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Designing for Machine Longevity - A Literature Survey

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ABSTRACT: Complex machines are increasingly expensive to develop and build, which causes many to be maintained in service for longer than initially designed, as they still effectively perform valuable tasks. Longlasting, effective service lives of centuries rather than decades are a valuable characteristic for certain machines in several industries, whether for continual service, extended storage, or extremely remote deployment, such as in military service, agriculture and space exploration. Although there are various archival publications that focus on longevity, we seek to identify product architecture decisions which impact a machine's longevity and can then be extrapolated out for timescales greater than 100 years. We refer to this as hyper-longevity. This paper seeks to find patterns in the literature that can identify causes linked to longevity effects, their frequency in the literature, and the types of impacts they have in facilitating longevity.

KEYWORDS: machine longevity, literature survey, durability, reconfigurable

1. Introduction and Literature Survey

The longevity of complex powered machines is an increasingly important topic in today's world. These machines are relatively new to the world, only coming into common use during the industrial revolutions of the 18th and 19th centuries (Van Neuss, 2015). They have major impacts on the individuals, firms, and societies that use them. The initial costs for such machines can be very high, particularly when both the product and process technologies are still novel (M.V. Tatikonda, 2000). While the capabilities of these machines are used to justify their expenses, increasing costs and functional requirements can drive the need for machines that properly function for more than a hundred years in such areas as agriculture, defense, and space exploration. We refer to these lifespans of over a century as hyper-longevity in this paper.

As we progress through the 21st century, we observe increasingly more demand for complex powered machines to be valuable long past their initial intended lifespan, or returned to service despite high costs and functional shortcomings. For example, the Russo-Ukraine War (2022-present) has seen T-54 tanks (first used in 1948) shipped east from Siberia to reenter service (Malyasov, 2023). As diesel engines are resilient (Smil, 2007) and Russia still produces diesel fuel (Agency, 2022), they were able to return these 74-year-old machines to service. The United States produced the last B-52 Stratofortress in 1962. Currently, it is paying an estimated $32 billion dollars to extend their service life to 2050 (USAF, 2019). Neither of these machines are serving in their original roles (Trevithick, 2023), yet they still provide a meaningful function.

In 2010 the average age of a tractor in the United States was over 25 years old, with many of the oldest models being the most popular (Murphy et al., 2010). This trend may be growing even stronger as agricultural auctions and sales frequently have tractors from the 1970's that generate the highest demand (Toulas, 2020; Jacobs, 2020). This is despite some safety concerns (Murphy et al., 2010), and the lack of certain modern functionalities and ergonomics. Some equipment companies are re-entering the manufacturing market targeting the older style tractors, and claiming service lives of 30-40,000 hours (Roesler, 2023) or 30-40 years. This is a significant increase from the 4-16,000 hours or approximately 10 years predicted for common tractors in some studies (Mileusnić et al., 2019).

Space exploration is a new and expanding industry, with its market size predicted to grow from $630 Billion USD in 2023 to $1.8 trillion USD by 2035 (McKinsey and Company, 2024). As a critical factor in modern economies (Corrado et al., 2023), both governments and private industry have large incentives for longer-lasting vehicles. Every launch requires massive expenses, with SpaceX's Falcon 9 costing $62 Million USD (Kramer, 2023) before the payload, making it relatively cheap due to re-usability. The International Space Station has seen its service life extended to three decades, and is estimated to have cost over $150 Billion USD. The Voyager probes launched by NASA in 1977 are the first missions to go beyond our solar system, which they achieved in 2012 and 2018 and are hoped to continue for decades more. The complete mission cost up to 1989 was $865 Million USD or 8 cents per US resident per year (with the yearly cost decreasing the longer they remain in service) (Laboratory, 2023).

Products with longevity are durable, and considered both useful and desirable by users for a long period of time Jensen et al. (2021). All of the previous examples show the need for governments, researchers, and industry to have long-lasting machines for both functional and economic reasons. This paper seeks to identify patterns in the literature on how product architecture decisions affect the longevity of machines from published findings. By using techniques from the Product Architecture Strategy and Effects (PASE) Method (Rice et al., 2024b) and a system of custom-tuned Large Language Models (LLM) (Rice et al., 2024a) to aggregate data from hundreds of papers, we will identify useful insights for designers and decision-makers for creating long-lasting machines.

The rest of this paper is organized as follows: Section 2 discusses the research goals, and Section 3 describes the approach used for gathering the data from the literature. Section 4 presents the results, and Section 5 provides concluding remarks, limitations and discussion of potential future work in this area.

2. Research Goal: Identifying product architectural impacts on longevity

A product's longevity is a complex topic that is impacted by many factors, including society, economics, functional requirements, and not least of all the product's architecture. A machine can last for long periods of time due to design decisions, as well as simple use and environmental factors. A machine used sparingly and stored in a protected environment may maintain its original functionality, but no longer serve a useful purpose. Components in working order may be irrelevant if there is no ecosystem producing the needed fuel, or items it operates on. A machine seeing regular use however, may be upgraded, a supply system maintained for consumables, etc. Design decisions can have great impact on the ability to maintain a machine and its required ecosystem.

Product architecture is the arrangement of, and interfaces between, major parts and subsystems of a component or system (Mattson and Sorensen, 2019). It is related to the system's mass and geometry as well as its functional organization and degree of modularity. We include in our goal the influence of material selection, as it greatly impacts key physical characteristics of a product, such as geometry and durability. We hope to identify what elements of product architecture impact a machine's longevity. As hyper-longevity is an extension or even just a specific subset of the design for longevity, it is believed that most, if not all, of the aspects identified will be of use in the design for hyper-longevity, enabling the purposeful design of these kinds of inter-generational machines.

Product architecture has been researched for decades as shown by Ulrich (1995) and Clark (1989). Our intent is to uncover existing knowledge on how product architecture effects longevity, and how that can be used for design decisions when trying to achieve hyper-longevity. By aggregating knowledge from various sources that may not have been put into the same context before, we ultimately hope to identify patterns and principles that guide a designer in making decisions that impact the longevity of the product they are developing. The PASE method (Rice et al., 2024b) is an enabling framework for identifying such patterns and principles.

The PASE method was developed to explore effects of product architecture decisions and will be modified slightly as we work to specifically find effects dealing with longevity. While we intend to focus on machine longevity, it is recognized that those who design civil infrastructure have a great deal of experience with service lives greater than one hundred years.

Our focus on machines, however, will limit the applicability of some knowledge pertaining to infrastructure. A machine, particularly a mobile one, cannot simply continue making itself heavier by increasing the size and thickness of components to maximize their durability and wear life as gravity and inertial forces would prevent it from running efficiently and effectively. Therefore, observations from the literature that focus on infrastructure will not be included in the present paper. Nevertheless, we recognize there is likely useful information to be gained from this field, with properly directed exploration.

We recognize that the amount of literature in this field to review to be considered comprehensive is enormous. This paper does not attempt to be comprehensive, but instead, seeks to identify some of the methods affecting machine longevity — specifically those related to product architecture decisions and their effects on the longevity of a machine.

3. Approach: Extracting Product Architecture Effects on Machine Longevity

To review large amounts of the literature traditionally requires hundreds of man-hours to discover patterns and useful observations at any scale. Modern large language models (LLMs) however, can greatly reduce that burden and speed up the process, as long as proper safeguards are maintained to prevent hallucinations or other errors from affecting the collected data.

3.1. General Framework

The LLM-based approach utilized by the authors consisted of four main steps:

1) Acquire potential papers using common archival database search engines.
2) Process papers using scripts and LLMs to extract relevant information (termed *insights*)
3) Manually code the LLM-generated insights into *causes* and *effects*
4) Consolidate and review the coded results

This approach allows for quickly processing thousands of papers for relevant information, reducing the man-hours needed to compile such a survey. By coding the insights and analyzing the results, patterns can be identified as to what causes are linked to longevity effects, their frequency in the literature and the types of impacts they have in facilitating longevity.

3.2. Detailed Steps

This section describes each step of the general framework as well as the Enabling Technologies and Methods we used to identify specific causes of longevity from product architecture as described in the literature.

3.2.1. Step 1: Paper Acquisition

All of the papers in this study were identified and acquired using Scopus, a peer-reviewed literature database from Elsevier. Scopus was selected for its size, search filters, database metrics, and mass download plugin. 2,809 unique papers were extracted from Scopus using the keywords shown in Figure 1. This number was reached by those papers which were identified by the Scopus search and were available for download.

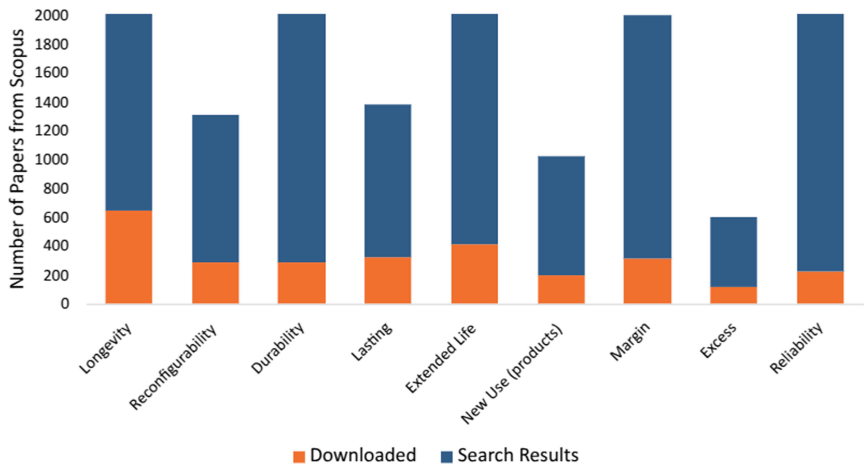

Figure 1. Number of papers returned for each Keyword

Scopus search filters and database metrics were used to generate a Boolean query for each keyword. Every query searches the Scopus database for its respective keyword and limits the search to relevant source types and themes. The searches were constrained to include only peer-reviewed journal articles written in English about engineering. Additional constraints were applied to database metrics to filter out articles that were unlikely to contribute engineering insights. The keywords used were: Longevity, Reconfigurable, Durability, Lasting, and Extended Life (for products)

For example, the search query for "Longevity" excluded papers with terms associated more with biology such as "Clinical Study," "Animal Experiment," and "In Vitro Study." The process was continued until the database metrics reflected the intent of the search, and the search for each keyword returned Scopus's maximum of 2000 papers or fewer. For each final search result Scopus's bulk download plugin was utilized to download fifty papers at a time. Of these fifty, each download would retrieve papers from compatible journals accessible from Brigham Young University's network. In all, only 22.25% of the papers returned by the search were available for download. Figure 1 shows the numbers of each keyword returned and downloaded for this survey.

3.2.2. Step 2: Computer Aided Processing

After acquiring the papers identified above, they were processed using a Python script that parsed the text into separate paragraphs, and removed artifacts from the PDF files that might interfere with the LLMs which would later interact with this data, such as headers, footers, and metadata. The output was a JSON file containing a list of paragraphs with both unique source and paragraph identifiers (Allowing for any paragraph to be later traced back to its originating paper). This file could then be entered into the first of the LLMs described in Rice et al. (2024a), or Model-1. This custom-tuned BERT LLM classifies each paragraph on whether it is of interest relative to product architecture and its influence on longevity. All paragraphs of interest are then returned in a second JSON file. Model-1 was tuned specifically to identify paragraphs that contained effects from product architecture.

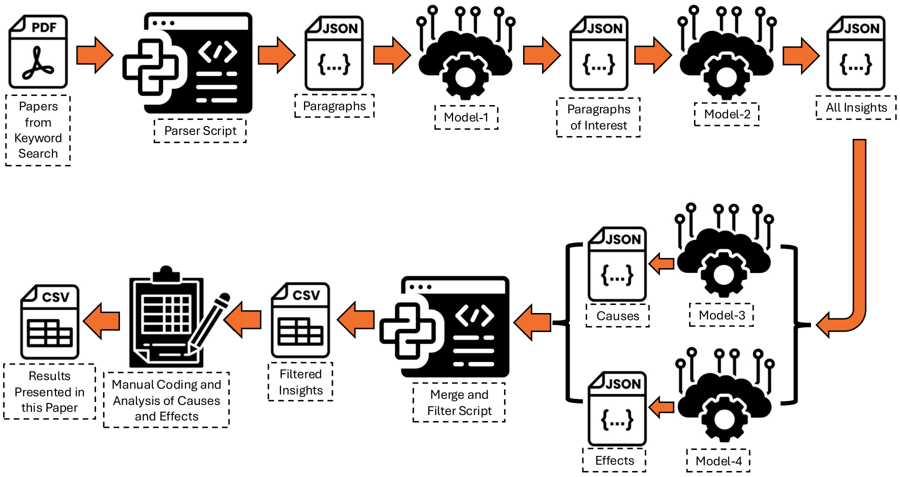

Figure 2. Computer Aided Processing Flow

This second output file of paragraphs of interest (which maintains the source and paragraph identifiers) can then be processed by a second LLM, Model-2. This model processes each paragraph of interest and summarizes it into simple cause-and-effect statements, each with its own unique identifier. According to the PASE method described in Rice et al. (2024b) these are known as *insights* and ideally describe an element of product architecture and one of its effects. The insights generated by Model-2 were then processed by both Models-3 and 4, which identified the cause and effects for each insight respectively. These outputs were then merged and filtered by a Python script, returning only those with keywords relating to longevity in a CSV file. The full flow of the computer aided processing can be seen in Figure 2.

3.2.3. Step 3: Manual Coding

A total of 4,101 insights identified and then manually coded by a single rater in one round. The coding identified the specific causes and effects within each insight. Whenever there was more than one cause or effect present in an insight they were both noted, using a comma as a delimiter to separate them (See Table 1 for an example). Effects were not coded as either positive or negative, but simply as a category. The rater referred only to the paragraph in the document from which the insight had been generated, allowing for it to be indexed and referenced if more context is needed for clarity.

Table 1. Example of Insights and Manual Coding

Insight	Cause	Effect
Commonality increases reliability & maintainability of parts	Commonality	Maintainability, Reliability
Composites increase the durability of the product	Material Selection	Durability

One result of this manual review of each insight, was to remove those instances that were either results of hallucinations or that were irrelevant to the desired topic of machine longevity by coding them as “Non-Applicable”, as well as all insights from any non-english language journals that had not been excluded by earlier filtering attempts.

3.2.4. Step 4: Consolidation

Once the initial coding of each insight was complete, the identified causes and effects were grouped and reviewed to verify that they were unique, and that no duplicate or synonymous categories had been created. After consolidation the majority of the causes were in 14 main categories as shown in Table 3. The effects were primarily in six categories described by the keywords used in the Python filter script:

durability, excess (margin), long-lasting, longevity (extended-life), reconfigurability (reconfigurable and new use), reliability. Maintenance was a seventh category of effects found among the insights, even though it was not part of initial search terms. Approximately 7% of the classified insights contained causes and effects which could not be integrated into these main groups. As none of these groups were mentioned by more than 1% of the sources, they are not shown in Table 3 or Figure 3.

4. Results

This section describes and discusses the observations made on the identified causes of longevity and which of the original effects searched for had information found. It also discusses the impacts a product's longevity can have according to the insights extracted in this survey.

4.1. Observations

From an initial pool of 2,809 unique papers acquired by the basic screening as described in Section 3.2, 1,047 of these papers returned 4,101 insights from the LLMs and python scripts in Section 3.2.2. After manually grading the insights (see Section 3.2.3), only 809 papers contained insights pertaining to some aspect of longevity, with 146 papers referring only to construction and infrastructure. Figure 1 shows the number of papers found for each keyword, and Table 2 how many of the 1,952 papers were kept after the processing and filtering steps, which were Steps 1-4 described in the previous section.

Table 2. Number of Papers in each major step

# of Sources	Description
2809	Unique papers acquired through the initial screening process
1047	Unique papers that contained potential insights after sorting
809	Unique papers that contained insights relevant to longevity
663	Unique papers containing insights relevant to machine longevity

4.1.1. Causes

Modularity was the most common causal term in this set of literature and insights, with over 40% of all sources containing at least one insight related to modularity. This result is similar to the strategy of "Using modular architecture" from the PASE database, which was the most common strategy found in curated set of 17 papers for that study (Rice et al., 2024b). This is likely due to modularity being a very common topic within the product architecture space, but may also be a result of the the PASE database being used to tune the LLMs from Section 3.2.2. The LLMs may more frequently recognize statements about modularity as it was very common in the PASE dataset, which may bias the findings as other terms, along with their variations, could be less recognized, causing their statements to not have been returned as often as they would have in a completely manual review.
The frequency of Modularity or Modular Architecture or a related term appearing is an indication that it has an observable effect on longevity, and has been frequently studied and remarked upon. Integral Architecture was also in the top 5 causes. While perhaps not intuitive, it should not be surprising that integral architecture will also necessarily impact anything that modular architecture does, as the two are generally opposing methods or paradigms. Figure 3 shows the next most frequent causes are Materials and Component Selection. Materials referred to the types of materials selected, as well as treatments and coatings for those materials or components. Materials chosen for a machine greatly impact its longevity, as it impacts wear, strength, corrosion resistance, etc. Component selection references how and why a particular component or type of component is selected, such as custom designed or off-the-shelf. This impacts the amount of design work needed from the team. Controls refers to the architectural decisions around mechanical and digital controls, direct input, feed-back, etc. Controls greatly influence how a machine operates, and the speeds with which it acts or reacts.

CAUSES \ EFFECTS	Durability	Excess	Long-Lasting	Longevity	Maintenance	Reconfigurable	Reliability	
Commonality	5		1	1	1		14	22
Components	8	2	2	7		13	56	88
Controls	1	2		2		4	33	42
Customization	1							1
Detection	4			2			12	18
Energy	2	2		11	1	2	10	28
Integral	5			5	1	3	73	87
Modular	53	15	4	43	7	89	378	589
Maintenance	3			3			20	26
Materials	77	1	7	27	1	7	45	165
Margins		2		2	1		5	10
Optimization	1	1		1			8	11
	160	25	14	104	12	118	654	

Figure 3. Frequency of pairings between Causes and Effects

Table 3. Percent of Sources referencing a causal category

Cause	Sources	Insights
Infrastructure Specific	146 (18.0%)	522 (27.3%)
Modular Architecture	339 (41.9%)	684 (35.7%)
Materials	115 (14.2%)	195 (10.2%)
Components	87 (10.8%)	137 (7.2%)
Integral Architecture	71 (8.8%)	110 (5.7%)
Controls	33 (4.1%)	57 (3.0%)
Commonality	22 (2.7%)	30 (1.6%)
Energy	16 (2.0%)	30 (1.6%)
Margins	15 (1.9%)	80 (4.2%)
Detection	14 (1.7%)	23 (1.2%)
Optimization	10 (1.2%)	15 (0.8%)
Maintenance	7 (0.9%)	28 (1.5%)
Customization	3 (0.4%)	3 (0.2%)

Modularity, Material Selection, and Component Selection are by far the most common causes of longevity to emerge in this survey, indicating that they have some of the greatest impacts on longevity for machines. Integral Architecture and controls or arrangements are the next most frequent causes, though significantly less frequent than the first three. These results indicate that the use of modular and integral architectures, the choice of materials, types of components and their arrangement, and the type of controls are areas with large impacts on machine longevity for designers to consider. Future sampling of more papers would be needed to see if this pattern continues or is only true of this set.

4.1.2. Effects

Effects on the longevity were part of the original search terms, such as the five keywords used for identifying papers. Additional words and terms were also used in evaluating which insights would likely be valuable in Section 3.2.2. While there were some effects that were extremely specific, most could be grouped and identified in the categories seen in Figure 4. The number of sources mentioning an effect

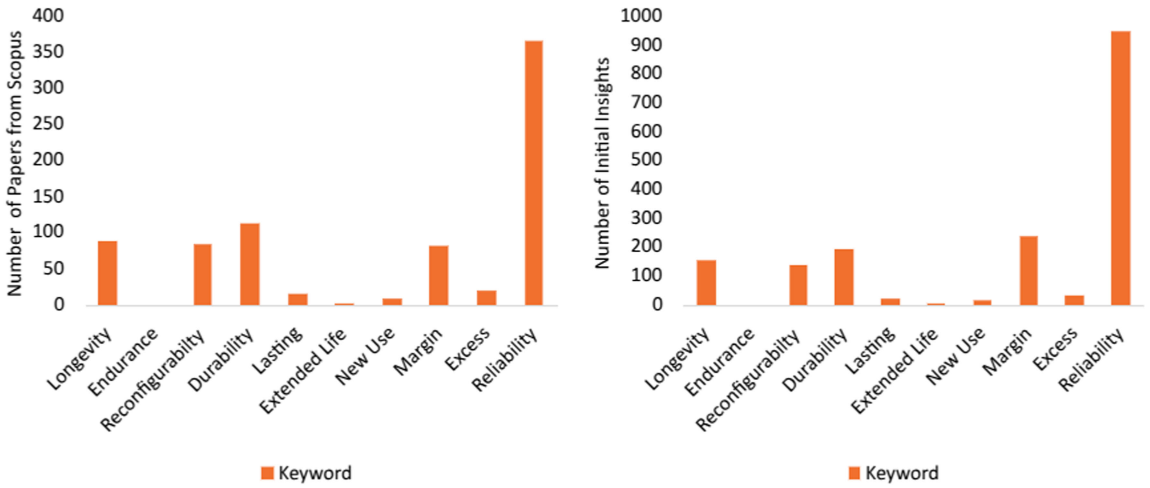

Figure 4. Initial Papers and Insights with Keywords

correlates strongly with the number of insights found with those effects. Durability, Reliability, Longevity, and Reconfigurabilty (reconfigurable) being the four most common effects mentioned. This is to be expected, given the method used to identify the initial papers. The patterns between causes and these effects being the most interesting as seen in Figure 3. New Use returned no results and perhaps the term re-use would have been a better choice.

4.1.3. Infrastructure

Infrastructure — particularly static structures and construction materials not generally found in machines that move or experience inertial forces — was an expected result. Approximately a quarter of insights coded were about an infrastructure such as pavement, concrete, or a building. These came from 146 papers, showing that longevity is a common topic in that field, and many papers were included despite filter criteria to screen for non-infrastructure based papers.

4.2. Effects of Longevity

One group of insights found, which did not fit into the original defined search, but were considered relevant nonetheless, were those which referred to the effects longevity has on the product. About 2% of the sources mentioned the effects of reconfigurabilty, durability, longevity, and/or robustness. These noted impacts on investment or long-term costs, satisfaction, quality, maintenance, types of architecture needed (integral vs modular), design complexity, performance, and materials. The large number ofReferences found to civil engineering topics such as building architecture, concrete and paving mixtures, and other infrastructure topics when trying to screen them out, shows that this area of engineering places much emphasis on the topics of durability and longevity in their construction.

5. Concluding Remarks

This section discusses the findings, the potential utility of the longevity observations found, and possible future work in this area of research.

5.1. Findings

Product architecture decisions are made early and greatly affect the downstream success and processes for the design. A key conclusion of this study is that the degree of modularity of a system's architecture, along with the materials selected, commonality of parts and components, and integral architecture of certain features are the greatest impacts on the general longevity of a design — specifically in its durability, reliability, and ability to be reconfigured for new uses.

Modularity is shown to directly impact the reconfigurabilty of a machine in this survey. This allows, for example, military machines that may no longer be competitive in their original mission to continue in service with a new mission set, such as the B-52 bomber no longer being used for gravity nuclear bombs (Kristensen, 2017), yet are maintained in service. As users' needs change, the ability to reconfigure a machine so that it evolves with those needs is critical according to Allen et al. (2014). Modularity and Commonality (the 6th highest in our results) often impact reliability together, as common modules reach greater maturity over generations (Hackl et al., 2020). In this case, the longer lasting a machine, with replaceable modules that are being upgraded each iteration, will result in ever greater reliability. Materials that increase the product's durability, by resisting wear and/or corrosion, will also increase the lifespan of a machine. The relatively high number of insights from Controls indicates it may have a large impact on a machine's reliability, and reconfigurability. This indicates it is a potential area to be further explored.

5.2. Efficiency of Literature Review Process

Out of 1,952 papers initially identified in the screening, only 409 were ultimately referenced by the insights identified and coded as relevant to this search. Importantly, acquiring the nearly 2000 papers was done in a few hours, and over half of them were then removed by the computer-aided processing. In Rice et al. (2024a) it was estimated that each paper searched for paragraphs of interest was reduced from 90 minutes to one minute, and that generating each insight would have taken about 10 minutes, and was now less than a second. This translates into 2,895 man-hours saved in step one of this approach, and as step two returned nearly 100,000 insights before they were filtered down to the 2,541 insights that were manually coded, an estimated 16,589 man-hours were saved during this paper. There is however a loss of detail and potentially paragraphs and insights missed by the computer-assisted process.

5.3. Future Work

This paper's dataset is not comprehensive of all product architecture choices that can effect the longevity of a machine. Future work includes analyzing a larger selection of literature in a similar manner, as well as more in depth analysis of the relationships shown from this survey. This could be done to better understand the nuances of when a particular cause generates one of the effects shown by the results in Figure 3. It cannot be assumed simply because a particular cause can or may affect the system in a certain way, that it always will affect it. Finally, the large amount of information available from the infrastructure field indicates that techniques for increasing longevity which are used by civil and construction engineers could potentially be of use in the mechanical and aerospace engineering fields.

Acknowledgments

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References

Agency, I. E. (2022). *Energy fact sheet: Why does russian oil and gas matter?*

Allen, J. D., Watson, J. D., Mattson, C. A., and Ferguson, S. M. (2014). Evaluation of system reconfigurability based on usable excess. *In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, volume Volume 2B: 40th Design Automation Conference*, page V02BT03A037. American Society of Mechanical Engineers.

Clark, K. B. (1989). *Project scope and project performance: the effect of parts strategy and supplier involvement on product development.*

Corrado, L., Cropper, M., and Rao, A. (2023). Space exploration and economic growth: New issues and horizons. *Proceedings of the National Academy of Sciences*, 120(43):e2221341120.

Hackl, J., Krause, D., Otto, K., Windheim, M., Moon, S. K., Bursac, N., and Lachmayer, R. (2020). Impact of modularity decisions on a firm's economic objectives. *Journal of Mechanical Design, Transactions of the ASME*, 142.

Jacobs, C. (2020). *Farmers are buying up old tractors because...* Available at: https://www.thedrive.com/news/31761/enormous-costs-of-new-tractors-drive-demand-of-40-year-old-equipment-to-all-time-highs (Accessed on Nov 07, 2023).

Jensen, P. B., Laursen, L. N., and Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. *Journal of Cleaner Production*, 313:127951.
Kramer, M. (2023). *Spacex's starship could transform the space industry*. Available at: https://www.axios.com/2023/04/18/spacex-starship-transform-industry (Accessed on Oct 30, 2023).
Kristensen, H. (2017). *B-52 bomber no longer delivers nuclear gravity bombs*. Available at: https://fas.org/publication/b-52-bombs/ (Accessed on Dec 07, 2024).
Laboratory, J. P. (2023). *Voyager: Did you know?*
Malyasov, D. (2023). *Russia deploys ancient t-54 tanks to ukraine*. Available at: https://defence-blog.com/russia-deploys-ancient-t-54-tanks-to-ukraine (Accessed on Nov 01, 2023).
Mattson, C. A. and Sorensen, C. D. (2019). *Product Development: Principles and Tools for Creating Desirable and Transferable Designs*. Springer Nature.
McKinsey and Company (2024). *Space: The $1.8 trillion opportunity for global economic growth*. Available at: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-the-1-point-8-trillion-dollar-opportunity-for-global-economic-growth (Accessed on Nov 26, 2024).
Mileusnić, Z., Tanasiijević, M., Miodragović, R., Dimitrijević, A., and Urošević, M. (2019). Tractor lifetime assessment analysis. *Journal of Agricultural Sciences*, 25(2):197–204.
Murphy, D. J., Myers, J., Jr., E. M., Cavaletto, R., May, J., and Sorensen, J. (2010). Tractors and rollover protection in the united states. *Journal of Agromedicine*, 15(3):249–263.
M.V. Tatikonda, S. R. (2000). Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE Transactions on Engineering Management*, 47(1):74–87.
Rice, S. E., Sannar, B. C., Mattson, C. A., and Anderson, M. A. (2024a). Extending the product architecture strategies and effects database through large language models. volume Volume 3B: *50th Design Automation Conference (DAC) of International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, page V03BT03A057. American Society of Mechanical Engineers.
Rice, S. E., Sannar, B. C., McKinnon, S. A., Humphrey, T. M., Mattson, C. A., Sorensen, C. D., and Anderson, M. L. (2024b). Product architecture strategies and effects matrices for early evaluation and selection of product architectures. *Design Science*, 10:e41.
Roesler, S. (2023). *Big equipment, rome plow to build new big bud tractors*. Available at: https://agupdate.com/farmandranchguide/news/crop/big-equipment-rome-plow-to-build-new-big-bud-tractors/article_bf3a04e6-9811-11ed-a7c8-63c45a8db0b8.html (Accessed on Nov 07, 2023).
Smil, V. (2007). The two prime movers of globalization: history and impact of diesel engines and gas turbines. *Journal of Global History*, 2(3):373–394.
Toulas, B. (2020). *Demand for older tractors skyrocketing and prices rising*. Available at: https://www.industrytap.com/demand-for-older-tractors-skyrocketing-and-prices-rising/51742 (Accessed on Nov 07, 2023).
Trevithick, J. (2023). *Antique t-54 series tank appears with russian forces in ukraine*. Available at: https://www.thedrive.com/the-war-zone/antique-t-54-series-tank-appears-with-russian-forces-in-ukraine (Accessed on Apr 2023).
Ulrich, K. T. (1995). *The role of product architecture in the manufacturing firm*.
USAF, G. (2019). *B-52h stratofortress*. Available at: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104465/b-52h-stratofortress/ Accessed on Sept 07, 2023.
Van Neuss, L. (2015). *Why did the industrial revolution start in britain?* Available at SSRN 2696076.