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A Decision Support Tool for Improving Value Chain Resilience to Critical Materials in Manufacturing

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Abstract. A number of non-energy materials have been identified by the EU as being critical to the manufacturing sector and wider economy. A material is termed a critical material when it has a "high economic importance combined with a high risk of supply shortage" relative to other materials as defined by the EU. This criticality of specific raw materials will become increasingly acute as the escalating use of finite resources continues, driven by increasing consumer demand for an ever wider variety of products by a growing global population. Critical materials are vital elements in the value chain yet many manufacturers are unaware if they are affected by the use of a critical material in their operations. We have previously developed a framework that takes a systematic approach to identifying, assessing and mitigating risk associated with critical materials bilaterally up and down the value chain. In this paper we examine how this framework can be facilitated for application in industry through the specification and development of a decision support tool.

Keywords. Rare Earth Elements, Critical Materials, Resilience, Supply Chain, Risk Management

1. Introduction

This paper continues the research presented in a previous publication titled "A Framework for the Resilient Use of Critical Materials in Sustainable Manufacturing Systems"[1]. The paper highlighted the need for improved business support for manufacturers who might be exposed to the risk of interrupted supply of these critical materials (CM)[2] providing a systematic approach to identifying and quantifying this risk via the framework. Further research identified the need for a tool to help implement this framework within organisation, to manage due to the large datasets involved, the complexity of the supply chain, the potential from both direct and indirect use and the specialist knowledge required to gather and interpret the information on rare earth supply chain risk [3]. This paper describes the requirements and key specifications of this tool and provides a detailed description of the implementation of the first part that supports the identification phase of the framework. The paper begins with a brief introduction to the framework, followed by an outline plan of the tool and finally a detailed description of the first phase using simulated data to demonstrate its application.

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2. Framework Summary

The framework [1] provides a systematic approach for undertaking a risk assessment of whole or part of a manufacturing operation to the impacts associated with disruption to supply of critical materials within its value chain and to support the effective management and mitigation of these risks. The framework has similarities with well establish assessment methodologies such as those used in LCA and Lean Manufacturing [1], [3], [4][5] . The requirements of the framework were deduced through a review of academic literature and state-of-art industrial practices. Primary data was also collected from businesses via telephone and email questionnaires and direct communication. A summary of the key findings for the requirements of the framework is illustrated below in Table 1.

2.1. Five Phases of the Framework

The Framework consists of five phases that must be implemented iteratively as illustrated in Figure 1. The Pre-phase defines the goal and scope of the project. Phase 1 develops an inventory based model of the company's value chain that quantitatively and qualitatively identifies the frequency and scale of the occurrence of critical material use and the potential impact on the business in terms of lost production and sales. This allows each of the CM's identified to be prioritised in terms of business importance.
In Phase 2 an assessment is carried out to gain a deeper understanding of the current general risks associated with the supply of the material and any unique risks associated with its particular application and use. Phase 3 uses the outputs from the earlier phases to develop suitable risk avoidance and mitigation strategies to improve the overall resilience and sustainability of the business. The fifth phase is an interpretation phase termed the post-phase that runs in parallel with each of the proceeding phases ensuring that the outputs of each phase are in line with the aims and objectives defined at the beginning of the project

3. Tool Overview

The tool design must enable the facilitation of all requirements of the framework through incorporation of the five phases described above. The tool must also meet the needs of the user in areas including ease-of-use, compatibility and integration with existing risk and value-chain management policies. The mitigation phase should be incorporated into business continuity planning with triggers from the output of the assessment phase. The overarching process flow is illustrated in Figure 1 showing the flow of information from the pre-phase through phases 1 and 2 to Phase 3.

Table 1. Summary of Framework Requirements

Aspect	*Framework requirement*
Proactive/reactive risk management	A proactive approach to CM risk management and resilience
Business scale	Should be applicable to all sizes of business
Identification of CM risk	Must enable identification of each specific CM risk
Value-Chain risk	Must enable the identification of where in the value chain, both upstream and downstream, a CM risk may impact the business
Quantification of risk	Must enable each CM risk identified to be assessed with regards to the potential impact on the business

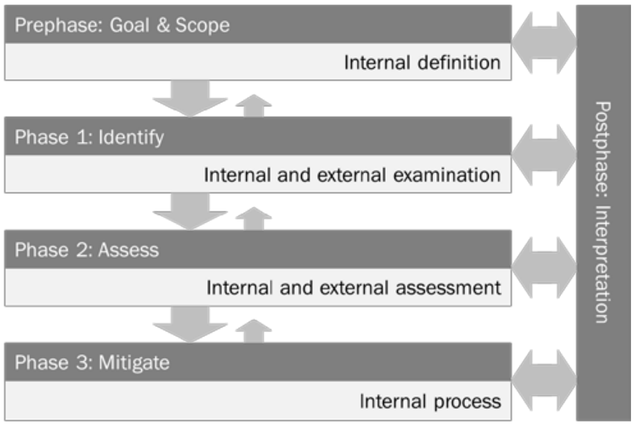

Figure 1. Overview of Five Phase Resilience Framework

The Post- phase runs in parallel with each of the other phases and allows interpretation of each phase to ensure that the output is in line with the specific aims and objectives defined at the start of the project in the Pre-phase. If these criteria are met then one may progress to the next phase, if the criteria are not met then the phase is iterated until they are met or alternatively, if after multiple iterations the original criteria proves impossible to meet then the original goal and scope may need redefining and so the process is iterated in its entirety.

3.1. Pre-phase "Goal & Scope" specifications for tool

The tool must allow the unique overall goal and scope requirements to be set by each unique user. This means the tool must have the capability to be applied to only those areas determined by the user. This could mean it is applied to the entire manufacturing operation or alternatively may be bespoke to just those specific areas determined by the user. E.g. a single or selected multiple product lines, specific customers or contracts, product lines selected by specific criteria such as percentage turnover or sales revenue. The tool therefore must enable the unique scope to be easily customised and variable for each unique user. In practice this would mean the tool must facilitate the input of external data specific to the critical materials [2] and internal data specific to every unique user (e.g. a manufacturer) with a specific scope (e.g. all product lines to one specific customer) that can be varied (e.g. changed to another customer or to include the whole operation) and adjusted (e.g. due to a change in product design or process etc.).

3.2. Phase 1 "Identification" specifications for Tool

The tool must identify each CM that pertains to the manufacturer and specify to which product and/or process it is associated with. Table 2 illustrates the information required to be output by the tool for the Phase 1 CM identification. In Table 2 the first column titled "Critical Material" names the critical material identified.

Table 2. Table illustrating modes and points of impact for CM association within a value-chain

Critical Material	Product Lines Affected	Modes of Impact	Points of Impact
Neodymium (Light Rare Earth Element)	Product A Product B	Raw material directly used in manufacturing of product	Upstream – Product A +B Material availability
Germanium	Product C	Raw material directly used in manufacturing process F	Upstream - Process F Material availability
Gallium	Product B	Component Z known to contain CM	Upstream – Product B Component availability
Indium	Product A Product C	Component Z known to require CM in its manufacturing process	Upstream – Product A + C Component availability
Magnesium	Product B Product C	Raw material required for known downstream use of product	Downstream – Products B + C Sales risk
Graphite	Product A	Known use in linked products	Downstream – Product A Sales risk

The second column titled “Product Lines Affected” lists each product line identified (illustrated here with examples Product A, B or C) as having an association with the named CM from column 1. The third column titled “Modes of Impact” states the how the CM relates to that product line. Examples given in Table 8.3 are illustrative and not an exhaustive list but do show the main ways a CM may impact a product line. Row 2 gives an example of when a CM may be a raw material used directly in the manufacture of a product so that the material forms part of the finished product e.g. neodymium being used to manufacture a magnet[6]. Row 4 gives an example of when a CM may also be required for components that are directly required for the manufacture of a product line e.g. LEDs may be required that are known to contain gallium. Rows 3 and 5 give examples of when a CM may be utilised in a process required to make the product or a component contained in the final product but the material itself does not end up in the final product such as in the case of a catalyst e.g. germanium being used as a polymerisation catalyst in PET plastic manufacturing. Row 6 gives an example of the required data output when a CM is required in the known downstream use of the final product for example when a component manufactured is known to be utilised with another component that is manufactured by another company e.g. an automotive parts manufacturer whose products are used as a component in conjunction with a magnesium alloy die-cast component part that is manufactured by a different company, to create another distinct product such as a particular model of car further down the value chain. Row 7 gives an example of the data output required when a CM is required for a “linked” product. A “linked” product is defined here as a finished product not manufactured by the company itself and which is not a component that goes to create a new product. It is a finished product that is ancillary or complimentary to the original product being manufactured. E.g. a non-universal specific phone charging product is a “linked” product to a specific phone. The phone charger is in no way needed to manufacture a phone and vice versa however if that specific phone is not manufactured then there is no market for the corresponding phone charger. The fourth column titled “points of Impact” states how and where in the value-chain the CM impacts the business. It describes which product is impacted either through the unavailability of a CM directly used in a product, or product component or process. Material availability for use directly in the product or in a process is described as an upstream risk as the risk occurs higher up in the value chain and may result in the inability to manufacture a product line. Downstream risk is where CM affects the business after the point of manufacturing either by affecting a known use of a product line or affecting the viability of a product known to be linked to the use of a stated product line both of which may result in the inability to sell a manufactured product.

3.3. Phase 2"Assessment" specifications for tool

The tool enables assessment of risk for all CMs identified in Phase 1 and generates reports for the user. Data on the external risks of supply is updated through an external database for each CM using qualified and peer-reviewed sources. The tool incorporates an internal risk assessment methodology and communicates the data used for calculation and the results. The tool enables a ranking/weighting system to enable bespoke assessment of CM risk with regards to the user's own assessment preferences (e.g. a particular CM may have a high external supply risk but the same material may present a low internal risk due to the ready availability of a substitute material). The external CM risk assessment is combined with the internal CM risk assessment to give an overall risk score for each CM with regards to the unique risk it poses to either the entire operation or the specific scope defined in the prophase such as a particular product line or key customer for example. The tool risk assessments must be compatible with existing risk assessments and relevant policies and practices of the business implementing the tool. Microsoft Excel has been identified through communication with various potential tool users as potentially the most universal and ubiquitous programme that meets the functional requirements of this phase. However to ensure compatibility with any other risk assessment methodology employed by a user of the tool there will be the option to manually input the internal risk assessment data at this stage.

3.4. Phase 3"Mitigation" specifications for tool

The tool must support the selection of the most appropriate mitigation strategy for each CM aspect identified. This phase must enable bespoke mitigation options defined by the user. The mitigation options generated in the report are derived from the outcomes of the identification and assessment phases and allow for ranked mitigation options to be selected by the user. There will be the option for trigger points for various bespoke mitigation strategies to be embedded in the assessment stage e.g. when the price of a material hits a predefined level or when demand for a product line drops or rises above a set limit. These predefined levels will be set and adjustable by each tool user so that the mitigation responses generated can be pre-planned and bespoke to the circumstances of the company using the tool. The mitigation strategies that a manufacturer may choose to employ following the assessment phase should be formulated during the implementation of the tool. This will enable the tool to be linked to the manufacturer's bespoke business continuity plan so that predetermined strategies can be automatically set into action based upon the results of the assessment phase. Critical materials resilience should be fully incorporated into the core business continuity plan and detail every aspect of the various mitigation strategies alongside the criteria for triggering their deployment.

3.5. Post-phase "interpretation" specifications for tool

The tool must allow for interpretation and iteration of each of the previous four phases. In practicality this will mean the ability to redefine parameters set in each of the previous four phases. This means the tool must be adaptable and dynamic allowing adjustment in line with changing business policies and strategies. It could also mean a phased implementation as a manufacturer may choose to apply it to only certain parts of the business or specific product lines in the initial roll-out and then gradually apply it to the rest of the business as and when it is deemed appropriate as the goal and scope in the Pre-phase is redefined through this interpretation phase. This post-phase will also allow for refinement and improvements in data entry and risk analysis scoring and weighting in all previous phases after each iteration. The functionality of the tool allowing for manual alongside as automatic data input at every phase provides the potential at this Post-phase to generate a tool report and then another after changing single or multiple variables in the earlier data input (e.g. different weightings or rankings in the Phase 2 risk assessment to represent a potential change in circumstance and therefore risk) allowing comparison and potentially alternative mitigation options.

4. Conclusions and future work

The specifications described will ensure that the tool provides a flexible and effective means of implementing the framework. It allows the integration of existing company databases to identify direct uses of the critical materials as well as highlighting potential secondary uses or interactions both up and down the value stream. The outputs from one phase can feed into the next phase of the tool or be extracted and used within other decision making processes. It allows risk assessment bespoke to the company to be combined with external materials data for analysis and report generation. The discrete phases and iterative process allow for experimentation with changes in variables. The comparison of the reports generated has the potential to offer insight into how changes in current circumstances may cause significant changes in risk that may in turn effect the mitigation options available or what is ultimately deemed the most effective or desirable strategy to choose. Future work will detail the remaining stages and provide an industrial case study to demonstrate the application of the tool.

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