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Component level strategies for exploiting the lifespan of steel in products☆

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ABSTRACT

Approximately 40% of annual demand for steel worldwide is used to replace products that have failed. With this percentage set to rise, extending the lifespan of steel in products presents a significant opportunity to reduce demand and thus decrease carbon dioxide emissions from steel production.

This article presents a new, simplified framework with which to analyse product failure. When applied to the products that dominate steel use, this framework reveals that they are often replaced because a component/sub-assembly becomes *degraded*, *inferior*, *unsuitable* or *worthless*. In light of this, four products, which are representative of high steel content products in general, are analysed at the component level, determining steel mass and cost profiles over the lifespan of each product. The results show that the majority of the steel components are underexploited – still functioning when the product is discarded; in particular, the potential lifespan of the steel-rich structure is typically much greater than its actual lifespan. Twelve case studies, in which product or component life has been increased, are then presented. The resulting evidence is used to tailor life-extension strategies to each reason for product failure and to identify the economic motivations for implementing these strategies. The results suggest that a product template in which the long-lived structure accounts for a relatively high share of costs while short-lived components can be easily replaced (offering profit to the producer and enhanced utility to owners) encourages product life extension.

1. Introduction

Over two million fridges and freezers are thrown away in the UK each year. The average lifespan of these refrigerators is eleven years, with newer models often only lasting half that time (BBC, 2004). Such swift replacement is often attributed to compressor failure. Over a period of ten years, lubricant loss from the compressor causes the small bearings to wear out. With compressor replacement cost comparable to that of a new refrigerator, consumers typically choose to replace rather than repair. The other components in a refrigerator, which account for the majority of the metal content, are still functioning at product end-of-life: the outer case, door, interior fittings and heat exchanger are all working when the fridge is discarded. These components could be used for longer, and are therefore currently under-exploited. Hence, the title of this article refers to 'exploiting' the long functioning lifespan of steel in products, as opposed to 'extending' the lifespan of components that may already be functioning at product end-of-life.

The refrigerator is just one example of how the potential lifespan of the components in a product are poorly exploited; the discarded goods in nations' scrap yards suggest this is inherent in 'throwaway societies'.

The replacement of discarded products drives production and emissions from industry. This paper investigates how to increase the lifespan of a product's **steel** components, as reducing steel production would have the greatest impact on industrial emissions; the production of steel accounts for more emissions than any other material. In 2008, it accounted for approximately 9% of the world's anthropogenic carbon dioxide emissions attributed to energy and processing (IEA, 2008). Industrial data reported by Worrell et al. (2007) and BCS (2007) shows that most of the energy needed in the manufacture of steel products is used in the creation of the liquid metal, not in post-solidification forming and fabrication. The liquid metal is produced by one of two routes: the reduction of the metal oxide found in naturally occurring iron ore (primary production) or by melting scrap (secondary production). Assigning a single figure emission intensity to steel production is complex, as it depends on the relative scale of primary and secondary production and the carbon intensity of the electricity supply. However, Milford et al. (2011) provide approximate ranges of carbon dioxide intensities

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(from 100% primary to 100% secondary) equal to 1.6–0.4tCO_2/t of steel. Allwood et al. (2010) predict that from 2008 to 2050 global demand for steel will double. Moreover, they predict that the share of steel production required to replace buildings, equipment, transport and other steel products will increase from 40% to 80% in this period. In light of this, reducing demand by exploiting the lifespan of steel in products could help meet the IPCC's target of reducing global emissions to half of 1990 levels by 2050. An analysis equivalent to that set out in this paper could be conducted for sources of embodied emissions other than steel.

New products are often more efficient than older ones; there is, therefore, a trade-off when extending the life of a product between saving the embodied emissions associated with new production and failing to take advantage of the latest efficiency improvements. This trade-off has been well studied, for example with regard to product remanufacture by Gutowski et al. (2011), product design and utilisation decisions by Skelton and Allwood (2013) and product reuse by Devoldere et al. (2009). In addition, the optimal life of a range of products that face this trade-off has been calculated for cars by Kim et al. (2003), for fridges by Kim et al. (2006) and for air-conditioning units by De Kleine et al. (2011). However, these papers assume that use phase emissions improvements can only be achieved through product replacement. The product upgrade strategies put forward by this paper could be used to secure use phase emissions improvements while prolonging the life of the structural core of products. As a result, although the pursuit of use-phase emissions improvements is not tackled directly by this paper, it is compatible with its findings.

The literature on design for long-life components and products is focused on methods to repair and upgrade using three related strategies: standardisation, modularity and functional segregation.

Standardised components and reversible, uniform joints facilitate easy replacement and adjustment because the same tools and techniques can be used. Webster and Costello (2005) suggest establishing a standardised 'kit of parts' for steel framed buildings, determining a limited number of regular component sizes predrilled with boltholes at set intervals.

Modular design separates a product into distinct components/sub-assemblies with standardised interfaces, usually with reversible connections so that they can be easily replaced and upgraded. Palani Rajan et al. (2005) attempt to assess the effect of modularity on products' lifespan using a "change modes and effects analysis" for seventeen consumer goods. They assess the likelihood of a product being discarded after potential changes to how it is used (e.g. a kitchen chair now used as a computer chair) and find that greater modularity increases the lifespan of the product because it is more adaptable (e.g. a multi-bit screwdriver is more adaptable than a fixed-bit equivalent).

The first step in functional segregation is to identify the function that each element of a product performs. Once isolated, the product or component can be redesigned so that only the elements most susceptible to failure need be replaced. Reversible connections aid functional segregation by allowing easy, quick replacement; Morgan and Stevenson (2005) and Bogue (2007) both consider this a critical enabler of longer lifespan products. Durmisevic and Brouwer (2002) argue that traditional construction techniques encourage integration rather than segregation of components, causing demolition of buildings when only small alterations are required.

Brand (1994) introduces a useful tool to analyse functional segregation by examining the interaction between components within a product. He distinguishes six systems within a building that he depicts as layered upon each other. Each layer changes at a different rate and affects the adjacent layers. Brand notes that building alteration decisions are usually based on the slower-changing layers (e.g. structural capacity), but occasionally a faster-changing layer causes major alterations because it cannot be modified independently (e.g. installing heavy equipment requiring structural strengthening). Cooper and Allwood's (2012) analysis on reusing components at product end-of-life shows that many components are still functioning even if the product has become degraded. For example, wear of the engine often leads to car replacement, even though many other car components are not degraded. In this paper, the time for which these non-degraded components would continue to function is termed 'residual lifespan'.

There are no studies that analyse the causes of failure of steel products and that assess the extent to which failure occurs at the product rather than the component level. In light of these findings, this study addresses the following questions:

1. Why are steel intensive products replaced?
2. Do we exploit the steel in products?
3. How can we reduce demand for steel by better exploiting the steel components in products?
4. What pragmatic strategies are associated with these objectives?
5. What would motivate us to adopt these strategies?

2. Why are steel intensive products replaced?

The causes of product failure are multifaceted, ranging from inevitable physical degradation over time, to the deliberate curtailment of product life by producers seeking to force replacement purchases, to the voluntary premature replacement of products by consumers in the pursuit of psychological (as opposed to purely functional) benefits. Efforts to create a single set of reasons for product failure from these various influences include: Woodward (1997), who distinguishes between functional lifespan, physical lifespan, technical lifespan, economic lifespan, social and legal lifespan; Cooper (2005), who makes the distinction between absolute (forced) and relative (unforced) obsolescence; Thomsen and van der Flier (2011), who focus on buildings and identify four types of failure along two axes (endogenous–exogenous/physical–behavioural); and van Nes and Cramer (2006) who define four types of failure (wear-and-tear, improved utility, improved expression and new desires).

In order to examine life extension strategies to reduce steel demand, a set of failure modes is required that applies to all the key end-uses of steel, and is pertinent to both household and commercial product replacement decisions. Table 1 displays the failure framework constructed for this purpose, containing four failure modes. Further information on how this proposed failure framework relates to other existing similar frameworks is provided in the thesis, Skelton (2013).

The two rows of the framework distinguish between failure that arises from a change in the state of the product, and failure that arises from a change in the desires of the user. The columns distinguish between changes that affect only the current individual product and user, and more systemic changes that come about through developments elsewhere in the market. These systemic changes could be due to the performance of rival products, changes to the environment in which the product is used, or alterations in the regulations that govern its use.

The failure modes – *degraded*, *inferior*, *unsuitable* and *worthless* – have been applied to Cooper and Allwood's (2012) catalogue of steel products, which includes all products that account for at least 1% of global end-use demand for steel. This was done by mapping the catalogue's detailed causes of failure onto the failure framework using the definitions presented in Table 2.

Fig. 1 combines the resultant information on product failure with data on the final destination of global steel production and the average life of steel products from Cooper and Allwood (2012).