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2004

NASA FACULTY FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER

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The Effect of Infrastructure Sharing in Estimating Operations Cost of Future Space Transportation Systems

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Introduction

NASA and the aerospace industry are extremely serious [1] about reducing the cost and improving the performance of launch vehicles both manned or unmanned. In the aerospace industry, sharing infrastructure for manufacturing more than one type spacecraft is becoming a trend to achieve economy of scale. An example is the Boeing Decatur facility where both Delta II and Delta IV launch vehicles are made. The author is not sure how Boeing estimates the costs of each spacecraft made in the same facility. Regardless of how a contractor estimates the cost, NASA in its popular cost estimating tool, NASA Air force Cost Modeling (NAFCOM) has to have a method built in to account for the effect of infrastructure sharing. Since there is no provision in the most recent version of NAFCOM2002 to take care of this, it has been found by the Engineering Cost Community at MSFC that the tool overestimates the manufacturing cost by as much as 30%. Therefore, the objective of this study is to develop a methodology to assess the impact of infrastructure sharing so that better operations cost estimates may be made.

Infrastructures

Infrastructure in manufacturing refers to resources such as facilities, equipment, engineering and skilled labor, tooling, inspection devices, material handling devices, transportation equipment and methods and other requirements necessary to manufacture, store, and transport launch vehicles, both manned and unmanned. To manufacture launch vehicles, necessary equipment and buildings housing this equipment constituting the physical facility are required. The right engineering skills and critical touch labor skills are absolutely essential to build reliable and cost effective launch vehicles. Tooling in the form of assembly fixtures have to be built and maintained. Because of the low production volume, stringent inspection procedures and quality control measures have to be in place to ensure quality products. Unique inspection, test and other equipment may be necessary for each element of a launch vehicle. Soft tooling may lend some flexibility for manufacturing more than one element. Common tooling and inspection devices will also help reduce program costs and save considerable amount of lead time.

In the commercial world, especially in the automotive industry, it is not uncommon to see centralized design and development before the product design and tooling are passed on to an assembly plant. Automobile assembly plants are routinely built to assemble more that one type of vehicle on the same line. This practice is not very common in commercial aircraft manufacturing. However, aircrafts with different options are assembled on the same line. Due to extremely low volume of production in the case of space launch vehicles, the practice of infrastructure sharing has not taken off. But it is being looked at very favorably in the interest of reducing mission costs. The recent decision by Boeing to move the production of Delta II launch vehicles to the Decatur facility built to make Delta IV launch vehicle is an indication that infrastructure sharing

Will be necessary to realize economy of scale. To achieve cost reduction, it may be necessary to examine a program critically right at the conceptual design stage. Contract regulations may have to be modified to take advantage of infrastructure sharing. Infrastructure sharing will require that the vehicle design have common elements. For example the diameter of core and length may be very similar or the ratio of length /diameter may be very close. The major assumption here is that any required machining of panels is subcontracted and the facility is responsible only for the assembly.

Ground Rules

The following ground rules are used in this study.

- Expendable launch vehicles
- Shuttle derived vehicle with a payload carrier similar to shuttle C
- Both ET and payload carrier are made at the same facility
- Limited production quantities
- Not more than four flights per year
- Units stored until use.
- Six year shelf life
- Shared infrastructure
- Examine only production phase

Methodology Used

Extensive literature search was made using the REDSTAR library resources at Science Application International Corporation (SAIC). A report by Chrysler Corporation [3] describing how best the infrastructure at MAF could be better utilized was found to be invaluable. The report based on a study made in the early 70's is very thorough. It outlined a detailed capacity utilization plan for the manufacturing of orbiter and drop tanks at MAF. Several other documents related to external tank manufacturing and shuttle and shuttle-C were also reviewed. Documents available in the public domain describing the capabilities of MAF were reviewed. The LM-Michoud website was visited to get educated on the capabilities at the facility. MAF was visited with Spencer Hill, a colleague from the Engineering Cost Group at MSFC. The Lockheed Martin personnel that the author interfaced at MAF were very cooperative and provided extremely useful LM proprietary data. The author during the visit also made several interesting observations related to the study. These data were analyzed for the report. None of the data could be included in this report because of the proprietary nature of the data. It was found the facility to be a humongous one occupying over 800 acres. A lot of state-of-the art assembly and welding equipment are operational. The friction stir welding equipment is one-of-a-kind and very impressive. The fiber placement machine for composite materials was awesome. Richard Webb [6] of KT Engineering is another source that provided data used in this study.

Production Rate Curve

As described in the Parametric Cost Estimating Handbook [2], production rate effect may be explained as changes that can be expected in hours/unit of producing the X-the unit if an item if produced at a given production rate. If the production rate is increased, as can be expected, the hours for the X-the unit will decrease. Taking into account the effect of learning, the production rate curve may be described as below.

Y, Cost for the X-th unit = $A^* X^b * Q^r$ ……………………………………………………… (1).

Where A = Cost of the very first unit or the cost of Theoretical First Unit (TFU)
X = Unit number
b = Learning curve slope
Q = Production Rate / Year
r = Production rate curve slope

Obviously the net effect of adding the production rate effect (Q^r) is to adjust the cost of TFU accounting for the production rate. It is stated in the NAFCOM99 manual [5] that the rate effect may be ignored or treated differently in different models. It is further suggested that the rate curve slope may be derived from historical data holding the learning curve slope constant. There could be a correlation between the production rate and the learning curve.

The author very strongly believes from the available historical production cost data of external tank at MAF, a different approach is required for developing the slope of the production rate curve. The historical ET production data could not be provided in this report in the interest of protecting the data. However, it should be pointed out that the total cost for producing up to four units remains at a constant level. This is due to the fact that a subcontractor doing the machining of aluminum panels would have to amortize most of the tooling and CNC programming cost with the first four units. Since all the fixed costs are to be absorbed in the first four units, it is suggested that a new rate curve slope. Note that this may vary from program to program.

Using the last three data points, the author determined the production rate slope to be 60%. The same approach used by several cost professional was used in developing the rate curve slope. The author is of the opinion that a different approach may be warranted. The rate curve slope computed does not deviate very much from the production rate curve slope being used by Richard Webb [6]. He has come up with a rate curve slope of 63.10% from data available in the public domain. In the judgment of the author based on the available ET production data, a 60% production rate curve slope would be justifiable whenever quantities produced are four or more. It should be cautioned that rate curve might not be applicable for production quantities of less than four for items like ETs.

Effect of Infrastructure Sharing

To investigate the potential cost savings that could be realized by making use of the available infrastructure and critical skills at MAF for more than one program, the operating contractor, LM was asked during the visit to quantify potential cost savings that can be expected using the concept of shared infrastructure. Since the LM personnel that hosted the visit were apprised of the intent of the visit they were prepared to provide the necessary data and answer many questions that the author had. Three major functional areas were identified. They are: facilities, overhead and management and skilled or touch labor. As a follow up, two of the LM cost personnel made a visit to MSFC and provided additional data in response to the author's request. During this visit meaningful discussions were made related infrastructure sharing. The LM personnel provided several interesting data related to capacity, critical skills, and overhead costs that can be used to justify the production of both ET and payload carrier at the same facility.

From the data collected in person and additional data provided during the follow up visit, the following inferences are made. Note that only general comments are made without disclosing any proprietary data.

- A savings of about 30% per year from the recurring cost may be realized if both ET and payload carrier are built at Michaud making best use of the available infrastructure and critical skills. The estimated savings are based on a build rate of 2/year for each program.
- The total cost (both DD&T and recurring) stabilizes after 2-units/ year.
- By extrapolation, it may be stated that a build rate of 3/year for each of the two programs will minimize the total unit cost.
- Labor costs and other direct costs may substantially be reduced with infrastructure sharing.
- Management and supervision costs may be reduced with shared infrastructure.

Further the following intangible factors may be considered in making a decision about infrastructure sharing.

- Availability of equipment facility without having to spend additional money on production and inspection equipment.
- Availability engineering and skilled expertise to minimize the effect of learning.
- Ease of managing more than one program.
- Better control of programs.

To verify the percentage savings with shared infrastructure claimed by LM, a method was needed. After examining a couple of possible methodologies, it was decided to embark upon the weight based CER methodology. Weight based CER has been very well accepted and used among the engineering cost group at NASA. It is also documented very well in NAFCOM99 manual [5]. In spite of the fact that the NAFCOM software tool has been offering complexity generators approach to account correctly for a variety of cost drivers; the conventional first pound cost approach has still the merit. For many elements that have well defined geometries, it is possible to determine the weights accurately. The first pound cost approach effectively considers the unique / weight relationship for all hardware items.

Flight hardware cost may be estimated using the first pound cost approach from the equation below.

$$Y = A X^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where A = First pound cost
X = Weight of the hardware
b = slope

Slope values for different hardware items derived based on 100 different weight driven CERs obtained from parametric models developed at MSFC, GSFC, JPL, and NASA HQ are listed in a table in the NAFCOM99 manual.

A similar approach has been used in estimating the cost savings that could be realized if two programs with almost identical geometrical relationships were undertaken at the same facility. The geometrical relationship used to identify similarities is the length / diameter ratio. The two elements compared here are: structures and mechanism of ET and payload carrier.

The weight for the structures and mechanism for ET is 62,993 lbs. The first pound cost and the cost slope are: 0.0116 and 0.7 respectively for this element. Therefore the total cost of this element is computed as below.

$$Y = 0.0116 * 62{,}993^{0.7} = \$26.5438M$$

The estimated weight of a notional payload carrier is found to be 61,814 lbs. The cost slope for this element is also 0.7. Therefore the cost is computed as below.

$$Y = 0.0116 * 61{,}814^{0.7} = \$26.1950M$$

If these two elements were made at the same facility, the total weight would be 124,807 pounds. Using the same first pound cost and the cost slope values, the cost if these elements are made in the same facility is determined as below.

$$Y = 0.0116 * 124{,}807^{0.7} = \$42.8376M$$

If these two elements are made at different facilities, the total cost for making both the elements would be 26.5438+26.1950 = $52.7388M. If both of them are made at the same facility based on the total weight of the elements, the cost savings would be about $9.9012M. This results in a percentage cost savings of 19%. The percentage cost savings is in line with the reported [4] cost savings by Lockheed Martin, the operating contractor of the Michoud facility.

Conclusion

Several interesting and useful problems have been investigated, analyzed and reported here. The approach presented for developing the production rate curve slope seems to be very practical and realistic. If applied in practice for items produced at a rate of higher than four, it may prove to be very valuable. The approach indicated for determining potential cost savings that can be realized using shared infrastructure has some merit. It definitely warrants further investigation. The operating contractor of the Michoud facility has provided ample data and convincing percentage savings that could be realized if more than one program is undertaken at Michoud. This has been verified by a very simple methodology developed by the author. Even though, the potential savings estimated is different, the concept of infrastructure sharing has merit. It is prudent for NASA to take a serious look at the available infrastructure at Michoud in pursuit of developing cost effective future space transportation system for exploration of both lunar and mars planets.

Acknowledgements

The author would like to thank the entire team of cost professionals in the Engineering Cost Group in the Transportation Directorate of Marshall Space Flight Center. Special thanks are due to Steve Creech, Barbara Stone-Townsend, Spencer Hill and Charles Hunt. The cooperation and unflinching help extended to the author by the Lockheed Martin personnel at Michoud is very much appreciated. It certainly was a very enjoyable and highly productive summer for the author.

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