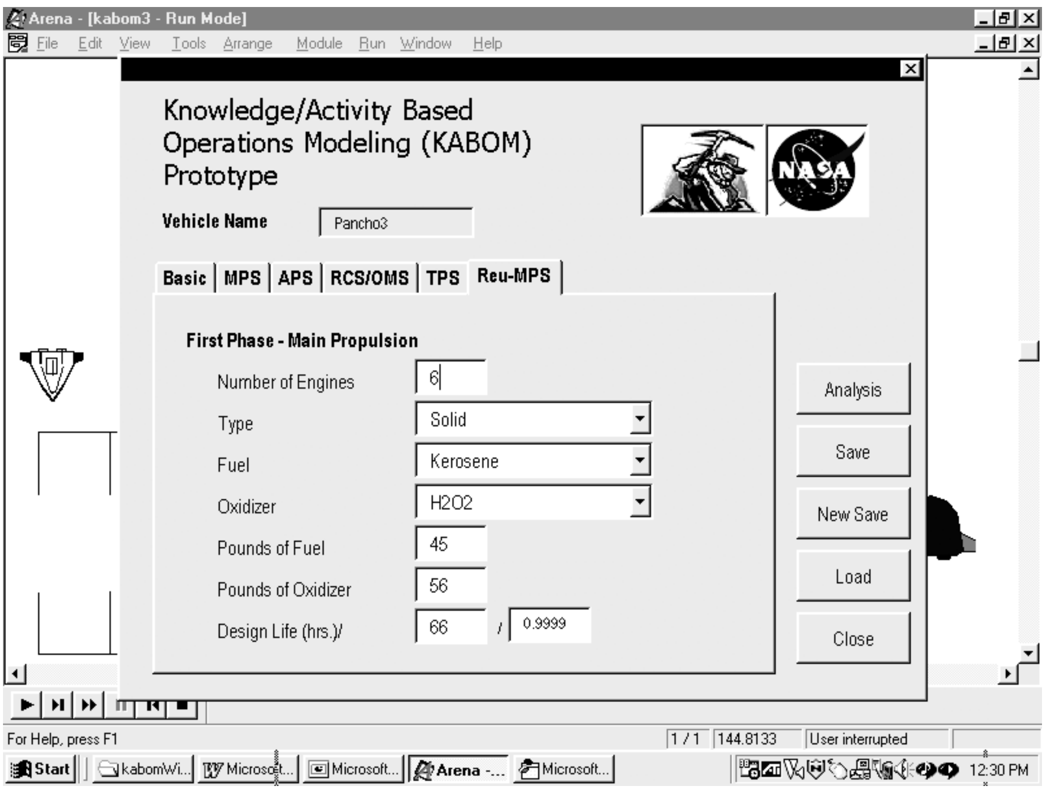

Figure 4: Snapshot of Vehicle Inputs Form – Propulsion Inputs for the Second Stage

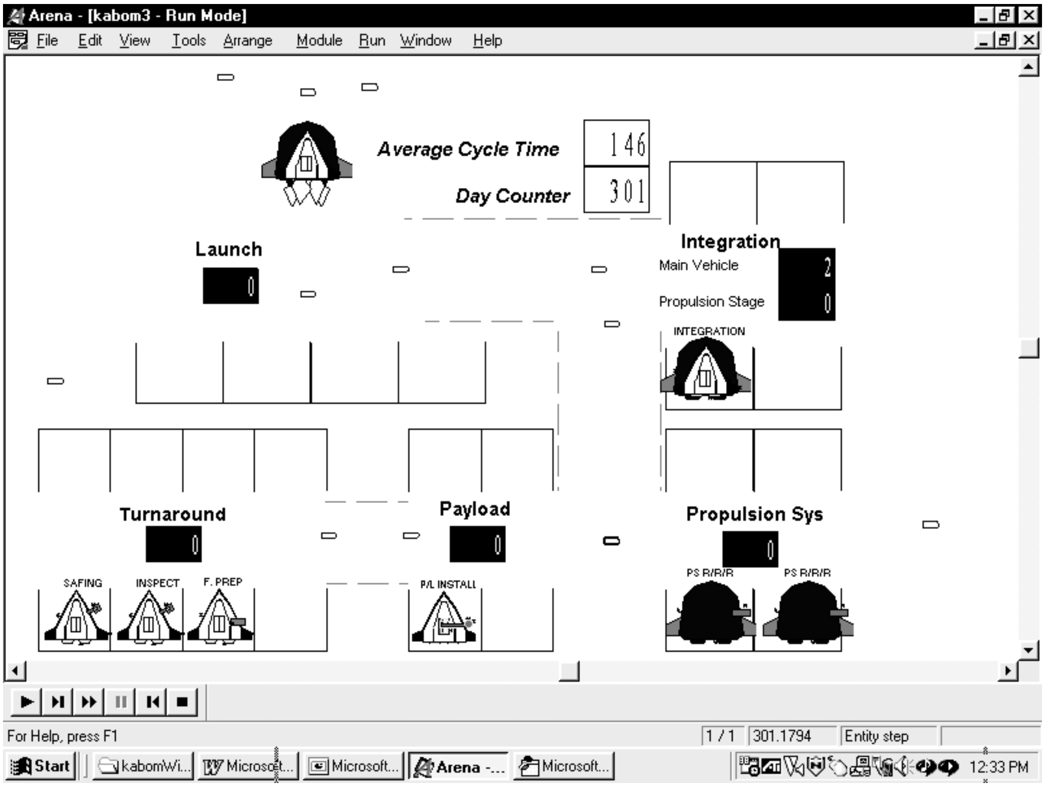

Figure 5: Snapshot of Simulation Animation; View of all the Spaceport Operations

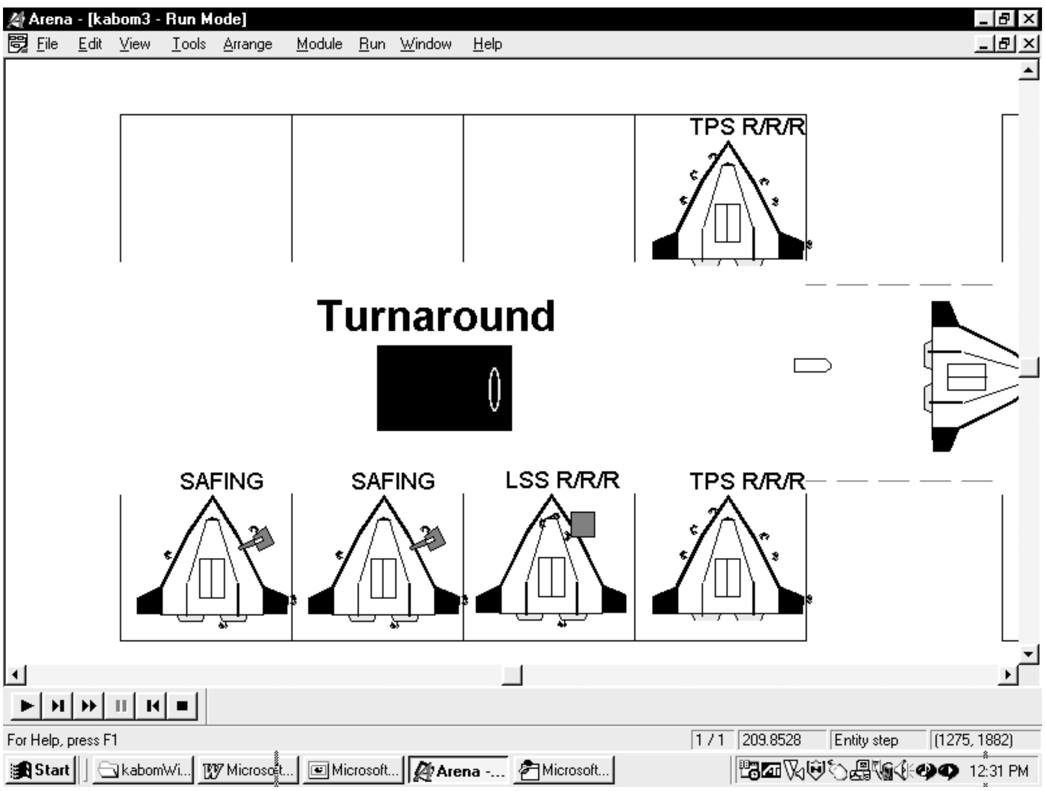

Figure 6: Snapshot of Simulation Animation; Zoom of the Turnaround Area

ACKNOWLEDGMENTS

The authors gratefully acknowledge the work and support in this project of Carey McCleskey and Russell Rhodes of NASA, the Kennedy Space Center, the Vision Spaceport team, and the NASA/ASEE faculty fellowship program.

REFERENCES

Aderoba, A. 1997. A generalized cost-estimation model for job shops. *International Journal of Production Economics*. 53: 257-263.

Christenson, R. L. and D. R. Komar. 1998. Reusable Rocket Engine Operability Modeling and Analysis. *NASA/TP – 1998-208530*. Marshall Space Flight Center.

Dhavale, D. G. 1990. A Manufacturing Cost Model for Computer-integrated Manufacturing Systems. *International Journal of Operations & Production Management*, 10(8): 5-18.

HRST (Highly Reusable Space Transportation) Synergy Team. 1997. A Catalog of Spaceport Architectural Element with Functional Definition. Unpublished Report.

Mankins J.C. 1998. Lower Cost for Highly Reusable Space Vehicles. *Aerospace America*. March: 36-42.

Marx, W., N. M., Dimitri. and D. P. Schrage. 1998. Cost/Time Analysis for Theoretical Aircraft Production. *Journal of Aircraft*, 35(4): 637-646.

Ong, N. S., L. E. N. Lim, and K. T. Yeo. 1993. Manufacturing Cost Modeling for Electrical Interconnections. *International Journal of Operations & Production Management*, 13(2): 63-75.

Ryan, R. S., and J. S. Townsend. 1998. Fundamentals and Issues in Launch Vehicle Design. *Journal of Spacecraft and Rockets*, 34(2): 192-198.

Scott, W. B. 1998. Airline Ops Offer Paradigm For Reducing Spacelift Costs. *Aviation Week & Space Technology*. June 15: 64-67.

Vision Spaceport. 1998. Spacelift Benchmarking & Architectural Modeling. 1998 Project Plan. Unpublished Report, May 1998.

Zapata, E., and A. J. Ruiz-Torres. 1999. Space Transportation Cost Modeling and the Architecture Assessment Tool- Enhanced. *Proceedings from the International Astronautical Federation Conference*, Amsterdam.

AUTHOR BIOGRAPHIES

ALEX J. RUIZ-TORRES is an assistant professor at the College of Business Administration at UTEP. He received his B.I.E, M.S.I.E and Ph.D. I.E. from Georgia Tech, Stanford, and Penn State respectively. He is a member of INFORMS, POMS, and DSI. His interests include simulation, scheduling, cellular manufacturing, and space transportation systems design. His email is `<aruiztor@utep.edu>`.

EDGAR ZAPATA is a NASA engineer at the Kennedy Space Center and part of the Space Shuttle engineering team. His responsibilities include assuring future space transportation development and designs build on the Shuttle and previous operations experience, all with the goal of furthering space transportation. He received a B.S.M.E. from the University of Puerto Rico. He is an active member of American Institute of Aeronautics and Astronautics. His professional interests include space transportation technology development, cost modeling and analysis, and design analysis for affordable system development. His email is `<Edgar.Zapata-1@ksc.nasa.gov>`.