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Paper Session II-B - The Selection of a Launch Vehicle

Joel S. Greenberg
President, Princeton Synergetics, Inc., Princeton, NJ

Carissa B. Christensen
Policy Analyst, Princeton Synergetics, Inc., Princeton, NJ

THE SELECTION OF A LAUNCH VEHICLE

Joel S. Greenberg
President
Princeton Synergetics, Inc.
Princeton, NJ

Carissa B. Christensen
Policy Analyst
Princeton Synergetics, Inc.
Princeton, NJ

ABSTRACT

The selection of a launch vehicle should not depend on any single vehicle attribute (i.e., price, reliability, availability, insurance rate, final payload placement accuracy, etc.), but rather on the effect of the interaction of multiple vehicle attributes in combination with payload configuration and sparing/maintenance strategy.

For commercial organizations, selection decisions should be based on performance measures such as ROI and risk. For government operations, selections should be based on measures such as present value of life cycle cost in combination with availability constraints. Methods for analyzing launch vehicle and related choices are described together with parametric results illustrating important tradeoffs.

INTRODUCTION

Comparative assessments of launch systems too often focus on one particular attribute, without fully considering the context in which that attribute exists. The availability of subsidized insurance from foreign launch companies is a good example. Without examining the many interrelated system attributes and user needs, it cannot be asserted that less costly or more easily available launch insurance will attract payload owners to foreign firms over domestic ones.

The selection of a space transportation system for a particular mission is a complex process that requires the consideration of many factors including availability, cost, payload delivery capability, payload placement accuracy, reliability of launch operations, failure/recovery modes, and cost and availability of insurance. Because these factors vary significantly among transportation systems, it is not valid to concentrate on only one parameter (such as insurance rate, or launch cost) when deciding upon a launch vehicle. It is necessary to consider all of these factors and to establish their combined effect on mission economics. Also to be considered are the interactions with payload configuration and sparing/maintenance strategies.

The importance of assessing multiple attributes of transportation systems is demonstrated by considering a typical communications satellite business venture and a typical government space mission. For the private sector the impact of transportation choice is demonstrated in terms of return on investment (ROI), consisting of expected rate of return and variability of rate of return (i.e., risk). For government missions, the impact of transportation choice is demonstrated in terms of present value of life cycle cost and availability. Particular emphasis is placed upon total system considerations -- transportation system, payload configuration and sparing/maintenance concept.

Simultaneous consideration of multiple attributes of launch vehicles requires the use of simulation techniques. Two Monte Carlo simulation models (DOMSAT III and SATCAV) were developed that allow transportation systems and related operations to be simulated within the context of the business or mission requiring the transportation services. The simulation models make possible the determination of the impacts of utilizing alternative transportation systems and related operations on the pertinent business and mission performance measures.

DOMSAT III is a financial simulation model of communications satellite business ventures. It was developed and used to assess the impacts of technology, transportation system choice, maintenance scenarios and other factors on financial performance, with special attention to impacts on return on investment (ROI) (both return and risk, measured as the standard deviation of return.) It is important to explicitly consider the risk dimension because cost, demand and other uncertainties, coupled with launch vehicles that have different reliabilities, have a significant effect on risk, and different associated risks change the value of a given rate of return.

SATCAV is a Monte Carlo satellite cost and availability model specifically developed to establish life cycle cost and availability statistics associated with the many alternatives faced by mission planners. These alternatives include transportation system choice, maintenance and sparing concepts, as well as technology utilization. The government mission planner is normally concerned with establishing the minimum life cycle cost approach that will meet mission availability requirements (for example, at least x sensors available y percent of the time).

SELECTION OF A LAUNCH VEHICLE: PRIVATE SECTOR

DOMSAT III is a dynamic stochastic planning model of generalized communications satellite business ventures. It allows for consideration of multiple communications services, demand and cost uncertainties, subsystem reliabilities (random and wearout failures) and sparing concepts, expendable and/or reusable transportation systems and associated reliabilities, alternative placement/replacement/service/repair scenarios using ground- and/or space-based facilities, and technology changes with time. It develops risk profiles of both financial and non-financial performance measures.

The ability to model the financial performance together with the specification of the business scenarios, provides the means for establishing the financial performance impacts of:

- Spacecraft technology programs (e.g. on-orbit propulsion),
- Transportation technology programs,
- Alternative space transportation systems (i.e., Shuttle, Ariane, Proton, etc.) with different mission modes (expendable vs. reusable), reliability, payload placement accuracy, price, etc.,
- Improved final payload placement accuracy (in GEO),
- Different insurance rates as compared with the self-insurance option, explicitly taking into account the level of risk,
- Spacecraft configuration alternatives including transponder arrangements and sparing concepts, and
- Alternative upper stages.

In addition, DOMSAT III is specifically configured so that it can be used to establish the financial performance impacts of alternative placement/replacement/service/repair policies utilizing either ground- or space-based facilities. It must be emphasized that the selection of a transportation system should be based upon the consideration of the business and not the consideration of the cost to place a single satellite into orbit. The DOMSAT Model considers the complete business and therefore requires a complete set of business related data such as the desired number of satellites and the desired launch dates, types of services offered, demand forecasts (including associated uncertainties), transponder pricing, price elasticities, expenses, tax related data, etc.

To illustrate the considerations associated with the selection of a launch vehicle, a typical but hypothetical fixed satellite services business venture was planned. The postulated venture represents a carrier that launches and operates three satellites with the objective of generating revenue through leasing transponders. Figure 1 illustrates the comparison of launch alternatives (at a fixed transportation price) in terms of the reliability of the launch vehicle and final payload placement accuracy. The effect of improved payload placement accuracy potentially extended payload life through additional station- keeping propellant. Of course, the actual extent of the life increase is dependent on the reliability performance of all of the payload subsystems. Two curves are shown in Figure 1. The lower curve reflects a satellite with an eight year wearout and the upper curve reflecting a five year increase in wearout life of the on-orbit propulsion system due to improved payload placement accuracy. It should be noted that a low reliability launch vehicle with improved payload placement accuracy may yield higher returns and lower risk that a highly reliable but less accurate launch vehicle. On the other hand, all other things being equal, launch vehicle reliability may reduce expected ROI and increase risk by several percentage points.

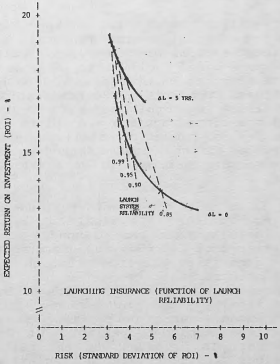
Figure 2 illustrates the tradeoff between launch system reliability and launch cost. The significant effect of increased transportation cost in combination with low reliability is evident both on the expected ROI and the risk. Figure 3 illustrates the impact of insurance rate and the self-insurance option on the expected ROI and risk. It can be seen that the no-insurance option is equivalent (at a slightly higher level of risk) to an insurance rate of approximately 18 percent.

Finally, two specific situations are summarized in Table 1 to illustrate the combined effects of a number of transportation system attributes on expected ROI and risk. The specific attributes are indicated together with their combined impacts on ROI and risk. For the case illustrated, low reliability and high insurance rate (Case B) are more than compensated for by transportation cost and payload placement accuracy.

SELECTION OF A LAUNCH VEHICLE: PUBLIC SECTOR

The SATellite Cost and AVailability Model is a dynamic stochastic life cycle cost and availability model that simulates the launch and on-orbit operations associated with the initiation and continuing operation of a generalized space mission comprising multiple satellites each with multiple sensors.

FIGURE 1 TRANSPORTATION SYSTEM IMPACTS ON ROI STATISTICS OF A TYPICAL COMMUNICATIONS SATELLITE BUSINESS: IMPACTS OF LAUNCH SYSTEM RELIABILITY AND PLACEMENT ACCURACY



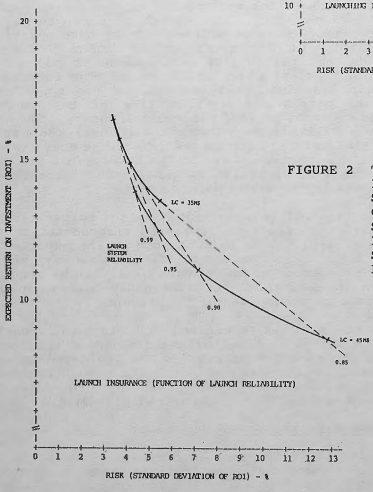


FIGURE 2 TRANSPORTATION SYSTEM IMPACTS ON ROI STATISTICS OF A TYPICAL COMMUNICATIONS SATELLITE BUSINESS: IMPACTS OF LAUNCH SYSTEM RELIABILITY AND LAUNCH COST

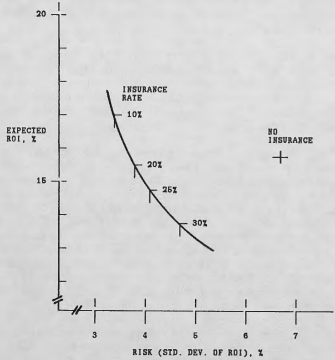


FIGURE 3 LAUNCH & PAYLOAD INSURANCE IMPACTS ON ROI STATISTICS OF A TYPICAL COMMUNICATIONS SATELLITE BUSINESS

TABLE 1 ILLUSTRATIVE COMPARISON OF TRANSPORTATION SYSTEM CHOICE

	SYSTEM ATTRIBUTE:				RESULTING:	
	RELIABILITY	INSURANCE RATE(%)	P/L PLACEMENT (SAT LIFE/YRS)	TRANSPORTATION COST($M)	EXPECTED RETURN(%)	RISK (ST DEV/ROI)
CASE A:	.95	15	8	45	13.6	4.3
CASE B:	.85	30	10	35	17.0	3.5

SATCAV simulates launch operations of a multistage vehicle by considering the reliability associated with the performance of major operations (including payload checkout and testing) and the consequences of a priori specified types of failures in terms of cost incurring events and time delays. Delays that may result from different types of failures are taken into account in the simulations. Both expendable and recoverable launch vehicles and upper stages may be considered. SATCAV simulates the random and wearout characteristics of a multi-sensor satellite determining when specific failures occur and when maintenance actions are required to respond to critical failures.

SATCAV encompasses alternative maintenance scenarios that include both ground spares and on-orbit active or dormant spares. Both launch on failure and launch in anticipation of wearout failure alternatives are available. Different transportation scenarios may be selected for placement and maintenance flights from nine (9) scenarios, five of which include space-based assets.

SATCAV develops cost, event, availability and cause of failure statistics reports as well as an event timeline report. The developed availability statistics take into account sensor and subsystem random and wearout failure characteristics, sparing strategy, transportation scenarios, delays associated with different types of failures, and duration of on-orbit testing.

The SATCAV Model develops the life cycle cost and availability statistics frequently used as the primary performance measures when configuring satellites and selecting transportation systems. Life cycle cost minimization within availability constraints requires the simultaneous consideration of satellite configuration, sparing strategy, transportation scenario and launch vehicle. To illustrate the complexity of the comparison process two typical missions are considered: the first requiring that two critical sensors be available, and the second requiring that at least four critical sensors be available. The level of "available", i.e., availability, is discussed in the following paragraphs and the effect it has on the selection of transportation system and sparing concept.

Figure 4 illustrates the life cycle cost and availability tradeoffs in terms of sparing strategy for a mission comprising two (2) operational satellites plus spares with the expected wearout life of each satellite being 7 years. Availability is measured as the chance that two or more sensors will be operational at any point in time. Dormant spares are assumed not to fail while they are in the dormant state but that the probability of start-up of a dormant spare may be less than 1.0 (as indicated by the dormant spares curve). Three sparing alternatives are indicated: active spares (0,1,2), dormant spares (with different probability of turn-on), and launch in anticipation (from 0 to 2 years) of expected wearout failure but launch on random failure. It can be seen that the minimum cost approach is a function of the required level of availability. For example, at low level of required availability (i.e., 80-85%) the launch in anticipation strategy is best; at higher required levels of availability the active spares option is best. Figure 5 illustrates the life cycle cost and availability tradeoffs in terms of sparing strategy for a mission comprising five (5) operational satellites plus spares. Availability is measured as the chance that four or more sensors will be operational at any point in time. As in Figure 4, three sparing alternatives are indicated. Launch in anticipation of wearout failures is the best strategy except if a very high availability is required. For a very limited set of conditions, dormant spares (2) may be preferred but at high levels of availability, active sparing is the only viable alternative.

The above is presented for illustrative purposes only and should not be taken as a general rule. The minimum life cycle cost approach within an availability constraint is a function of anticipated standdown time (given a failure), launch vehicle reliability, and other factors.

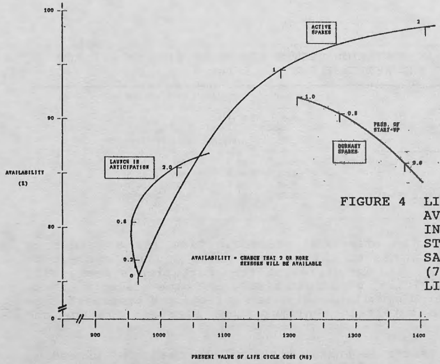


FIGURE 4 LIFE CYCLE COST & AVAILABILITY TRADEOFF IN TERMS OF SPARING STRATEGY: 2 OPERATIONAL SATELLITES PLUS SPARES (7 YR. EXPECTED WEAROUT LIFE)

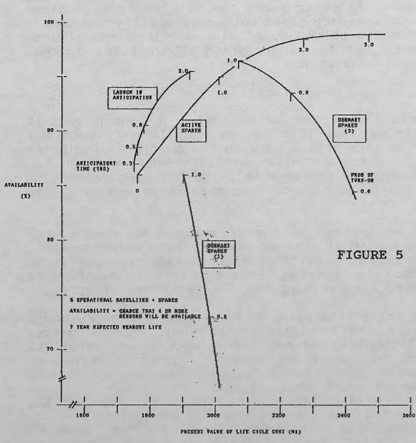


FIGURE 5 LIFE CYCLE COST & AVAILABILITY TRADEOFF IN TERMS OF SPARING STRATEGY: 5 OPERATIONAL SATELLITE PLUS SPARES (7 YR. EXPECTED WEAROUT LIFE)

TABLE 2 EFFECT OF TRANSPORTATION SYSTEM STANDDOWN TIME ON PRESENT VALUE OF LCC AND AVAILABILITY (LV REL=0.9)

	RANGE OF UNCERTAINTY OF STANDDOWN TIME			
	0.2 - 1.0 YEARS		0.4 - 2.0 YEARS	
ALTERNATIVE	LCC(M$)	AVAIL(%)	LCC(M$)	AVAIL(%)
DORMANT SPARES (2) (0.8 PROB. OF TURN-ON)	2226	93.3	2087	83.9
ACTIVE SPARES (1)	2010	94.9	1896	88.5
ACTIVE SPARES (2)	2268	98.4	2109	94.7
LAUNCH IN ANTICIPATION (0.8 YEARS)	2052	91.3	1686	77.7

Table 2 illustrates the effect of standdown time (as a result of launch failures) assessments on the present value of life cycle cost (lcc) and availability. Since different transportation systems will have differing reliabilities, standdown times, and other factors, these all need to be considered simultaneously when selecting a transportation system, together with satellite configuration, sparing strategy and maintenance concept.

Another complicating factor is annual cost and the chance of exceeding annual budget constraints -- in other words the problem is to achieve the minimum life cycle cost approach given both availability and annual budget constraints. Since the SATCAV Model also develops annual cost statistics it can be used to iterate on considered alternatives to seek a solution within specified constraints.

SUMMARY/CONCLUSIONS

This paper has demonstrated that the selection of a launch vehicle should not depend on any one specific launch vehicle attribute but rather on the effect of the interaction between the multiple attributes of the launch system in combination with satellite configuration and sparing/maintenance strategies. Implementation of this recommendation requires effective simulation modeling of launch vehicles and satellite systems.

Simulation modeling can be applied at the individual firm or agency level to support decision-making of payload owners. With existing tools and techniques, it is possible to simultaneously consider transportation system attributes, satellite sparing strategies and maintenance concepts, accurately taking into account their interactive effects.

In addition to venture specific analyses, broader economic assessments of launch vehicle systems can be improved if they include better information about the relationship between launch systems and satellite systems. Usually demand for launch services is linked to supply in terms of payload capacity and launch cost (sometimes including insurance). This paper has demonstrated, however, that other factors, such as payload placement accuracy, may interact in such a way that the vehicle with the higher launch cost becomes the more economical choice. Simulation modeling of these relationships can be an effective means of improving the accuracy of projections of competitive supply and demand in the launch vehicle industry.