A Framework to Develop and Evaluate Circular Economy Readiness within the Rail Sector

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Abstract

The circular economy (CE) brings together the key aspects of sustainable development by creating solutions for environmental protection and economic gains. It is evident from the research that existing approaches do not rely upon systems thinking and therefore lack the holistic approach necessary to optimise CE value.The aim of this research project assesses the drivers and blockers for CE adoption within the context of the effective deployment of systems thinking in relation to the concept of a Circular Economic Management System that promotes CE competition. The scope of research has focussed on CE deployment within Asset Management ISO 55000 Series of standards. However, during the course of the literature review it became apparent that the context of asset management systems are driven by business goals. If the business goals did not value the adoption of themes for example CE activity then the asset management system would not be obliged to consider them. This is a missed opportunity. Systems theory/thinking is a prerequisite for effective deployment of CE. For the purposes of this research it will focus on the deployment of systems theory/thinking with the deployment of CE within the rail sector as a proxy, within an asset management context. The findings can be assimilated across multiple sectors. This study is based upon a comprehensive literature review of the incentives for CE activity within the rail sector. This research will contribute towards future research that looks to develop a Circular Economic Readiness Framework for the Rail Sector.

Keywords

Circular Economy, System thinking, Soft Systems Methodology (SSM), Viable Systems Methodology (VSM), Problem Solving Methodologies.

1. Introduction

The Circular economy (CE) brings together the key aspects of sustainable development by creating solutions for environmental protection and economic gains. It is evident from the research that existing approaches do not rely upon systems thinking and therefore lack the holistic approach necessary to optimise CE value.

The original scope of research was focussed within the context of the CE deployment within Asset Management (ISO 2014) - the management of the whole life of assets. However, the literature review revealed three insights. Firstly, the Standard " enables an organisation to realize value from assets in the achievement of its organizational objectives" (Stahel 2008). Secondly, if the business goals did not value a particular theme e.g. the adoption of CE then the asset management system would not be obliged to consider them (El-Akruti et al. 2013). Thirdly, Ness and Xing (2017) recognises the focus on CE adoption for the built environment incorporating asset management and wider stakeholder/actor engagement. This is a missed opportunity and also represents a challenge for industry. For example, within an asset management systems context this also brings into play what external capabilities the assets enable e.g. sustainable (e.g. green based energy production) or non-sustainable (e.g. fossil fuel based energy production) outcomes.

For example, Network Rail (the UK Railway Operator soon to be subsumed into Great British Railways) following the Williams-Shapps Review (The William Shapps Plan for Rail, 2021) has already started to generate CE momentum with the call for CE activity from publishing its Environmental Sustainability Strategy Network Rail (2020). This strategy commits to establishing a CE policy to reduce resource use and waste by 2022; to changing its asset policies and standards to include circular economic aspects by 2023 and to reflect the impact of climate change by 2024. These changes will involve both material use and redeployment and changes to procurement, as well as implementing a series of metrics by 2024. In future, the industry is likely to consider environmental sustainability issues in the same way as it does operational and performance impacts in its decisions.

In addition, whilst CE is an emergent industrial philosophy and a practice that is a response towards sustainability, it is evident and paradoxical that the adoption of CE is being undervalued. In some respects also being hindered because of the variable definitions of sustainability itself. For example the introduction of sustainability accounting can obscure the real issues King. D., (2013) and could be perceived as a tick box exercise. Where sustainability remains an ambiguous concept open for interpretations (Hopwood., et al 2005) and, whilst CE is still an emerging practice it can be argued that there is no commonly agreed concept of CE. (Moraga et al,. 2019) Without a single lens to see through, different actors have distinct interpretations of what CE could or should depict (Blomsma and Brennan, 2017) where the connection to sustainability is not always clear (Kirchherr et al., 2017).

This research picks up on these observations and hypothesises that a key reason why CE may be undervalued and the link between sustainability is unclear is that the organisations CE Management System is not expressed sufficiently in systems thinking terms. As it should logically follow that the more CE the organisation and its products and services are, by definition, the more sustainable the organisation will become.

Within the context of railway systems it is important to also point out that travel by rail is regarded as a more sustainable form of transport when compared to other means. If the total CE effort and CE value of railway systems were expressed then this should increase the overall sustainability value of rail even further, however it is suggested that this fundamental relationship is not recognised.

For example any man made intervention on the environment is usually supported by a business case where the triple bottom line is supported across the three sustainability dimensions (e.g. social, economic and environmental) (Beske and Seuring 2014), (Winter and Knemeyer 2013). Therefore, if railways adopt or are already adopting CE activity, that effort should be captured and promote railways as being even more sustainable than they already are. This research also looks for evidence to support this link as clearly this would represent a significant business driver to adopt CE activity within the rail sector. The hypothesis also requires that the organisation defines its own CE Management System, where it is specific to the organisation itself and in relation to other organisations that adopt a similar ethos. Organisations should be able to respond to the question; what is your CE management system and the CE value it creates? and taking this a step further what other companies are you connecting with within your supply chain that increase the overall CE value of your commercial proposition network?

This research project is limited to the deployment of CE within the rail sector as a proxy. This study is based upon a comprehensive literature review that identifies the deployment of incentives for CE activity within the rail sector deployed through systems theory/thinking. The literature review also includes the deployment of asset management practices as CE enablers to generate CE value. The paper reviews papers and articles from Science Direct (www.sciencedirect.com), Emerald Insight (www.emeraldinsight.com), Inderscience (www.inderscience.com), Springer (www.springer.com), Taylor & Francis (www.tandfonline.com), IEEE Xplore (ieeexplore.iee.org/Xplore/home.jsp), Google Scholar (scholar.google.co.uk), websites of organisations working/promoting CE (e.g. www.ellenmacarthurfoundation.org; www.theiam.org; www.bsonline.org) These organisations are considered prominent sources of CE and Asset Management guidance.

The aim of this research project is to assess the drivers and blockers for CE adoption within the context of the effective deployment of systems thinking within the rail sector. And then the longer term objective will be to develop a framework that is based upon systems thinking that assesses the effectiveness of one CE Management System against another, therefore providing a potential basis for CE competition. To achieve this aim, the following research objectives are defined:

- What are the drivers that promote rail industry stakeholders to compete with their products and services as being more sustainable than others by adopting CE practices?
- What are the barriers that hinder rail industry stakeholders to compete with their products and services as being more sustainable than others through CE practices?

With the aim and objective established, this paper is broken down into eight sections. Section 2 explains the research problem statement and it does this by explaining the generic CE challenge/value situation model. Section 2 also includes the research scope. Section 3 describes the research methodology and the criteria for locating the studies. Section 4 describes the synthesis and analysis, Section 5 provides the findings. Section 6 provides conclusions and recommendations for a future framework and concludes with opportunities for further research.

2. Research Problem Statement and Research Scope

The research problem is described across four conjoined dimensions. When combined, these dimensions are intended to drive evidence of CE value and effectiveness within and across a network of organisations.
The model is shown diagrammatically in Figure 1 with a supporting narrative for each dimension:

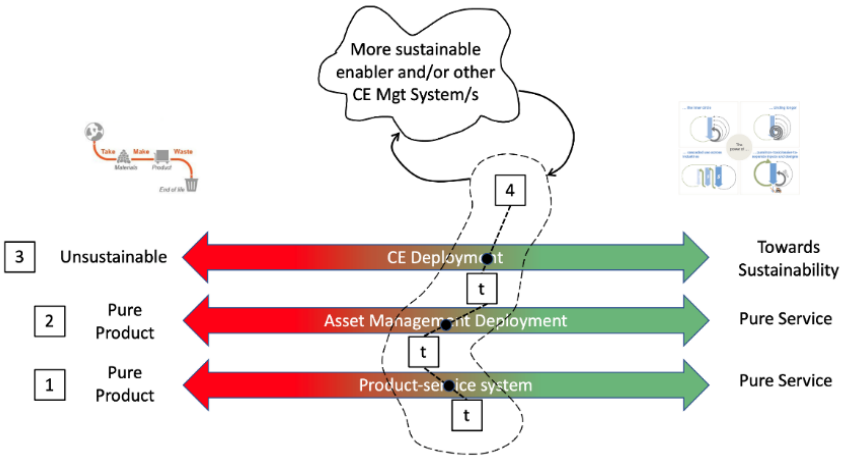

Figure 1. The Circular Economic Management System Challenge

This dimension relates to the identity of the organisation and its inherent or emergent operating model/s within the context of enabling CE activities towards the organisations own sustainability (or survivability) (Figure 1). For example, if an organisations existence is purely based upon profits alone from adopting take, make waste practices and has little regard of the effect its products and services have on wider social, economic and environmental impacts then by definition the business is unsustainable. Figure 1, dimension 1 shows two ends of a spectrum and uses an example of a Pure Products operating model at the poor performing end of the spectrum on the left hand side. This is where the organisation for example just manufactures goods and has little interest in the product after it has been sold. Whilst the good performing end shows Pure Service as an example of a more circular economically effective business operating model. This is where organisations generate revenues from what the product enables not the sale of the product. For example Rolls Royce (2012) who operate their CorporateCare® service that essentially sells engine thrust to airlines, or Power by the hour. However, product service systems operating models are not necessarily a panacea (Tukker 2004). It is the business that defines its own operating model/s..

This dimension relates to the range and deployment of CE related Asset Management interventions that are designed and implemented to manage the asset. For example to design and support multiple asset lifecycles where asset materiality gets deployed across those asset lifecycles. Theres the need to consider asset life extension strategies, development in repairability strategies etc. An example of existing asset management and asset management/CE extended features are shown in Figure 2 adapted from (ISO 2014) and Ellen McArthur Foundation (EMF) It is implied that the more advanced and strategic deployment of asset management practices would sit towards the good performing end of the spectrum. Many of these types of capabilities already exist or can be adapted or extended within the practice of Asset Management. In many respects whilst guidance can be developed for the deployment of generic CE practices within and across asset management systems, what the organisation actually does within an asset management context and how it does it will also be directly related to the operating model (or organisational goals) that the organisation decides to adopt (see definition of dimension 1 above).

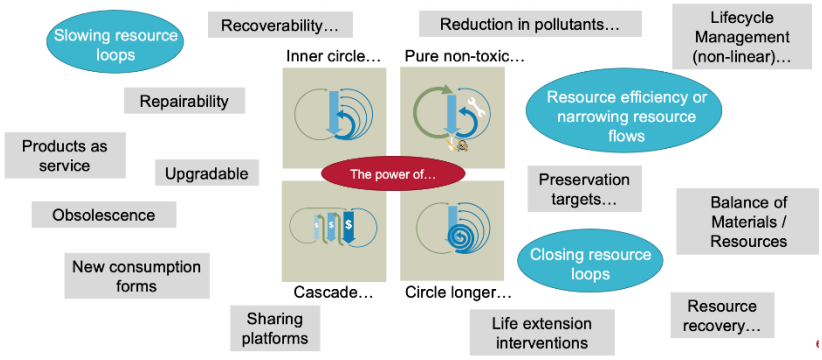

Figure 2. Using Asset Management enablers as 'the circular economic footprint' of assets and asset systems

This dimension is the combined CE outcome or product of the dimensions 1 & 2 (Figure 2). The high performance end on the right of the spectrum is purposefully interpreted as the succinct definition of sustainability drawn from The Donnella Meadows Project (Definition of Sustainability) (Figure 3):

> 1. *Renewable resources shall not be used faster than they can regenerate.*
> 2. *Pollution and wastes shall not be put into the environment faster than the environment can recycle them or render them harmless.*
> 3. *Non-renewable resources shall not be used faster than renewable substitutes (used sustainably) can be developed.*
>
> *By those conditions there's not a nation, a company, a city, a farm, or a household on earth that is sustainable. Virtually every major fishery in the world violates condition 1. The world economy as a whole is violating condition 2 by putting out carbon dioxide 60-80% faster than the atmosphere can recycle it. But to make things worse, I would add two more sustainability conditions that I think are obvious.*
>
> 4. *The human population and the physical capital plant have to be kept at levels low enough to allow the first 3 conditions to be met.*
> 5. *The previous 4 conditions have to be met through processes that are democratic and equitable enough that people will stand for them.*

Figure 3. Definition of Sustainability - The Donnella Meadows Project - Academy for Systems Change

This definition is influenced by the practice of Systems Dynamics (SD) one of several Systems Thinking methodologies/methods which is appropriate with the management and understanding of the ebb and flow of finite resources (Meadows et al., 2009). It is broadly accepted that our historic and current way of working is not sustainable therefore we should be always striving for the least worse option or rather, measuring how well we can exceed thresholds or expectations by and not interpreting minimum thresholds as a form of compliance (Figure 3).

The concept of sustainability has a broad range of dimensions. These can include but not be limited to organisational sustainability, environmental impact or other hybrids. In addition, States and International Bodies issue directives by which organisations have to comply with or respond to for example EU and UK Non-Financial Reporting Directive (NFRD), The EU Taxonomy for sustainable activities (EU Taxonomy), and in the UK A Roadmap Towards Mandatory Climate-related Disclosures (RTMCD) and Task Force on Climate-related Financial Disclosures (TCFD) to name only a few.

This research takes the view that these types of sustainability drivers are lagging i.e. put in place in response to the outcome of the climate change that has already happened in an attempt to prevent climate change getting any worse. In this case the term sustainability is far too broad and needs to be bounded by further dimensions as suggested here. For example this research does not focus on the link between CE and sustainability but makes the assumption that the more CE you are the more sustainable you become.

In addition, the observation is also made that non-compliance is essentially illegal therefore why wouldnt organisations want to prove how removed their products and services are from being illegal? This forms an important standpoint of for example ethics in engineering, ethics embedded within organisational identity and the future CE competition framework.

This dimension is essentially the organisations or network of organisations CE Management System that defines and integrates all three dimensions at a point in time or a state of readiness. This dimension also includes a link to the more sustainable enablers and/or other CE management systems (the external impacts and capabilities) which the asset systems enable. For example within the context of railways it enables a broad range of societal, environmental and economic benefits/capabilities compared with for example alternative transport modes. The organisation should identify its CE status, and always strive to be more ready than it was before. It is this system that relies upon Systems Theory/Thinking in order to create CE value. Whereby systems can be defined as the interconnected set of elements that is coherently organized in a way that achieves something (Meadows et al., 2009) and Systems Thinking being the adoption, interpretation, and exploitation of multimethodological approaches to develop, adapt and/or understand systems. This research considers the application of at least two problem solving methodologies (PSMs) and a number of systems thinking methods (Jackson 2006) Strategic Options Development and Analysis (SODA) and `Soft Systems Methodology (SSM) (Checkland 2001) as PSMs open up a new paradigm of analysis where a paradigm is a set of rules for identifying a valid scientific problem and for recognising what would constitute a solution to it (Mingers and Rosenhead 2001).

In this context the organisation can design its system from what it does now towards a more CE future for example the CE management system could:

a. Strategies to de-risk the supply chain to mitigate price volatility
b. Improve product durability, and utility
c. Lease products instead of selling them
d. Enable a procurement policy that favours the use of products that rely upon recycled materials.
e. Implement materiality as an asset registration function of the Asset Management System. The Asset Management System can target the reduction of new material dependency.
f. Alleviating Client burden of disposal of your products because you need them back as part of your future product design.
g. Declaring your existing CE interventions and building and growing that as part of your organisations identity. Promoting your own organisations viability for investment.

The development to create, operate and manage the CE management system can also draw upon additional fundamental systems theory/thinking concepts such as viability as well as the ability of the organisation to be aware of the CE competitive environment it wants to work in and its own ability to respond to it. Therefore, these interdependencies or views can be represented within a theoretical framework that assess the viability of the CE management system at a point in time:

I. The outcome of applying the framework must result in a viable proposition i.e. a viable CE management system. Therefore the foundation of the framework should rely upon and should be assured against the application of Viable Systems Theory (VSM) (Beer. S, 1981) VSM can be deployed in design mode i.e. designing an organisations operation and feedback loops from scratch or analytical mode i.e. determining systems or business systems strengths, weaknesses and failures. For the purpose of this research the application of VSM will be used in design mode. The use of VSM in analytical mode assumes systems already exist and the line of enquiry would use the design mode criteria to identify strengths and weaknesses of an existing management activity and process.
II. The horizon that the CE management system scans. The horizon being not only that which is embedded in law (e.g. The Circular Economy Promotion Law of the Peoples Republic of China) but that which is the opportunity and risk of the organisation/s market proposition that the organisational system should protect and respond to or take advantage of. For example being more CE than the competition. The horizon scanning activity relies upon the deployment of Ashbys Law of Requisite Variety. (Ashby, R. 1961).
III. The understanding of values and belief systems and sub-systems that define not only the overall identity of the CE management system but the value of it that is transposed through the circular economic network or value chain and its interoperable components. E.g. the sub-systems that make up the viable system. The values and belief systems relies upon the deployment of Soft Systems Methodology.

IV. The main systems theory/thinking interdependencies are not new but when combined they appear to be novel when deployed within a circular economic management systems context.

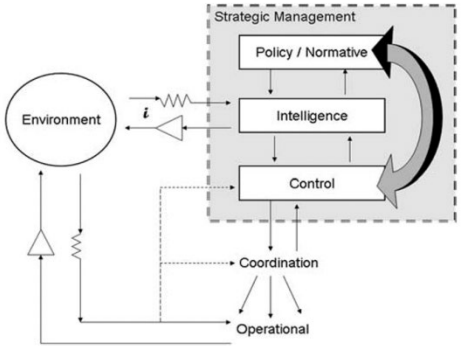

Figure 4. Some basic systems theory components and relationships

To describe just the engagement of VSM for example, Figure 4 has been taken from The Intelligent Systems Methodology (Ganzert. C et al 2012) that combines the above three systems theories within an operating model. The model is an adaptation from Beer, S. (1985) and Espejo et al (1996). In this case the intent (object) of the model is to gather intelligence for learning purposes about a range of subjects that are important to the organisation. i.e. to make the organisation more intelligent relevant for an intelligence and learning organisation. In this context Intelligence can be replaced by any subject matter such as CE effort for any product or service or any output from an organisation that it decides to produce.

However, for the purpose of the theoretical framework it is necessary to transpose each of the top level elements, interpreted through VSM and into circular economic meanings. For example:

Strategic Management = the organisational boundary that sets the emerging values of circular economic identity and beliefs and future position within the organisation in relation to what it does. For example adapting the business operating model. i.e. we are going to develop and implement our circular economic management system and capability, continually improving our circular economic credentials and linking that capability to our supply chain.

Policy / Normative = Circular economic identity that wraps around the products and services and/or dependent policies within the organisation. For example seek to create strategic partnerships through our supply chain or continually increase our resource recovery through our asset management systems.
Intelligence = (or this could be the product or service combined with the identity of the organisation. For example manufacture the highest scoring circular economic product) This also should consider the CE risks and opportunities in relation to becoming more or less circular economically competitive. E.g. the most CE product of its kind.

Control = how the distribution of resources is optimised to meet the CE opportunities or risks that the organisation has identified

Coordination and Operation = relates to the organisational subsets of how the organisation operates in further detail and includes the necessary audit and assurance activities that validate that the output of the combined parts of the organisation, and its wider network meets the CE risks and opportunities that have been defined through the intelligence gathering.

i = represents the requisite variety (the width, content and context of the horizon) that the organisations market decides to work within. For example this may be a manufactured component/s, systems e.g. a railway system or services.

It is suggested that the above systems theory viewpoints can be readily translated across to the organisations engaged with the development and the lifecycle of products and services the organisation produces including the network of stakeholders or actors. It is also suggested that Asset Management could be used as an enabler to coordinate the value of that CE activity within and across organisational systems.

2.1 Research Scope

This research project is limited to the deployment of CE within the rail sector as a proxy but the concepts described above are intended to be applicable across any domain including the built environment. Within a systems theory context one of the first tasks would be to define the area of focus and in this case it is bounded by railway systems and what railway systems enable.

The purpose of railway systems have evolved since their inception. Railways initially created huge efficiencies compared with alternative transport methods at that time by enabling massive volumes of raw materials to be transported to factories and ports creating vast economic wealth.

Railways should now be seen as significant socio economic and environmental enablers, used to interconnect communities, transport freight and supporting people to travel, perpetually improving the opportunities for employment, education, and boosting local and wider economies and wellbeing.

With the pending impact of climate change, Governments are keen to adopt zero carbon initiatives and looking into ways and means in which climate change can be reversed (COP26). For example in the UK where emissions related to electricity generation plunged by 66% between 1990 and 2019 mainly through the reduction of the reliance on fossil fuel, the equivalent reduction in emissions for transport which is now the largest source of emissions in Britain, was just 5%. (Economist. 2021).

If railways are supposed to represent a primary and sustainable means of transport then the metrics and value of that sustainability needs to be promoted and made consistently transparent. These metrics need to be managed and evolve over the lifecycle of the railway service and those emergent and sustainable value streams need to be placed into the wider socio economic and environmental contexts. For example in the UK guidelines exist in justifying the railway business investment case mainly on economic grounds (The Green Book) and subsequent detailed guidance (Transport Analysis Guidance (TAG)) However there are few or consistent approaches to quantify the sustainability value and impact of passenger or freight railway systems in relation to the alternative transport system with which the rail systems could potentially displace or the value of those benefits that only railway systems can facilitate.

For example using high speed rail passenger journeys to displace much higher polluting short haul domestic flights, optimising rail freight journeys to displace air polluting road freight and reduce road congestion, or the promotion of active travel for commuters to cycle or walk to stations considering active travel has the potential to lead to NHS savings of roughly UK£17 billion over a 20 year period (Jarrett, J. et al. 2012).Within a systems thinking context this relationship would be a justified feedback loop where the railway system would be considered an enabler.

Recognising the need to shift the focus towards broader sustainability metrics, the UK Government have carried out a review of The Green Book (Green Book Review 2020) with recommendations for levelling up, the initiative for enabling a balanced society across North and South and specifically mentioning the Governments recent legal requirement to achieve net zero carbon emissions by 2050.

Given measures of understanding the sustainability of railways is only recently emerging (UIC. 2016) and the application of these sustainability metrics are inconsistent (not effective as they could be) across railway systems across the globe (Azzouz, L. 2019) Governments and organisations should be seeking to adopt a portfolio of zero carbon strategies. One key enabler towards achieving sustainability is the adoption of CE activity.

CE activities promote the responsible and cyclical use of resources with the aim of contributing towards sustainable development. In principle, it can be seen as how supply chain looping strategies are designed to reuse, refurbish, recycle, minimize, eliminate, share, and optimize material and energy use while maintaining firm profitability (Nandi et al, 2020).

Given that in general current sustainability drivers are lagging and the link between the circular economy and sustainability is unclear, it then must follow that there are no general business drivers at present for circular economy activity unless they are specifically legally stated or otherwise as requirements. This is on the basis that sustainability by its generally accepted broader definition must represent a larger spectrum of which circular economic activity must play an active part.

For the purpose of this research the assumption is made that sustainability drivers will eventually mature and be redefined towards the definition as described in Figure 3. Also, the reverse logic must hold true in that the more circular economic the organisation is, the more sustainable it will become i.e. organisations should not have to wait until there is an external driver (e.g. a legal requirement or client demand) to enable circular economic activities, it should be a requirement already built in as part of the organisations identity, strategy and wider sustainability credentials. The premise being that circular economic value is expressed through circular economic management systems.

3. Research Methodology

A potential gap has been identified that translates as to how systems thinking can be applied to exploit CE practices and value within the rail industry. The rail sector has been selected as a proxy. This research looks to analyse the published literature using a systematic literature review (SLR) adapted from Garza-Reyes (2015) which will contribute towards filling this gap. Table 1 provides the high level steps in carrying out an SLR by describing the phases, objectives, method adoption tools used and their location within the article.

A systematic literature review is a specific methodology that locates existing studies, selects and evaluates contributions, analysis and synthesises data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known. (Bryman et al,. 2009)

A systematic literature review differs from a literature review in the traditional sense as a systematic review is a self-contained research project that studies a clearly defined question. In contrast, an expert review (Gough, 2007) is enabled by the skill, knowledge and experience of the reviewer and does not adopt a clear method therefore is subject to hidden bias. The systematic review research activity sets boundaries around subject scope and explains rationale implying subject relevance and quality criteria as to aid transparency of interpretation and replication. In this context systematic reviews exploit evidence based practice and whilst this practice has never sought to provide answers, the outcome of systematic reviews inform decision making and action (Sackett et al., 1996).

In particular, where there is little evidence or knowledge gaps, this signifies a research need and raises questions for future research. The primary focus of this SLR is to research the drivers and barriers for CE adoption and hence CE competition in relation to products and services being more sustainable than others within the rail sector. In addition, the research will consider the adoption of Systems Theory/Thinking to design the effectiveness of CE deployment and value (CE Management Systems) within the rail sector, where that value is enabled through the deployment of Asset Management practices. The research only includes articles that have been published with a direct focus and within the purview of Circular Economy/Systems including relationships to CE Competition, Systems Theory/Thinking and Asset Management with the deployment of asset management within the rail sector. For example, articles including references to VSM, SODA, SSM or Ashbys Law of Requisite Variety would be included as these (amongst others) are recognised as systems theory multimethodological concepts. The scope of research is shown diagrammatically in Table 1. Similar ideas or concepts not directly addressing them from this perspective were excluded. For example, Circular Economic Business Models would only be included if they were linked to the application of systems theory multimethodological concepts as described here (table 1).

Table 1. SLR Phases, objectives, methods, tools and location within the article (adapted from Garza-Reyes 2015)

SLR Phases	Objectives	Method	Tools	Article's Section
1 Scope Formulation	Formulate the scope of research			2
2 Locating Studies	Locating, Selecting and Evaluating Relevant Literature	Definition & use of Electronic Databases	Science Direct, Emerald Insight, Inderscience, Springer, Taylor & Francis, IEEE Xplore, Google Scholar	3
3 Study Selection and Evaluations		Definition of search period	2000-2021	
		Definition and use of inclusion/exclusion criteria	**Inclusive**: Circular Economy, Systems Thinking, Railway, Asset Management – Peer reviewed articles or journals of proceedings of international conferences **Exclusion**: CE business models with no relation to Systems Theory/Thinking.	
		Definition & use of Search Strings	Circular Economy, Systems Thinking, Asset Management, Railways	
4 Analysis and Synthesis	Synthesising and analysing selected articles	Selection of method for synthesis and analysis of qualitative research	Thematic Synthesis	4
		Coding and extraction of data	Mendeley computer software	
5 Reporting and Using the results	Reporting of findings			3, 4, 5 & 6

Given the particular construct shown in Figure 5 is bounded and includes key subject matter and the need to understand evidence of interdependencies or a line of sight between them and within a rail context, a systematic review process will be applied to make sure the review is reproducible, focussed and transparent with high levels of reliability and reduces the risk of the introduction of bias (Briner and Denyer, 2012).

3.1 Search Criteria for Locating the Studies

The term Circular Economy is maturing and is becoming more refined. However, within the context of systems theory and systems thinking, scope and boundaries are designed and defined by the observers of systems. Hence other subjects may be considered, deployed and overlap. Observers or designers of systems are not necessarily blinkered by following a single methodology when designing systems but may reflect upon several multimethodological approaches and combining elements that are relevant to their context. Creativity plays a major role in designing systems. The primary driver for the systems design is focussed on the outcome or intended impact of the system. For example, implementing more railways should reduce road congestion and pollution created from polluting road passenger and freight vehicles. For the purpose of this study the following definition of the circular economy was used:

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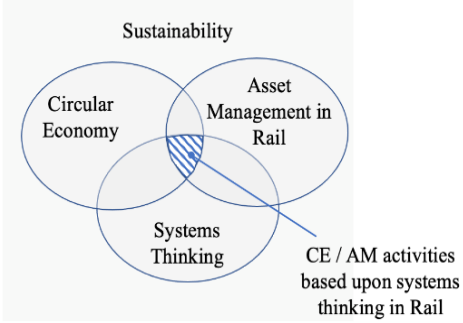

Figure 5. Diagram showing scope of research

The circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (Ellen MacArthur Foundation, 2015).

Importantly this definition requires restorative activity which suggests reversing the lagging sustainability drivers previously discussed. In addition, for the purpose of this research the research period will start from 2000 which includes for example some of the earlier terms used for similar circular activities such as Cradle to Cradle (Braungart, 2008) Using the search period as a constraint, the following key inclusion search strings were used:
Search 1 – *CER: "Circular Economy" AND "Railway".* This search is aimed at determining evidence for two outcomes:

- if circular economic deployment is a recognised practice within railway systems
- does circular economic value within a systems thinking context also contribute towards rail as being a more sustainable means of transport compared to other means for example having a positive societal and environmental impact.

Search 2 – *CEAM: "Circular Economy" AND "Asset Management"* This search is aimed at determining any evidence of the deployment of CE practices within the field of Asset Management.

Search 3 – *CESTAM: "Circular Economy" AND "Systems Thinking"* This search is aimed at determining evidence of a "Circular Economic Management System" based upon existing systems theory/thinking concepts. Search 3 originally included the additional search string "Asset Management" but this returned a null return. Given that systems thinking is a multimethodological approach comprising a broad range of approaches and techniques to support the design of and understand systems, the research excludes CE business models that have not engaged the deployment of systems theory/thinking within the business model design. For example, this research proposes the deployment of for example systems thinking approaches including VSM, SSM and Ashbys Law of Requisite Variety to design CE Management Systems. Therefore, searching for the deployment of Systems Theories was a requirement of the research. Mendeley Reference Manager was used to sort, codify and categorise articles for descriptive analysis and thematic synthesis.

4. Synthesis and Analysis

Several methods can be used for the synthesis and analysis of qualitative information. For example qualitative meta-summary, meta-ethnography, grounded theory, thematic synthesis and qualitative meta-analysis (Barnett-Page and Thomas, 2009).

Given there is the requirement to adopt circular economic activity to support sustainability, there is the need for circular economic intervention of some sorts. There is a requirement also to understand acceptance and effectiveness of circular economic activity, therefore the most appropriate method would be to adopt a thematic synthesis of the information returned from the search criteria. This would involve developing a range of descriptive themes to yield analytical viewpoints. The thematic synthesis method has also been successfully applied to extract thematic information of management integration literature (Garza-Reyes, 2015).

The thematic synthesis of research is shown in Figure 6. In particular this has been shown as a causal loop diagram of interrelated themes that should influence the impact on circular economic activity within asset management related to rail that incorporates the adoption of systems thinking. Some of these external themes should exist in order to promote CE activity within the rail sector.

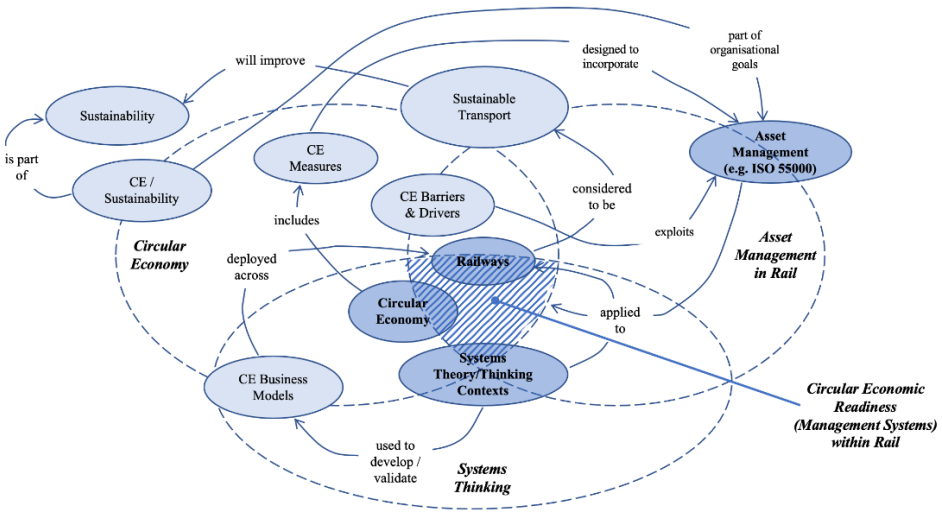

Figure 6. Thematic synthesis of research subjects for CE drivers and barriers within Rail, enabled through Asset Management based upon Systems Theory/Thinking

5. Reporting of findings

The return on the key search criteria as well as extended search criteria was identified, filtered, sorted and catalogued and confirmed for inclusion in the review through an iterative selection process shown in Table 2.

Table 2. Overview of paper identification, selection and inclusion

	Search 1	Search 2	Search 3	
Identification	24	46	185	Identified through database searching
Screening	21	39	101	Post removal of duplicates
Eligibility	11	12	31	Post abstract review
Included	6	8	11	Post full text review

Due to the low return, the search criteria was extended to include “Circular Economy” AND “Barriers and Drivers”, “Circular Economy” AND “Business Models”, “Circular Economy” AND “Measures”. The extended criteria although not intended to be comprehensive was used to validate the direction of research.

The 25 articles are represented visually in the thematic synthesis diagram in Figure 6. The diagram has been mapped out to show the interdependencies of the different subject matter within an Operational Research or interventionalist context (Gregory, A. J. et al. 2020) For example Soft Systems Methodology (SSM) (Checkland, P. and Scholes, J. 1999) has been deployed to present a representation of the existing complex situation in Figure 6 where there are divergent views about the value and deployment of circular economic activity in general but in particular in this study to do with railway systems. The interdependencies (arrows) represent possible drivers that should influence the reaction of one area (or key driver) of the diagram to the next. The interdependencies are not intended to be comprehensive but provide an indication of the direction of research and application of the research and the identification of the gap within context.

Search 1 returned research on a component-based Life Cycle Assessment model (Bortoli, et al 2020) with clear and reusable Life Cycle Inventories (LCIs) this could be a relevant Asset Management practice although the paper does not refer to this activity as being part of the wider asset management discipline, but it should be. When taking into account the triple bottom line (TBL) (Liu et al 2019) challenges the TBL against actual sustainability which aligns with observations in this research. The reuse of railway infrastructure (Cardoso de Matos et al 2021) looks to re-use railway infrastructure for alternative purposes (e.g. alternative and extended asset lifecycles) from an architectural perspective. (Delgado et al. (2021) considers steel slag as the by-product of the steel industry for use as an alternative material for railway track ballast. This provides a good example of material circularity across sectors. (Chen et al 2020) considers circular economic approaches for repair and waste minimisation of structural

materials used in railway tunnels and (Phuluwa, H. S et al) researches materials recovery from rail vehicles. All of these approaches would easily fall within the purview of Asset Management within a circular economic context. Search 2 returned eight references in relation to the deployment of asset management within the context of ISO 5500X. (Hanski et al 2016) recognises that the discipline of asset management has paid little attention to CE and likewise CE has not paid any attention to Asset Management whilst identifying a number of asset management enablers that would support CE value. Ness and Xing (2017) identifies linking CE with the built environment and purpose, function and value of the built environment within the wider purpose of what the asset serves within the socioeconomic and environmental contexts. That particular research would align with the proposed concept in this paper of "A Circular Economic Management System". Pais, J. E. de A. et al. (2021), proposes econometric models to the Life Cycle Assessment (LCA) of physical assets within a circular economic context. This approach is related to for example a circular economically enhanced alternative means of understanding limited parts of current physical asset lifecycle value as part of a lifecycle analysis.

Search 3 returned 185 references which were further filtered down to include the actual reference or deployment of systems theory/thinking methodologies or methods. For example a search on the application of VSM, SSM or Ashbeys Law of Requisite Variety or SD on the basis that these may have been relied upon in part or in whole to define circular economic activity or systems within a systems thinking context. From the 185 papers none referred to the deployment of VSM or Ashbys Law of Requisite Variety. Four papers out of the eleven referred to the application of SSM, this is within the context of adaptive systems (Hussain et al 2018) which is a limited reflection on what systems thinking and problem structuring is. Similarly (Lugnet et al 2020) provides a limited description of systems thinking which includes a description of SSM but does not apply its application within context. In relation to understanding stakeholder interests (Gregory, A. J. et al. 2020) proposes a framework that enables researchers to compare and contrast approaches to stakeholder engagement and derive learning about what works where, how and why. This is relevant when designing viable circular economic networks involving multiple stakeholder views. Ness and Xing (2017) proposes a model for a resource efficient built environment that builds upon a number of extant models and is aimed at "synergistic community transformation," seeking to accommodate the world views of multiple actors in pursuit of common goals, by the application of soft systems methodology. That research includes the deployment of Strategic Asset Management and is related to the built environment of which railway systems are a part.

The remaining seven papers referred to the systems thinking method (see (Jackson 2006) on differences between methodology and method) of Systems Dynamics. Systems Dynamics in the research papers is applied within the context of considering the ebb and flow of finite resources in this case materials under specific scenarios or industry areas. (Barnabe 2021) for small sized agrifood companies, (Nogueira et al 2019) discussed the requirement to take a wider systems view by adopting eight innovation lenses by which measures could be appreciated. However, the systems thinking perspective is limited by taking an SD view point.

One observation made on the work of (Whelan et al 2018) was about the challenge associated with teaching student engineers CE and using as an enabler the serious game In The Loop which covers a broad range of CE challenges that students have to overcome when being taught CE at University. In this case observations of systems thinking were identified. However, this may better be described as students observed CE risks and opportunities whilst playing the game to which systems thinking could have been deployed to mitigate risks and create opportunities. However, the University course didnt cover the teaching of systems thinking.

This research has identified a number of gaps from the outcome of the literature review exercise which include:

- There is limited evidence that systems thinking tools and techniques have been applied effectively across the CE environment. This opens up the opportunity to understand the deployment of systems thinking in much greater depth across CE to increase the value of CE interventions and interdependencies.
- There is a limited application of CE activities across rail and there is no evidence to suggest that if rail did adopt CE activity then this would make rail become a more sustainable form of transport compared with other transport modes. This links to the deployment of systems theory and is an important area that requires urgent further investigation if the value of CE is to be promoted within a rail context.
- The application of CE around asset lifecycles within the context of Asset Management is only recently emerging. It would appear that the most appropriate subject that manages asset lifecycles would be Asset Management. The linking of CE opportunities, Systems Thinking and Asset Management would potentially present a number of powerful insights that could promote visibility of CE values and influence the concept of circular economic competition.
- No evidence was found around the development of the concept of A Circular Economic Management System as being a means for an organisation or a series of organisations to present their CE proposition. This

opens up the opportunity to explore how organisations can identify their own CE value and identify and how the organisation transforms itself to become more circular economic through a CE system.

6. Discussion, Conclusions and Recommendations for Further Research

This research has investigated whether there are any drivers that promote rail industry stakeholders to compete with their products or services as being more circular economic than others. The research approach considered the adoption of Systems Theory/Thinking being that systems thinking is a prerequisite to create circular economic capability.

In developing that capability this research proposed the concept of a Circular Economic Management System which adopts systems thinking principles itself and the adoption of Asset Management as a practice for implementing and enabling the circular economic activities within the rail sector. Asset Management is a key discipline that manages the built environment or any asset. The thematic synthesis in Figure 6 shows a range of interfaces that would impact the value of circular economic activity within the rail sector. These interfaces and interdependencies have been touched on in this research but each interface is a research area in itself.

Limited evidence is found of circular economic activity within rail and CE is not placed within a competitive framework. There is evidence that broader sustainability drivers are more widely recognised than CE initiatives. This presents a challenge even though its already widespread recognition of the need to report beyond territorial and direct greenhouse gas (GHG) emissions (Setos et al 2014) Adopting CE activity by definition would be a complementary and could represent a structured approach to accelerate the drive towards sustainability.

The findings from the research around the application of systems thinking within the context of how it is deployed across the circular economy is disappointing. Evidence suggests that a large proportion of research material that includes the term systems thinking doesnt discuss the application of systems thinking multimethodologies at all and those that do, the majority appear to apply the use of Systems Dynamics within the context of materials management. SD is only one of several multimethodological approaches that can be adopted using systems thinking, so the broader systems thinking toolset has not been taken advantage of. Only a few papers apply SSM in terms of understanding and managing stakeholder values and expectations which is highly relevant to this research. This suggests there is an important requirement to learn, or re-learn and unlearn Systems Theory/Thinking practices particularly with the deployment of CE concepts.

Systems have boundaries, for example defined by the observer (Luhmann. N, 1995). The observer of the system for example may only draw a boundary around materials as just one theme. Therefore that is all that is dealt with within that context. Systems Thinking has no bounds and it is up to the observer/s to define the boundaries of individual systems and how multiple themes and multiple systems integrate or interact ideally enabling greater value than the sum of its parts.

This draws upon another observation around the value of railway systems being sustainable transport systems compared with other means. No evidence was drawn to suggest that if railways adopted circular economic activity, railway systems would be considered even more sustainable than they already are. This supports Seto and colleagues (2014, 966) acknowledgement that, effective spatial planning (the built environment of which railways play an integrated part) is characterized by “interlinked and coordinated efforts that are synergistic, and the sum of which are greater than each individual part incrementally or individually.” This synergistic viewpoint or “synergistic community transformations” (Xing et al. 2013; Zhu et al. 2015) which uses SSM to take into account the world views of multiple actors in pursuit of common goals. However this is not deployed within the context of for example of what railway systems enable but could be.

There is clearly a gap in the deployment of Asset Management to accompany or integrate CE enablers as most asset management practices closely align with CE practices. Therefore there will be the need to research the potential to integrate (BS 2017) and (ISO 2014) with a systems thinking backdrop. This could influence the requirements or the design of a generic Circular Economic Management System that should be applied within the organisations context. That could adopt the combined input of both standards. Thereafter forming the basis of the Circular Economic Readiness Framework upon which circular economic competition could then be formed.
For this environment to exist governments/procurement bodies should state that investment decisions will now be made on how circular economic value propositions are thus supporting the concept of circular economic competition. This would be the example of the external driver that would make circular economic activity more prominent and set the wider horizon challenge to accelerate circular economic innovation and accelerate our path towards greater sustainability.

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