An Analytic Explanation for Vertical Integration Behavior in the Marketplace

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ABSTRACT

Vertical integration is a costly and difficult-to-reverse strategy with significant risks, yet it has experienced a sharp rise in popularity within the satellite manufacturing sector over the last decade. This paper explores how commercial parametric cost estimating tools can be used in combination with business-case analysis to understand why firms are increasingly pursuing vertical integration strategies in this sector. The authors build on previous research presented at the NASA Cost & Schedule Symposium, further exploring how these types of tools can be used to identify motivations for vertical integration. Picking up where the initial research left off, this analysis uses financial return, rather than cost, to evaluate firm decisions to vertically integrate. Specifically, the new research evaluates the expected net present value (NPV) for a hypothetical satellite constellation when using two different acquisition approaches ("traditional" vs. "vertically integrated"). Results indicate that when considering financial return, the breakeven constellation size between the two approaches shifts outward by as much as 30 – 50% versus a comparison based on cost alone. These results provide greater context around firm decisions to vertically integrate in this sector and help to explain several inconsistencies seen in the previous research effort. Finally, this paper also demonstrates how the framework for this analysis is extensible to modeling vertical integration decisions in other manufacturing sectors.

INTRODUCTION

Manufacturing in the space industry has historically been a time-consuming and expensive process, dominated by a small number of highly specialized firms. Behemoths such as Boeing, Lockheed Martin, and Airbus have held as much as 80% of the sector at certain times. Drawing upon deep technology heritage and industry expertise, these companies have maintained a relative oligopoly on spacecraft manufacturing and wielded their power to generate significant revenues.

With a traditionally heavy government customer base, high barriers to entry, and relatively low competition, manufacturers have had little incentive to pursue a vertically integrated manufacturing approach. Certainly, given the complexity of space systems, the appetite required to take on the additional technical risks associated with integrated operations would be enough to scare off any manufacturer[1]. Not to mention that a vertically integrated strategy could, potentially, even lower a firm's overall profit, if using a standard cost-plus government procurement approach.

Enter Elon Musk, Jeff Bezos, Paul Allen, and a host of return-hungry investors. Emboldened by the success of technology ventures, this new breed of space cowboy burst on the scene armed with significant capital and the expectation that each dollar be used efficiently, effectively, and with a purpose. These entrepreneurs cast aside the norms of the established space industry, exchanging extended development cycles for agile methodologies focused on reducing costs and trimming unnecessary company baggage. The results of these efforts have been astounding, causing a significant transformation in the launch industry not seen since the 1970s. Behind the success of SpaceX, Blue Origin, Stratolaunch, and others is a surprisingly consistent trend: vertical integration[2][3].

What is Vertical Integration?

Vertical integration refers to a firm bringing additional elements of the industry value chain under common ownership[4]. Simply put, it involves bringing previously out-sourced operations in-house. Firms can vertically integrate both upstream (away from the end user, e.g. into raw materials production) and downstream (closer to the end user, e.g. into providing data analytics), depending on their relative location in the supply chain. Figure 1. illustrates this process in-depth[5].

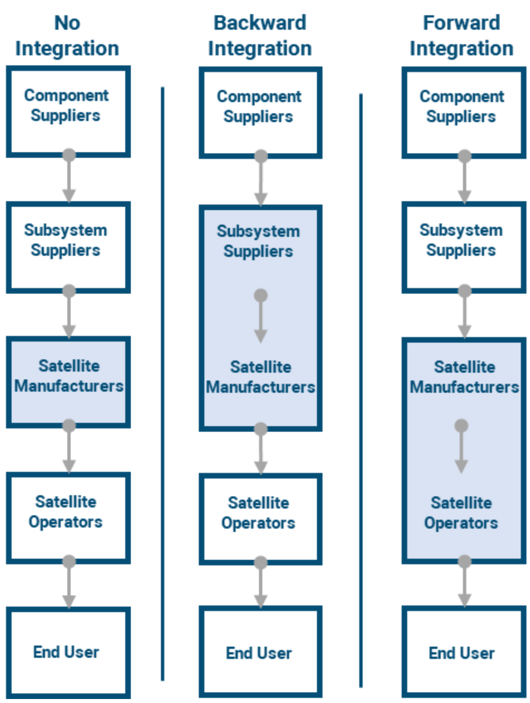

FIGURE 1. VERTICAL INTEGRATION EXAMPLES

In industries such as Oil & Gas, a fully vertically integrated approach is not only common, but a necessity of doing business. In other areas, such as the automobile sector, firms may prefer quasi-integration approaches or its equivalents (such as long-term contracts). In general, vertical integration strategies are adopted as a means of increasing efficiency, controlling costs, and reducing 3rd party risk. It is important to note that in order for the strategy to be effective, the benefits from these effects must outweigh the high setup cost and additional risks associated with integrated operations.

Rise of Vertical Integration in the Satellite Sector

Nearly 15 years after the advent of SpaceX and Blue Origin, the space industry is almost unrecognizable. The Constellation program is long gone, LEO has replaced GEO as an investor's playground, and large, performance-driven platforms are being replaced by swarms of small satellites. Where before there existed a culture of mark-ups, downward pricing pressure and a shift towards commercial revenue streams has spurred increased interest in maintaining cost effective and efficient operations.

Driven in no small part by vertical integration activity in the launch sector, the satellite sector is now beginning to show a greater propensity to manufacture, integrate, operate, and even manage end user sales entirely in-house. Particularly in the small satellite segment, major players such as Planet, Spire, and GomSpace have already at least partially adopted this strategy, and SpaceWorks research suggests many more firms are still to follow[6].

The allure of vertical integrated operations, a la SpaceX, is hard for satellite manufactures to resist. An increased focus on large, disaggregated satellite constellations (vs. single, highly capable spacecraft), contributes to the need for economies of scale to close capital-intensive business cases. Inconsistent component suppliers additionally provide headaches that vertical integration promises to resolve. For many in the small satellite sector, this operational paradigm may even be an imperative in order to develop the emerging markets they hope to serve.

Still, vertical integration is a costly, and virtually irreversible corporate strategy, with significant associated risks. While the benefits can be great, firms that fail to effectively implement put themselves at an extreme disadvantage, one that could be costly in an industry where first-to-market firms seem to trump fast-followers more often than not – a fact not likely to be lost on executive leadership. So, what is it that makes vertical integration suddenly so compelling in an industry that once seemed to barely know such a strategy existed?

In an attempt to better understand the corporate motivations behind the rise in vertical integration across the satellite manufacturing sector, SpaceWorks has invested significant effort into investigating how internal and external control, risk, and evolving industry trends are changing the way satellite manufacturers operate. The results of this ongoing research were originally presented at the NASA Cost & Schedule Symposium and additionally appeared in the 2019 SpaceWorks Nano/Microsatellite Market Forecast[7,8]. This latest installment of the continually evolving series expands on the previous study effort by considering additional key venture performance metrics and serves to expand the industry's understanding of vertical integration behavior in the marketplace.

SUMMARY OF PAST RESEARCH

Corporate Motivations for Vertical Integration

The initial foray by the authors into the modeling of vertical integration behavior in the satellite sector was presented at the 2018 NASA Cost & Schedule Symposium. This prior research focused specifically on the impact of vertical integration on Average Per Unit Costs (APUC) of two types of small satellite constellations: a 3U satellite constellation (used for satellite Internet-of-Things connectivity), and a 300 kg satellite constellation (used for broader, low latency communications). The two constellations in question were chosen as representative examples of the types of ventures currently under development in the marketplace. As shown in SpaceWorks' 2018 and 2019 Nano/Microsatellite Market Forecast, the small satellite sector is aggressively diversifying into communications applications and, given their current stage, are likely to be actively considering different satellite manufacturing approaches[9,10].

As part of this initial study, satellite costs were quantitatively modeled using Galorath's SEER-H cost estimation tool. Costs were estimated using both a traditional approach, in which the majority of the system components were purchased from external vendors, and a vertically integrated approach, in which the manufacturer handled the entirety of the development and production process in-house. Results for the two procurement approaches were evaluated for constellations of various sizes, ranging from as few as 16 satellites to as many as 256. In addition to the baseline case, market conditions that may incentivize vertical integration were also modeled. The relevant market characteristics considered were: Market Power, Quality Control, and Vendor Disruptions.

As commonly expected, upfront costs associated with a vertically integrated approach far surpassed initial costs in a traditional manufacturing approach. However, by comparing the APUC for different constellation sizes, a breakeven point, (that is, the number of satellites at which a vertically integrated approach becomes more cost effective than the traditional manufacturing approach) was identified. This breakeven point is of particular interest to the overall investigation, as it provides insight into how economies of scale play a role in firm's decisions to vertically integrate. Practically speaking, it informs the required number of satellites before the benefits from these economies of scale outweigh the additional upfront costs. Further, when examining sensitivities to unique factors present within the marketplace, the magnitude shift in the breakeven point serves as a surrogate for evaluating how compelling this condition is for vertically integrating. The results of these APUC calculations can be found in Figures 2 – 9.

Baseline Case

The results from the baseline cases in this study indicated a satellite constellation size breakeven of 88 satellites in the 3U case, and 39 satellites in the 300 kg case. These results indicate that economies of scale play at least some role in the decision to vertically integrate. It appears from these cases that constellations larger than this breakeven point would achieve lower costs due to economies of scale by bringing manufacturing in-house. Additionally, the widening relationship between APUC as constellation size increases demonstrates that the larger the size of the constellation in question, the more attractive vertical integration becomes from an APUC perspective.

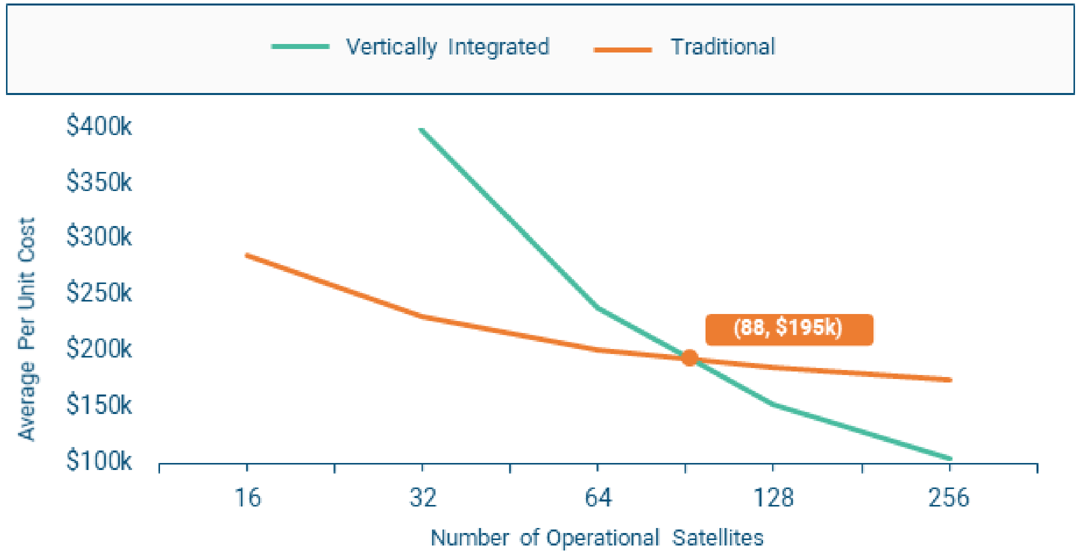

FIGURE 2. 3U CONSTELLATION COMPARISON APUC BASELINE CASE

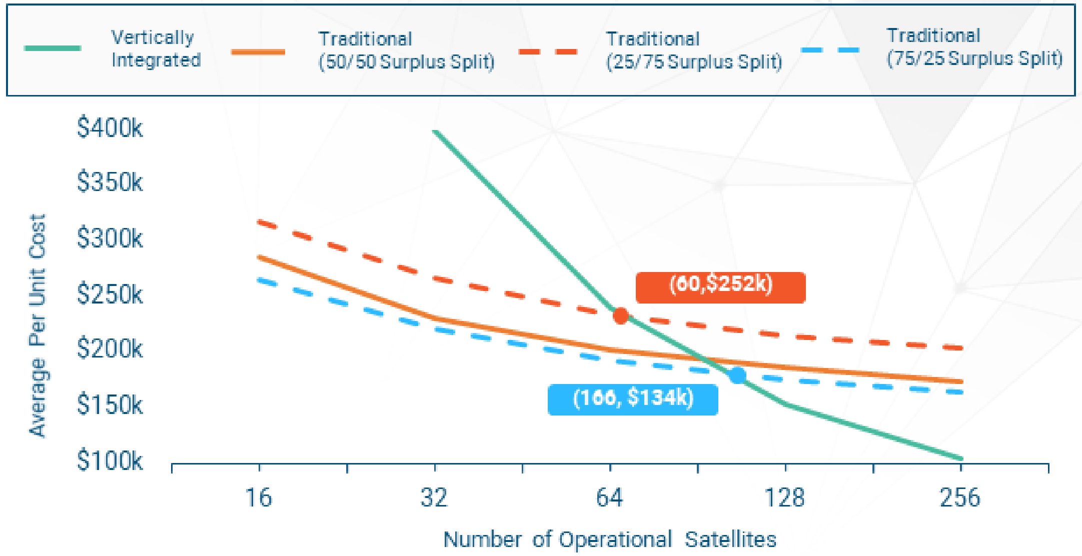

FIGURE 4. 3U CONSTELLATION COMPARISON APUC MARKET POWER SENSITIVITY

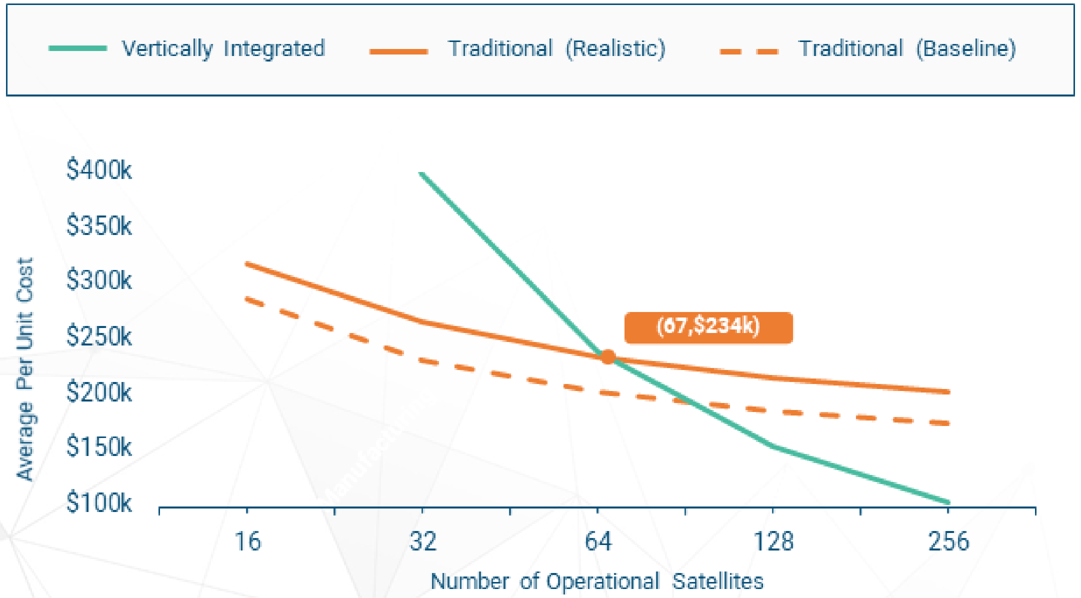

FIGURE 3. 3U CONSTELLATION COMPARISON APUC MARKET REALISTIC CASE

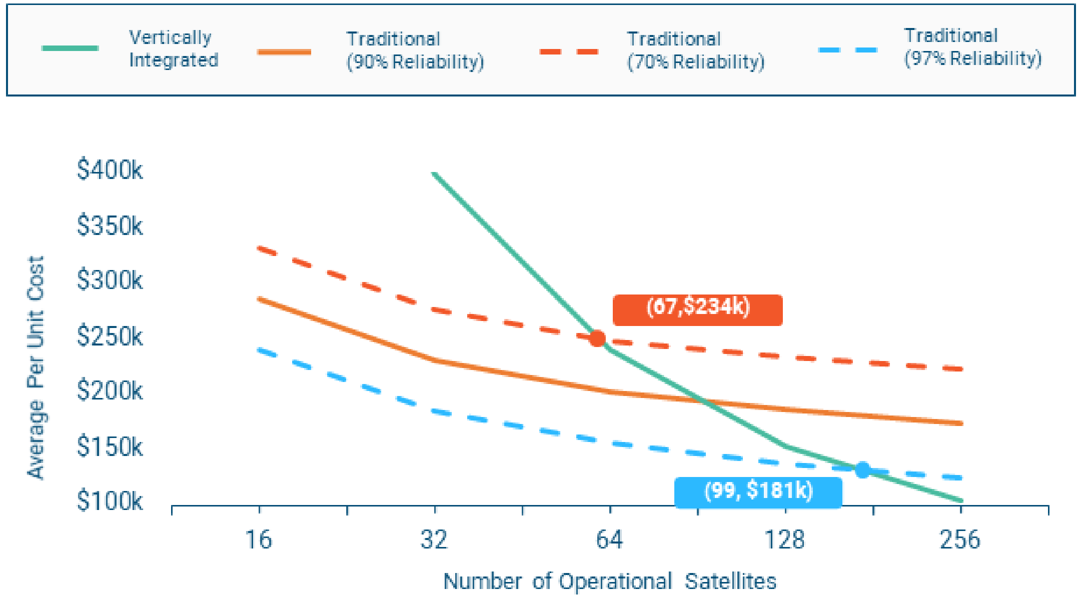

FIGURE 5. 3U CONSTELLATION COMPARISON APUC QUALITY CONTROL SENSITIVITY

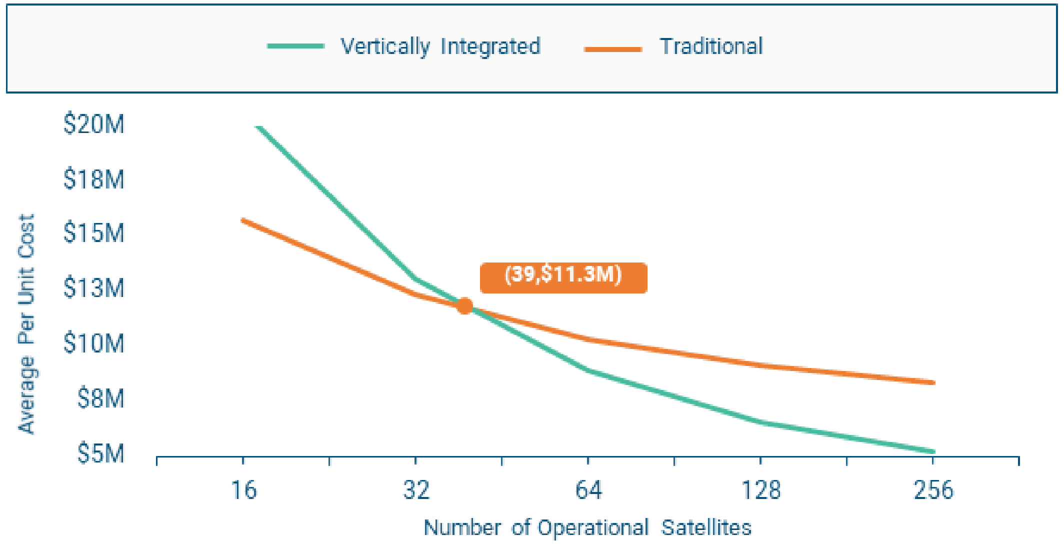

FIGURE 6. 300kg CONSTELLATION COMPARISON APUC BASELINE CASE

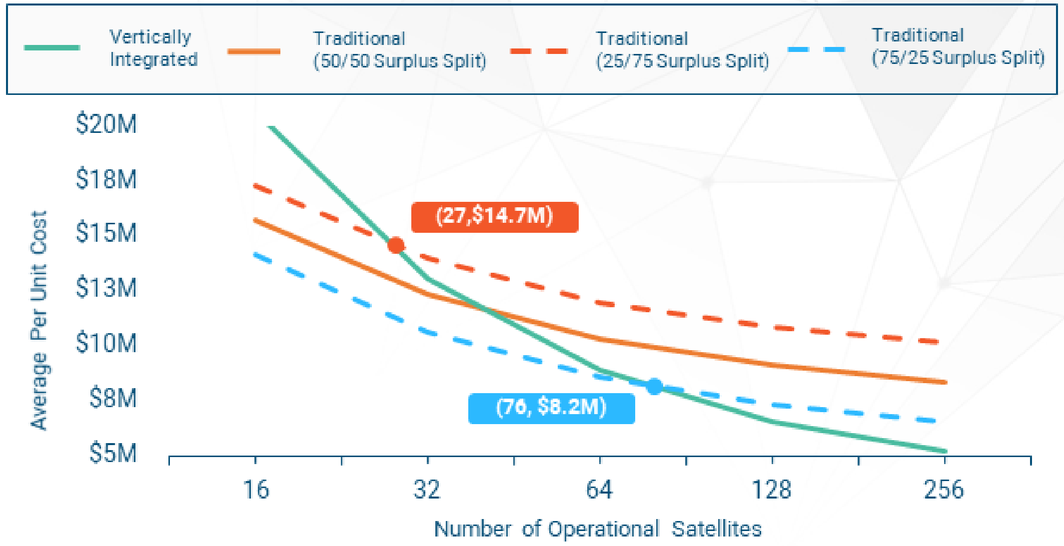

FIGURE 7. 300kg CONSTELLATION COMPARISON APUC MARKET POWER SENSITIVITY

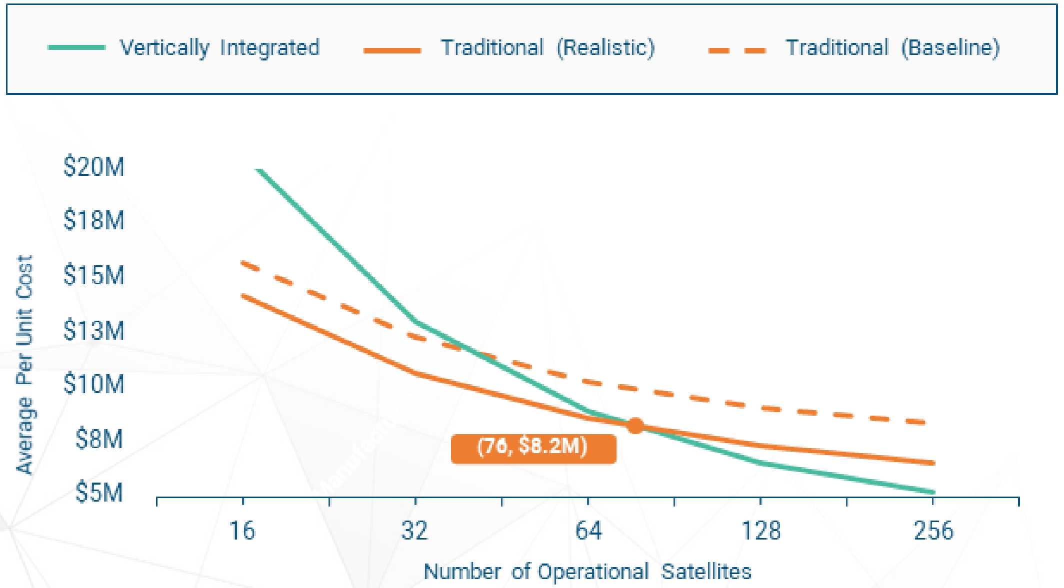

FIGURE 8. 300kg CONSTELLATION COMPARISON APUC MARKET REALISTIC CASE

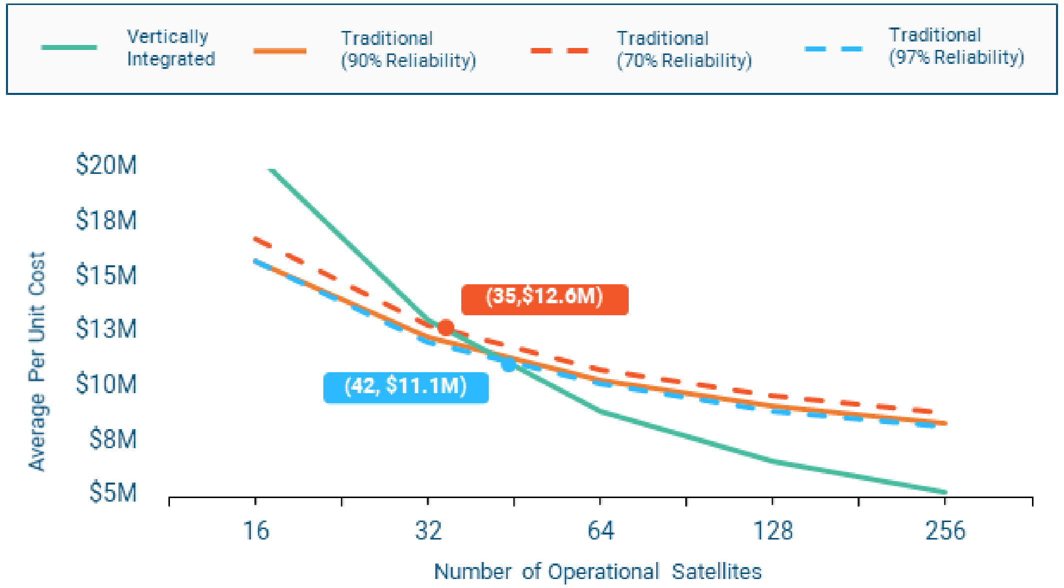

FIGURE 9. 300kg CONSTELLATION COMPARISON APUC QUALITY CONTROL SENSITIVITY

Still, one must refrain from taking the baseline results out-of-context. The additional cases considered in this study highlight how consideration of different marketplace characteristics impact the overall satellite constellation breakeven point.

Case #1: Market Power

In Case #1: Market Power, the ability of manufacturers to negotiate favorable rates from their component vendors was considered. To simulate this effect, supplier/manufacturer split of the surplus received from the aforementioned economies of scale was modeled (see the *Extensibility to Other Research* portion of this paper for more on this modeling approach).

From the results of this case, it appears market power dynamics have a significant impact on the breakeven between the two procurement approaches. This case demonstrates that when market power dynamics favor suppliers, the satellite constellation size breakeven point decreases by around 30% (making a vertically integrated approach viable at smaller constellation sizes). Conversely, if market power dynamics favor the manufacturer, the breakeven is shifted outwards by over 90%. These findings depending on the rates manufacturers are able to negotiate with their suppliers, vertical integration may be more or less advantageous. Given this, it can be concluded that any realistic evaluation of the breakeven point between traditional and vertically integrated manufacturing approaches must take market power dynamics into account.

Case #2: Quality Control

In Case #2: Quality Control, the ability of firms to exert greater control over their internal processes when using an integrated approach was considered. While increased control can manifest itself in many ways, such as quicker design iterations or streamlined testing, the ultimate end result is assumed to be a higher quality product. For the purposes of evaluating this market dynamic, overall satellite reliability, or failure rates, were varied to simulate the impact of different levels of internal control.

The results of this case indicate that quality control has a clear impact on satellite APUC, though it is less significant than the impact of market power. Improvements from increased quality control depend largely on the starting point – when traditional manufacturing yields high baseline reliability rates, the impact of bringing operations in-house is muted, as seen in the 300 kg case. In the 300 kg spacecraft scenario, status-quo reliability is already quite high, leaving little room for improvement. Because of this, the breakeven point is only reduced or increased by 10% when varying levels of internal control. In contrast, for the 3U spacecraft, status-quo reliability is quite low, leaving greater room for improvement. The breakeven in this case shifts as much as 25% when exerting different levels of internal control. An important finding of these results is that internal control can be a powerful motivator for vertical integration, but only if well executed. Increased control over processes must manifest itself as improved reliability (or reduced failures) in order to reduce satellite APUC. Additionally, this case illustrates that substantial improvements in reliability must be achieved, as marginal improvements yield minimal change in the satellite constellation breakeven. To this point, it is worth noting there is some precedence in the marketplace for achieving substantial quality improvements when using a vertically integrated approach[11].

Case #3: Supplier Disruptions

The final case from the initial research investigated the role of supplier disruptions in motivating firms to vertically integrate. Research from McKinsey & Company's "When and When Not to Vertically Integrate" indicates that high transaction costs can be a compelling reason for vertical integration[3]. While satellite companies typically make a small number of transactions for a large number of highly specialized assets, resulting in low transaction costs, increased transaction costs are likely to occur in the case of vendors ceasing to sell baselined components. Under this scenario, a new vendor would be needed, and thus, an additional transaction. To simulate this higher transaction cost scenario, vendor disruptions on several key value subsystems were considered after the 16^{th} unit, forcing the manufacturer to re-develop the subsystem around a new component.

Results seen in this case indicate that concerns regarding vendor disruptions may be overstated, potentially leading to a mistaken motivation for vertical integration. In the 3U case, a vendor disruption only shifted the breakeven point by 1-3%. The relatively low development costs in this segment allow the additional transaction costs to be amortized over the size of the constellation with relatively minimal impact. The 300 kg segment saw a comparatively greater impact, with vendor disruptions shifting the constellation breakeven by 3 – 17%. Higher development costs in this segment, and a smaller number of satellites, cause the impact of vendor disruptions to be more concentrated. Ultimately, it appears that a single vendor disruption on an individual subsystem has relatively little impact on APUC (and thus, motivations to vertically integrate). This research postulates that if component design were forced in-house due to a vendor disruption, or multiple vendor disruptions occurred at once, it may present a more compelling case for vertical integration. Note that the results of this case are not shown, as it was not considered as part of the current research effort.

Market-realistic Case

The baseline and subsequent cases in this study considering various sensitivities to market conditions were all evaluated independent of one another. To capture a more accurate picture of the marketplace, the final case integrates all previously examined cases together, and assesses current market conditions in the 3U and 300 kg segments to create a "market-realistic" case. This case is meant to depict the most accurate point-of-departure for understanding corporate motivations for vertical integration and serves as the starting point for any future research.

For the 3U case, it was assessed that while market power dynamics were balanced in this segment (yielding no change from the baseline), current component reliability rates were less than initially modeled. Lower reliability rates observed in this segment indicate that there is significant room for improvement via exerting greater internal control over manufacturing processes. This shift in reliability makes vertical integration more cost effective than traditional manufacturing approaches at smaller constellation sizes. Ultimately, the market-realistic case for this segment moved the constellation size breakeven inward from 88 satellites to just 67 satellites.

Within the 300 kg segment, it was assessed that market power dynamics tended to favor the manufacturer, due to a large number of component suppliers moving into this space from the GEO communications market. As manufacturers are thus able to negotiate more favorable supplier rates, the case for traditional manufacturing is strengthened. Ultimately, the market-realistic case for this segment moves the constellation size breakeven outward from 39 satellites to 76 satellites.

Study Conclusions

The analysis provided in *Corporate Motivations for Vertical Integration* yielded a great deal of insight into firm's motivations behind vertical integration decisions. The primary takeaways from this study are that economies of scale and market power dynamics have a dramatic impact on the cost-effectiveness of vertical integration approaches. Additionally, the study concludes that quality control can be a compelling motivation for vertical integration, but only if the increased internal control is able to yield significant improvements in satellite reliability rates. Finally, the study also notes that while the results appear to indicate many of the constellations currently proposed or in-development would benefit from vertical integration, this strategy should be approached with caution, as it is costly, near irreversible, and bears significant risk. It advocates for a wholistic approach to evaluating vertical integration decisions, considering market expectations in the future (not just current trends), and a variety of financial and organizational factors.

ORIGIN OF CURRENT RESEARCH EFFORT

Corporate Motivations for Vertical Integration established a valuable baseline for understanding motivations for vertical integration in satellite manufacturing, but its focus on average per unit cost provides a limited view of how companies make financial decisions. A critically neglected component in this study was the time value of capital. In all businesses, capital deployment decisions must be weighed against opportunity cost.

For the purposes of financial modeling, the opportunity cost of deployed capital is often estimated by using discounted cash-flows to account for the return that could have been generated if the capital were simply invested at nominal market return rates[12]. Most commonly, this value is shown as the net present value (NPV), or the current-year value of the stream of cash flows, discounted against the average market return.

The evaluation of vertical integration decisions in the context of NPV, rather than cost, is particularly important to this research, as vertically integrated firms require significantly more upfront capital than their traditional manufacturing counterparts[5]. As identified in the previous research effort, development costs associated with a 3U satellite are over 5x more when using a vertically integrated approach than a traditional approach ($10.6M vs. $1.6M). Even in the 300 kg case, vertically integrated development costs are more than 2x those in the traditional approach ($239M vs. $114M).

Further, as many of the companies pursuing large satellite constellations are backed by venture capital, they face additional constraints regarding available capital and expected return[13]. It appears that relatively few small satellite companies could afford to adopt a fully vertically integrated approach at their outset, due to Series A funding rounds of less than $10M[14]. Even if these initial constraints were lifted, as firms operating with limited access to capital, one might question the decision to spend such a large amount upfront, given that cost savings would not manifest themselves until much later. Further, as the typical venture capital investment cycle involves a successful exit within 7 – 10 years, it is conceivable that a traditional manufacturing approach could actually yield a better NPV during this timeframe (thus, a potentially higher valuation), due to its lower initial capital requirements.

The current research effort is meant to address this key gap left from the initial study. At its core, the effort was developed to evaluate the role that the time value of capital plays in a firm's decision to vertically integrate. Research presented here builds on the initial models created for the *Corporate Motivations for Vertical Integration* study, and integrates them with business-case analysis to examine the impact of NPV on vertical integration decisions in the satellite manufacturing sector.

METHODOLOGY & ASSUMPTIONS

The overall study methodology was concerned with estimating costs (manufacturing and business operations) and revenues for two hypothetical satellites ventures. Similar to *Corporate Motivations for Vertical Integration*, the two satellite ventures consisted of a 3U constellation, nominally for the purposes of serving the satellite IoT market, and a 300 kg constellation, nominally for the purposes of serving the broader low-latency communications market. Both ventures were assumed to be begin with zero operational satellites and relatively few employees. The general approach was to establish credible estimates for costs and revenues associated with constellations of various sizes using different manufacturing approaches (traditional and vertically integrated), then assess their relative return on investment.

Comparing the return metrics (in this case, NPV) between the two approaches can then be used to determine a new satellite constellation breakeven point, where the vertically integrated approach becomes more financially attractive than the traditional approach. Evaluating the results from the APUC satellite constellation breakeven estimates obtained in the initial research against the updated results based on NPV demonstrates the impact of the time value of capital on vertical integration decisions. The final outcome of this analysis is intended to provide additional insight into how the consideration of financial return metrics, not just cost, paints a more complete picture of marketplace behavior, and may provide additional context around vertical integration behavior seen in the marketplace.

The primary methodology and assumptions for this research are broken into two separate parts: cost modeling and business case modeling

Cost Modeling Methodology

Manufacturing Costs

Modeling of manufacturing costs for this effort used the same methodology established in *Corporate Motivations for Vertical Integration*. It involved using Master Equipment Lists (MELs) developed by SpaceWorks as the primary input, supplemented by the Price Systems' *Unit Learning Curve Framework*[15]. For each of the two satellite types, costs were modeled using the SEER-H estimating software in accordance with best practices outlined in the NASA SEER Space Guidance document[16].

Heritage assumptions were varied to appropriately capture traditional vs. vertically integrated procurement approaches. In general, the traditional approach leveraged an "Average Modification" component baseline, while the vertically integrated approach leveraged a "Make" component baseline to reflect key differences in development effort associated with each manufacturing process. More details regarding modeling manufacturing costs can be found in the *Extensibility to Other Research* section of this paper, where a general approach to modeling vertical integration decisions is discussed.

Cost models for both the traditional and vertically integrated approaches were repeated for satellite constellation sizes of 16 – 256 satellites, allowing for average per unit costs (APUC) to be calculated based on the overall constellation size. APUC was calculated using the following equation:

$$\frac{(Satellite\ Development\ Cost + Constellation\ Production\ Cost)}{Total\ Number\ of\ Satellites}$$

By plotting APUC vs. constellation size for the two approaches, the constellation size breakeven point can be identified. This satellite constellation breakeven indicates the number of satellites that must be produced before a vertically integrated approach becomes more cost-effective than the traditional approach.

An overview of the cost modeling process in its entirety can be seen in Figure 10. Specific details for each of the case-specific modeling approaches applied to considerations of market characteristics can be found in the *Extensibility to Other Research* portion of this paper. For the purposes of documenting the methodology of the current study, it should be noted that only the market-realistic case from the previous effort was used.

Satellite production was spread over a multi-year period in an effort to accurately reflect historical marketplace performance of emerging satellite firms. During the first two years of venture operations it was assumed that two satellites would be launched as technology demonstration missions. These early prototypes would help the firm to refine their design and pursue outside investments for their full constellation. As such, the third year of operations was modeled as a "capital raising" year in which no satellites are produced. It is not until the

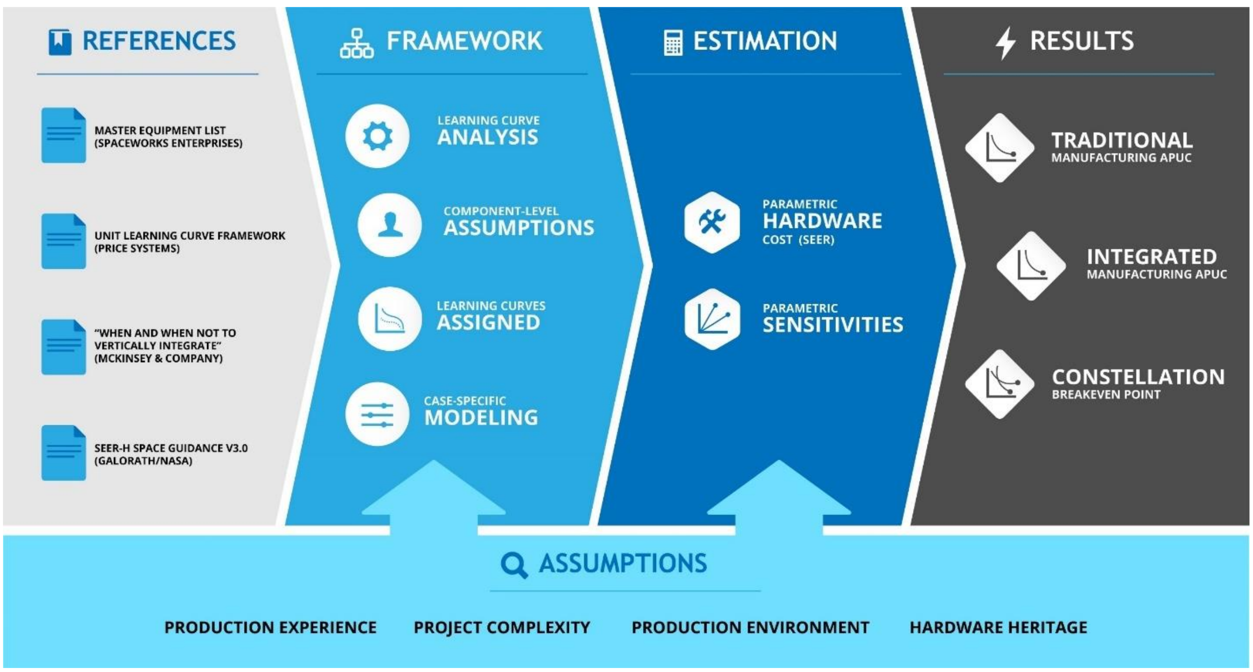

FIGURE 10. MANUFACTURING COST METHODOLOGY

fourth year of operations that the venture begins full production of its satellite constellation. Additionally, production in these first years were assumed to be limited as manufacturing processes, personnel, and management techniques are established. Full-capacity production operations are assumed to begin in year seven. A detailed breakdown of maximum year-over-year satellite production counts used for this analysis can be seen in Table 1.

TABLE 1. SATELLITE PRODUCTION ASSUMPTIONS

Year	Max Satellites Produced (3U)	Max Satellites Produced (300kg)
Year 1	0	0
Year 2	3	3
Year 3	0	0
Year 4	16	4
Year 5	32	16
Year 6	64	32
Year 7	100	64
Year 8	100	64
Year 9	100	64
Year 10	100	64

Maximum number of satellites produced in a given year varies based on the satellite size, reflecting differences in the production processes of Cube Satellites vs. larger Micro Satellites. The traditional and vertically integrated approaches for satellites of the same size were assumed to have the same maximum production value.

Non-Manufacturing Costs

To accurately consider the impact of NPV, it is critical to fully account for all costs associated with the expected revenue streams, meaning additional costs outside of manufacturing must be considered, even if they are equivalent across the two approaches. For the purposes of simplicity, the authors broke out these additional costs into only two categories: launch and business operations.

Launch costs were relatively easy to estimate, as readily available rideshare pricing can be found via Spaceflight Industries, Innovative Solutions in Space, and others[17]. Baseline launch costs used for this analysis were $240k per satellite (3U) and $8M per satellite (300 kg). Arguably, if deploying an entire constellation, a satellite operator could negotiate for a lower per-unit launch cost, however, the scope of this type of negotiation was outside of this research effort and not considered.

Business operations costs in this context were intended to encompass the non-manufacturing workforce and facilities associated with each of the satellite ventures. To approximate a reasonable "functional workforce" cost estimate, the authors leveraged employee distributions from several well-known satellite start-up companies (including Planet Labs, Spire, Astrocast, and Capella Space). These workforce distributions served as analogies so that year-by-year functional employee counts could be estimated for each hypothetical satellite venture in the study. The functional employee counts were then multiplied by industry standard, fully-burdened labor rates to calculate annual business operations costs.

Business Case Modeling Methodology

Revenues

Iridium Communications is a company founded in 2001 that currently operates a network of Low Earth Orbiting (LEO) satellites used for voice and data communications[18]. As a publicly traded company, Iridium is required to publish financial disclosure statements including their annual revenue and operations costs. Given the availability of this data, as well as the near-perfect business model match with the ventures being evaluated, Iridium's performance was identified as representative of the types of revenues that could be generated by a satellite communications company. Of particular interest to this effort, Iridium segments out the specific portion of its revenue attributable to IoT offerings, in addition to its overall satellite communications revenue. These two numbers provide excellent basis-of-estimates for both the 3U IoT satellite constellation and the larger 300 kg communications satellite constellation.

To estimate expected revenues for the two constellations, Iridium revenues were scaled based on two factors: constellation capacity and real-time coverage penalty.

Constellation capacity dictates the total data throughput and amount of ground terminals that can communicate with the constellation (i.e., number of total subscribers/customers), making it perhaps the most critically important scale factor for estimating revenues. The real-time coverage penalty is also essential to estimating revenues, as a wide variety of additional customer segments and price points are enabled once satellite communications constellations are able to provide real-time coverage[19]. Integrating the two scale factors, revenues for the two satellite constellations were estimated using the following equation:

$$(Iridium\ Revenue) \times \frac{(Constellation\ Capacity)}{(Iridium\ Capacity)} \times (Realtime\ Coverage\ Penalty)$$

As a reminder, Iridium revenues for the 3U constellation only include those associated with IoT offerings, while revenues for the 300 kg constellation include Iridium's total revenues associated with its broader offering portfolio.

Capacity for each of the two satellite constellations was estimated based on the total number of operational satellites. For the 3U constellation, each satellite was assumed to have a capacity of 0.2 Gbps, while the larger 300 kg constellation was estimated to have a capacity of 4 Gbps per satellite. While technical characteristics of a satellite would vary greatly based on their overall design, these estimates are consummate with what has been seen in the marketplace, and provide a reasonable basis-of-estimate for evaluating the total potential constellation capacity.

Additional Business Model Considerations

In developing the business model for the two satellite constellations in question, several additional assumptions had to be made regarding the discount rate, NPV year, revenue growth, etc. Table 2 details the remaining assumption parameters used for this analysis not covered elsewhere in the *Methodology & Assumptions* section.

TABLE 2. GENERAL BUSINESS MODEL ASSUMPTIONS

Parameter	3U	300kg
Discount Rate	7%	7%
NPV Year	Year 10	Year 10
Revenue Growth Rate	8%	8%
Satellite Operational Life	5 years	7 years

Before closing out the *Methodology & Assumptions* portion of this paper, it is important to note that this research's primary aim was not to comprehensively evaluate the business model associated with a satellite IoT or communications venture. The effort was intended to develop a reasonable estimation of expected revenues associated with a hypothetical venture so a realistic NPV could be calculated and compared across traditional and vertically integrated manufacturing approaches. Revenues and non-manufacturing cost estimates in this paper are intended only to be representative, not predictive. A number of key assumptions were made in order to model a representative business case for the two satellite constellations – assumptions were made based on historical analogies present in the marketplace, but are not intended to be infallible. For any company looking to evaluate vertical integration decisions, the calculations could differ, potentially significantly so. It is important to consider that this representative case is only meant to establish a baseline that allows for generalizations to be made about how the time value of capital impacts the decision of firms to vertically integrate.

RESULTS

The results of this analysis provide additional context around the decisions of satellite firms to vertically integrate. Of particular interest to this research, new satellite constellation breakeven points for both the 3U and 300 kg satellite constellations were identified. Additionally, results from this investigation yielded additional insights into expected year-over-year cash flows and maximum exposure rates, which are important financial metrics for consideration when evaluating major corporate strategy decisions.

3U Constellation Results

Evaluation of net present value for the hypothetical 3U IoT satellite constellation venture presented intriguing results. The baseline case provided an updated breakeven point of 61 satellites, a shift inward, rather than outwards, from the initial point identified when only considering average per unit costs (64 satellites). Results for the 3U satellite constellation can be found in Figure 11 and Table 3.

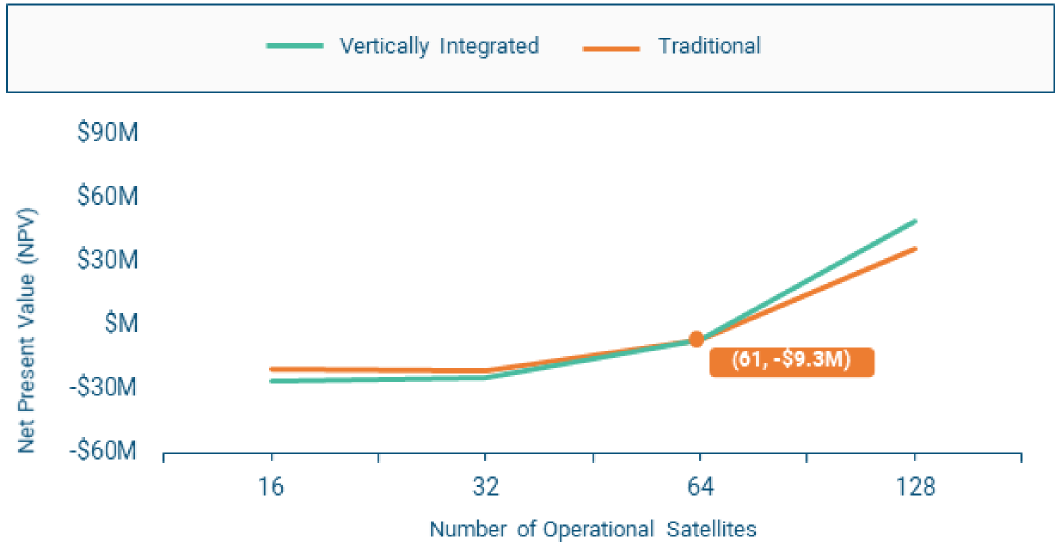

FIGURE 11. 3U CONSTELLATION COMPARISON NPV BASELINE case (7%)

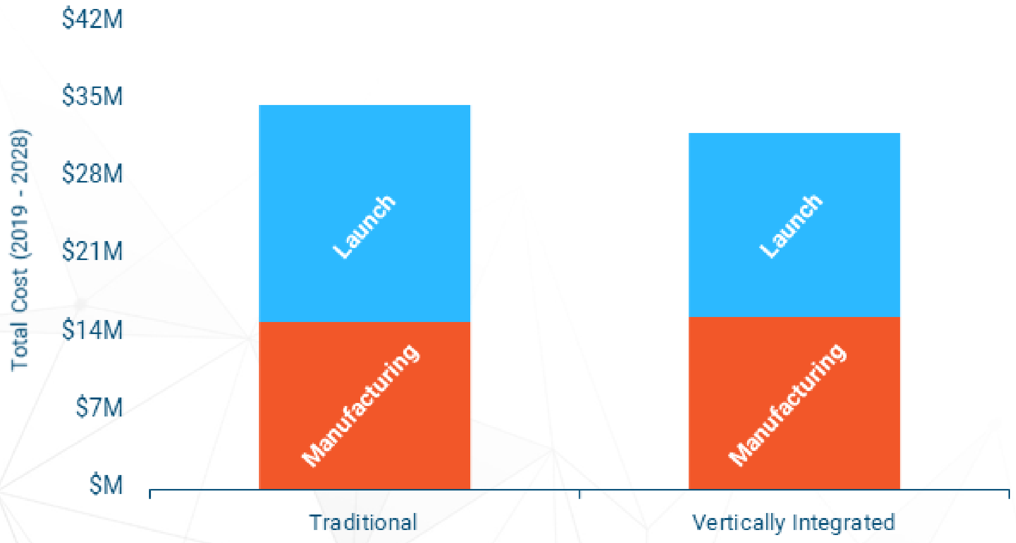

FIGURE 12. 3U CONSTELLATION COMPARISON – BREAKEVEN CASE (61 SATELLITES) MFG. & LAUNCH COSTS

FIGURE 13. 3U CONSTELLATION COMPARISON NPV DISCOUNT RATE SENSITIVITIES (2%, 8%, & 20%)

TABLE 3. 3U SATELLITE CONSTELLATION COMPARISON NPV BASELINE (7%)

# of Satellites	Traditional NPV	Vertically Integrated NPV
1	($21.1M)	($28.0M)
2	($21.5M)	($27.9M)
4	($21.5M)	($27.9M)
8	($21.8M)	($28.1M)
16	($20.5M)	($25.7M)
32	($20.8M)	($24.2M)
64	($6.1M)	($6.1M)
128	$36.7M	$49.3M
256	$245.6M	$298.8M

An inward shift in the satellite constellation breakeven is initially quite curious, as it was thought that integrating the time value of capital would make vertical integration less attractive (shifting the point outward), given the large upfront costs associated with this approach. At only 61 satellites, the manufacturing costs of the vertically integrated are actually higher than the traditional approach, in addition to being more highly concentrated in earlier time periods. Based on any amount of financial logic, these two features should combine to result in a lower NPV for the vertically integrated approach. The resolution of this paradox comes by considering the launch costs.

Figure 12 depicts the manufacturing and launch costs for the baseline breakeven case (61 satellites). As seen in this graphic, manufacturing costs are slightly higher in the vertically integrated approach (as expected), however, launch costs, are lower than the traditional case. The reason for higher launch costs in the traditional approach is due to overall satellite reliability. Under the current assumptions, based on the findings from *Corporate Motivations for Vertical Integration*, reliability for the traditional approach was benchmarked at 70%, as compared to 90% for the vertically integrated approach. Lower reliability manifests itself as a requirement to produce more units to achieve the same number of operational satellites. While this additional cost is accounted for in the APUC breakeven calculation, the APUC only considers manufacturing, not launch costs. Since launch costs are a relatively large percentage of total satellite cost (nearly 50%), this has a significant impact on the breakeven point. Even though launch costs occur in later periods than the manufacturing costs, their magnitude is significant enough to shift the breakeven inwards. To confirm these results, launch costs were set to zero (artificially making them the same for both approaches) and the breakeven was observed to shift outward to 88 satellites, indicating that launch costs are, indeed, responsible for the inward shift.

An evaluation of the impact of varying discount rates, shown in Figure 13, yielded interesting, if unsurprising, results. Discount rate sensitivities of 2%, 8%, and 20% were chosen to demonstrate how different capital lending environments could impact firm's decisions to vertically integrate. The rates chosen reflect that of "risk-free" capital (e.g., U.S. Treasury Bonds), private-sector debt capital (e.g., corporate bonds), and high-risk capital (e.g., venture capital). At a 2% discount rate, vertical integration becomes more attractive at a smaller constellation size – 44 satellites rather than 61. Conversely, at a 20% discount rate, vertical integration becomes less attractive, and the breakeven point shifts outward to 94 satellites. These trends are consistent with expectations, as discount rates impact capital expenditures in early periods more than those in later periods, making vertical integration appear less attractive under higher discount rate assumptions. The identification of constellation breakeven points, however, does contribute to the overall body of research into vertical integration behavior in the satellite manufacturing sector, and the implications are more broadly discussed in the *Insights & Analysis* portion of this paper.

It is worth noting that the breakeven point under any of the discount rates considered occurs at a negative NPV. While this would seem to indicate that a vertically integrated approach is always the best approach for a satellite IoT venture (as vertical integration is always more attractive, given a positive NPV), the results should not particularly be interpreted this way. These results are intended to provide context around how satellite constellation breakeven points differ when comparing NPV and APUC calculations, not to fully characterize expected returns for satellite communications ventures. The breakeven point and magnitude of change from the baseline and previous research effort are of much greater extensibility than the NPV itself.

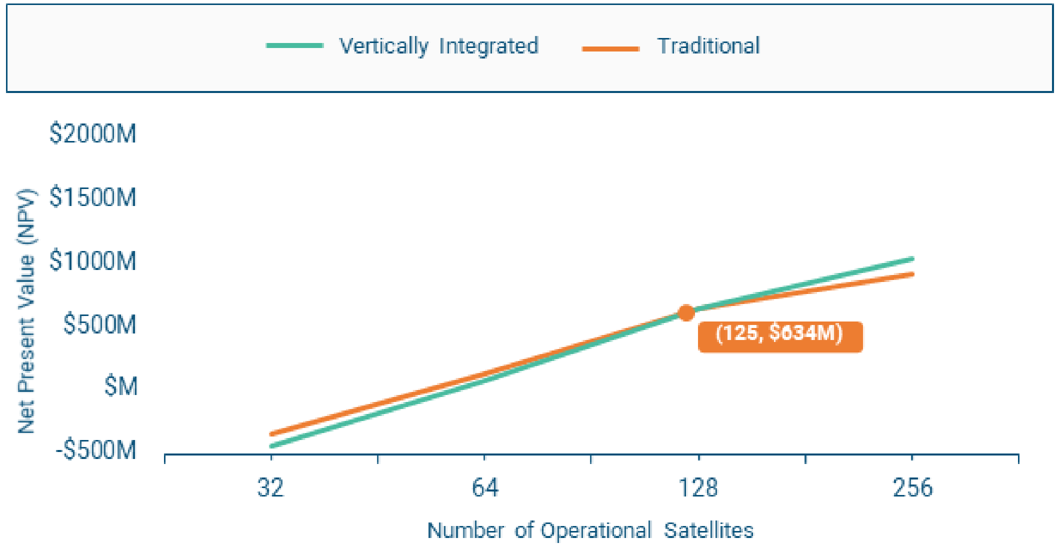

FIGURE 14. 300kg CONSTELLATION COMPARISON NPV BASELINE CASE (7%)

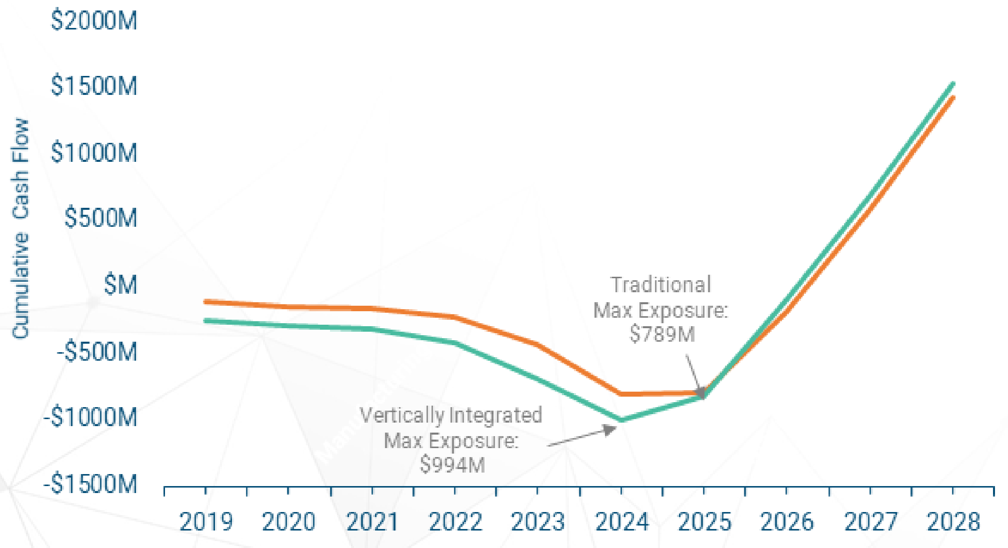

FIGURE 15. 300kg CONSTELLATION COMPARISON – BREAKEVEN CASE (125 SATELLITES) CUML. CASHFLOW

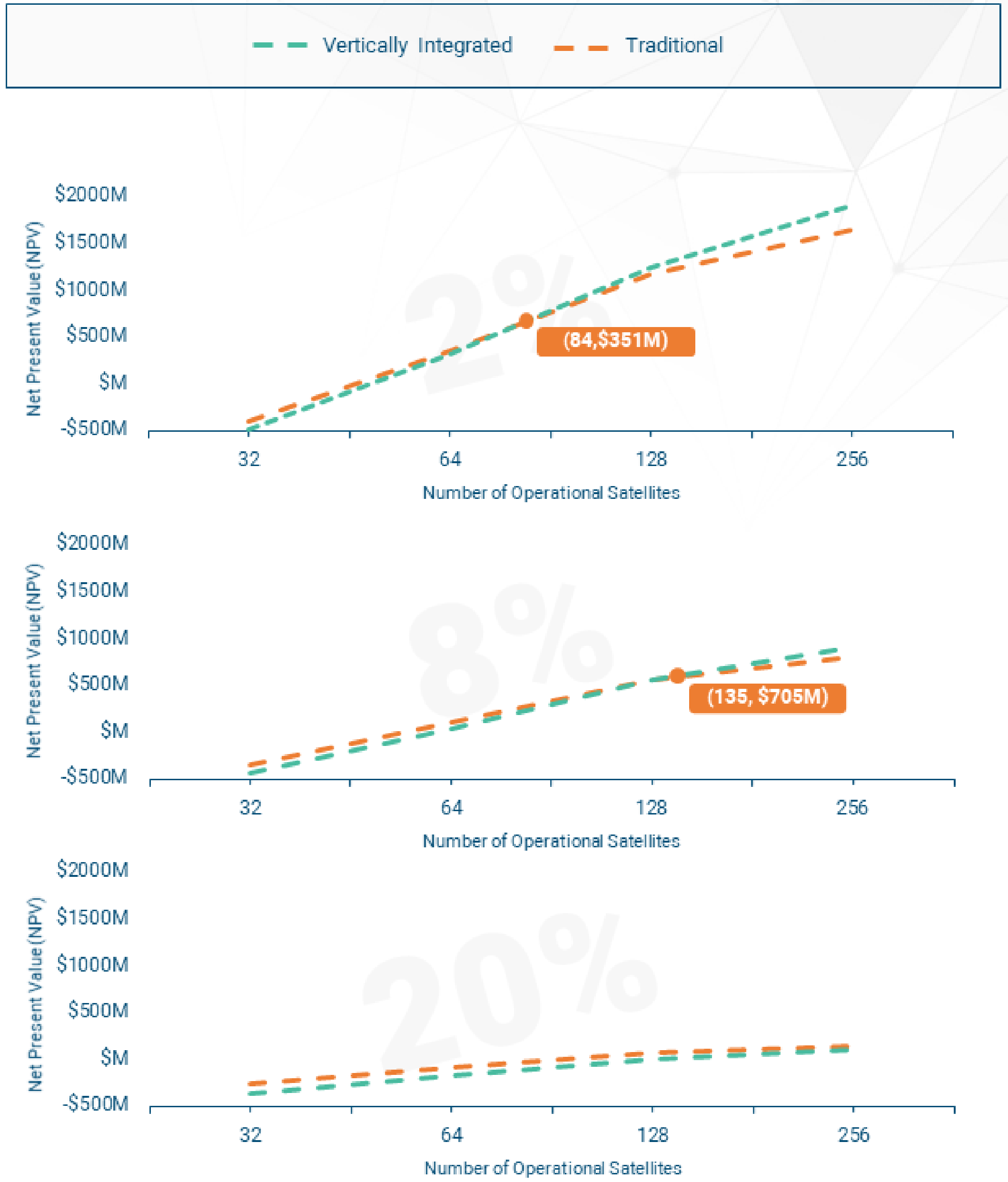

FIGURE 16. 300kg CONSTELLATION COMPARISON NPV DISCOUNT RATE SENSITIVITIES (2%, 8%, & 20%)

300 kg Constellation Results

Results from the 300 kg constellation were less surprising than those seen in the 3U. The overall increase is more significant than originally thought, but does follow the expected trend. When considering NPV, the satellite constellation breakeven shifted outwards, from 76 satellites to 125 satellites, an increase 50%+. Results of 300 kg constellation can be found in Figure 14 and Table 4.

TABLE 4. 300 kg SATELLITE CONSTELLATION COMPARISON NPV BASELINE (7%)

# of Satellites	Traditional NPV	Vertically Integrated NPV
1	($167M)	($287M)
2	($178M)	($201M)
4	($201M)	($317M)
8	($241M	($355M)
16	($312M)	($419M)
32	($344M)	($436M)
64	$138M	$78M
128	$651M	$655M
256	$927M	$1,050M

At 125 satellites, the breakeven point for the 300 kg constellation is significantly greater than that seen in the 3U. Additional upfront capital expenditures associated with the vertically integrated approach in the 300 kg constellation are nearly 10x of that seen in the 3U constellation, contributing to a longer payback cycle. Figure 15 demonstrates this payback cycle in the form of year-over-year cumulative cashflows in the breakeven case. As seen in this graphic, maximum exposure occurs in 2024 for the vertically integrated approach, two periods after the it occurs in the 3U constellation. Due to the cost of capital, the longer payback cycle has a dramatic impact on overall NPV, shifting the breakeven outwards by a substantial magnitude.

It is also worth pointing out that the maximum exposure, that is, the largest amount of capital that could be lost on the venture, is approximately 21% higher for the vertically integrated approach ($994M) than the traditional approach ($798M) in the breakeven case. While this fact is not directly relevant to the overall evaluation of the impact of NPV, it is an important consideration for overall investment decisions.

Another interesting difference between the results of the 300 kg case and the 3U case is the impact of launch costs. While launch costs played a central role in the NPV calculation for the 3U constellation, it had relatively little impact in this scenario. In fact, when holding launch costs equivalent, the cost impact isn't enough to shift the constellation breakeven at all. Reliability rates in this segment are both high and clustered – 97% for the traditional approach and 99% for the vertically integrated. The result of this clustering is that total satellites produced are nearly identical between the two approaches, and thus, launch costs are as well.

Figure 16 depicts the impact of varying discount rates on the 300 kg constellation. While results in this segment followed the same overall general trend (lower discount rates make vertical integration more attractive), discount rates had a more significant impact on breakeven than seen earlier in the 3U scenario. The additional upfront capital required by the vertically integrated approach is highly sensitive to the discount rate, due to the magnitude of this investment ($115M). A reduction of 5% (from 7% to 2%), reduces the breakeven by 81 satellites. Even shifting the discount rate by 1% (from 7% to 8%), pushes the breakeven outward by 10 satellites. When considering a discount rate of 20%, there is no breakeven point, as the traditional approach is always more attractive (at least up to constellations of 256 satellites).

INSIGHTS & ANALYSIS

NPV calculations provide additional context around the decisions of firms to vertically integrate in the satellite manufacturing sector. The results of this study demonstrate that the high upfront capital requirements of a vertically integrated approach must be considered when evaluating decisions to integrate. The results indicate that the cost of these higher expenditures in early periods shift the breakeven by as much as 30 – 50% (as compared to the APUC constellation breakeven).

Perhaps the most interesting finding of this study is the dramatic impact that reliability rates have on vertical integration decisions. Because satellite failures typically occur after the satellite is commissioned on-orbit, launch effectively doubles the cost of each failed satellite. As seen in the 3U case, the additional launch costs associated with low reliability had such a dramatic impact that it can actually shift the breakeven inwards, rather than outwards, when considering NPV.

This finding has several important implications. First, it indicates that quality control is likely the biggest motivation for vertical integration, not market power, as identified in the initial *Corporate Motivations for Vertical Integration* study. While market power has a larger impact when looking at APUC, the true impact of improved quality control can only be seen when integrating launch costs. This information appears to be consistent with what is being seen in the marketplace, as several notable CubeSat operators have publicly cited improved manufacturing processes as their chief motivation for vertical integration, while few have made mention of market power[9].

Second, given the impact of low reliability rates, there is an important implication for component manufacturers: make better components. Suppliers, understandably, would prefer not to see the current trend towards vertical integration, as it not only eliminates potential customers, but also can create new competitors, if vertically integrated firms begin licensing or selling their own components[20]. Improvements in commercially-available component reliability would reduce both manufacturing and launch costs associated with the traditional manufacturing approach, making vertical integration less attractive until larger constellation sizes.

Finally, this finding implies that as launch costs continue to fall, the financial impact of lower reliability rates will drop correspondingly. Higher launch costs in this case lower the NPV of the traditional approach by more than they do in the vertically integrated approach (because of the larger number of satellites that must be launched). It is worth noting, however, that even if launch costs were $0.01 per satellite, the breakeven point is only shifted outwards by 21 satellites. This result indicates that while falling launch costs do have an impact, the maximum effect may be relatively low. Of more interest, perhaps, is the impact that rising launch costs could have on the constellation breakeven point. If launch cost trends were to reverse, vertical integration would become more attractive, as it has higher reliability rates.

The results from the 300 kg case do not show the same sensitivity to launch costs, due to the clustering of reliability rates (97% for the traditional approach and 99% for the vertically integrated approach). Without a significant differential in reliability, the total number of satellites launched varies little between the two strategies, minimizing the NPV impact. Again, this finding corroborates the idea that if commercially available components had higher reliability rates, vertically integrating to improve quality control would be a less compelling motivation.

Evaluation of discount rate sensitivities also yielded insight into the motivations behind vertical integration. Based on the results of these sensitivities, when discount rates are low (i.e., borrowing is inexpensive), vertical integration becomes attractive at lower constellation sizes. When borrowing is expensive (i.e., discount rates are high), vertical integration becomes less attractive and the breakeven point shifts outward.

The 2% discount rate shown in the first sensitivity reflects the borrowing terms for risk free capital (e.g. U.S. Treasury Bonds)[21]. If a satellite manufacturer were able to borrow at this rate, a vertically integrated approach becomes attractive at 44 and 84 satellites for the 3U and 300 kg constellations, respectively. While this point helps to establish the overall trend for varying discount rates, it is not particularly realistic. Even when financing using corporate bonds, rather than say, venture capital, a private firm is unlikely to secure such a low discount rate. A more realistic discount rate is 8%, shown in sensitivity #2, which reflects the issuing discount rate for Iridium's corporate bonds[22]. This discount rate reflects a slight premium over the market average (7%) seen in the baseline case – 65 and 135 satellites for the 3U and 300 kg constellations, respectively.

Of greater interest than either of the first two sensitivities, is the third sensitivity, which uses a 20% discount rate. Rarely do publicly traded companies use such a high value, however, it is exceedingly common for venture capital investors (with many going as high as 30 – 60% for early-stage ventures)[23]. When considering a high discount rate, vertical integration becomes less attractive, are the breakeven shifts outwards by around 50% in the 3U case, and over 100% for the 300 kg case (in fact, outside of the constellation size range considered in the study).

The ramifications of this finding are significant and may dramatically change the way satellite manufacturers seeking venture capital approach vertical integration decisions. Given that a 20% discount rate is arguably much lower than the traditional rate venture capitalist investors would use, the satellite constellation breakeven point is likely to shift outwards even further than shown in this sensitivity. Because venture capital investors value capital so highly, they may favor the traditional manufacturing approach due to its lower upfront capital requirements. While vertical integration may be more beneficial in the long run, the long payback period may be unsettling to these types of investors, particularly at smaller constellation sizes.

These sensitivity studies also indicate that ventures using larger satellites (such as 300 kg), may find that vertical integration does not seem attractive at all. Even at lower discount rates, the breakeven point is in the 100s of satellites, significantly larger than many of the constellations in development. Capital required to pursue a vertically integrated strategy in this segment may be too great to abandon traditional manufacturing approaches.

CONCLUSIONS

The findings of this study help to provide greater context around the decisions of satellite manufacturers to vertically integrate and offers an analytic explanation for this behavior observed in the marketplace. Specifically, the insights generated by this research around reliability rates and launch costs contribute to a better understanding of why vertical integration is more popular for smaller satellite sizes.

Additionally, examining breakeven sensitivities to discount rate illustrates the impact that the borrowing environment has on a firm's evaluation of vertical integration decisions. For established, publicly traded firms, issuing of bonds may be a viable option for securing lower discount rates and make vertical integration appear more attractive. For new firms seeking to raise venture capital, high discount rates may have the opposite effect, making traditional manufacturing more attractive, depending on their constellation size.

A summary of all major findings of this study is detailed below:

- NPV has a distinct impact on the breakeven point between traditional and vertically integrated manufacturing approaches
- Higher expenditures in early periods when using a vertically integrated approach reduce the NPV when compared to traditional manufacturing, generally shifting the breakeven point outwards
- Lower reliability rates have a compounding impact due to launch costs, which can actually shift the breakeven point inwards, defying the generally observed trend
- Improved quality control, not market power, is likely the most compelling motivation for firms to vertically integrate, as it reduces both manufacturing and launch costs
- The capital borrowing environment (i.e., discount rate) has a dramatic effect on constellation breakeven points
- Vertical integration is more attractive at lower discount rates, while traditional manufacturing approaches are more attractive at higher discount rates

While each of these findings enhance the overall body of research, there are still many remaining lines on inquiry. Specifically, questions remain around the consistency of these trends for satellites of different sizes and applications, as well as around whether quasi-integration approaches are more effective than either strategy considered.

Perhaps the biggest gap in this research effort, however, is the consideration of constellation replenishment rates. This investigation centered around a one-time constellation deployment. It assessed the NPV of a satellite venture launching and deploying their full constellation, then collecting revenues on the constellation with no replenishment. While this approach may be realistic for larger satellite sizes due to their longer operational life, it is certainly not consistent with marketplace behavior in the 3U segment.

For most operators in the CubeSat segment, satellite lifetimes are low (2 – 5 years), and satellites must be continually replaced in order to maintain effective coverage and consistent revenue streams. In such an operating environment, constellations are not one-time deployments, but rather a continuous effort, with the entire constellation being turned over every few years. The result of this business model is a significant increase in the total satellites produced to maintain a consistent operational constellation. When considering multiple constellation iterations, it is feasible that the constellation size breakeven point is much lower than established in this research. The "true" constellation breakeven point is, thus, still to-be-identified. Results from such an investigation, however, are a topic for another paper altogether.

Taking a step back from the immediate subject matter, this study also has broader implications for the field of cost estimation and analysis. This research demonstrates how industry standard cost modeling tools can be used in combination with business case analysis to understand behavior of firm's in the marketplace. As logical actors, firms are driven by financial motivations, and proper modeling of the true economic environment can shed light on their behavior. While market characteristics may require new methods and additional layers of abstraction (such as those described for modeling market power and quality control), commercially available tools are capable of capturing their intricacies.

This novel use of cost tools requires a degree of comfortability with subjectivity. Effective modeling of this type involves applying broad frameworks and making analogies to similar ventures in the marketplace, rather than relying on defined benchmarking studies. This behavior is likely quite foreign to the average cost analyst, and, perhaps even reprehensible. This initial reaction is understandable, as the primary purpose of cost analysts is typically to create objective and defensible estimates. The common thought is that it is better to default to industry-wide knowledge bases than to make a personal judgement call. Still, leveraging these subjective inputs, frameworks, and 'loose' analogies can yield fascinating insights into market behavior, as demonstrated in this study.

The trade space, rather than the absolute value, is the key to responsibly using these modeling approaches. As seen in both previous effort and in the current study, analysis should be concentrated on the magnitude of change from the baseline case when modifying subjective parameters. By approaching the results with this in mind, trends can be observed and analyzed, providing context around how different operating environments and firm characteristics shift the decision-making framework for these corporate actors.

It should not be concluded from this paper, however, that subjective factors should be modified lightly. While they can provide insight into why firms approach the same decisions differently, they also introduce a great deal of risk when assessed incorrectly. The proper context for framing these decisions is to force the business to consider "what if" scenarios. For example, "what if we have a great deal of production experience?" or "what if our satellites have low reliability?". By establishing a comprehensive trade space, these questions are pushed onto the business, and decision makers are put in positions to assess the answers to these questions themselves, rather than forcing the cost analyst to make a judgement call. With the ramifications of these assumptions well-articulated in the trade space, the risk of a poor assumption is clear, and the business can make an informed decision as to whether that risk is something they are willing to take on. Using cost tools in this fashion builds upon decades of work in the cost analysis field, and can provide analytic explanations for behaviors observed in the marketplace.

EXTENSIBILITY TO OTHER RESEARCH

The takeaways from this broader view of how the methods, models, and approaches used in the current study are applicable far beyond the satellite industry. They can be used to understand firm behavior in the marketplace across a variety of fields. To facilitate the proliferation of these ideas, a general methodology and framework used for this effort is provided in the following section, highlighting an analytic approach to evaluating vertical integration decisions.

As established in the current study, it is important to consider a wholistic approach to costs and revenues to effectively calculate NPV. Appropriately assessing manufacturing and business operations costs will depend largely on the initiative in question (i.e., these will differ significantly between, for example, and automotive project and an aerospace project), and is out of the scope for this discussion. Rather, it is simply important to note that a reasonable estimate for both should be calculated, and that these values should remain consistent across the two manufacturing approaches in order to isolate the impact of different manufacturing methods.

The core difference between vertically integrated and traditional manufacturing approaches, unsurprisingly, is manufacturing costs. As such, specific attention should be paid to how these costs are modeled. While most commercially available parametric cost tools are capable of modeling the unique differences of each approach, the methodology outlined here is particularly tailored to using Galorath's SEER-H cost estimating software. The major differences between the two manufacturing approaches (from a modeling standpoint) are illustrated in Figure 17. Parameters particularly impactful to overall manufacturing costs are highlighted in blue.

Key differences between the approaches primarily boil down into two categories: experience and that learning rates. Experience governs both hardware heritage, as well as prior production/development projects. Learning rates refer to parameter assumptions for prior production units and expected cost savings due to economies of scale.

Prior Experience

For the vertically integrated approach, a baseline category of "Make" should be used for hardware heritage. This baseline is, of course, subject to change as necessary to accommodate industry best practices for modeling. The central theme, however, is that a vertically integrated approach effectively starts from scratch. For a traditional manufacturing approach, the baseline recommended hardware heritage category is "Modification – Average", or more specifically, "Subcontract – Modification Average". This recommendation operates under the assumption that component suppliers have prior hardware projects that can be modified to meet the current design requirements. It is important that all

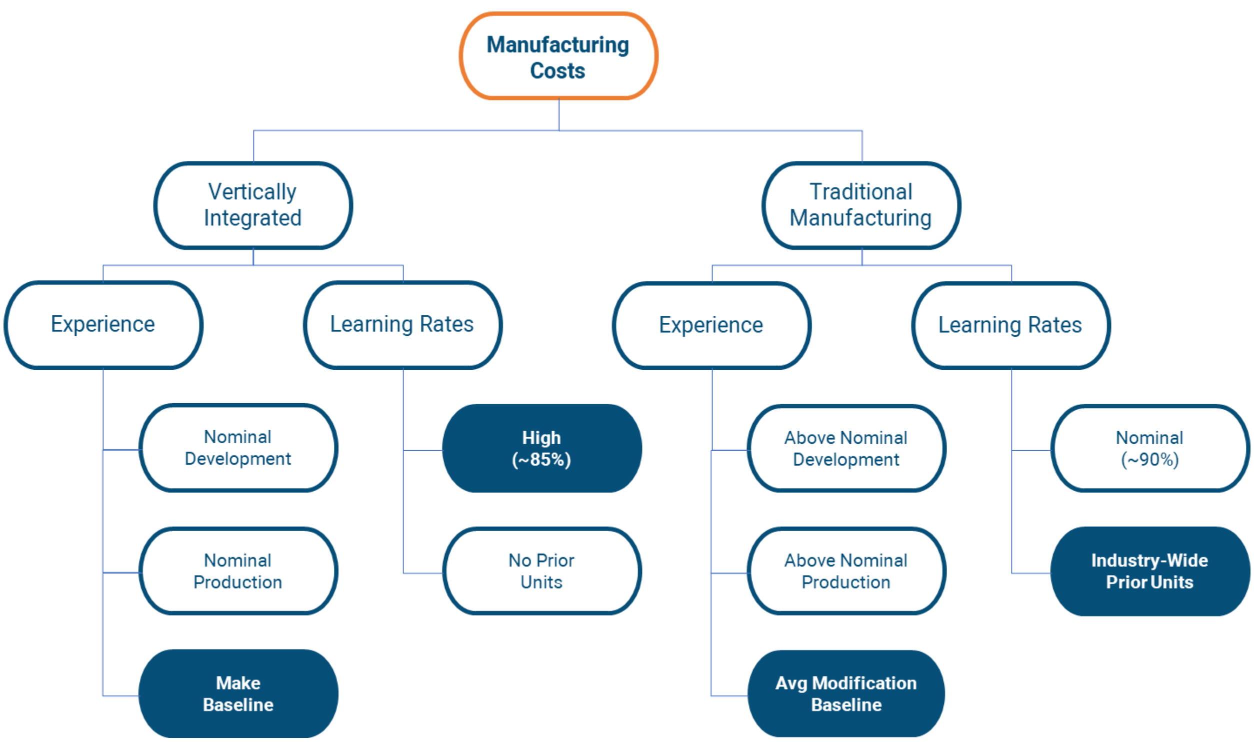

FIGURE 17. MANUFACTURING COST DIFFERENCES

of the components be classified as a "subcontract" to reflect it will be coming from a 3rd party vendor. For each of these elements, the vendor fee should be added – the fee value depends on what is standard in the industry being evaluated. Production and development experience will likely also vary by industry, depending on the number of units usually produced. The general difference that should be captured is that the vertically integrated approach reflects less production/development experience than the traditional manufacturing approach. Again, exactly what these parameters should be set to in order to illustrate this difference will depend on lot sizes common in the industry being evaluated.

Learning Rates

Besides experience, the other major differences between modeling a vertically integrated and traditional manufacturing approach are in learning rates. In general, the learning curve value should be lower in the vertically integrated approach, to reflect the firm's relative inexperience (and thus high potential to see improvements from learning). Although learning rates should be dependent on those commonly seen in the industry, the Price Systems' *Unit Learning Curve Framework* is excellent resource for manually assessing appropriate rates. Generally, when modeling traditional manufacturing, this learning curve assessment should be approached from the perspective of the industry at large (for example, whether the industry at large has established processes with a high degree of automation). The vertically integrated approach should take into account only the specific company being evaluated (which likely has a lower degree of established processes, etc.). This same approach should be taken when assessing prior production units. Prior production units can be a critical driver in the unit cost, so special care should be paid to ensuring these are properly assessed at the industry-level, at least to the correct order of magnitude.

The combination of experience, learning rates, and fee capture the bulk of the differences between traditional and vertically integrated approaches, but not all. As outlined in *Corporate Motivations for Vertical Integration*, market power and quality control also play a significant role in accurately capturing realistic market conditions.

Market Power

The concept of market power refers to the ability of firms to negotiate better rates from their suppliers. Practically speaking, suppliers grant discounts when buyers purchase large lot sizes because they are able to achieve greater economies of scale. The discount suppliers can offer is dictated by how much they can save when producing at scale.

A simplistic way to simulate this is to evaluate the costs associated with such a bulk buy (subject to the supplier's learning rates). This value represents the true cost to the supplier, and thus, the lowest possible price that they could offer. Subtracting this value from the cost of a bulk buy without learning (i.e., a learning curve of 100%) illustrates the total 'surplus' of the bulk purchase. This surplus is the value that can be split by the vendor and the purchaser, depending on the negotiated discount.

Varying the split of this discount effectively simulates market power dynamics. In markets where buyers are favored, they will take more of the surplus, while in markets where suppliers are favored, they will maximize their own benefit. Market power dynamics will vary according to industry and sometimes even specific market segments. Whenever possible, they should be assessed in conjunction with experts from industry purchasing departments. After characterizing the current market power, surplus should be split accordingly and the supplier's share of the surplus added to 'floor' estimate (i.e., estimate based on the supplier's learning rates) to reflect the costs associated with the traditional manufacturing approach.

Quality Control

Integrating the impact of quality control is more problematic than market power, as improved control in vertically integrated approaches can manifest itself in many ways. For example, it can result in faster design iterations, greater reliability, or streamlined testing, among other benefits. One way to model these effects is to assume the eventual result of these improvements is more reliable products. To simulate this impact, it is necessary to integrate failure rates into the overall calculation.

To account for failure rates, a relatively straight forward process can be used. First, assess the overall failure rates present in traditional and vertically integrated manufacturing approaches. Second, multiply the overall failure rate times the number of units intended for production to get the total number of defective units. For example, given a 100-unit production run and a 10% failure rate, 10 units are expected to be defective (100 x 10% = 10). Additionally, of the 10 units produced to compensate, 1 of those is expected to be defective (10 x 10% = 1). Therefore, in order to have 100 operational units, 111 must be produced.

When evaluating the breakeven point, the number of operational units should be considered, although the total units produced to achieve this figure will be higher (as it includes the additional units to compensate for failures). Exact failure rates will differ significant by industry and, again, potentially by market segment within that industry. Whenever possible, empirical evidence of industry failure rates should be used to accurately capture the impact of improved quality control in vertically integrated approaches. While quality control is a major motivator in satellite manufacturing (due to low component reliability rates), in more established industries it may have very little impact (as status-quo failure rates are quite low).

Summary

This general framework is meant to serve as a starting point for considering a number of relevant factors in evaluating traditional vs. vertically integrated approaches. It is not, however, comprehensive. The authors are hopeful that this framework and the associated modeling approaches will spur new ideas for simulating market dynamics using commercially available cost estimating tools. This paper demonstrates how useful such simulation tactics can be for developing an analytic explanation for firm's behavior in the marketplace and the authors intent is to interest more researchers in pursuing this line of inquiry.

CITATIONS

[1] Buzzell, R. *"Is Vertical Integration Profitable?".* Harvard Business Review. Jan. 1983

[2] "*What is Vertical Integration?*". Corporate Finance Institute.

[3] O'Callaghan, J. "*Stratolaunch Proves It Is Still on Track With 'Major' Rocket Engine Test"*. Forbes. Nov. 8, 2018.

[4] Stuckey, J. and White, D. *"When and When Not to Vertically Integrate".* McKinsey Quarterly. Nov. 3, 1993.

[5] "*Vertical Integration".* The Economist. Mar. 30, 2009.

[6] Williams, C. and DelPozzo, S. *"A Different Approach: Vertical Integration in Satellite Manufacturing"*. SpaceWorks Insights. Jan. 28, 2019.

[7] Williams, C., et al. *"Corporate Motivations for Vertical Integration".* Presented at NASA Cost & Schedule Symposium: NASA GDFC Greenbelt, MD. Aug. 2018.

[8] DelPozzo, S. and Williams, C. *"Nano/ Microsatellite Market Forecast: 9th Edition".* SpaceWorks Insights. Jan. 28, 2019

[9] Williams, C. and Doncaster, B. *"Nano/ Microsatellite Market Forecast: 8th Edition".* SpaceWorks Insights. Jan. 30, 2018

[10] Foust, J. "*New Companies Needed to Maintain Small Satellite Market Growth"*. SpaceNews. Jan. 31, 2019.

[11] Foust, J. *"Smallsat Developers Focus on Improving Reliability"*. SpaceNews. Aug. 8, 2018.

[12] Gallo, A. *"A Refresher on Net Present Value"*. Harvard Business Review. Nov. 19, 2014.

[13] Faloppa, D. *"The Discount Rate in Startup Valuation"*. Equidam. Nov. 18, 2015.

[14] Foust, J. *"'Golden Period' for Space Startup Investment Continues".* SpaceNews. Sep. 12, 2018.

[15] Mislick, G. K. *"Cost Estimation: Chapter 10, Learning Curves Unit Theory".* Presented at ICEAA Professional Development Workshop: Atlanta, GA. Jun., 2016.

[16] *"SEER-H Space Guidance".* Galorath, Inc. Jun. 18, 2018.

[17] *"Spaceflight Industries".* Presented at Small Payload Rideshare Conference: John Hopkins University/Applied Physics Laboratory Laurel, MD. Jun. 9, 2015.

[18] *"Iridium Communications Inc. Form 10-K for Fiscal Year Ended December 31, 2016."* EDGAR. Securities and Exchange Commission, 2017.

[19] Roberts, R. *"Can the Internet of Things (IoT) Survive without Satellite?"*. Thuraya. May 25, 2014.

[20] Russell, K. *"DHV Technology to Bring Spire's Solar Panels to the Space Industry".* Satellite Today. Mar. 22, 2018.

[21] Mohendroo, M. "*Some Common Mistake to Avoid in Estimating and Applying Discount Rates"*. Deloitte. Spring 2014.

[22] *"Iridium Communications Bond…".* InvestopoliNews. Mar. 19, 2018.

[23] Bhagat, S. *"Why do Venture Capitalists Use Such High Discount Rates?"*. University of Colorado at Boulder. Nov. 10, 2013.