Title: “Optimal Commonality and Reliability: A Life Cycle Costs Perspective”

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Topic: Technology management, product design

Abstract

Production and service companies use capital intensive systems to manufacture their products or render their services. For example, lithography systems are critical for operations in the semiconductor industry, aviation engines and avionics are vital in their industry, and MRI scanners are critical in healthcare. The users of such capital intensive systems require high system availability, because unavailability results in production or service losses of millions of dollars. However, realizing such high system availability at a low cost is a major challenge without the help of the Original Equipment Manufacturers (OEMs). Therefore, users of capital goods close full service contracts with the OEMs (e.g. ASML, Philips, GE, and Pratt & Whitney). Under such a contract, the system users pay the OEM a periodic fee, and the OEM becomes responsible for the system availability during the usage period. As a result, modern OEMs are responsible for the entire life cycle of systems, and are therefore primarily interested in minimizing the total costs accrued throughout the systems' life cycle.

The Life Cycle Costs (LCC) have increased over the last years because systems are getting more complex and OEMs offer a higher variety of systems. In an attempt to alleviate the burden of a higher variety, OEMs typically use common components in multiple different systems of their product portfolio. For example, identical rotor blades are used in multiple different aerospace engines or the same positioning sensors are used in various lithography systems. The main motivation for commonality usually comes from a marketing and production perspective: Offering more different systems with a relatively small increase in the
production costs. However, we show that even when the production costs increase substantially, component commonality still reduces the total LCC.

We model commonality as follows. Any system consists of components, and we say that components - from different systems - belong to the same *component family* when they fulfill the same functionality, but are not necessarily identical. Therefore, the OEM can decide per component family whether to use a single common component for all systems, or to use a dedicated component per system, as illustrated in the following figure:

Note that a component family may correspond to rotor blades in the case of aerospace engines, to positioning sensors in lithography systems, or to electric motors in MRI scanners.

Next to the decision to make a component common or not, there are two important decisions that impact the LCC. These concern the reliability of the component (how often will a component fail) and the amount of spare parts stock that is kept for after-sales services. The OEM's objective is to optimize this decision triad such that the LCC is minimized.

In practice, the problem is typically tackled in a sequential fashion, because each decision is taken at a different time epoch, possibly by a different department. First, the OEM decides whether to use a common component for all systems, or a dedicated component for each. Secondly, the design department determines the reliability for the component(s) of the chosen alternative, and subsequently fixes the design. Finally, the spare parts stock levels are
determined by the after-sales services department. Clearly, such a sequential approach is sub-optimal for minimizing the total LCC. After-sales services are typically not taken into account explicitly during the early design phase, at which time the OEM has the ability to determine 70-85% of the LCC. Yet, after-sales services may constitute up to 70-80% of the LCC, and thus are pivotal in an effort to lower the LCC.

Therefore, we propose an alternative approach that takes after-sales services, component reliability, and the commonality decision into account simultaneously. We refer to this approach as the integrated LCC approach. This approach is based on an appropriate mathematical modeling of LCC under either the use of a common component or the use of dedicated components.

Our main contributions are as follows. First (1), we show how our original problem formulations, which appear to be intractable, can still be studied when considering asymptotically equivalent problem formulations as the cost of spare part unavailability approaches infinity. For these tractable problems (common and dedicated), we show that (2) the benefits of component commonality reach beyond the ones derived from a marketing and production perspective. That is, commonality reduces the LCC in many cases, even when the production costs of the common component are higher than those of the dedicated components. Thirdly, (3) we illustrate that using the sequential approach underestimates the attractiveness of commonality, and it can yield arbitrary large LCC increases. Hence, we strongly recommend the use of the integrated LCC approach in the decision making process. Finally, (4) we prove - for two relevant special cases - that the optimal reliability level for a common component is higher (lower) than for dedicated components, only if the extra investment in production costs of all components can (cannot) be earned back throughout the time horizon that the components are used.