Costing Commonality: Investigating the Impact of Platform Divergence

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Abstract— **Commonality strategies have become an important means of cost-sharing across systems, particularly in long lifecycle aerospace applications such as the Joint Strike Fighter. However, decreases in realized commonality (divergence) have important implications for the cost-sharing effects of commonality. We review the results of a recent study at the Massachusetts Institute of Technology (MIT) of 16 firms and 8 Government organization, which was chartered to evaluate the costing of commonality benefits. We conclude that the size of commonality investments has been underestimated – our data reveal the cost of developing common systems is 12%-50% above the unique design cost. We find evidence to suggest that divergence has cost consequences, notability creating higher quality expenses and requiring additional manufacturing coordination.**

We examine in detail the potential use of development cost allocation as a management practice for incentivizing commonality. We show that lead variants bearing platform costs achieved weaker investment returns and re-captured few benefits from later variants. We propose a framework for evaluating the consequences of each cost allocation, which explicitly captures the impact of individual variant decisions on the platform's cost structure, building on existing work used in decision-making in the Joint Strike Fighter program. We conclude with management guidance gathered from the case studies for reinforcing commonality incentives.

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1. INTRODUCTION

Commonality strategies have become an important means of cost-sharing across systems, particularly in long lifecycle aerospace applications. Past examples of commonality in aerospace examples include the Joint Strike Fighter, sharing engines, structures and controls across 3 variants, and the Goddard Common Flight Software [1]. However, recent research has highlighted that many systems see large decreases in realized commonality – such as with the Joint Strike Fighter falling from 80-90% commonality intended to 30-40% realized [2]. These decreases in commonality have important implications for the cost-sharing effects of commonality. We review the results of a recent study by the Massachusetts Institute of Technology (MIT) of 16 firms and 8 government organization, which was chartered to evaluate the costing of commonality benefits, the associated returns from commonality investments, and the potential impact of divergence on commonality benefits.

We review briefly the two main findings of this study – sizing commonality investments and divergence cost consequences. This study provides new case data on the size of commonality investments – we conclude that the additional initial effort to design common systems varies between 12% and 50%, above the cost of a unique system. These costs are larger than those suggested in the literature

	Heavy Equipment	Rail Equipment	Vehicle Manufacturer	Helicopter	Automotive
Dominant benefit	Manufacturing Econ.	Shared Development	Bulk Purchasing	Shared Dev & Reduced Inventory	Reduced Inventory
Development Cost	$30M	$X0M	$146M	$6.75B	NA
Volume	X00,000	X00	X000	257	
Current Phase	Complete Lifecycle	Certification	Pilot Production	Fullscale Production	N/A
Primary commonality driver	Cost	Market	Cost	Cost	Cost
Secondary commonality driver	Competition	Competition	NA		
Commonality metric	Yes	No	No	Yes	
Lifecycle costing	Yes / No	No	Yes		
Benefit projection for funding?	No	No	No	Yes	Yes
Sole lead variant investment?	No	No	No	No	Yes
Funding source	Corporate / Factory	Corporate	Product Line	Contract	Corporate
Largest volume first?	N/A	No	Yes	No	
Variant addition?	Yes	Likely	No	No	
Lead Profitability?	Strong	Weak	N/A		
Cost Growth to Date?	2-5% of margin	33% of cost	None	High	

Figure 1 - Case summary matrix. Note that a different benefit dominates in each of the cases.

[3,4], lending credence to the concept that commonality requires significant up front investment. We find evidence to support the concern that divergence implies lower savings from commonality, ranging from reduced inventory savings to increased quality expenses.

We then review one aspect of the study in detail – the choice of development cost allocation, and its impact on incentives for commonality in the development process. We find that there are defined advantages to allocating all of the costs to the lead variant, but that there is a broadly unacknowledged consequence – lead variants tend to achieve lower profitability levels. We define a range of possible allocation bases, and discuss the relative merits of each in the context of a framework.

Finally, we conclude with guidance for developing commonality strategies in project-based organizations, where customized orders and low volume production dominate over the traditional product-based view of standard products and high volume production.

2. Case Study Overview

The study overall capture 16 firms and 8 Government organizations, of which 2 firms were in the Aerospace / Defense industry, and all 8 of the government organizations were Aerospace / Defense related. The study then down-selected to 3 core cases, and 2 additional 'detailed discussion' cases - Figure 1 shows a comparison among the 3 core cases and the 2 detailed discussion cases. The cases span a number of industries, with the intent of capturing a wide span of commonality management practices and contexts. However, all cases were chosen for their similarity to the aerospace context, notably capital-intensive manufacturing in slow clockspeed industries. Note that the primary benefit of commonality varies among the cases discussed, partially correlated with the volume produced. The variables listed below form the basis for the detailed case analysis which was conducted.

For this study, a 'variant' within the platform was defined as a separate product for sale, sharing some components with

Platform	Premium	Max. Subsystem Premium	Variants
Heavy Equipment	25-50% ($1-2M)	50%	4 (6-12% / variant)
Rail Equipment	29% ($X.6M)	100% (Software)	1-25 (?)
Vehicle Equipment	12% ($10M)	200% (Electrical)	4 (3% / variant)

Figure 2 - Commonality premiums for three core cases

other products on the platform. Typical platforms involve less than 10 variants, although many minor configurations options are available.

3. COMMONALITY INVESTMENT PREMIUMS

At the initiation of this study, we conducted a literature review to determine the available state of knowledge on commonality investments. We were specifically interested in how much common programs cost to develop. The existing design and management literatures on commonality have captured individual data points on the profitability of platforms [5], [6], and includes several profitability models [7], [8], only two statistical studies attempted to compare profitability [9], [10]. Neither of these profitability studies captures a measure of the size of the commonality investment. The only literature source which estimated this premium was [4], which postulated that each additional variant added after the first JSF variant would cost an additional 20% in development.

As discussed in [3], this research provides the first actual data on design premiums, and the first comparison of design premiums vary across platforms. The definition of premium used was "how much more would it cost to make a common part, compared with the cost of designing a part for a single variant?". This information was elicited from interviewees in the 3 cases – in the Rail and Vehicle cases, a detailed analysis of premiums was conducted at the subsystem level, and is summarized in Figure 2.

As shown in Figure 1, the magnitude of commonality premiums is large relative to the development cost of a single vehicle. This suggests that common development programs consist of more than "hooks and scars", as frequently discussed in the aerospace context. The case studies suggest that these premiums require significant management protection in order to prevent erosion and subsequent cost duplication. The mechanisms of possible protection are further explored under Commonality Cost Allocation.

4. DIVERGENCE COST CONSEQUENCES

In order to motivate the examination of management practices for commonality, we devoted a significant fraction of the study to the hypothesis that falling commonality levels would result in reduced benefits achieved. We traced benefit trajectories through the three detailed case studies, in the presence of commonality changes. In [3], we found support for the hypothesis that divergence has cost consequences, notably reducing inventory benefits, creating higher quality expenses and requiring additional manufacturing coordination.

For example, Heavy Equipment saw commonality within its product line fall from 40% to 20% parts shared across all variants, resulting in higher Raw and Work In Process (WIP) inventory, higher safety stock levels, and foregone inventory savings of $5.7M per year. Other benefits required additional, unforeseen costs to achieve prescribed levels. For example, in order to retain (and grow) quality, the size of the quality team was grown from one quality engineer to four quality engineers and technicians.

Although divergence cost consequence represent a fairly straight-forward logical proposition (less sharing implies lower savings), the mitigation strategy is far more complex. Previously in [11], we explored bottom up (parts-level) incentives for commonality. In the remainder of this paper, we explore a top-down incentive, namely the allocation of development cost among variants, as a means to foster sharing.

Platform*	Profitability	Cost Allocation	Forecast?
Heavy Equipment (other)	Cost = $ Millions	Costs of integration & test	Informally factored in
Rail Equipment	50% of margin goal	Partial cost (marginal costs + a contribution)	Explicit strategy, no IRR target
Vehicle Manufacturer	Cost = $ Millions	Costs of integration & test	None

*Only instances where with a clear lead variant

Figure 3 - Lead-Pays cost allocation has a noticeable impact on lead profitability

5. COST ALLOCATION PRACTICES OVERVIEW

In the following three sections (Section 6-8), we explore the options available for distributing development costs for shared components across the platform. The underlying logic of this incentive is best as expressed as a tension. Distributing costs widely reduces the cost to each variant, but also creates a distributed responsibility for decisions, which may be difficult to manage. Forcing one variant to bear the entirety of the common development cost saddles one variant with large expenses, but also centralizes responsibility.

We explore these two broad ideas (centralized vs. distributed) in detail in the following sections.

6. WEAKER LEAD VARIANT RETURNS UNDER LEAD-PAYS DEVELOPMENT COST ALLOCATION

Several firms described a policy of 'lead-pays', or allocating all of the common costs of a platform to the first variant. This section explores the advantages, consequences, and frequency of the use of this policy.

The sample captured by this research included several organizations who require 'lead-pays' in some cases – the Automotive firm studied, for example. However, none of the 3 full cases had a 'textbook' example of 'lead-pays'. The Heavy Equipment case captured interviews on a development program different from the primary program of study, where a new subsystem was being rolled out across the organization, and a lead integrator was chosen – the first machine to receive the subsystem. This is not the classic 'lead-pays', because the program was only responsible for the costs of integration and test, not the full development costs. A similar program was observed in the Vehicle Manufacturer. The Rail Equipment case is also not a textbook case, in that the lead did not bear a full cost allocation. However, conceptually it begs treatment under lead-pays, as it did not have a formal cost allocation arrangement (as discussed in the next section), and the intent of the decision was similar to lead-pays – to help fund development, rather than to necessarily maximize profitability.

Our hypothesis was that 'lead-pays' variants would be less profitable as compared with follow-on variants, as the lead would have to bear costs in excess of it's scope, and which it was unable to recover from later variants.

In the Heavy Equipment and Vehicle Manufacturer cases, interviewees describe the non-recurring cost impact of being the lead in the millions of dollars, as shown in Figure 3. These were commonality investments, which later variants would be able to leverage directly, such as system characterization tests, process for integration tests, and integration hardware development. In the Rail Equipment case, the lack of clear cost allocation rules makes separating the commonality investment challenging. By its participation, the lead not only bore some fraction of non-recurring, it also experienced a dynamic effect of being a lead, that is, it absorbed cost growth from the platform.

The case data make it conceptually clear that the practice of allocating all common costs to a lead, does in fact lead to significantly lower profitability for lead variants. The particular level of impact is dependent on the common cost : total cost fraction, and the distribution of market sizes to which the variants are targeted. The conceptual points that are of central interest for commonality costing are therefore: is this strategy explicit, how are expectations set around lead-pays performance, and under what conditions is this a useful strategy?

The cases reveal that this can be an explicit strategy – all lead-pays situations were described as intentional choices. For example, in the Rail Equipment case, the decision to accept the lead contract was made by the President of the firm, one of few platform decisions explicitly made at that level.

Understanding of the cost consequences of the lead-pays cost allocation varied. While both Heavy Equipment and Vehicle Manufacturer Platform Managers were quick to point out the order of magnitude, neither had made an effort to bookkeep these investments separately. Awareness of the consequences was higher in the Rail Equipment case, owing dominantly to the fact that the contract was let externally, forcing some accounting around contract performance. It can be concretely said that all firms in the sample were aware of some level of cost consequences, but none felt it was important enough to have performed detailed analysis.

What is most interesting is how firms showcased a disconnect between strategy decisions and consequences. All of the firms kept Internal Rate of Return (IRR) calculations at a variant level, but none had modified the IRR expectations due to the lead-pays cost consequences. The consequences were either informally logged (the Vice President responsible for the Heavy Equipment example was expected to 'informally forgive' poorer IRR performance on the basis of lead-pays investments), or not logged at all.

The concern that this 'explicit strategy, implicit consequences' raises is false organizational learning. Premature evaluation of a platform, based solely on the IRR of the lead-pays variant, would under-represent the benefits of commonality, as none of the benefits accrue until the second variant development begins.

There is clearly a range of intent for lead-pays. In some firms, it arises opportunistically, whereas in others it is a formal corporate policy. This research would suggest that lead variant IRR targets should be modified when lead-pays is organizationally formalized, as the extent of the consequences are much broader and systematic. In opportunistic cases, platform managers need to examine both the possible cost consequences, as well as the advantages conferred, before deciding whether modified IRR targets may have adverse consequences (like challenging variant managers less on cost targets) or would most accurately represent targets for their program.

As a sub-hypothesis, we sought to examine whether lead-pays behavior was a reaction to the risk of write-downs from unrealized second variants, in a strict accounting sense. None of the cases provide supporting evidence – it was uniformly rejected. Interviewees described how this accounting criteria would not have been salient to managers.

However, interviewees did describe other pressures for lead-pays investments. Centralizing control was the primary pressure – it enables the one variant to have full ownership of common parts, and therefore reduces the risk of diffuse responsibility leading to poor design outcomes. In particularly, this may prove effective when the lead is at risk of being swamped by requests for functionality in common components. Restricting the investment to a level where it can be borne entirely by one variant has the effect of constraining the possible scope of the common components.
The other pressure for lead-pays was driven by variant-cancellation risk. The Vehicle Program Manager described how later variants were at risk of cancellation for financial reasons. Allocating all of the common costs to the lead improved the performance of the at-risk variant. Had the later variant been cancelled, it would have also forced cancellation of the lead, as the economies of scale would be diminished. Therefore, this was a cost worth internalizing on the part of the lead.

As we've noted above, lead-pays can beneficially restrict the scope of common components. We've noted that this is desirable in some situations. However, if this behavior arises unintended, it may be detrimental. Specifically, lead-pays may lead to underinvestment at a platform level, as there is only so much investment a lead can bear.

Based on the cases, the following signs are consistent with underinvestment.

- Failure to take clear wins due to near-term budget constraints
- Difficulty financing commonality across lifecycle and firm functions
- Repetition of design effort, desire for larger scope
- Divergence due to underperformance on later variant's criteria

Having examined the advantages and disadvantages of allocating all cost to the lead variant, we can now move on to cost allocation schemes that spread the charges among variants.

7. Development Cost Allocated Among Variants

The chart below (Figure 4) provides an overview of the concepts and actions that are expected from Research and Development (R&D) cost allocation. The blue boxes at the top indicate the cascade of concepts. For example, choosing a cost allocation partially determines the variant's awareness of platform costs, which in turn enables (or disables) a variant to influence design decisions. The spread of influence among variants has a number of effects, listed on the right in blue – it can drive the variant to participate more in the platform, or to pro-actively seek out other variants for sharing, in order to boost its own volumes. However, it can also have negative effects, such as a enabling a variant with strong control to customize the platform to its needs.

The green boxes illustrate the link between cost allocation

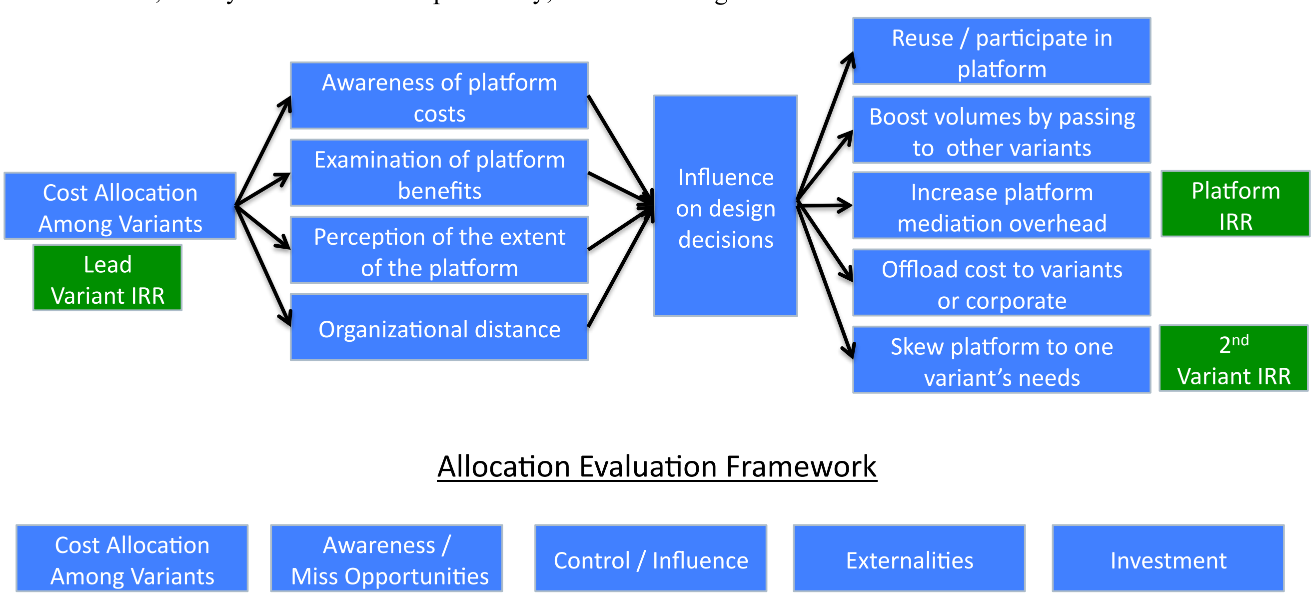


Figure 4 - Framework for understanding expected outcomes from cost allocation

Platform	Allocation
Heavy Equipment **Platform**	First 4 variants, allocated R&D and tooling by **volume**
Heavy Equipment Common Operator **Subsystem**	Lead of 5 variants, with 80% of volume, allocate R&D by **volume**, but **lead** pays all common tooling
Rail Equipment **Platform**	Standalone development **centrally** funded, minor lead (<20% of volume) paid only **marginal** costs
Vehicle Equipment **Platform**	Leads (2 of 4, 70% of volume) pay **marginal** costs of R&D, remaining variants fund common costs of R&D (not sub-allocated to the 2 variants)
Vehicle Equipment **Subsystem**	R&D can only be paid **by one program**, later variants free.
Automotive	Lead variant **pays** R&D, unless 2nd <1 year away
White Goods	Required co-investment by a 2nd variant

Figure 5 - Cost allocation practice by platform

and the resulting return on investment for the platform. As shown in the previous chart, allocating all the cost to the lead variant has a negative impact on the lead's IRR. However, the 2nd variant's IRR can also be impacted by cost allocation, particularly if the allocation allows the first variant so much control (and in the absence of strong platform-level decision-making), the lead customizes the common components to its needs – this has the effect of forcing divergence on the second variant, who has to create more unique content than anticipated. There are also platform-level effects, separate from the sum of variants, in that certain allocation strategies require significantly more time spent on platform mediation. From this conceptual map, we can begin to see that the R&D cost allocation has an important impact on the total investment return from the platform.

On the bottom of the diagram, a matching allocation evaluation framework is illustrated, summarizing the concepts. The categories correspond to the top section of the diagram – the four dimensions of *Awareness / Miss Opportunities* are therefore Awareness of platform costs, Examination of platform benefits, Perception of the exten of the platform, and Organizational distance. The Investment impact is shown as the fifth element of the Allocation Evaluation Framework, measured as the IRR of the sum of the variants. This will be used to compare different allocation outcomes.

Figure 5 provides the data from the case studies, showing the number of variants, the allocation base chosen (in **bold**), and ancillary rules and conditions for the cost allocation. For example, choosing a 'volume-based' cost allocation for Variant 1 building 40,000 units and Variant 2 building 60,000 units would allocate 40% of development costs to Variant 1.

The first observation is that there is a spread of different allocations used, even within an individual firm. Although there is variation, the cost allocation was not universally treated as a decision variable. In the Vehicle Manufacturer platform, for example, the cost allocation was decided within a week, when a request from central finance came in asking for information. Others projects identified allocation as a strategic choice, such as the Heavy Equipment Subsystem noted above, where the participating variants discussed several allocations as well as the intended outcomes from the allocation.

The main principle that was elicited for choosing a cost allocation base was to align the allocation with the variant with dominant requirements. The situation that interviewees sought to avoid was where performance constraints or organizational power would enable a variant to enforce expensive requirements, without having to bear the cost of those requirements.

Cost allocation bases

Volume-based when there is a dominant volume
Variant-based (an even split among variants) when there is no dominant volume
Negotiated for preventing high performance, small volume variant from dominating requirements
Centralized to enable mediation among warring parties
Marginal after development paid and adaptation cost is low

Note that aligning cost allocation with dominant requirements is simply a heuristic. The ideal situation is to carry the analysis forward to projected volumes and variant margins, coupled with the understanding of the cost impact of individual requirements on the shared common cost. This analysis would enable one to determine whether lower performing and cheaper variants are able to compete given the imposed common costs, and whether higher performing variants are benefiting from the volumes and sharing with other variants, despite the inevitable performance compromises of platform development.

However, in the absence of this idealized analysis, this heuristic allows for the broad programmatic incentives to be aligned with the desired behavior in the design process.

Other program factors could also supersede this heuristic. Large lifecycle offsets can make it difficult to place costs other than with the lead variant. Technology development strategy can force highest performing variants later in the process (and therefore likely lower cost allocations) as the technology is characterized and built-up. In order to illustrate two important program factors, we compare two platforms using the allocation framework.

Interviewees stressed the importance of determining the appropriate cost allocation. While organizational arrangements and process steps for mediating among variants have some leverage, they face an uphill battle when the cost allocation is fundamentally misaligned. The question that arises is therefore how to initiate the allocation discussion.

A comparison of our cases reveals that funding sources can help drive the allocation discussion. Note that the concept of funding is separate from allocation, as the allocation can in some cases be determined after the fact and often serves different corporate purpose.

Funding across a composition of Profit & Loss (P&L) groups was observed to create an allocation discussion. For example, in the Heavy Equipment case, the Common Operator Subsystem was funded across a number of P&L groups, triggering several management and accounting discussions, resulting in an explicit allocation choice.

Funding under one P&L, or centralized R&D funding, does not create these same incentives. In the Vehicle Manufacturer case, the extent of P&L aggregation (combined with common assembly lines) led to little attention paid to allocation.

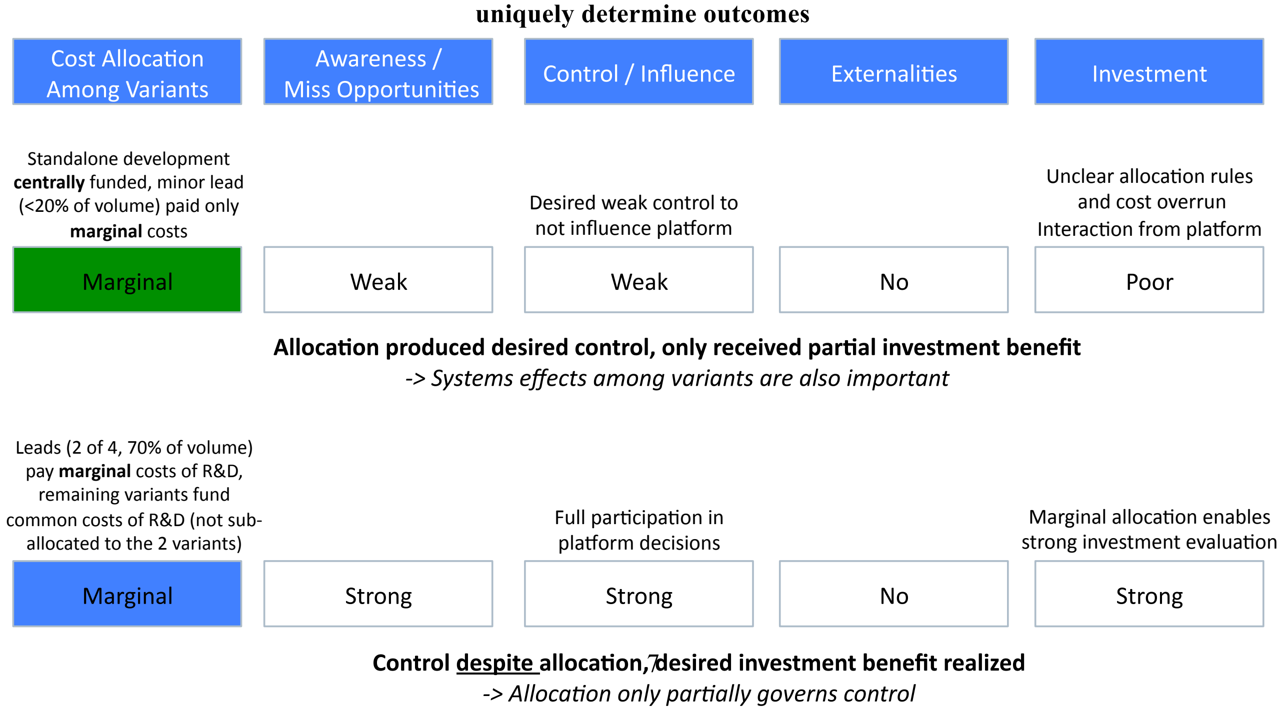
8. Framework Comparison of Development Cost Allocation

In this section, we compare an allocation practice across 2 cases, in order to examine key similarities and differences. Given the definitions of the five Cost Allocation Evaluation Framework shown in Section 7, we qualitatively evaluated the firm's practices and the resulting outcomes on a scale of 'Poor/Weak', 'Average', and 'Strong'.

Subject 1: Marginal Cost Allocation to the "demonstrator lead" in Rail Equipment

As described in the case, the "minor lead" (<20% of intended platform volume) was built and sold in order to help cover the R&D costs of platform development. A detailed allocation was not constructed, but in general, interviewees described the costs allocated as simply the marginal costs for this minor lead variant.

Figure 6 - Framework comparison of two cases using the same cost allocation. Conclusion - cost allocation does not uniquely determine outcomes



Subject 2: Marginal Cost Allocation to both leads in Vehicle Manufacturer

As described in the case, the first 2 variants (of 4 total variants), representing 70% of the total volume, were explicitly allocated only the marginal costs of R&D. The remaining 2 variant covered the full common costs.

Figure 6 below shows a comparison of these two marginal cost allocation practices.

Subject 1 produces the intended effect from an awareness and control perspective – the lead variant had weak control over platform design decisions, and from a constraints perspective, was generally subservient to the needs of the platform. However, the marginal cost allocation did not produce a strong investment performance, contrary to expectations. Specifically, this variant only achieved 50% of its margin target. The case describes how the finances of this variant were coupled to the platform development costs, via a limited labor pool and an intended design order (platform prototypes were to be constructed first). The net result is that delays in the platform development delayed the lead variant, during which the lead variant incurred recurring costs.

This illustrates that the allocation produced the desired control, but that the allocation did not produce the intended financial effect. The resulting takeway is that system effects among variants can play a role in the results of cost allocation decisions.

Subject 2 'failed' to produce the expected awareness and control outcomes – the two variants in question were treated as full partners on the platform, and were often the subject of dominant design decisions. However, the cost allocation did produce the intended investment evaluation – both appeared significantly more profitable than the remainder of the platform.

This illustrates that the cost allocation only partially determines the variant's influence and control over the platform. As it were, weak control was not a desired attribute – the platform manager made the decision on cost allocation in order to protect the two lead variants. The case reveals that these leads were built in a new factory, and were already bearing significant tooling costs. Further, they faced more organizational pressure around their financial performance, partially because they were intended for a market with historically lower margins. Therefore, the decision was taken in order to protect the lead variants' financial performance.

A comparison of these two marginal cost allocation subjects illustrates the presence of intervening variables in determining the balance of control in platforms. This is supported by previous research, which suggests successful platform management requires the coordination of organizational, technical, and financial incentives around the intended platform strategy – no one measure is enough.

6. Commonality Strategies in Project-Based Organizations

Readers often choose a product organization as their primary mental model for platforming activities. Indeed, it is instructive to assume that products can be reliably planned, in order to examine what levers exist for a fixed development activity.

However, platforming is often of interest to project-based organizations, as separate from product organizations. These organizations have close customer interaction, where an individual customer composes a large enough fraction of sales to merit dedicated design activity. Note that this is not necessarily restricted to government purchasing. The Rail Equipment case and the Helicopter case fall within this frame, and in the author's experience, the size of aerospace development projects typically creates project-based organizations.

While these organizations are typically low volume, we can recall that the dominant benefits to the firm are:

- Shared development cost across offset variants
- Shared tooling and associated fixed costs
- Bulk purchasing of components

The largest challenges we observed to platforming in project organizations are:

- Customization driving development benefits down
- Difficulty planning variants, resulting 'standard + options' setup

As a result, several actions are recommended specifically for project-based organizations.

(1) Separate out funding for commonality premium during funded projects, in order explicitly recognize the costs that should not be accounted for with the project. Otherwise, there is significant downward pressure on commonality benefits, and when corporate financials are simply the sum of project profitability, it will be difficult to bear investments on an individual project.

(2) Synchronize development and production schedule when possible.

(3) Set explicit downstream benefit goals. This is more difficult to track for project organizations than in product organizations, particularly because of the "this project is unique" argument. Nevertheless, if commonality investments are funded on the basis of reduced project engineering non-recurring, it only makes sense that this should be a measured outcome.

(4) Price benefit of standardization to the customer. Specifically, creating marketing activities responsible for defining the cost of options (as opposed to the price

of options) helps provide a balancing force to the inevitable upside of customization – additional revenue.

7. CONCLUSION

This paper presents the results of a study on the dynamics of commonality. We identify that commonality investments are larger than typically described in the literature, ranging from 12-50% over the cost of producing a unique variant. Additionally, we find that divergence, the tendency of common programs to see lower realized commonality than planned, has tangible impacts on the program in terms of reduced benefits and increased costs. For long-lived slow clockspeed aerospace applications like the Joint Strike Fighter and Bell UH-1Y / AH-1Z, the magnitude of commonality change can have a significant impact on the estimated vs. realized cost of the program.

We investigate in detail the potential use of development cost allocation to set program incentives for commonality. We find that allocating all costs to the lead variant can enable stronger program management, but at the risk of lower commonality levels, and with the defined consequence that the lead's return on investment is lower. We then survey a variety of cost allocation bases for splitting development cost, finding the guiding principle that the allocation base should be aligned with the dominant variant's requirements.

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BIOGRAPHY

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