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Comparing Life Cycle Costing and Performance Part Costing in Assessing Acquisition and Operational Cost of New Manufacturing Technologies

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Abstract

Even if practitioners want to adopt new manufacturing technologies, there is a lack of comprehensive tools to support their decisions, regarding both cost and sustainability. This paper reviews and compares the practical use of Life Cycle Costing (LCC) with a performance part costing (PPC) model, chosen based upon the criteria of providing in-depth analysis capabilities and the prospect of integrating cost and sustainability assessment. A case study of a Swedish gear manufacturer is selected, where the company investigates adoption of a new manufacturing technology. Since, this type of decision requires heavy investments e.g. in new machines, tools, linking performance with costs would be a prerequisite for performing well-informed decisions. Based on interviews, the level of detail requirements e.g., performance indicators, when acquiring new technologies are identified. LCC model cost parameters are compared with the PPC cost drivers and the data availability and estimation are discussed.

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Keywords: Life Cycle Costing (LCC); Performance Part Costing (PPC); Decision Support System (DSS); Gear Manufacturing

1. Introduction and motivation

Companies struggling to be competitive by being cost efficient are constantly in search for models and methods for assessing investments and improvement opportunities, to understand how to prioritize between different actions and choices. The challenge in doing so is often to leverage between details and the possibility to retrieve data of good quality and from different functions and systems within the company. Simpler models and methods are easier to use but the level of knowledge they provide are limited. More complex models and methods require more effort in retrieving input data, but provide a richer knowledge base for better and well-informed decisions.

There is an array of methods for assessing manufacturing and production costs. Both Jönsson [1] and Schultheiss et al. [2] have compared, different cost accounting methods (e.g. standard costing, activity-based costing, throughput accounting, life cycle costing), and manufacturing cost models based on their purposes, level of detail, principles and cost allocation strategies. Manufacturing cost models can be divided based on their different characterizations e.g. qualitative and quantitative approaches, microeconomics and macroeconomics techniques, top-down and bottom-up granularity levels, early prediction and late estimation applicability phases [2, 3, 4].

The most frequently cited cost methods are Activity Based Costing (ABC) originally proposed by Cooper and Kaplan, Time-Driven ABC (TD ABC) were developed by Kaplan and

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Andersson [5]. Since ABC is considered to be complicated and time consuming (due to requirement of activity data or unnecessary complex overhead allocation calculation), it has not been implemented largely in industry due to its perceived complexity [6]. Standard Costing is, on the contrary, frequently used in industry as an accounting method, but it contains too few parameters (mainly direct material and labor costs, not equipment data) to be suitable as a base for development of decision support for production development [7].

Throughput Accounting (TA) originates from Theory of Constraints with the purpose of maximizing the profit for the bottleneck process [8]. TA contains parameters both aligned to production but also other overhead costs for e.g. product development. Life Cycle Costing (LCC) was initially used by US defense department to seek optimal costs for acquiring, owing and operating an equipment during its useful life (also including any disposal costs), were Woodward [9] presents an overview of the method. There are a few synonymous terms to LCC in the literature, e.g. Through-Life Costing (TLC), Whole-Life Costing (WLC) and Total Cost of Ownership (TCO), explaining cost throughout the life cycle of a product, system or project. The different use of these terms is a subjective choice [10]. These cost calculation methods usually do not include the three performance parameters (quality, productivity and availability) of the Overall Equipment Efficiency (OEE) measure, or lost profit, although Life Cycle Profit (LCP) were introduced already 1983 in literature [11]. To remedy this shortcoming, Performance Part Costing (PPC) methodology was proposed [1], to serve as a base for developing decision support for production development, production location and investment in new technology issues.

The PPC model is a manufacturing cost analysis method, with the purpose of supporting mid and higher management within the manufacturing industry, in detailed decision-making concerning e.g. adoption and deployment of alternative manufacturing technologies. In an ongoing research project, the focus is on comparing cost and sustainability for conventional gear machining with powder metallurgy (PM) gear manufacturing. An in-depth comparison of manufacturing processing routes cost for both technologies based on performance and quality requirements from customers on the produced part will be aligned with the sustainability impacts of each technology [12].

Since the purpose of the ongoing research project is to assess costs for alternative manufacturing technologies, LCC is an appropriate method to consider. In this study, the interest is in use of LCC within the operation phase to evaluate how to plan production in alternative paths of the production system (PS) and what future alternative paths are needed to operate the PS efficiently. The authors have previously been using and developing the PPC methods for different purposes and one motivation for this case study is to compare the two calculation methods used for developing cost based decision support tool for alternative manufacturing technologies. The intention is to take learnings from LCC-development on major manufacturing equipment life cycle aspects to future PPC-development. Having said that, this article provides information and answers the aforementioned aims by comparing these two calculation methods applied in a gear manufacturing case study.

2. Calculation methods comparison

In the following paragraphs, Life Cycle Costing (LCC) and Performance Part Costing (PPC) are compared considering their calculations methods, included parameters and applications. Less detailed costing models without equipment cost and performance, such as Standard Costing or e.g. throughput accounting were not evaluated in this study.

2.1. Performance part costing (PPC)

The PPC model was developed with the purpose of providing a detailed decision support when e.g., prioritizing between different production development activities [12] or choosing between different production location alternatives [13]. It is designed to follow the manufacturing processing routes, and to determine the part cost per unit for batch production. It incorporates technical performance parameters with economic parameters to evaluate the intact influence of production performance on cost [1]. The inceptive purpose of the cost model is to analyze and compare scenarios for varies production development cases to assist the realization of the improvement opportunities rendering the best cost efficiency.

The formulation of the model is based on the imperative cost drivers, related to tools, equipment, personnel and others, required to complete manufacturing activities from raw material to finished part. The complete manufacturing cost per part (k) is evaluated in an accumulated way where each process step's cost is added as the input cost to the next. The raw material cost is considered in the first processing step. Equations 1, 2 and 3 illustrate the PPC model, and table 1 defines their input parameters including their units. 'In the equations k_{cp} is the hourly equipment cost during the operation, and k_{cs} is hourly equipment cost during downtime or idle. k_{cp} and k_{cs} are calculated based on parameters e.g. annual work time, technical lifespan, investment, equipment footprint and annuity [14].

$$\boldsymbol{k} = \frac{k_A}{N_0}\left(\frac{N_0}{(1-q_Q)}\right) + \frac{k_B}{N_0}\left(\frac{N_0}{(1-q_Q)(1-q_B)}\right) + \frac{k_{CP}}{60N_0}\left(\frac{N_0 \cdot t_0}{(1-q_Q)(1-q_P)}\right) + \frac{k_{CS}}{60N_0}\left(\frac{N_0 \cdot t_0}{(1-q_Q)(1-q_P)} \cdot \frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}}T_{Pb}\right) + \frac{k_D}{60N_0}\left(\frac{N_0 \cdot t_0}{(1-q_Q)(1-q_P)(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}}T_{Pb}\right) + \frac{1}{MD}[K_E + K_G + K_{RW}] \quad (1)$$

$$\boldsymbol{k_{CP}} = \frac{K_0 \cdot \frac{i(1+i)^n}{(1+i)^n - 1} + k_{ren} \cdot \frac{N_{ren}}{n} + Y \cdot k_Y + T_{plan} \cdot \left(\frac{k_{Mh}}{h_{P,M}} + k_{ph}\right)}{T_{plan}} \quad (2)$$

$$\boldsymbol{k_{CS}} = \frac{K_0 \cdot \frac{i(1+i)^n}{(1+i)^n - 1} + k_{ren} \cdot \frac{N_{ren}}{n} + Y \cdot k_Y}{T_{plan}} \quad (3)$$

Table 1. PPC Input parameters [14].

Description	Symbol	Unit
Running/maintenance hours	hP,M	h/h
Hours per year and shift	hyear	h/year
Interest rate	i	%
Annual cost of producing a product	K	SEK
Investment	K0	SEK
Tool, lubricant and additive costs	kA	SEK/unit
Material cost per part	kB	SEK/unit
Personnel costs	kD	SEK/h
Cost of Maintenance	KE	SEK
Handling and storage costs	KG	SEK
Maintenance cost of equipment/hour	kMh	SEK/h
Eq. running costs (e.g. energy)	kph	SEK/h
Cost for renovation	kren	SEK
Cost of reworking	kRW	SEK
Annual cost of production area	ky	SEK/ m2
Market demand (production vol./yr)	MD	Unit
Estimated equipment lifetime	n	Year
Nominal batch size	N0	Unit
Numbers of operators	nop	-
Number of batches connected to a specific tool	npA	-
Number of renovation during the lifetime of the equipment	Nren	SEK
Scrap rate	qB	%
Speed loss rate	qP	%
Rejection rate	qQ	%
Downtime rate	qS	%
Nominal cycle time per part	t0	Min
Production time for a batch	Tpb	h
Required production time	Tp	h
Total paid and planned production time during a given period	Tplan	h
Set-up time	TSU	Min
Utilization rate in reduced production	URP	%
Area of production and area needed to facilitate production	Y	M2

2.2. Life Cycle Costing (LCC)

LCC is a method to evaluate cost throughout the life cycle of a product or a system. LCC was originally implemented by US department of defense in the 1960s, and after that it has been utilized in other settings e.g. consumer products, equipment acquisition in manufacturing firms [1]. LCC has three forms of 1) conventional LCC also known as financial LCC, 2) environmental LCC (eLCC), and 3) Societal LCC (sLCC). Conventional LCC is the original method and in some ways is similar to TCO. eLCC is affiliated with Life Cycle Assessment (LCA) in terms of system boundaries, functional unit and methodological steps. sLCC incorporates monetarization of other externalities containing both environmental and social impacts [10].

What cost parameters precisely that must be included in a LCC analysis varies among different models and case studies and is rather limited by data availability and/or selected based on the aims of the studies [9]. E.g. LCC cost categories in [10, 15, 16, 17, 18] have some similarity in parameters between different aggregation levels but are not the same. Based on these LCC case studies mostly related to machine tools, the following common cost components, shown in table 2, is proposed as the base of this comparative study.

2.3. PPC and LCC comparison

Prior to this research article, there is no study comparing these two methods in detail, except in [1, 20] (see pp. 15-17) were 2 out of 21 models compared with PPC were based on LCC. In order to compare these two costing techniques, the scope of each method need to be the same. One key factor in this regard is the selection of the target group, the group with a specific perspective that the analysis is done for/from. In LCC, the target group can be a single actor in a value stream e.g., manufacturer, end-user or it can consider the complete value stream prospect. Selection of the target group usually dictates the level of essential details, for which data need to be collected and analyzed later on. However, prior to discussing those aspects, since PPC model initially considers a single actor, in this case a gear manufacturer, among the three types of LCC, selection of conventional LCC would be adequate for this comparison. This is because eLCC and sLCC unlike the single actor view of the conventional LCC both consider the complete life cycle or value stream of the product, system or project [10].

Table 2. LCC cost distribution [10, 15, 17, 18, 19].

Cost component	Cost elements
Acquisition costs	Initial capital cost, equipment cost, reconditioning cost, tool cost, spare part cost, installation cost, education and training cost, cost for buffer/ outsourcing production during installation/reconditioning, cost for ramp-up
Operation costs	Wage and related costs, material cost (incl.. transportation and handling), tool cost, rent cost (incl. e.g. space, heating, ventilation), Energy cost (incl. electricity, gas, compressed air), Media costs (incl. e.g. water, fluids and additives), cost of poor quality, downtime cost, occupancy cost, setup cost
Maintenance costs	Incl. preventive and corrective maintenance, inspection cost (incl. e.g. general, warranty), repair cost, wage and related cost
Disposal costs	Disposal cost of building, machinery, equipment (incl. e.g. service fee, landfill fees), cost of recycling materials (incl. e.g. collection, disassembly, taxes, service fee, landfill fee)

Table 3. Comparison of PPC and LCC cost components.

LCC cost distribution	PCC input parameters
Acquisition costs *(Initial capital cost, equipment cost, installation cost)*	K_0, k_{cp}, i, n
Maintenance costs and reconditioning and spare part costs (part of Acquisition costs)	K_E, k_{Mh}, $h_{p,M}$, K_G
Tool cost (part of Acquisition and operation costs)	k_A
Wage and related costs	k_D
Material cost (incl. e.g. transport and handling)	k_B, K_G
Rent cost (incl. e.g. space, heating, ventilation)	K, k_y, Y
Energy cost (incl. e.g. electricity, gas, compr. air)	k_{ph}
Media costs (incl. e.g. process fluids and additives)	k_A
Cost of poor quality, downtime cost	K_{RW}, q_B, q_p, q_Q, q_S,

Occupancy	k_{cp}, k_{cs}
Setup cost	T_{su}, k_{cp}, k_{cs}

Table 1 and 2 illustrates the PPC parameters and LCC components respectively. Table 3 takes the LCC cost components and correlates them with the related PPC parameters. E.g., in LCC acquisition costs, three elements of initial capital cost, equipment cost, and installation cost are correlated with K_0 (investment), kcp (Hourly machine cost during operation), i (interest rate) and n (estimated equipment lifetime). In the PPC model, K_0 is the total investment cost and include equipment full investment cost e.g. installation, education, training, and ramp up cost, 'kcp' consists of annuity of investment in equipment, cost of equipment renovation (spare parts and personnel), facility costs, cost for planned maintenance including spare parts and cost of consumables and energy. 'i' is in percentage and 'n' is in number of years.

To provide another example, in LCC operation costs; wage and related costs are correlated to k_D (personnel costs). In the PPC model, k_D consists of salary costs, employer contributions, number of personnel, cost of working clothes etc., holiday, parental and sick leave and proportion of working hours with relevant equipment.

It can be seen from the table 2 and 3 that LCC acquisition, operation and maintenance costs are fully covered by PPC model. This accounts for the majority of LCC cost components. However, since PPC is a manufacturing cost model, which provides practitioners with a snapshot of a manufacturing company 'current' production aiming to optimize the production development within the factory walls boundaries, it does not include the majority of disposal costs except in k_B (material cost per part) which includes cost of scrapped parts. For the same exact reason, focusing on current production, in contrary to LCC approach which includes all future costs and then convert them to their present value by means of implementing a 'discounting', the PPC model does not use discounting or any similar techniques.

Another aspect is 'timing' in the LCC operation stage, the influence of production time elements e.g. cycle time, step up time, batch production time, to the best of the authors knowledge, is not clearly understandable from the published cases, since in the cases [15, 16, 21] cost calculation for the LCC operation stage was not been provided. However, the LCC model includes costs for ramp-up, education and training costs that something not explicitly included in the PPC model.

Regarding uncertainty and sensitivity analysis, Woodward [9] noted that due to the high level of costs assumption and estimation in LCC during data retrieval and its associated uncertainty, conducting sensitivity analysis are essential regardless of the available data quality. To advance PPC method further to include sensitivity analysis, upper and lower margins of error for each cost are included. These two percentage numbers provide the opportunity to estimate not only a fixed number but also estimated min and max values of a sensitivity analysis. The estimation of the intervals are based on market intelligent and interviews with production and process engineers and higher management in the case company. With utilizing PPC, different scenarios can be experimented to analyze the effect of change in the value of one cost driver to another or on the total manufacturing cost. Hence, the influence of these intervals can be analyzed similar to the LCC method as shown in analysis done by Kara et al. [22].

3. Gear manufacturing: Industrial case study

The case study company is a Swedish sub-contractor to the commercial vehicle industry. The object chosen for the LCC analysis is an in-production spur engine gear with annual production volume of 4,000 units. The production processing routes for the selected gear is as follow. The forged raw materials are bought from a supplier. The production starts with soft machining processes (Turning → Hobbing → Deburring), then marking and washing afterward. After the heat treatment, which is outsourced, the gear wheel is hard machined (Turning → Grinding) and finally washed [7].

The company has not practiced LCC prior to this study, and hence, it would like to create LCC knowledge with assessing the acquisition and manufacturing costs of this case study gear. After interviewing production and process engineers, higher management and visiting production facilities of the company the following assumptions and data are gathered. The company could retrieve both technical and financial data for the gear from 2010, and approximately 36,000 units have been produced during last 8,5 years. The company assumed that it would produce 63,500 units of this spur gear over 15 years based on the gear application and their market intelligent on the order.

This LCC analysis includes the acquisition costs, operation costs, and maintenance costs including the entire detailed cost breakdown listed on table 2 (see section 2.2 above). End of life costs (e.g. disposal costs) is assumed to be near zero by the company based on the selling the scrap parts and equipment and its associated financial gains.

Prior to this study, in the same research project an analysis of manufacturing cost for the same gear with the PPC model is conducted with the aim of benchmarking the company's current cost model with PPC [7]. The results indicated that using PPC model, e.g. manufacturing costs are more accurately allocated to the activities, and mark-ups (e.g. overheads) are eliminated. Given the fact that, the PPC model provided more precise operation costs for the object under study and as table 3 (see section 2.3 above) shows that the LCC entire operation costs is covered by PPC model, this study utilizes PPC model to calculate LCC operation costs. To comply with LCC procedure, discount and escalation rates are added to the PPC calculated operation costs. The LCC for the spur engine gear under study is defined as follows in equation 4:

$$\text{LCC} = \sum_{c=1}^{3}(\text{Acquisition costs}) + (\text{Operation costs} \times \text{SPV*}) + (\text{Maintenance costs} \times \text{SPV*}) \quad (4)$$

$$\text{SPV*} = \left[\frac{1+e}{1+i}\right]^n \quad (5)$$

Where c is either a single production equipment (e.g. hard turning) or a production cell with various equipment. In this case, c consists of two different cells and one stand-alone equipment. $SPV*$ is the Single Present Value, where the escalation rate and discount rate are incorporated in the same calculation as seen in equation 5 [23].Where e is the escalation rate, which is the rate of increase in the price of a specific commodity. The simple way to determine future costs is to inflate costs known today with a relevant escalation rate. The discount rate i is used to discount future cost. n is the study period e.g. physical or technical life span of an equipment, or estimated period of use [23]. For this study inflation rate of 2% based on Statista (the portal for statistics), and discount rate of 7%, based on [10] suggestion and a dialogue with case company are selected. The distribution of total LCC, for the selected spur engine gear with the production volume of 63,500 units over 15 years calculated based on equations 4 and 5, is illustrated in figure 1. The distribution of operation cost shares, calculated by PPC model, is separately illustrated in figure 2.

As it is shown in the table 3 (see section 2.3), the PPC model considers some cost parameters in evaluating manufacturing costs, namely, K_0 (investment), k_{cp} (Hourly machine cost during operation), i (interest rate) and n (estimated equipment lifetime), which are considered in the acquisition cost in LCC. Hence, there are some cost elements in the figure 2, which are considered in both operational and acquisition costs considering LCC cost distribution.

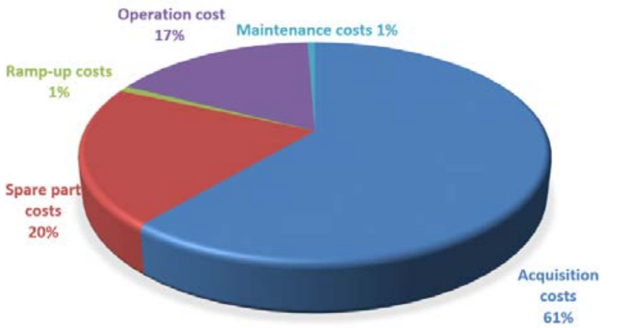

Fig. 1. Cost distribution of different LCC stages for the studied gear

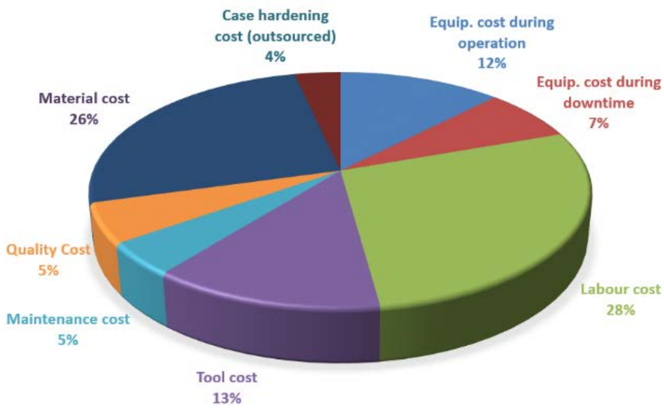

Fig. 2. Distribution of total operation costs using PPC method

In this study, as the LCC analysis is from the manufacturer perspective, the gear manufacturing company primarily has the influence over its operation processes. Thus, the PPC model operation costs breakdown embedded in LCC analysis could assist the company to further evaluate in-depth each operation costs driver to identify improvement opportunities to optimize the operation processes and reduce LCC. In this case, optimizing the operation costs will have effect on other LCC cost components. E.g., the ramp-up costs is determined as one week of production cost by the company, thus reducing operation cost, would reduce the ramp-up costs too.

4. Discussion and conclusion

The main purpose of PPC model is to assist higher management and manufacturing personnel with their decisions related to improvement activities in manufacturing systems as a decision support system (DSS). As mentioned in the introduction, one scenario can be the adoption of a new manufacturing technology. The PPC model must be able to define and analyze the current manufacturing conditions and planned decisions [1]. LCC focus differs from that of PPC. LCC also aims to act as a DSS, but in assessing the total cost related to buying or making, owning and disposal of a product or system [1] and dynamic LCC [24] mainly aims to add the dynamics of these parameters which may be appropriate in both LCC and PPC especially for maintenance planning.

Timing of the analysis is another factor that distinguishes these two approaches from each other. As mentioned in the section 3.3, PPC focus is on current manufacturing activities of a company in their currently utilized production systems. However, LCC has two main different types when it comes to timing, namely *ex ante LCC* and *ex post LCC* [24]. The former is a prospective approach rooted in evaluations and judgements. It is usually applied in the early stages of decision-making e.g. in planning phase prior to an acquisition. The former is a retrospective approach rooted in definite confirmed outcomes. It is usually applied at the end of a project [1, 10].

In overall, the authors suggest that it is not correct to compare PPC and LCC as a trade-off to replace one to another. PPC, in nature, is a modular model and can be implemented in different manufacturing settings. Windmark et al. 2016 [25] illustrated the *'onion shell model'*, where different process support costs e.g., IT support, quality assurance, inbound logistics can be added to the main manufacturing costs, and their effects on total manufacturing cost can be analyzed.

There are a few studies suggesting that LCC in machine tool industry is seldom published, and due to complexity of the approach and difficulties associated with retrieving and analyzing large body of objective data simplified in actual use [16, 17, 26]. It was found a bit difficult to compare different LCC studies with each other, since what cost parameters that are included in a LCC analysis varies among different case studies, based on interpretation of scientist or practitioner on how to distribute costs. Whereas, the PPC calculation methodology is formulated and described in detail in both academic and practice settings. Hence, this article suggests that the PPC model can be used as a part of an LCC analysis focusing on manufacturing cost (incl. acquisition costs) and operation cost (incl. maintenance costs) e.g. according to LCC categorization on [10]. This case study illustrated an example of implementing this in section 3.

E.g., Windmark et al. 2018 [27] has used the PPC model to evaluate the selection of different manufacturing techniques based on cost performance ratio. We argue that implementing models such as PPC focusing on only one stage in the whole life cycle of a system, in this case manufacturing stage, like in

[27] could result in losing the full life cycle perspective and thus avoiding or neglecting other major costs when comparing alternative manufacturing options. Especially when e.g., this case study result, according to figure 1, shows that operation costs is not the major or largest cost element in this spur engine gear. We instead suggest that in order to advance PPC method further to be suitable for comparing different alternative manufacturing technologies, PPC needs to adopt a holistic perspective and learn from LCC approach to include all the steps before starting the operation stage. When it comes to sustainable production, considering only manufacturing stage costs is certainly inadequate for evaluation of alternative manufacturing technologies considering their sustainability impacts. Integration of eLCC and sLCC to assess the whole value-chain from cradle-to-grave provide a deeper system understanding, and PPC can be a part of that.

5. Outlook

In the future work, the authors have a plan to gather sustainability data and integrate sustainability assessment with cost in the PPC model. One approach is to learn from environmental and social impact assessments and their correlation with cost in LCA, eLCC and sLCC. Thus, the authors will conduct LCA and eLCC studies in parallel for the same spur engine gear. The results will be compare with similar studies for the powder metallurgy (PM) gear manufacturing processes to compare the sustainability impact and cost of these two manufacturing technologies over their life cycle stages.

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