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Analysing causes of avoidable waste in complex systems: a case study from the nuclear industry

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ABSTRACT

This paper explores why complex systems produce avoidable waste, and presents a new qualitative method to help managers think strategically about waste avoidance. Some approaches to analysing waste creation focus on measuring waste (e.g. Life Cycle Assessment), while others model process solutions (e.g. Lean). However, these are somewhat limited as (a) measures are not always appropriate and do not identify solutions, (b) modelling human as well as process factors is needed as both cause waste, and (c) implementable solutions should be understood and socially negotiated by powerful stakeholders as well as modelled by analysts. Furthermore, the interlinked nature of industrial processes means that managing sources of waste may be complicated by system perturbations from up/downstream operations that stimulate waste creation. Recognising this, we reflect on a new approach, called Waste And Source Analysis – WASAN, that supports the analysis of: sources of waste and how to manage them; wider systemic factors such as how up/downstream operations cause waste generation; and supports stakeholders in exploring and negotiating solutions to optimally manage these sources and systems. We also propose a framework to think through the human and technical reasons for why sources produce waste: behavioural, knowledge, material, processing and systemic (BKMPS) causes of waste. We use this framework to reflect on a case study of applying WASAN to analyse radioactive sources in the UK's nuclear industry. Our theoretical contributions reach beyond waste minimisation and systemic thinking as we consider the generic factors needed to analyse other complex systems.

1. Introduction

The generation of hazardous waste such as heavy oils, caustics and radioactive materials is a global environmental issue, not least for the international nuclear community. Radioactive wastes are reviewed by the International Atomic Energy Agency (IAEA) through its 'Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management' which requires member states to regularly report their waste and regimes of waste management, including the USA (DoE, 2011) and the UK (DECC, 2011). Also, there is an international expectation that countries take a strategic view of their radioactive waste and put systems/plans in place to manage them, for example, see regulations for the USA (EPA, 2012) and Europe (EC, 2011).

In some production systems, complexity arises when it is difficult to identify all factors associated with the creation of waste, their interrelationships and their consequences for the creation of waste. In such systems, some hazardous sources can generate contaminant uncontrollably which creates new wastes as well as significant implications for safety. In these instances, other risks can also increase e.g. primary risks from the hazard, secondary risks from a confluence of hazards, environmental risks and business risks. On business risks, the management of hazardous waste is often complicated by costs, reputational risks (Carnes et al., 1998) and the desire for public representation in decision making (Rogers-Hayden and Pidgeon, 2008). These aspects encourage waste avoidance strategies (Bautista-Lazo and Short, 2013) to ensure that lower volumes/hazards are eventually disposed of (Hatfield and Ott, 1993). Thus, process designers are encouraged to (1) avoid avoidable wastes by designing them out of production processes, and (2) minimise unavoidable wastes by designing 'monitoring and control' functions to ensure processes stay within design.

An example of such complex systems is the UK's nuclear industry where the estimate for remediating the waste exceeds £45bn and will take 120 years (DECC, 2011) – an expensive, complex and intergenerational problem (Taebi, 2012). Also, the industry

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has a small number of extreme examples where legacy radioactive waste is poorly understood and documented which complicates its management, causes the proliferation of more waste, presents a significant hazard, and absorbs scarce resources (DECC, 2011). To address home-grown examples, the authors worked with the UK's nuclear regulators (the Office of Nuclear Regulation, the Environment Agency, the Scottish Environmental Protection Agency) to develop a qualitative methodology called Waste and Source Analysis – WASAN. The WASAN method seeks to understand causes of, and solutions to, radioactive waste that could be avoided. Unlike other methods to analyse waste, the novelty of WASAN is that it examines the entire system that creates waste to understand systemic up/downstream effects and how these create conditions that cause waste generation i.e. analysing input > process > output systems. Underpinning WASAN is the view that waste minimisation is achievable (in part) by controlling the source of waste and making decisions that recognise how the wider system may affect this source (Musee et al., 2007).

This paper explores generic issues of analysing systems that create waste with the aim of understanding how to create optimal conditions to reduce avoidable waste. This includes analysing how to closely manage the sources to avoid waste in the first instance, how to respond to up/downstream fluctuations which may affect waste sources elsewhere in the system, and how to select between strategic actions to minimise waste. Through applying WASAN as a decision making instrument we reflect on its potential to capture information on, and solutions to, various causes of waste.

The structure of this paper is that we first examine the theoretical context including: causes of waste creation, analysing waste-producing behaviour and knowledge, and methodologies for analysing waste-producing systems. We introduce the case study of avoidable waste generation in the nuclear industry and present the WASAN methodology used to analyse waste arisings. Through the case study we reflect on the methodology before discussing the importance of our results for analysing complex systems.

2. Theoretical context

This section begins by discussing causes of waste and the availability of analytical methods to analyse these causes. We then consider how the principles of systems thinking may allow the identification of hidden reasons for waste creation in complex systems.

2.1. Causes of waste

Production waste has been defined as “anything other than the minimum amount of resources which are absolutely essential to add value to the product” (Rawabdeh, 2005, p801). Canel et al. identify “anything” as equipment, materials, parts, space and workers' time. Analysing these wastes is very much a research topic, for example, Mirabella et al. (2014) developed options to recover and reuse food waste and Fikru (2014) assessed the environmental performance of waste handlers. Philosophies such as Lean (Martínez-Jurado and Moyano-Fuentes, forthcoming) seek to eliminate waste by removing unnecessary activities to reduce costs, improve efficiencies and strengthen effectiveness. Underpinning such philosophies are techniques to structure thinking on waste. For example, Ishikawa Fishbone diagrams (Ishikawa, 1985) explore root causes of wastes, value stream mapping visualises desirable futures for processes and builds an implementation plan (Marimin et al., forthcoming) and keywords prompt thinking on waste/causes e.g. 7 types of muda (Ohno, 1998) and TIMWOOD (Rawabdeh, 2005). Such techniques tend to present the main causes of waste as material, processing and systems (see Table 1) – a classification that results from viewing operations as technical systems rather than as human activity systems where behaviour and knowledge are key (Checkland and Poulter, 2006). When behaviour and knowledge are included they have lower prominence e.g. in Ishikawa diagrams. An eighth waste has been discussed alongside the seven MUDA wastes – often presented as employee involvement or unused creativity of staff. Our conceptualisation of behaviour and knowledge causes of waste is broader and puts the responsibility not only on the organisation (e.g. to use creativity), but also on the staff to behave and think about their practices.

The causes of waste in Table 1 can be an avoidable (unintended) or unavoidable (intended) consequence of production (Kronenberg and Winkler, 2009). Unavoidable waste is a designed feature of production e.g. storing polluted water in a vessel meaning the inside skin of the vessel becomes waste. Avoidable waste occurs when production/operations move away from its original design e.g. due to longer storage in suboptimal conditions, the vessel fails, releasing the pollutant onto other materials that are then waste. Thus, avoidable waste may be the undesired consequence of complex waste sources being mismanaged. Beyond mismanagement, suboptimal conditions are propagated by disruptive external factors (Musee et al., 2007) as up/downstream operations can move away from their original design and create conditions that encourage avoidable waste e.g. longer storage in the vessel may be due to downstream processes being unable to accept it as incoming materials to be processed on-time. Thus, analysing avoidable waste generation should consider the material, processing, systemic and human causes of wastes (Table 1) as well as the internal/external conditions that exacerbate them – the waste-creating system.

2.2. Methods for analysing systems that create waste

Research has developed sophisticated quantitative methods to evaluate waste-creating systems. For example, Life Cycle

Table 1
Causes of waste.

Ishikawa fishbone	Types of muda
Material	
Materials: Production inputs which are not to specification	*Defects:* Non-compliant material requiring reworking or rescheduling
Processing	
Machines: Inadequate operation of equipment to process materials wastelessly	*Over-processing*: Putting more effort, cost or refinement than is needed into processing
Measurement: The mis-calibration of equipment creating avoidable waste	*Work in Process* (WIP): Items not being actively processed bring delays and can create avoidable waste
Method: Ineffective or inefficient processing techniques	*Defects:* Non-compliant processing causing the need for reworking or rescheduling
Systemic	
Environment: The impact of negative external factors on operations	*Transportation*: The movement of materials creating undue damage, loss and delay without adding value
Management: Poor monitoring and control of operations enabling out-of-design processing	*Inventory*: Poor systems management causing excessive raw materials, WIP, or finished goods
	Over-production: Creating too much product for no benefit
	Waiting: Like WIP (above), items waiting to be processed bring delays and can create avoidable waste
	Motion: Systemic effects of producer, worker or equipment causing damage, wear and safety concerns
Human	
Man: Poor knowledge and ill-advised behaviour of process operators	