THE IDENTIFICATION OF CRITICAL BARRIERS TO PLM IMPLEMENTATION

by

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LIST OF ABBREVIATIONS

CMM – Capability maturity modeling

CR – Customer Requirements

CRM – Customer Relationship Management

DEMATEL – Decision-Making Trial and Evaluation Laboratory

ERP – Engineering Resource Planning

ICT – Information and Communication Technologies

IRM – Inter-Relationship Map

ISP – Information System Plan

IT – Information Technology

MCDM - Multi Criteria Decision Making

MMDE - Maximum Mean De-Entropy

NPD – New Product Development

OEM – Original Equipment Manufacturer

PDM – Product Data Management

PLM – Product Lifecycle Management

QFD – Quality Function Deployment

SCM – Supply Chain Management

SME – Small to Medium Enterprise

SOA – Service Oriented Architecture

ABSTRACT

Product Lifecycle Management (PLM) is a well-known strategy used to improve business and manufacturing operations. Even with the attractive benefits it can provide, many companies struggle to successfully implement PLM solutions. This study proposes that this is due to a lack of knowledge on the critical barriers that affect the implementation of PLM solutions, and that reliance on the opinions of PLM professionals alone are not enough to create a successful implementation plan. This study addresses these issues with following research questions, what are the barriers to PLM implementation and is there a difference between those identified in literature and those confirmed by professionals, is there a difference between barrier impact rankings, based on professional opinion and those determined utilizing the DEMATEL method, and what are the critical barriers determined using the DEMATEL method supplemented by the MMDE algorithm? To answer these questions a series of two surveys were sent out to professionals in the PLM space with experience working on PLM implementation projects. The first of the two surveys was used to confirm the barriers that exist within the PLM implementation process. The second of the two surveys was used to gather information on the perceived impact of barriers and the causal relationships between barriers in the form of relationship matrices. To analyze these matrices the DEMATEL method supplemented by the MMDE algorithm was used. This study did not intend to provide absolute solutions to the critical barriers identified in this study, rather it intended to increase the success rate of PLM implementations by, confirming the barriers identified in the literature, providing information on the relationships between the barriers to PLM solution implementation and determine which of the barriers can be considered critical. Following these results of this study, the DEMATEL analysis method may supplement existing PLM implementation frameworks allowing companies to identify the critical barriers to implementation, allowing for better allocation of resources and ultimately a more successful PLM implementation.

1 INTRODUCTION

In an increasingly digital world Product Lifecycle Management (PLM) presents many unique benefits to companies that can successfully implement a PLM solution into their business practices. A review of literature highlighted benefits such as reduced costs, an improved ability to capture and manage product data, increased collaboration, improved manufacturing operations and better business decisions. Many companies large and small are attempting to implement PLM solutions to realize these attractive long-term benefits, which stem from the inherent ability PLM has to organize the complexity that comes from the development and support of products today (Brown, 2016). The adoption and implementation of a PLM solution is becoming increasingly important if a company plans to remain competitive as the world becomes more globalized and products become more customized (Erasmus & Jacob, 2015). This makes a PLM solution a requirement for companies that are looking to enable cross-functional collaboration and innovate utilizing data that are captured throughout a product's lifecycle (Johansson et al., 2013). With these developments it is not surprising that companies are attempting to implement PLM solutions. Unfortunately, Johansson et al. (2013) found that "most PLM initiatives fail, not due to a lack of capabilities in the software but is rather an effect of how the PLM projects are scoped and implemented". Johansson et al. (2013) go farther by claiming that even when an implementation does not fail, "70% of PLM investments fail to meet management's expectations". Interestingly Rangan et al. (2005) found that despite the high level of failure, "PLM deployment and implementation issues are not seen as interesting by the current research community". Consequently, there have been few studies that explore a comprehensive list of the barriers that companies face when implementing PLM solutions. These studies focus on a single company or a very specific area of manufacturing and either a few of the more commonly seen barriers or merely acknowledge that there are barriers to the implementation process. Some of the only studies to directly investigate the barriers to the implementation and use of PLM solutions were conducted by Arendt (2008), Koomen (2018) and Singh and Misra (2018-2019) in the past few years with Singh and Misra (2019) conducting a study on the barriers critical to PLM institutionalization. While their findings are useful for the basis of a list of commonly found barriers to PLM implementation Arendt (2008) and Koomen (2018) focus exclusively on barriers that SMEs face and assume that their findings can applied to larger companies without exploring the relationships between barriers. Through various journal articles Singh and Misra (2019) compiled a list of barriers to PLM institutionalization and utilizing the causal relationships between barriers identified by the DEMATEL method determined the critical barriers within their list. While a great start to the investigation of the barriers to PLM implementation according to Singh and Misra (2018b) their discoveries focused on the institutionalization of PLM and “were limited to manufacturing industries based in India”. This distinction allows the use of their research methodology to explore the critical barriers to PLM implementation. This study follows the DEMATEL method utilized by Singh & Misra (2019b) in their study of the critical barriers to PLM institutionalization in India, builds off the barriers identified in various studies and aims to confirm the existence of these barriers with professionals within the PLM space. This research intends to increase the success of PLM implementations by providing a list of the confirmed barriers to PLM implementation, and through the use of the DEMATEL method supplemented by the MMDE algorithm, determine the critical barriers to the implementation of PLM solutions and utilizing the resulting impact relationship map (IRM) create an allocation framework to address the confirmed barriers. Ultimately, providing additional information and guidance to better address barriers during the implementation process. This study does not intend to solve or provide solutions to the confirmed or critical barriers. Rather it intends to increase the success rate of PLM implementations by providing additional information on which barriers are prevalent within PLM implementations and determining which of these barriers are critical to the implementation of PLM solutions.

1.1 Statement of Purpose

When implementing a PLM solution there will be barriers that are encountered. These barriers if not addressed correctly, can result in a failure to achieve implementation goals, leading to a company not fully realizing the benefits that a PLM solution can offer. In the literature surrounding the implementation of PLM solutions many different barriers, in many different studies were identified. However, there was not an agreed upon collection of which of these identified barriers present themselves during the implementation process. The purpose of this study is to confirm which of the identified barriers are faced during the implementation of PLM solutions, and by utilizing causal relationship matrices in the DEMATEL method and a calculated threshold value from the MMDE algorithm, determine which of the confirmed barriers are critical to the implementation of PLM. Following the impact relation map (IRM) created from the DEMATEL method and MMDE algorithm, a framework to properly address the critical barriers can be created.

1.2 Significance

With the continued rise of Product Lifecycle Management adoption and implementation, it is becoming increasingly relevant for companies to begin creating and integrating their own PLM solutions. Even though the concept of PLM is not a new and has been around for a over 30 years there are still many unresolved issues that companies face when beginning to implement PLM solutions into their businesses. For a concept that has very well studied and documented benefits, it is surprising that many PLM implementation projects fail. With authors such as Singh et al. (2019a) arguing that no academic research identifies the critical barriers of organizations face when adopting PLM, or as Kung et al. (2015) states the "previous research fails to investigate adaptation problems among management intervention, the usage model, and the need to fulfill KPIs". This issue is exacerbated by existing studies focusing solely on larger manufacturing companies leaving many of the issues faced by SMEs ignored (Singh & Misra, 2018a; Koomen, 2018; Silventoinen et al., 2009). Current literature on PLM is focused on large companies with ample resources, and their processes. In the literature surrounding SMEs, the PLM aspect of business processes has been an increasingly interesting topic, but the research is still scarce (Singh & Misra, 2018a). Without a change in how PLM solutions are implemented the high rate of project failure will remain. The identification of the barriers faced, and subsequent determination of which barriers are critical to success, is the first step to improve how PLM solutions are implemented to reduce the project failure rate. Without a determination of critical barriers, many PLM implementation projects may continue to incorrectly allocate the resources needed for a successful outcome. It is important to note that this research does not intend to present concrete solutions to the determined critical barriers. Rather it intends to showcase how barrier impact determined by professional opinion alone is inaccurate, and an additional process is required to accurately calculate a barriers impact and ultimately determine which barriers are critical to the success of a PLM implementation project. If a discrepancy between barrier impact identified by professionals and impact determined through the use of the DEMATEL method supplemented by the MMDE algorithm can be proven, it can then be proposed that the DEMATEL method itself can be integrated within existing PLM implementation frameworks allowing companies to better determine the impact of each barrier and which are critical to their implementation, ultimately allowing for better allocation of resources and a more successful PLM implementation project.

1.3 Research Questions

This study addresses the following research questions:

1. What are the barriers to PLM implementation and is there a difference between those identified in literature and those confirmed by professionals?
2. Is there a difference between barrier impact rankings, based on professional opinion and those determined utilizing the DEMATEL method?
3. What are the critical barriers determined using the DEMATEL method and the MMDE algorithm?

1.4 Assumptions

The following assumptions will be made during this study:

1. Participants have professional level knowledge of Product Lifecycle Management and its implementation.
2. Participants will be able to complete the survey or interview completely.
3. Participants will provide honest responses.

1.5 Delimitations

The following delimitations will be made during this study:

1. This study is limited to using the DEMATEL method and does not utilize other MCDM techniques.
2. This study does not present concrete solutions to the confirmed or critical barriers.

1.6 Limitations

The following limitations will be made during this study:

1. This study is limited by the participants willingness and their ability to complete the survey, honestly and to the best of their abilities.
2. This study assumes that participants are confident in the answers that they provide.
3. Qualtrics Survey Software will be the only tool used to create and administer to the survey.
4. The small sample size for this study does not allow for the findings to be generalized the larger PLM community, specific enterprises, or enterprise areas.

2 LITERATURE REVIEW

2.1 What is PLM?

The general idea of PLM is very well known amongst companies and scholars alike. Githens (2007) and Grieves (2006) define PLM as an "integrated, information- driven approach comprised of people, processes/practices, and technology to all aspects of a product's life". According to Erasmus & Jacob (2015) and Kärkkäinen et al. (2012) the general concept of product lifecycle management (PLM) is inherently focused on the management of data, information and knowledge combining enterprise-wide product and process innovation. PLM as described by Batenburg et al. (2006), Johansson et al. (2013), Singh and Misra, (2019b) and Stark (2005) is the systematic approach of managing a company's products, as well as all information related to these products, across the complete lifecycle, from the early stages of conception through design and manufacturing, to service and disposal or recycling of the product. This activity of managing a company's products all the way from "cradle to grave" enables companies to efficiently take control of their products when they would otherwise not be able to do so Bokinge & Malmqvist, (2012). Encompassing the entire lifecycle of a product not only includes the data related directly to the product, but also the product lines, the technologies used, the organizational structures, the operational processes, the development methods, and human resources along every phase of the products lifecycle (Duigou et al., 2011; Grieves, 2006; Messaadia et al., 2016). Lee et al. (2008) combine all of these ideas to state that the "concept of PLM provides a definition of a completed product including all information and processes required to plan, develop, manufacture and support the product from concept through the end of its life integrating people, processes, business systems, and information". An important development that has enabled PLM is that of Information and Communication Technologies (ICTs). Any technology or system that allows a company or business to effectively manage the communication of information internally and externally can be considered an ICT. ICTs are one of the ways to increase productivity. The abilities of ICTs and their benefits have been realized by many larger companies and are beginning to penetrate the SME market Messaadia et al. (2017). Hewett (2010) states that he "considers PLM as an innovative ICT solution for SMEs", PLM benefiting from ICTs is accepted by other researchers such as Grieves (2006), Lee et al. (2008), Singh and Misra (2019b) and Stark (2015). However, they make the clear distinction that the concept of PLM itself is not an ICT but is enabled by ICTs in the form of PLM systems. The distinction between the concept of PLM and PLM systems are two areas that need to be addressed to appropriately explain what a PLM solution constitutes.

2.1.1 A Short History of PLM

According to Zammit et al. (2017) PLM with the tools and methods we know today "emerged in the early twenty-first century to manage the knowledge intensive process consisting mainly of market analysis, product design and process development, product manufacturing, product distribution, product in use, post-sale service, and product recycling", however the ideas behind PLM existed long before that. Before the advent of comprehensive PLM solutions companies where still using methods of organization and accompanying software to help manage their activities. Some of the most prevalent of these were engineering data management, enterprise resource planning and product data management systems (Srinivasan, 2011). There are key differences between each of these systems, but they all contributed to the evolution of PLM. Before 1990 these systems fell under the engineering data management umbrella, and they almost solely focused on users in the engineering department. Once the focus of the management system extended to other departments like production and purchasing, the name changed to Product Data Management (PDM) (Pels and Simons, 2016; Hewett, 2010). According to Pels and Simons (2016) "after 2000 the functionality that the software offered was further extended to support users in research and development, marketing and service and to support engineering collaboration with codevelopers in the supply chain. Consequently, the current name was introduced: Product Lifecycle Management". This need to extend the data gathered and supported originated in the aerospace and automotive industries which created a need for PLM as their products have long lifecycles which generate an immense amount of data that can be incredibly difficult to manage (Singh and Misra, 2018b).

2.1.2 The PLM Concept

It is important to make clear that PLM is more than just a collection of software that has been implemented into a company. It is an organizational, technology based, business approach to running company activities and it requires the managing of products over their lifecycle, starting with capturing new product ideas and controlling the product portfolio management, following with capturing all product definition data and extending to capturing the definitions of all life cycle processes and monitoring customer satisfaction (Pels & Simons, 2016; Erasmus & Jacob, 2015). The concept implies structural, cross-functional and long-term cooperation between actors in and outside the firm (Batenburg et al., 2006). “PLM is not an IT investment. PLM is the transformation of product development” Mr. Brian Shepherd, Executive Vice President PLM & SCM at PTC.

2.1.3 PLM Systems

One of the key enablers of a successful PLM implementation is a PLM system, yet many companies may mistake these systems for the entire concept of PLM, without modifying their organization to truly realize the benefits. “PLM systems have been recognized as a solution to support collaborative creation, management, dissemination and use of product assets including data, information and knowledge across extended enterprise, integrating people, processes and technologies” (Ming, et al., 2008; Urbinati et al., 2017). PLM solutions are supported by business IT tools that enable the PLM concept (Singh et al., 2019; K.-H. Kung et al., 2015). A PLM system builds a singular data structure by consolidating different systems and technologies into one enterprise-wide implementation (Urbinati et al., 2017). These systems often take the form of a software suite, utilizing integrated data and process meta models which are organized around an enterprise-wide database (Abramovici, 2007). “These databases contain all product definition related data, like requirements, calculation, 3D product models, test results, digital manufacturing models, marketing documentation, service documentation, service quality data etc.” (Pels & Simons, 2016). This centralized database helps to support coordination and fast communication of product definition information from one business solution to another (Pels & Simons, 2016; K.-H. Kung et al., 2015). Many different types of engineering information software comprise PLM systems, the main areas that these systems cover are technologies that support design activities, knowledge management systems, project management and workflow management tools and technologies to support relations through the supply chain. (Stark; Cantamessa et al., 2012). These technologies can include computer-aided design, computer-aided manufacturing, computer-aided engineering, enterprise resource planning, product data management, workflow management, production planning and customer relationship management (Koomen, 2018; Srinivasan, 2011; Penciuc et al., 2014). These systems are deployed within companies to support product data structuring and management throughout the product development process. They manage information through document life-cycle management and especially product data evolution using predefined workflows (Liu and Xu, 2001; Pol et al., 2008).

2.1.4 PLM Solutions

When the concept of PLM becomes enabled by a PLM system, it then becomes a PLM solution. The concept of PLM is enabled by a PLM system, which itself is a combination of business processes, methods, engineering applications and product data management systems" (Bokinge & Malmqvist, 2012; Singh & Misra, 2018b). A complete PLM solution includes a combination of the right technology, appropriate features, best practices approaches, and focused implementation methodologies (CIMdata et al., 2004). A reference or two here about enterprise architecture may not be a bad thing.

2.2 Benefits of PLM

The reason that many companies large and small are attempting to implement a successful PLM solution is the very attractive long-term benefits from the use of these solutions. PLM helps to organize the complexity that results from today's products and their development (Brown, 2016). The implementation of PLM into a company is becoming increasingly important if a company wishes to remain competitive as the world becomes more globalized and products become more customized (Kroes et al., 2009; Erasmus & Jacob, 2015). This makes PLM a requirement for companies that are looking to enable cross-functional collaboration and innovate utilizing data that is captured throughout a products lifecycle (Johansson et al., 2013). However, there is some discussion on when the benefits are felt by companies that utilize PLM. Alemanni believes that the benefits can be divided into short-term and long-term benefits (Alemanni et al., 2008). While others believe that PLM benefits are difficult to measure and cannot be easily transferred into monetary benefits (Silventoinen et al., 2009). This results in a wide variety of benefits that result from the implementation of PLM. The major benefits of PLM implementation from a variety of articles are listed below:

- **Reduced Costs** (Barba-Sánchez et al., 2007; Erasmus & Jacob, 2015; Johansson et al., 2013; Singh & Misra, 2018; Stark, 2011)

- **An improved ability to capture and manage product data** (Erasmus & Jacob, 2015; Garetti et al., 2005; Githens, 2007; Messaadia et al., 2016; Stark, 2011; Sudarsan et al., 2015; Urbinati et al., 2017)
- **Increased collaboration** (Barba-Sánchez et al., 2007; Erasmus & Jacob, 2015; Johansson et al., 2013; Kung et al., 2015; Lee et al., 2008; Messaadia et al., 2016; Silventoinen et al., 2009; Sudarsan et al., 2015; Urbinati et al., 2017).
- **Improved manufacturing operations** (Batenburg et al., 2006; Brown, 2016; Cimdata, 2002; Erasmus & Jacob, 2015; Hartmann, 2005; Lee et al., 2008; Messaadia et al., 2016; Stark, 2005, 2011)
  - **Faster development** (Batenburg et al., 2006; Cimdata, 2002; Erasmus & Jacob, 2015; Githens, 2007; Kung et al., 2015; Lee et al., 2008; Messaadia et al., 2016; Silventoinen et al., 2009; Stark, 2005).
  - **Higher product quality** (Messaadia et al., 2016; Silventoinen et al., 2009).
- **Better business decisions** (Burden, 2003; Erasmus & Jacob, 2015; Lee et al., 2008; Silventoinen et al., 2009; Stark, 2011; Urbinati et al., 2017)
  - **Lower cost of ownership** (Lee et al., 2008).
  - **Better business results** (Batenburg et al., 2006; Cimdata, 2002; Erasmus & Jacob, 2015; Johansson et al., 2013; Stark, 2005, 2011; Urbinati et al., 2017)

2.2.1 Reduced Costs

The implementation and utilization of a PLM solution within an enterprise can reduce the costs associated with everyday business operations such as portfolio management, product support and recalls (Erasmus & Jacob, 2015). PLM can also greatly reduce the cost of manufacturing efforts over a products lifecycle (Barba-Sánchez et al., 2007; Singh & Misra, 2018). These manufacturing efforts can take many forms such as product development, product maintenance and product disposal. According to Erasmus & Jacob (2015) and Stark (2011) PLM can “decrease product maintenance costs by up to 50%”. With the increased structure and organizational capacity that comes with a successful utilization of PLM the cost of transactions between different businesses and between a business and their consumers can decrease significantly (Barba-Sánchez et al., 2007). This reduction in costs can affect a company’s top and bottom line by increasing profits and reducing costs (Johansson et al., 2013).

2.2.2 An Improved Ability to Capture and Manage Product Data

One of the greatest challenges that companies of all sizes face today is how to manage the immense amount of data that is generated for each and every product. The implementation of a PLM solution allows a company to integrate the information from every stage of a products lifecycle, both managerial and technical, into one standardized database improving the ability to manage and utilize the collected data (Erasmus & Jacob, 2015; Stark, 2011; Sudarsan et al., 2015; Urbinati et al., 2017). Systematically organizing this data and a single standardized procedure to store and access this data from a product's lifecycle allows for better control, better access and less confusion when looking through a massive amount of data (Garetti et al., 2005; Messaadia et al., 2016). This results in better access to all related files and allows for the management of data gathered after a product leaves the factory doors which according to Grieves is the potentially greatest benefit that PLM provides (Githens, 2007).

2.2.3 Increased Collaboration

The use of PLM allows for a company to effectively communication with many different groups internally and those spread around the globe, increasing the access to ideas and information to develop new products (Johansson et al., 2013; Kung et al., 2015; Lee et al., 2008; Messaadia et al., 2016). This allows for companies to utilize distributed development and enables the communication and sharing of data with customers, suppliers, developers and other manufacturers (Erasmus & Jacob, 2015; Silventoinen et al., 2009; Sudarsan et al., 2015; Urbinati et al., 2017;). In addition to allowing increase collaboration the use of PLM can increase the speed and reliability of transactions between businesses and consumers (Barba-Sánchez et al., 2007). This usage of PLM "not only brings together all the parties involved with the realization of the product, but it also offers the producer of the product the opportunity to provide its customers with after-sales services" (Erasmus & Jacob, 2015).

2.2.4 Improve Manufacturing Operations

PLM can improve manufacturing operations as Lee et al. (2008) explains by allowing "enterprises to plan, measure, and track equipment availability, operation, safety, and maintenance". According to Brown (2016) this increase in the ability to plan helps to organize the "complexity of product innovation, product development, and engineering resulting from today's complex products and product development landscapes". This stems from the single version of truth that PLM provides regarding a product (Erasmus & Jacob, 2015; Stark, 2011). It can also reduce the risks associated with product development resulting in minimized manufacturing costs (Erasmus & Jacob, 2015; Messaadia et al., 2016; Stark, 2011). This can also result in the reduction of waste throughout a product's lifecycle (Hartmann, 2005; Lee et al., 2008). Compiling articles from Batenburg et al. (2006), Cimdata (2002), and Stark (2005), this reduction in waste stems from a lower amount of product faults and higher efficiency and according to Messaadia et al. (2016) a "more effective re-use of product parts, and disposal of products". In addition to management of product data PLM allows a company to monitor its products regardless of where it is in the lifecycle, allowing for better control and support of products in production (Erasmus & Jacob, 2015).

2.2.5 Faster Development

The increase in structured communication, data storage, and the easy and fast dissemination of knowledge, documents and expertise that embody PLM systems allows for the faster development of products (Silventoinen et al., 2009). This increase in development speed can be attributed to the increased product design efficiency and the usage of virtual representations of physical products that PLM offers (Githens, 2007). This results in a "shorter time to market, fewer engineering changes late in the lifecycle and less product faults" (Batenburg et al., 2006; Cimdata, 2002; Stark, 2005;). These increases in product development speed can turn weeklong endeavors into something completed in days (Silventoinen et al., 2009). The integration of all data sources for a product into one central system help to minimize any difficulties created during design changes (Kung et al., 2015). This further can reduce the time to market by additionally integrating chain management and procurement (Lee et al., 2008).

2.2.6 Better Business Decisions and Results

The utilization of PLM allows for companies to better make decisions related to their products and their direction moving forward. This ability to make decisions comes from PLM allowing a company to have complete control their products data even after they leave the companies doors (Erasmus & Jacob, 2015). PLM allows for there to be "One version of truth" (Erasmus & Jacob, 2015; Stark, 2011), this is enabled by a single system that supports and records all of the data a company would need, as Urbinati et al. (2017) states "so that people see the right information at the right time, and in the right context". In addition to storing and allowing access to specific data, PLM allows for the portfolio management and the usage of analytics to better organize data in order to make a more informed decisions (Burden, 2003; Lee et al., 2008; Silventoinen et al., 2009). Utilizing the inherently modular approach of PLM systems a solution can be gradually expanded to meet changing needs (Lee et al., 2008). With all of the business benefits that PLM offers it ultimately results in better business results as Urbinati et al. (2017) states by "maximizing the lifetime value of business' product portfolio". This results in increased profits (Batenburg et al., 2006; Cimdata, 2002; Stark, 2005), sometimes up to a product revenue increase of up to 30% (Erasmus & Jacob, 2015; Stark, 2011). The structured nature of PLM ends up "affecting both the companies' top and bottom line" (Johansson et al., 2013). Resulting in more informed decisions that lead to better business results.

2.3 PLM Adoption

With all of the benefits PLM provides it is understandable why many companies large and small are attempting to adopting PLM into their business. There are two key types of adoption that both need to be reached for a successful implementation of PLM to occur: individual and organizational adoption. *Individual* adoption focuses on how a user interacts with a new technology and how the way they work changes to fit into a PLM paradigm. *Organizational* adoption is the more commonly thought of aspect of adoption where a company analyzes different technologies and decides which of them to implement into their company environment (Messaadia et al., 2017). It is important to note that these adoptions of PLM are mainly happening in groups such as engineering and research and development that would traditionally use engineering technologies and these users are using are often using PLM systems as extensions of PDM instead of a full way of operating (Abramovici and Sieg, 2002; Rachuri et al., 2005; Lee et al., 2008; Schuh et al., 2008; Singh & Misra, 2019b). Pels & Simons (2016) claim that "on average 40% of all R&D employees use PLM with the usage of PLM in sales, marketing, finance and service is still very limited. With external customers and suppliers not having access to the PLM systems". The level of adoption of PLM systems can vary greatly between different countries and different types of companies. Abramovici (2007) stated that "only 8% of companies have a clear PLM vision and extensively implement PDM/PLM systems". While there are no complete numbers for the percentage of global adoption today, Saaksvuori (2011) stated that a study of PLM adoption in Finland in "August 2010 showed that 70% companies in Finland employing more than 500 people have already invested in a PLM solution. In addition, 17% consider the issue or they have a deployment in progress. Overall, this makes the total adaption rate almost 90%". Showing that there has been a huge wave of PLM adoption in certain places. The most extensive adoption of PLM solutions has taken place in larger, global corporations that mainly focus on automotive and aerospace industry, with some electronics companies beginning adoption (Saaksvuori, 2011). This can be partially attributed to the special preset templates that are available for the automotive, aerospace and machinery industries. PLM concepts can also be utilized in other sectors such as construction, transport, pharmaceutical, textile, chemical, life sciences or medical technology industries (Abramovici, 2007; Batenburg et al., 2006). Most of this adoption has been taking place in large firms, but SMEs have also begun to experiment with PLM adoption (Singh & Misra, 2019a).

2.3.1 SME Adoption

While large companies are ahead in the adoption and implementation stages of PLM the awareness that small companies have of these concepts is surprisingly high (Pels & Simons, 2016). Even though the awareness levels are very high, and that the adoption of PLM can be a source of competitiveness and sustainability (Messaadia et al., 2017). SMEs often do not feel the need to implement and utilize PLM in the way that larger companies would (Arendt, 2008; Messaadia et al., 2016). This reluctance to adopt PLM can be related to how these systems may not meet the needs of SMEs (Duigou et al., 2011). This would require either the system or the SME to undergo immense changes to properly implement a PLM solution. This idea of incompatibility is supported by Poe et al. (2008), who explains how SMEs have a very different way of completing collaborative projects than larger companies. This is further explained by the smaller structure of SMEs which could result in a non-standard method of project management that combines various roles that would normally be separate. This allows SMEs to be incredibly flexible during product development and results in each product's development being different (Pol et al., 2008).

2.3.2 Maturity Models

A keyway the readiness of a company can be determined is through the use of maturity models. Kärkkäinen et al. (2012) remark that PLM maturity model "be used to make the implementation of PLM better approachable and a more carefully planned and coordinated process". The idea of PLM maturity is highly applicable as a company that scores highly on maturity sees results closer to originally targeted goals, and improved effectiveness of an implementation (Kärkkäinen et al., 2012). Pels & Simons (2016) describe how the level of PLM adoption can be measured along five dimensions with a four-level scale for each of the dimensions. These dimensions are strategy and policy, monitoring and control, organization and process, people and culture, and information technology. The four-level scale is comprised of, when necessary, department, organization, and inter-organization (Pels & Simons, 2016). Stark's PLM maturity model categorizes four different stages traditional, awakening, adapting, and modern. These stages can be matched up with Pels & Simons four level scale of rating for each area of adoption (Stark, 2015). The origin of this maturity model relies on the idea of phases or stages, which a company must overcome as it as it "adapts to new cultural issues, processes, management practices, business concepts, and modes of operation" (Silventoinen et al., 2009). Saaksvuori (2011) provides the following maturity model:

Saaksvuori	*PLM maturity model*
Unstructured	The PLM topic has been recognized and its importance agreed. Work must be done to define and develop the PLM concept and standards. However, at present, there are no defined approaches concerning lifecycle management; all lifecycle and product management issues are resolved by individuals on a case-by-case basis.
Repeatable but intuitive	Lifecycle and product management processes have developed to the stage where similar procedures are followed by different people undertaking the same task within one organization (i.e. the processes function on ad hoc bases, corporate wide procedures or definitions do not exist). There is no formal development, definition, training, or communication of standard processes; all responsibility is left to individuals. There is a high degree of reliance on individual knowledge and therefore errors occur.
Defined	Processes and basic concepts are standardized, defined, documented, and communicated through manuals and training (on corporate level, in all business units – geographical, functional units). However, the human factor is important, there is no end-to-end PLM process supporting IT systems, all work is completely or partially manual from the process point of view. IT systems support individual parts of processes. The PLM processes or basic PLM concepts are not best-of-the-breed, nor are they uniform throughout the corporation, however they are formalized. There is common understanding of the to-be model how PLM shall be executed in the future.
Managed and measurable	It is possible to monitor and measure the compliance between processes and to take action where processes are not functioning well. Processes and concepts are under constant improvement and provide best practices. IT systems support PLM processes well. Process automation is used in a partial or limited way. Processes and concepts are developed through clear vision throughout the corporation. The state of uniformity of processes is clear.
Optimal	Processes and concepts have been refined to the level of best practice, based on continuous improvement and benchmarking with other organizations. IT is used in an integrated manner and process automation exists on an end-to-end basis.

Figure 1. This figure showcases Saaksvuori's (2011) five levels of PLM maturity.

There are many different maturity models each with different levels and ideas, but the result of their application is clear. If companies wish to implement and utilize PLM effectively, they need to show that they have the maturity to do so. Without an understanding of PLM maturity, many companies will be unable to effectively identify requirements or create the comprehensive plans necessary for a successful implementation.

2.3.3 PLM Implementation Planning and Requirements

Once the decision to implement a PLM solution is made, the arduous task of realizing a successful transformation begins. PLM implementations are complex and are no easy feat due to the immense organization changes that are required to reap the benefits of PLM. Often resulting in the scope of a PLM implementation being considerably large as Erasmus & Jacob (2015) states "because it spans the complete lifecycle of a product and therefore affects a wide range of processes within and outside the company". CIMdata et al. (2004) and Stark (2011) list the scope of PLM as including:

1. Managing a well-structured and valuable product portfolio.
2. Improving the financial return from the product portfolio.
3. Providing control and visibility over products throughout the lifecycle.
4. Managing product development, support and disposal projects effectively.
5. Managing feedback about products from customers, products, field engineers and the market.
6. Enabling collaborative work with design and supply chain partners, and with customers.
7. Managing product-related processes so that they are coherent, joined-up, effective and lean.
8. Capturing, securely managing, and maintaining the integrity of product definition information. Making it available where it's needed, when it's needed.
9. Knowing the exact characteristics, both technical and financial, of a product throughout its lifecycle.

It is recommended to take these implementations in a stepwise approach to avoid overwhelming an organization (Bokinge & Malmqvist, 2012; CIMdata et al., 2004). Erasmus & Jacob, (2015) recommend "conducting a pre-study before system selection, securing benefits for all stakeholders, establishing user involvement and top management support, improving processes before or simultaneously with the project, and performing a pilot study before doing a full implementation." These preemptive steps can go a long way to identify problems and create solutions long before they become problems that could plague a PLM system. Hewett (2010) echoes this sentiment stating that "it is critical that the objectives and expectations are properly determined and documented, the program is formally managed and the potential impact on the operations is well understood". According to Cantamessa et al. (2012) even after these steps are taken there is "a gap that always exists between the desired processes and the available support from the system". This results in two outcomes, the system being implemented needs to be customized to support a desired process or the process itself needs to be changed to fit within the system (Cantamessa et al., 2012;

Saaksvouri and Immonen, 2005). Hartman and Miller (2006) remark that even though the prepackaged functionality is extensive, it is not sufficient as these systems have often been scaled down and would not work out of the box.

2.4 The Barriers to Implementation

To identify which barriers are critical to PLM implementation, the barriers must first be identified. This section will cover the barriers that were discovered within academic literature. These provided a basis to create a list of barriers confirmed by industry professionals with experience in PLM implementation. A review of literature identified nine common barriers:

- **Complexity of Systems** (Abramovici, 2007; Batenburg et al., 2006; Garetti et al., 2005; Githens, 2007; Hewett, 2010; Johansson et al., 2013; Kung et al., 2015; Lee et al., 2008; Messaadia et al., 2016; Pol et al., 2008; Rangan et al., 2005; Saaksvuori, 2011; Silventoinen et al., 2009; Singh & Misra, 2018b, 2019b; Urbinati et al., 2017)
- **Lack of Interoperability** (Bokinge & Malmqvist, 2012; Duigou et al., 2011; Erasmus & Jacob, 2015; Hartman & Miller, 2006; Saaksvuori, 2011; Silventoinen et al., 2009; Singh et al., 2019)
- **Lack of Knowledge** (Arendt, 2008; Bokinge & Malmqvist, 2012; Cantamessa et al., 2012; Johansson et al., 2013; Messaadia et al., 2016; Messaadia et al., 2017; Pels & Simons, 2016; Penciuc et al., 2014; Saaksvuori, 2011; Singh & Misra, 2019b)
- **Lack of Training** (Bedolla et al., 2014; Bokinge & Malmqvist, 2012; Rangan et al., 2005; Urbinati et al., 2017)
- **Monetary Cost** (Alemanni et al., 2008; Arendt, 2008; Brown, 2016; Erasmus & Jacob, 2015; Hewett, 2010; Kung et al., 2015; Messaadia et al., 2016, 2017; Saaksvuori, 201; Silventoinen et al., 2009; Koomen, 2018)
- **Perception of PLM** (Bokinge & Malmqvist, 2012; Erasmus & Jacob, 2015; Garetti et al., 2005; Hewett, 2010; Johansson et al., 2013; Silventoinen et al., 2009; Singh & Misra, 2018b)

- **Resistance to Change** (Bokinge & Malmqvist, 2012; Garetti et al., 2005; Hewett, 2010; Kung et al., 2015; Pels & Simons, 2016; Rangan et al., 2005; Silventoinen et al., 2009; Urbinati et al., 2017; Zammit et al., 2017)
- **Security Concerns** (Singh & Misra, 2018a, 2018b)
- **Time Requirement** (Alemanni et al., 2008; Arendt, 2008; Batenburg et al., 2006; Brown, 2016; Hewett, 2010; Rangan et al., 2005; Silventoinen et al., 2009; Singh & Misra, 2018b; Urbinati et al., 2017)

2.4.1 Monetary Cost

Of all of the barriers that can impact any form of implementation cost is one of the most obvious and implementing PLM solutions can be very expensive (Kung et al., 2015). This cost issue can be attributed to how as Silventoinen et al. (2009) claims “the total costs of PLM implementation can be three times the original purchase price of the system, when taking into consideration the process and configuration changes”. This issue is compounded by the ROI that companies wish to see when implementing new technologies. The ROI of PLM solutions while significant does not appear immediately after implementation, so many companies consider the investment cost too high compared to the time needed to see returns. According to Brown (2016) this is due to how PLM implementations “have historically been known for long, expensive implementations and many companies do not have the will to wait for the ROI”. The cost of implementation is also directly related to how large and how complex the organization a company is, such that the larger the company, the longer and more expensive an implementation would be (Messaadia et al., 2017). These cost issues are much more prevalent for SMEs thinking about implementing PLM solutions, as they often do not have the resources that a larger company would have access to, such as internal personnel or external connections to support the implementation process (Saaksvuori, 2011). These areas where they are lacking resources would ultimately increase the cost of a PLM implementation because they would have to hire outside personnel to handle nearly the entire process. The sheer scale of an enterprise-wide implementation and the need for assistance seems to scare SMEs in terms of resource costs and deployment (Messaadia et al., 2017). These fears exist despite the knowledge management and other business benefits that the PLM solutions would otherwise enable (Silventoinen et al., 2009). Another source of anxiety for SMEs comes from the large-scale changes to the technologies used, company processes and working habits. This anxiety comes from the cost of changing these practices and how the benefits of such changes may not be fully understood (Silventoinen et al., 2009). An interesting divergence has happened between European and US SMEs, where monetary cost is still a main barrier for EU companies, but US companies have put more focus on a lack of information system plans (ISPs). While focused differently this barrier can be attributed to the lack of simple templates and methods to use when implementing PLM solutions (Arendt, 2008).

2.4.2 Time Requirement

The implementation of the PLM strategy is a very long-term investment, which can take up to seven years to be completed, not including any future additions or changes (Alemanni et al., 2008). This extensive time frame comes with the required information process analysis necessary to plan out a system implementation, the customization of the PLM system to fit a company's unique processes and the extensive training on new processes and systems, (Brown, 2016; Rangan et al., 2005). Similar to the cost the amount of time required to implement a PLM solution is directly related to how large and how complex a company's operations are since every process needs to be implemented and possible customized (Silventoinen et al., 2009).

2.4.3 Lack of Knowledge

There are two areas where there is a lack of knowledge required for a successful PLM implementation. The first is a lack of understanding of the requirements of the PLM concept within a company, and the second is the lack of knowledge to implement a PLM solution once the concept is understood. The exact meaning of PLM is already difficult to understand, and many companies have trouble relating their processes to a PLM initiative (Pels & Simons, 2016). The lack of understanding PLM concepts often results in misguided implementations that result in a project missing its potential benefits and being overly costly (Johansson et al., 2013). This lack of understanding can take many different forms, from companies incorrectly running the project as an IT software initiative instead of a way to improve a company's business approach, or it can have companies jumping to a solution that requires a large number of unnecessary customizations as the project became more about fixing problems instead of realizing potential business benefits

(Johansson et al., 2013). This can often be because a company based their PLM implementation on specific department needs instead of the need of the entire company, which can result in other department not being able to effectively integrate with the created system.

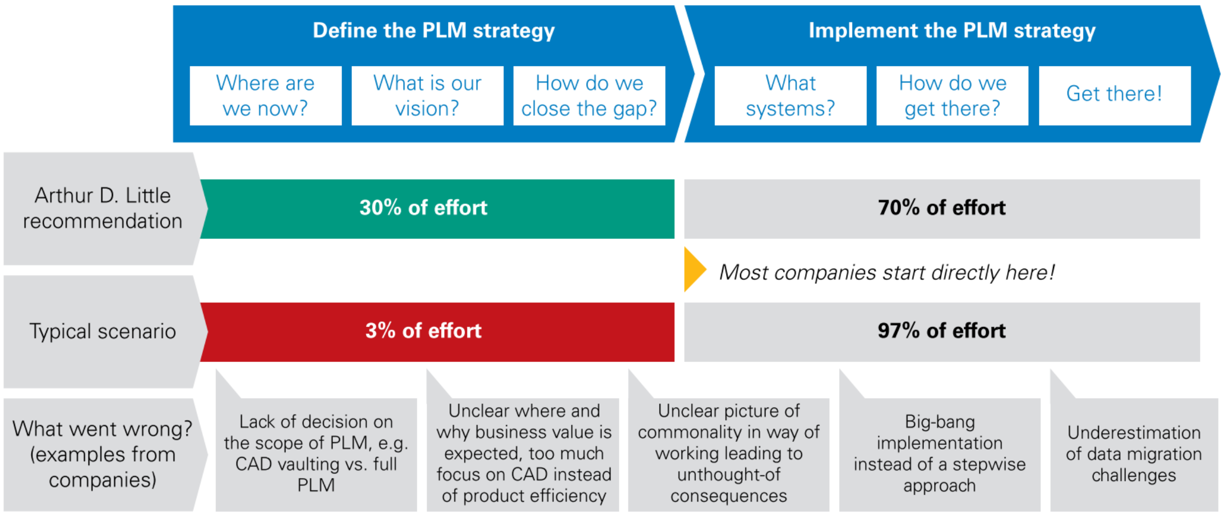

Figure 2. This figure highlights Arthur D. Little's PLM approach displayed by (Johansson et al., 2013)

As shown in Figure 2 companies often put little effort into planning out their PLM strategy and this often results in problems during the implementation of the systems. This is problematic because a PLM project requires a careful understanding of all business processes and how they would all need to interact with a centralized system to realize the benefits of the PLM approach (Garetti et al., 2005). This can stem from as Saaksvuori (2011) states the struggle "many companies have with integrating mechanic, electronic and software components and service elements into their PLM concept".

2.4.4 Lack of Training

Even if a company has a complete understanding of the PLM concept their challenges to implementing a PLM solution are not over. With all of the changes that need to be made to an enterprises' systems and operations there need to be people with the knowledge to implement the required modifications and the ability to train others in the use of the new systems and processes. This is necessary for the long-term success of a PLM system but presents a barrier that many companies face when implementing PLM solutions. This issue is due to the lack of definition of the skills and knowledge needed to implement a PLM system. According to Bedolla et al. (2014) "Today, there is no standard for defining the necessary skills and capabilities for a PLM expert and this makes it is impossible to define the educational path for new users". This is not to say that these skills and capabilities do not exist (they very much exist), but this knowledge is locked away in individuals that do not have a reason to share their experiences (Bokinge & Malmqvist, 2012; Rangan et al. 2005). This is even shown in the guidelines created for implementation, where suggestions are made but there is not an explained reason for the suggestion and no explanation for what may happen if that suggestion is not followed (Bokinge & Malmqvist, 2012).

Despite the progress made in understanding of PLM solutions in larger companies, the lack of knowledge is even more prevalent in SMEs as they have even less access to individuals within and outside their organization with the skills and knowledge to explain the benefits of the PLM. This results in SMEs that are not aware of PLM benefits for their case and often have difficulties understanding the potential of the technologies. (Messaadia et al., 2017; Silventoinen et al., 2009). This lack of knowledge is further shown by the US SMEs that are more focused on the lack of ISPs to implement these complex systems. This can provide a reason even financially sound SMEs are lagging behind in the adoption and implementation of PLM initiatives. This lack of ISPs is a result of people lacking the knowledge and skills required to implement such a system (Arendt, 2008; Messaadia et al., 2016).

2.4.5 Organizational Challenges

Related to the lack of knowledge is organizational challenges that come with PLM initiatives. According to Messaadia et al. (2017) "30% of companies consider themselves to be under-equipped regarding to information technology". Unfortunately, most PLM implementations fail not due to a software issue but due to a project issue where the project are scoped and implemented incorrectly (Cantamessa et al., 2012; Johansson et al., 2013). Johansson et al. (2013) claims "Arthur D. Little research shows that 70% of PLM investments fail to meet management's expectations". One of the reasons that the majority of implementations fail is due to an incorrect assumption as Hewett (2010) states that "PLM solution should be quick and easy to implement". This often results in incorrect time and cost estimations and can result expectation that will not be met (Hewett, 2010). Many of these incorrect estimates can be a result of a lack of communication between stakeholders. As Githens (2007) observed “often people cannot fully explain their activities, judgments, and objectives”. This communication issue can cause an even bigger problem when the required process information is scattered throughout the enterprise (Silventoinen et al., 2009). Being unable to accurately map how each user would need to interact with a newly implemented system can be a part of what is causing incorrect estimates as the number of processes required is not fully understood at the beginning of the implementation. This is especially an issue in SMEs where they usually describe their processes at a macro level and not at the level of detail that is needed to realize the benefits of the new business methods (Pol et al., 2008). This can also be attributed to how many SMEs rely on individual knowledge and not groups using a standardized procedure (Silventoinen et al., 2009). Resulting in an incomplete process map that would be used in the company’s implementation plan. Another issue that contributes to a misaligned implementation plan is how the vendors of PLM systems often disregard their customer’s requirements during system implementation often resulting in incomplete designs which require significant reworks to meet the customers’ expectations (Lee et al., 2008).

2.4.6 Complexity of Products

A factor that impacts almost every other barrier of implementation is the complexity of the entire PLM concept and the PLM systems that enable that concept. From a purely technological standpoint PLM is only considered as a medium intensive project but is a very high intensity project from an organizational approach (Garetti et al., 2005). This complexity stems from how PLM addresses the entire lifecycle of every product and all of the data that is associated with that cycle. In addition to tracking data PLM also requires a complete restructuring on how a company operates to realize the benefits (Garetti et al., 2005). Incorporating all of that data and a new way of operating presents a real challenge and significantly hampers the implementation of complete PLM solutions (Batenburg et al., 2006). This restructuring of an entire companies’ processes as Garetti et al. (2005) states “requires a remarkable effort not only for its implementation but also its reception”. The amount effort required is directly related to the size of the company because the larger a company gets the more factors need to be tracked and carefully controlled. However, this amount effort is still incredibly difficult for SMEs to reach as they often lack the resources, knowledge and skills necessary to effectively organize their systems (Silventoinen et al., 2009).

This challenge becomes even more of an issue for companies that already have IT systems in place as they would need to change all of their existing practices for those established systems (Kung et al., 2015). These changes would not be such a large issue if there was a standard way to implement these different aspects of PLM approach, unfortunately there are huge customizations that need to be completed for each PLM implementation and this extra complexity often scares companies investigating PLM implementation (Abramovici, 2007). With the immense amount of data that is being tracked within a PLM system the method of storage needs to be organized but with all of the different sources and locations of lifecycle data that system can become very difficult to navigate (Kärkkäinen et al., 2012). This can cause users confusion and delays when they are searching for a certain piece of data. Johansson et al., (2013) found that "if engineers were unable to find an existing component after searching for it for a maximum of three minutes, they would create a new article". This can result in an exponentially messier product environment as each correct article becomes harder and harder to find (Messaadia et al., 2016).

2.4.7 Lack of Interoperability

With the all-encompassing nature of PLM systems, they are often made to integrate a variety of existing software and data sources. This interoperability and potential modularity are important to these systems as it allows for the collection and diffusion of data from a wide range of difference sources (Duigou et al., 2011). This is easier said than done as Kung et al. (2015) state "integrating PLM into existing systems is difficult since enterprises may need to change established knowledge sharing practices to fit the system". Most of these PLM system packages are typically created by vendors that develop CAD systems (Hartman & Miller, 2006). Most of these different systems do not have the innate ability to communicate between each other or with the CAD systems from other vendors. This presents a problem as many companies are being forced to utilize one company's "options for organizing, managing, and archiving their product data" (Hartman & Miller, 2006). This results in many interoperability problems when data is sent between different companies (Singh et al., 2019). This can present many issues for SMEs who have many different avenues to pursue. They can for instance they can attempt to join one of their bigger customers systems so that they do not have to take on the burden of developing their own system (Erasmus & Jacob, 2015; Silventoinen et al., 2009). This can result in many changes to the way an SME functions as they are essentially mirroring a different organization. Another issue arises when an SME is a supplier to multiple OEM's potentially each with their own PLM system and data management requirements (Saaksvuori, 2011). Making a SME have to maintain multiple different procedures to comply with the requirements from their buyers can be system and resource intensive.

2.4.8 Security Concerns

With the implementation of PLM centralizing all of a company's processes and operations, some companies have raised potential security concerns. These security concerns arise from of some the benefits that PLM provides. Whereas collaboration can be an incredibly powerful tool, it can also open up a company for unwanted intrusion (Singh & Misra, 2018b).

2.4.9 Resistance to Change

With the implementation of a PLM solution requiring massive changes in the standard business processes, it also requires shifts in a user's cultural practices regarding work. This demands remarkable effort both for its implementation and for its reception (Garetti et al., 2005; Silventoinen et al., 2009). Much of these changes can be a result of the collaboration that PLM enables, and users need to accept that they need to work differently in how they handle data because they are now working on a potentially global scale (Zammit et al., 2017). However, these cultural changes can be very hard to implement, with how disruptive PLM implementation can be as Erasmus & Jacob (2015) state "it is often very difficult to convince all parties involved and affected that the change will be beneficial to them". This change can be made even more difficult when an existing system that has always worked is modified to fit into the new system (Kung et al., 2015). The cultural related issues related to changes often surface in users with engineering titles and they can often be one of the larger barriers to a project's success (Bokinge & Malmqvist, 2012; Hewett, 2010). As Pels & Simons (2016) found these engineers are often extremely good at the "adoption of technological principles, tend to show extreme high resistance to change where it concerns there working process" and Ranagan et al. (2005) found "several real-world deployments where cultural change management has turned out to be the ultimate stumbling block". This can result from changes to the way technical data is collected and maintained as Kung et al. (2015) state engineers are "reluctant to input detailed explanations for solutions in the project documents”. The resistance to change can be more prevalent in SMEs as they fear significant changes to a successful system and the risk associated with a new system (Silventoinen et al., 2009).

2.5 Summary

The literature review for this study covered four areas related to the implementation of PLM solutions, these included an overview of PLM, the benefits of PLM, PLM adoption, and the barriers to the implementation of PLM. The overview of PLM contained a short history on the development of PLM, the difference between the PLM concept and PLM systems and how to make a complete PLM solution, both the concept and enabling systems must be combined. A review of the benefits of PLM, outlined the following benefits: reduced costs, an improved ability to capture and manage product data, increased collaboration, improved manufacturing operations such as faster development and higher product quality, and better business decisions such as a lower cost of ownership and better business results. A short review of PLM adoption topics covered general PLM adoption, SME specific adoption, the idea of maturity models, and the requirements for planning a PLM implementation. Finally, the barriers to the implementation of PLM were explored and the following barriers were identified: complexity of systems, lack of interoperability, lack of knowledge, lack of training, monetary cost, perception of PLM, resistance to change, security concerns, and time requirement.

3 METHODOLOGY

This study follows the methodology utilized by Singh & Misra (2019) in their study titled Identification of barriers to PLM institutionalization in large manufacturing organizations: A case study. Where Singh & Misra (2019) worked to compile a list of critical barriers faced by large manufacturing companies in India after the completion of a PLM implementation project also known as the institutionalization phase. The goals of this study are to confirm the barriers to the implementation of PLM identified in the literature and through analyzing how the different confirmed barriers influence each other determine which of the barriers are critical to the implementation process. Allowing for implementation projects to better allocate the resources needed to address the confirmed barriers, resulting in a higher implementation success rate. This study began with a review of literature surrounding the barriers faced during PLM solution implementation. Once identified these barriers were further investigated through the use of a survey of professionals in the PLM space to confirm that the identified barriers exist in practice and to identify any additional barriers, not identified in the literature, to be included in this study. Once the revised list of confirmed barriers was compiled, a second survey was used to investigate the impact professionals believed that each of the confirmed barriers exerted and to explore the relationships between all confirmed barriers using a relationship matrix. The results for both surveys can be found in section 4 of this study and the survey questions themselves can be seen in Appendices A & B. For this study, professionals in the PLM space were contacted via email, LinkedIn and professional networks and asked for their participation. Professionals, for the purpose of this study, are considered to have at least participated in one PLM implementation project and have at least three years of experience in the PLM space. These professionals were selected as they would be able to provide insight into the barriers that they experienced firsthand when implementing PLM solutions. To analyze the complex relationships between barriers, the decision-making technique **decision-making trial and evaluation laboratory (DEMATEL)** method supplemented by the **maximum mean de-entropy (MMDE)** algorithm was used. The gathered data and findings are discussed in section 4 of this study. A map of the study can be seen in figure 3.

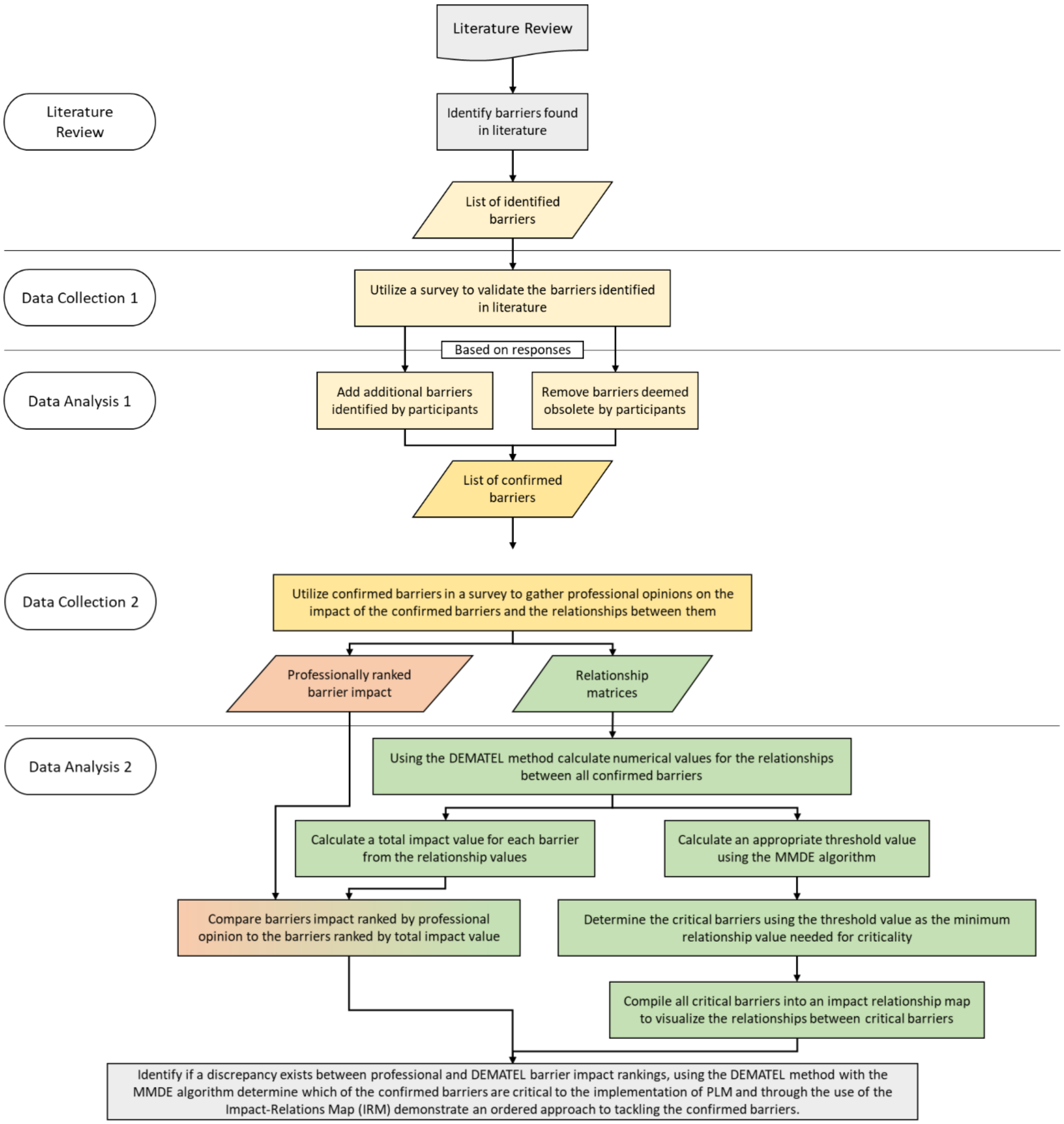

Figure 3. Study Map

3.1 Review of Barriers Identified in Literature

To identify barriers to the implementation of Product Lifecycle Management Solutions, academic journals were explored. The literature review resulted in the creation of a compiled list of identified barriers containing the following barriers shown in figure 4.

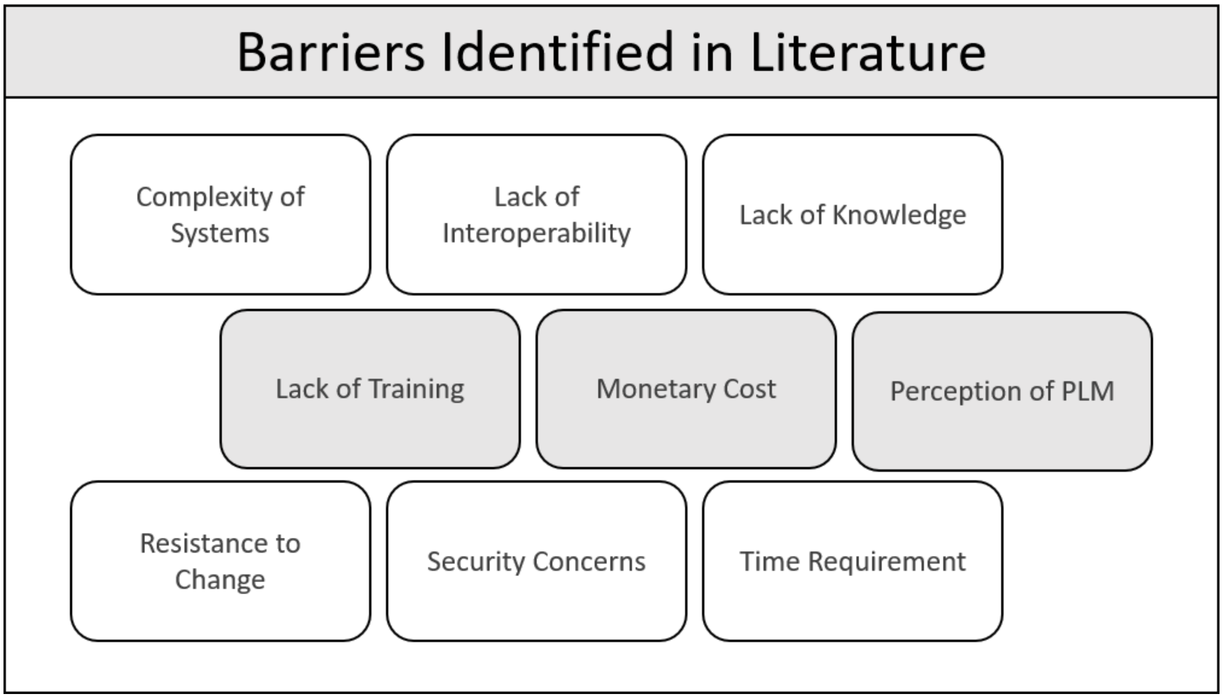

Figure 4. Barriers Identified in Literature

3.2 Collection of Data

The data for this study was collected in two separate instances, sources for both instances were professionals with experience in the PLM space. All survey responses were anonymous, and all survey questions can be seen in appendices A & B. The first instance was a survey to confirm the existence of the barriers that were identified within the literature review and was analyzed to revise the list of barriers by removing those barriers which professionals did not believe were present, or add additional barriers identified by the participants. The second instance utilized a survey built off of the revised list of barriers to determine how professionals ranked the impact of the confirmed barriers and to obtain an average initial relationship matrix on the influences each barrier exerts or receives. The inputs for the matrix require each barrier's influence on all other barriers to be measured on a Likert scale with a range of 0 meaning no causal relationship to 4 meaning a very high causal relationship and 2 meaning an average causal relationship.

3.3 Participant Description

For this study, professionals within the PLM space were contacted via email, LinkedIn and professional networks and asked for their voluntary participation. This included professionals with roles such as PLM consultant, PLM manager, PLM specialist, PLM engineer and PLM architect. These professionals that were contacted came from companies large and small that either utilize PLM in house, and or help other companies to implement PLM solutions. This included companies such as Lockheed-Martin, Rolls-Royce, Woodward, Razorleaf, Siemens, etc. To allow for the inclusion of professionals in smaller companies all participants were also asked to extend an invitation to participate to other professionals they believed would enhance the study. To have their responses included in this study professionals were required to have at least three years of experience in the PLM space and have participated in at least one PLM implementation project. To have participated in a PLM implementation project a participant had to be an active participant in the tasks during the implementation project. However, it is important to note that no one person can be a participant in every task during an implementation project. These tasks could take the form of having worked in laying out the groundwork for the solution such as determining where a company is on their PLM competency, the requirements to achieve a successful solution, the development of an implementation strategy to achieve company KPIs and determining which of the many PLM systems would work best for a solution. Participation can also take the form of solution configuration or development, where the participant has participated in the integration or modification of the systems that will be used to support the PLM solution. Finally, participation can also be the development or application of solution training resources to integrate the users that were not part of the implementation process. These requirements were selected as participants would be able to provide insight into the barriers that they experienced throughout an implementation project.

3.4 DEMATEL

This study utilizes the DEMATEL (Decision Making Trial and Evaluation Laboratory) method, developed by Fontela and Gabus with the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976. This method is used to analyze the cause-and-effect relationships between intertwined and often complicated elements within a collection (Chung-Wei & Gwo-Hshiung, 2009; Singh & Misra, 2019). According to Chung-Wei and Gwo-Hshiung (2009) "The most important property of the DEMATEL method used in the multi-criteria decision making (MCDM) field is to construct interrelations between criteria. The end product of the DEMATEL process the impact-relations map". There are five steps in the DEMATEL method, seen in figure 5:

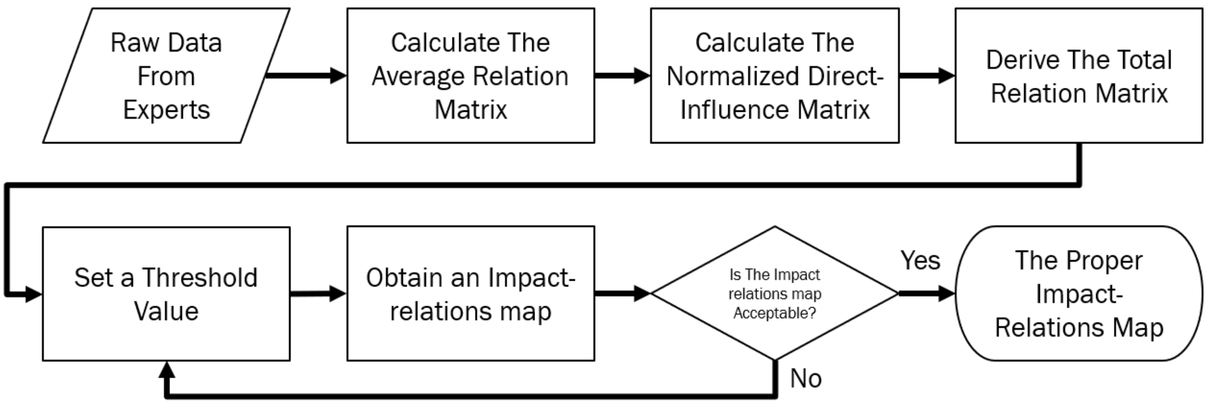

Figure 5. Steps of The DEMATEL Method

1. **Calculate initial relation matrix and the average matrix.**

After a list of the confirmed barriers to the implementation of PLM is created from the initial survey each participant in the second survey is tasked with creating an initial relation matrix. The initial relationship matrix is used to gather the relationship values between each confirmed barrier.

In the initial relation matrix given by Equation (1), the diagonal values are left blank or considered to be zero. The number of initial matrices will be equal to the number of study participants.

$$X^k = \left[x_{ij}^k\right] tXt \tag{1}$$

where k equals the number of respondents, $1 \leq k \leq U$; t is the number of factors considered and U is the number of initial matrices corresponding to each participant. The average matrix given by

Equation (2) needs to be calculated by taking averaged of all participants initial matrices resulting in the creation of the average matrix:

$$N \ = \left[n_{ij}\right] tXt \tag{2}$$

In which:

$$n_{ij} = \frac{1}{U}\sum_{k=1}^{U} x_{ij}^{k}$$

2. **Calculate the normalized direct relation matrix.**

The normalization of the average direct relation matrix is to be performed by utilizing the normalization factor given by Equation (3)

$$s = Min\left[\frac{1}{max_{1\leq i\leq n}\sum_{j=1}^{n}\left|n_{ij}\right|}, \frac{1}{max_{1\leq j\leq n}\sum_{j=1}^{n}\left|n_{ij}\right|}\right] \tag{3}$$

Then the normalized direct relation matrix (DR) can be calculated using Equation (4):

$$DR = s * N \tag{4}$$

3. **Calculate the total relation matrix.**

T represents the total relation matrix expressing all direct and indirect relation. To calculate T Equation (5) is used:

$$T = \lim_{k\to\infty}(DR + DR^2 + D^{R3} + \cdots + DR^k) = DR(I - DR)^{-1} \tag{5}$$

Where *I* is the identity matrix:

4. **Calculate the sum of elements in each row and column in total relation matrix (*T*)**

To calculate the sum of elements Equations (6 & 7) are used where W_j is the sum of the elements in the *i*th row and V_j is the sum of the elements in the *j*th column:

$$W_i = \sum_{j=1}^{t} m_{ij} = (i = 1, 2, \dots, t) \tag{6}$$

$$V_j = \sum_{i=1}^{t} m_{ij} = (j = 1, 2, \dots, t) \tag{7}$$

The values of V_j and W_i represent both the direct and indirect influences between the factors. Here, $(V + W)$ is calculated as the impact or prominence and $(W - V)$ as the relationship value. Positive values of $W - V$ represent the corresponding factor as causal factor, while the negative values of $W - V$ represent the corresponding factor as affected factor. These dependencies are visible on the inter-relationship map (IRM).

5. **Calculate threshold value**

The Total relation matrix *T* depicts the causal relationships between different critical barriers. Although there are many relations, only the profoundly correlated barriers need be considered, and less correlated barriers filtered out. A threshold value is used to filter the significant relations and help a decision maker to focus on the significant impacts which will be shown in the IRM. The threshold value (TV) is to be calculated by using the maximum mean de-entropy (MMDE) algorithm.

Following the DEMATEL method as described by the Fontela and Gabus the threshold value is determined by the researcher or by asking experts. This can present a problem when small changes to the threshold value produce a small change in the inter-relation map making the defining of the ideal threshold value difficult and time consuming (Chung-Wei & Gwo-Hshiung, 2009; Singh & Misra, 2019). Other studies utilizing the DEMATEL method use a simple average of the total relationship matrix or the results of a targeted literature review to determine the proper threshold value. While these approaches may provide a threshold value, they also introduce a great degree of variability. This study utilizes the MMDE algorithm to address this issue.

3.5 MMDE

The MMDE algorithm is based on the mathematical theory proposed by Shannon (2001) which was used by Li and Tzeng (2009) and Singh and Misra (2019).

Information Entropy

Entropy is normally associated with a physical measurement in thermal dynamics but has becoming an important part of information theory in social sciences. In this theory developed by Shannon (2001), Chung-Wei and Gwo-Hshiung (2009) state “entropy is used to measure the expected information content of certain messages and is a criterion for the amount of "uncertainty" represented by a discrete probability distribution”. This means that the amount of information contained in an event can be calculated, and in general the more predictable the outcome of an event is the less information is contained in that event. Resulting in the most information begin found where the uncertainty or difference between expected outcome and actual outcome is the greatest. The mathematical definitions described by these researchers are briefed below:

Definition 1: Let a random variable with n elements be denoted as $X = \{x_1, x_2, ..., x_n\}$, with a corresponding probability $P = \{p_1, p_2, ..., p_n\}$, then we define the entropy, H, of X as follows:

$$H(p_1, p_2, \dots, p_n) = -\sum p_i \log(p_i)$$

Subject to constraints:

$$\sum_{i=1}^{n} p_i = 1$$

$$p_i \log(p_i) = 0 \; if \; p_i = 0$$

By Definition, the value pf $H(p_1, p_2, \dots, p_n)$ is largest when $p_1 = p_2 = \dots = p_n$ and we denote this largest entropy as $H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}\right)$. Now we will define another measure for the decreased level of entropy: de-entropy.

$$H_{max} = H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}\right)$$

Definition 2: De-entropy, which is the decreased level of entropy, provides an estimate of the position of the node from the maximum entropy condition. The de-entropy of a discrete random variable *Z* with *n* elements is usually denoted by the symbol H^D and is defined as follows:

$$H^D = H_{max} - H = H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}\right) - H(p_1, p_2, \dots, p_n)$$

Mathematical denotations

Let us denote by g_{ij} the (i, j) element of the total relation matrix T, which shows the relation between the factors y_i and y_j. The relation matrix T can then be considered as a set having t^2 pair ordered elements. For each element g_{ij}, of the matrix T, the factors y_i and y_j are defined as dispatch node and receive node, respectively. While $C(T^{Di})$ and $C(T^{Re})$ represent the number of variables in the dispatch node set and receive node set. Moreover, $U(T^{Di})$ and $U(T^{Re})$ represent the unique number of variables in the dispatch node set and the receive node set, respectively.

Following the definitions given above and the calculated total relation matrix found using the DEMATEL method, the MMDE algorithm can be applied to calculate the proper threshold using the following steps, seen in figure 6:

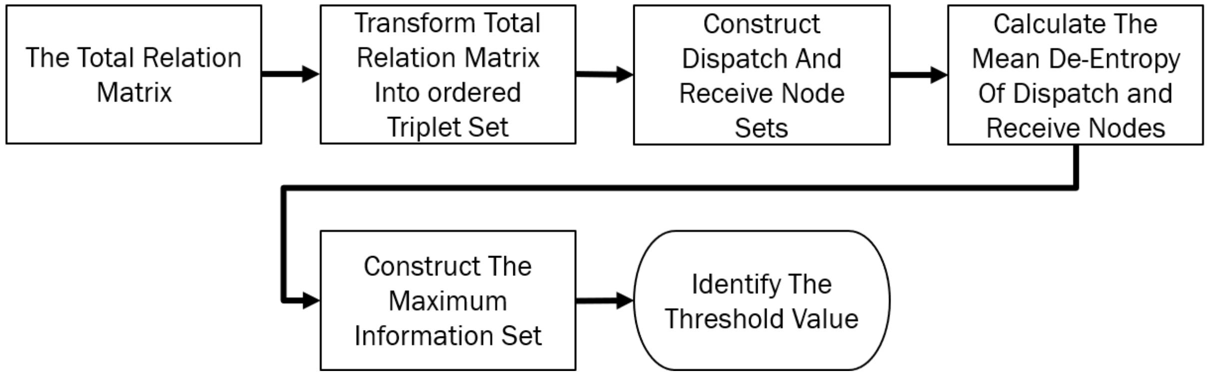

Figure 6. Steps of The MMDE Algorithm

1. **Transformation of relation matrix to an ordered triplet set T^***

This step converts the total relation matrix T into an ordered set of total relation matrix elements from larger to smaller values with their corresponding dispatch node and receive node and rearranged as set $T^* = (g_{ij}, y_i, y_j)$.

2. **Construction of the dispatch-node set (T^{Di}) and receive-node set (T^{Re})**

The second element of the set T^* is the dispatch node value, and the third element of the $T^*$is the received node value. Taking all the dispatch node values together, we have an ordered the receive node values, i.e., third element values from T^*, we have the ordered receive node dispatch node set, denoted by $T^{Di} = (y_i) = (y_1, y_2, \dots, y_n)$. Similarly, considering together set, which we denote by $T^{Re} = (y_i) = (y_1, y_2, \dots, y_n)$.

3. **Calculation of the mean de-entropy of dispatch node and receive node**

Taking the first r values at a time, we can form sets T_r^{Di} and T_r^{Re} and the mean
de-entropy for the first r sets of dispatch nodes or receive nodes can be presented as:

$$MDE_r = \frac{H_r}{U(T_r)}$$

4. **Determination of T_{max}^{Di} and T_{max}^{Re} using MMDE algorithm**

Next, we find the maximum value of MDE_r^{Di} and MDE_r^{Re} and the corresponding sets T_r^{Di} and T_r^{Re} denoted by T_{max}^{Di} and T_{max}^{Re}:

$$T_{max}^{Di} = \max\left(MDE_r^{Di}\right) = (y_1, y_2, \dots, y_r^{max})$$

$$T_{max}^{Re} = \max(MDE_r^{Re}) = (y_1, y_2, \dots, y_r^{max})$$

5. **Construction of the maximum information set and identification of the threshold value.**

Here, we consider the first t elements in T^* to obtain the subset, T^{Th}, which includes all elements of T_{max}^{Di} and all elements of T_{max}^{Re}. The minimum relation value in T^{Th} decides the threshold value. This procedure can be summarized by writing:

$$T^{Th} = \{g_{ij}, T_{max}^{Di}(y_i), T_{max}^{Re}(y_j)\}$$

The relation values above this threshold value show the most impactful relations among all possible relations among all factors. This information entropy method filters out the genuine relations to be critically considered.

4 DATA ANALYSIS

This section analyzes the input of professionals in the PLM space to identify the impact rankings and to establish the strength of the relationships between the confirmed barriers to the implementation of PLM solutions. Employing the DEMATEL method supplemented by the MMDE algorithm to determine which of the barriers are critical.

Responses for this study came from a variety of different sources, with no two responses coming from the same company. The companies that are represented in this study consisted of the following:

- Sustainable Solutions Corporation
- ASSA ABLOY
- Razorleaf Corporation
- Wherry Associates
- Bartech
- Teradyne, Inc.
- SEAKR Engineering
- Ultra-Maritime
- Eaton Aerospace
- Woodward

The participants were not asked to reveal their specific job role, as a combination of workplace and job role could potentially identify a participant in this study.

4.1 Survey 1 - Barrier Confirmation

As outlined in section 3 of this study in the initial barrier confirmation survey a set of two questions were given to participants to act as a way to filter the responses of those who do not meet the experience requirements for this study. In this regard participants were first asked to indicate how many years of experience they have within the PLM space. For the first survey instance ten complete responses were recorded with two incomplete responses. Any incomplete responses were removed from consideration.

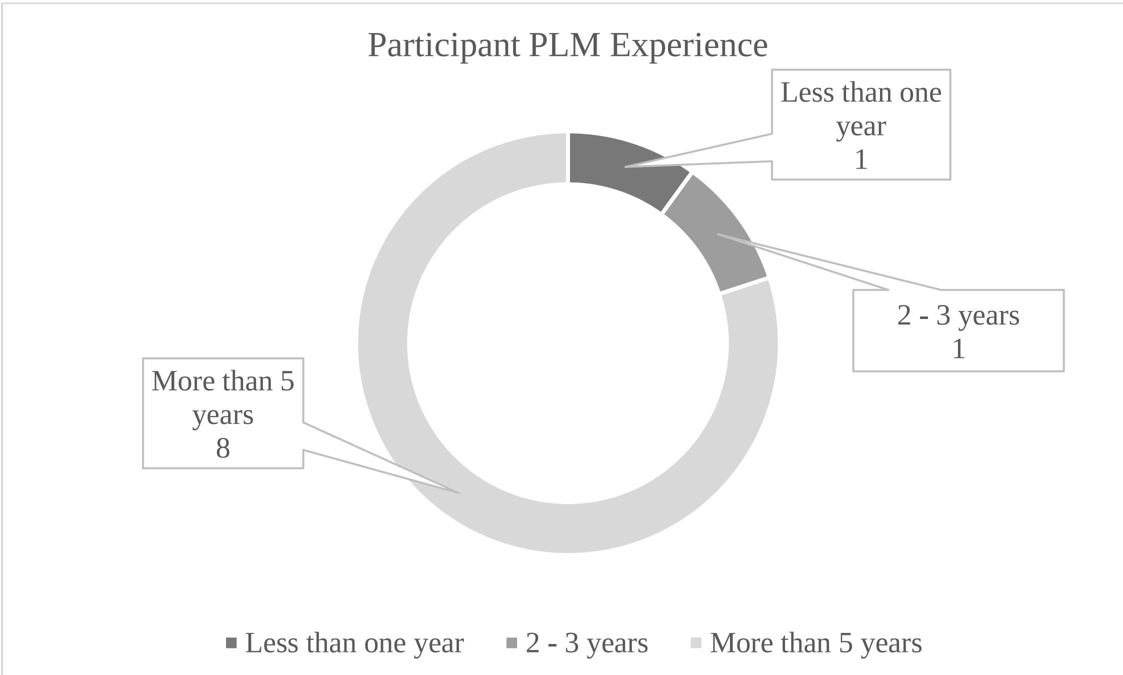

Figure 7. The number of years of experience each participant has in the PLM space.

As seen in figure 7, out of the ten completed responses 8 of the participants indicated that they have had five plus years of experience in the PLM space, with the remaining 2 responses evenly split between less than a year and 2-3 years at 1 each. Participants were then asked to indicate how many PLM implementation projects they have been a part of. As described in section 3.3, a PLM implementation project can be complex and an contain immense organizational changes. To have participated in a PLM implementation project a participant has had to be an active participant in the tasks during the implementation project. However, it is important to that no one person can be a participant in every task during an implementation project. These tasks can take the form of having worked in laying out the groundwork for the solution such as determining where a company is on their PLM competency, the requirements to achieve a successful solution, the development of an implementation strategy to achieve company KPIs and determining which of the many PLM systems would work best for a solution. Participation can also take the form of solution configuration or development, where the participant has participated in the integration or modification of the systems that will be used to support the PLM solution. Finally, participation can also be the development or application of solution training resources to integrate the users that were not part of the implementation process.

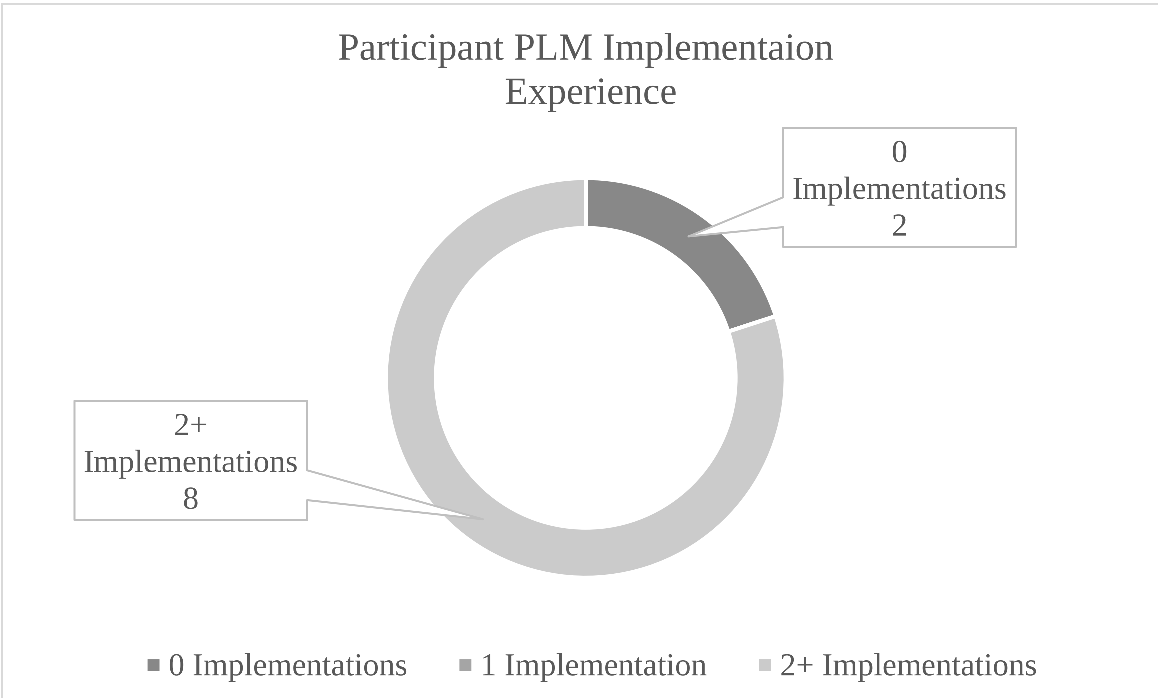

Figure 8. The number of PLM implementations undertaken by participants

As seen in figure 8, out of the ten completed responses 8 of the participants indicated that they have been involved with two or more PLM implementation projects, with the remaining 2 participants having not been involved in any PLM implementation projects. This combination of questions allowed for the filtering of the responses of the participants with little experience in the PLM space and with PLM implementations.

The barriers to PLM implementation that were identified in section 2.4, seen in figure 4, were then presented to the participants, who were asked to confirm or deny if they believed a barrier existed during the PLM implementation process. With the filtering of invalid responses, a total of eight applicable entries were recorded.

Table 1. The number of participants that showed belief regarding each of the identified barriers.

Barrier Confirmation Results					
Barrier	Yes		No		Total
Complexity of Systems	87.50%	7	12.50%	1	8
Lack of Interoperability	50.00%	4	50.00%	4	8
Lack of Knowledge	87.50%	7	12.50%	1	8
Lack of Training	75.00%	6	25.00%	2	8
Monetary Cost	75.00%	6	25.00%	2	8
Perception of PLM	75.00%	6	25.00%	2	8
Resistance to change	75.00%	6	25.00%	2	8
Security Concerns	62.50%	5	37.50%	3	8
Time Requirement	87.50%	7	12.50%	1	8

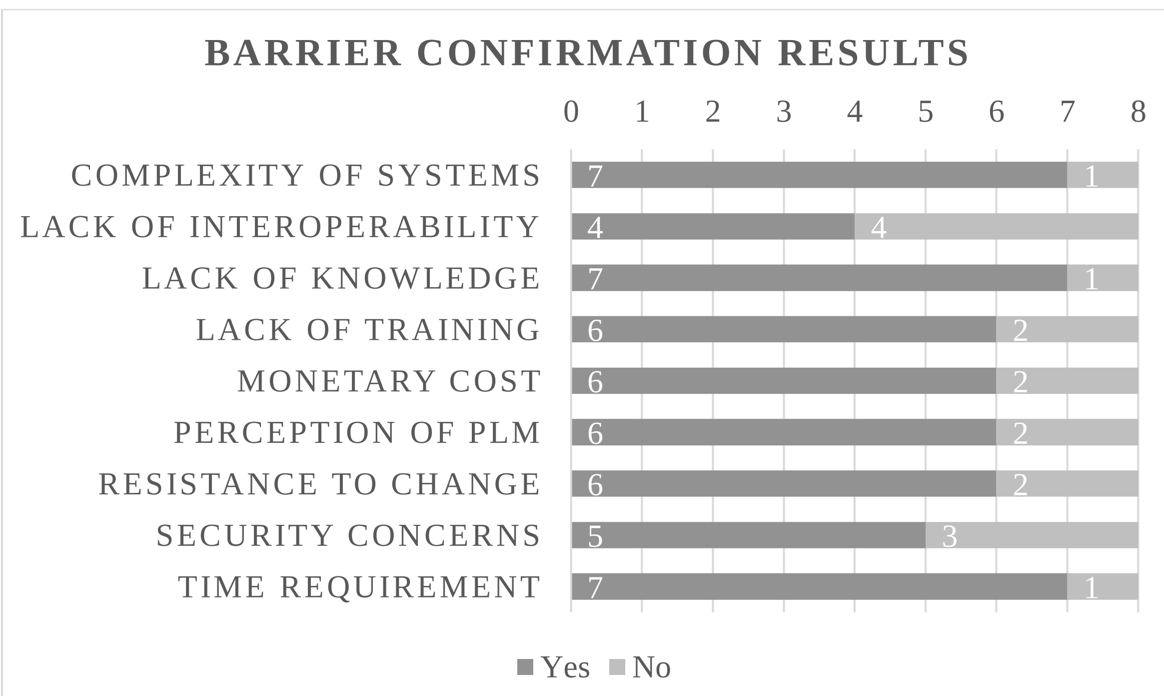

Figure 9. The number of participants that showed belief regarding each of the identified barriers.

As shown in Table 1 & Figure 9 participants clearly agreed that eight of the nine barriers identified in the literature are present in PLM implementations. However, the participants were evenly split on whether the barrier Lack of Interoperability was present during PLM implementation. Due to the lack of a consensus confirming that the barrier Lack of Interoperability exists, it was removed from the subsequent impact and relationship survey.

Finally, to allow for the identification and addition of barriers not outlined in section 2.4, participants were asked to identify any barriers to implementation they believed were not covered within the original survey. These responses were weighted as to only require participants to separately identify the same barrier in at least three times for its inclusion in the confirmed list of barriers. This was done as the question exploring additional barriers could be considered optional when compared to the other questions in the survey and the likelihood that a participant would provide an answer was therefore lower. Out of eight total responses, there were five unique responses to this question seen below:

- Lack of Consistency (for goals/scope, units, etc. between business-to-business requests for PLM).
- Lack definition of current business process.
- Lack of organizational change management (OCM) awareness by leadership, Fuzzy savings of productivity or error reduction, Lack of maturity/completeness of existing PLM systems, Underestimation of the magnitude of change required.
- I have seen with SAP implementation, that there is a real concern with the amount of customization necessary to make boxed software meet the needs / goals of a company.
- Configuration complexity Alignment on process enablement features/customization for a single PLM system supporting multiple lines of business.

These responses were grouped into two sets of three highlighting the need for two additional barriers to implementation seen below:

1. An organization's lack of knowledge of their own business practices
2. The complexity of the configuration required to support a PLM solution.

To accommodate the addition of a second knowledge-based barrier the barrier Lack of Knowledge was split into two different barriers called Lack of Knowledge on PLM Solutions and Lack of Knowledge on Current Business Practices. Similarly, the barrier Complexity of Required Configuration was distinguished from the barrier Complexity of Systems.

4.2 Survey 2 - Barrier Impact & Relationships

This section analyses the responses provided by participants in the secondary survey regarding which of the identified barriers they believe are the most impactful to the implementation of PLM solutions. The participants for this survey consisted of the 8 participants that met the requirements to participate in this study. Participants were given a list of the 10 barriers confirmed in section 4.2 and were asked to order them from 1 to 10 where 1 is most impactful and 10 is least impactful. A total of seven complete responses were recorded for this question, the resulting ranked list can be seen in Table 2.

Table 2. Averaged barrier impact ranking from most impactful to least impactful.

	Barrier Impact Rankings	
Rank	Barrier	Average Rank
1	Resistance to Change	3.14
2	Lack of Knowledge on PLM solutions	4
3	Complexity of Required Configuration	4.14
4	Lack of Knowledge on Current Business Practices	4.86
5	Complexity of Systems	5.14
6	Time Requirement	5.43
7	Lack of Training	5.71
8	Monetary Cost	6.29
9	Perception of PLM	6.71
10	Security Concerns	9.57

As shown in Table 2 the barrier Resistance to Change received the highest average impact ranking indicating that it is the barrier with the most impact on a PLM implementation project.

However, the first nine barriers all remaining relatively close to the barriers directly adjacent, less than the equivalent of one ranking position away. indicating there is not a clear consensus on where the impact of each barrier should be relative to the others. The only barrier that breaks this pattern by over 1 ranking position is Security Concerns, which received the lowest average impact ranking indicating that it is the barrier with the lowest impact on a PLM implementation project. The lack of consensus on the impact of the identified barriers is clarified when the barriers are sorted by standard deviation and variance as shown in Table 3.

Table 3. Barrier impact ranked by standard deviation and variance

Barrier Impact Ranked by Standard Deviation and Variance					
Barrier	**Minimum**	**Maximum**	**Mean**	**Std Deviation**	**Variance**
Time Requirement	1	10	5.43	3.42	11.67
Complexity of Systems	1	9	5.14	3.04	9.27
Lack of Knowledge on PLM solutions	1	9	4	2.78	7.71
Monetary Cost	2	10	6.29	2.55	6.49
Perception of PLM	2	9	6.71	2.12	4.49
Lack of Knowledge on Current Business Practices	2	8	4.86	2.03	4.12
Lack of Training	2	8	5.71	1.98	3.92
Complexity of Required Configuration	2	7	4.14	1.64	2.69
Resistance to Change	1	6	3.14	1.64	2.69
Security Concerns	8	10	9.57	0.73	0.53

Analyzing Table 3, it can be seen that nine of the ten barriers have a standard deviation over 1.00 indicating that the responses gathered have a very high level of variance and cannot be considered a reliable way to determine which barriers are most impactful and by extension cannot be adequately accounted for when implementing a PLM solution. These nine barriers also directly align to the nine barriers that fell within 1 ranked position of the barriers adjacent shown in Table 2. The uncertainty is exemplified by nine of the ten identified barriers ranking in the top two at least once while five of the nine were also ranked in the bottom two.

The only identified barrier to receive a standard deviation below 1.00, indicating a stronger agreement between the participants was Security Concerns. This aligns with the finding that the Security Concerns was the only barrier to be ranked more than 1 ranked position from the barrier adjacent. This confidence on the level of impact can also draws parallels in how Security Concerns was only confirmed to exist as a barrier by 62.5% of participants as seen in Table 1 & Figure 6.

Participants were also asked to indicate if there were still barriers that they believed were not covered in this survey. There were three responses to this question, but there was no consensus between the responses on any additional barriers. Each response mentioned different barriers such as, a sense of ownership, a general lack of leadership, or a when a change in leadership / acquisition of a company happens mid implementation. These responses can be seen below:

- An identified system admin. A sense of ownership of the PLM system.
- Lack of leadership support, reluctance to support a business case, attempting too large a transformation at once, poor legacy data quality, lack of a process culture
- Change in Leadership / Culture, Acquisitions of new companies or manufacturing sites

To combat the uncertainty surrounding impact that the identified barriers exert, a different approach is needed. This study utilized the DEMATEL method supported by the MMDE algorithm as a way to accurately consider the cause-and-effect relationships between barriers to determine the total impact a barrier presents and a determination of which relationships between barriers are critically impactful to the implementation of PLM.

4.3 Determination of Critical Barriers

This section analyses the relationship matrices obtained from professionals in the PLM space. A total of 5 complete matrices were recorded, with two participants not completing their respective relationship matrices, resulting in them being removed from subsequent calculations. The following procedures are outlined in section 3.4 to section 3.6. All calculations were performed in Microsoft Excel software. All participants’ matrices can be found in the appendix.

The average relationship matrix which is the average of all initial relationship matrices was calculated following step 1 of the DEMATEL method discussed in section 3.4. The calculated average relationship matrix is shown in Table 4.

Table 4. Average Relationship Matrix

Average Relationship Matrix (Direct Relationship Matrix)										
Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0	3.2	2.4	2.4	2.6	3.2	3.2	1.4	2.4	1.4
B2	2.2	0	2.4	2.6	3.2	3.2	2.4	1	4.2	1.6
B3	1.6	1.4	0	2.2	1.4	3	3.2	1.2	2.6	1.2
B4	1.4	1.8	2	0	1.8	3.2	3.8	1.2	2.6	1.4
B5	1.6	2	1	2	0	2.6	2.6	0.8	0.6	0.8
B6	1.6	1.4	2	1.4	0.8	0	3.4	1	1	1
B7	1.6	2.6	1.8	2	1.6	3.2	0	1	2.2	1.6
B8	1.8	2	0.8	0.8	1.4	2.4	1.8	0	1.4	1
B9	1.6	2	2.4	2.6	2.2	2.6	2.8	1	0	2
B10	2	2.6	1.2	1.6	2.8	2.2	3	1.6	3	0

The average relationship matrix was then normalized. The value of the normalization factor obtained using step 2 of the DEMATEL method, was found to be 0.043859649, and the normalized direct relationship matrix is shown in Table 5.

Table 5. Normalized Direct Relationship Matrix (DR)

Normalized Direct Relationship Matrix (DR)										
Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.0000	0.1404	0.1053	0.1053	0.1140	0.1404	0.1404	0.0614	0.1053	0.0614
B2	0.0965	0.0000	0.1053	0.1140	0.1404	0.1404	0.1053	0.0439	0.1842	0.0702
B3	0.0702	0.0614	0.0000	0.0965	0.0614	0.1316	0.1404	0.0526	0.1140	0.0526
B4	0.0614	0.0789	0.0877	0.0000	0.0789	0.1404	0.1667	0.0526	0.1140	0.0614
B5	0.0702	0.0877	0.0439	0.0877	0.0000	0.1140	0.1140	0.0351	0.0263	0.0351
B6	0.0702	0.0614	0.0877	0.0614	0.0351	0.0000	0.1491	0.0439	0.0439	0.0439
B7	0.0702	0.1140	0.0789	0.0877	0.0702	0.1404	0.0000	0.0439	0.0965	0.0702
B8	0.0789	0.0877	0.0351	0.0351	0.0614	0.1053	0.0789	0.0000	0.0614	0.0439
B9	0.0702	0.0877	0.1053	0.1140	0.0965	0.1140	0.1228	0.0439	0.0000	0.0877
B10	0.0877	0.1140	0.0526	0.0702	0.1228	0.0965	0.1316	0.0702	0.1316	0.0000

Using the normalized direct relationship matrix, the total relationship matrix was calculated following step 3 of the DEMATEL method in section 3.4 and is shown in Table 6.

Table 6. Total Relationship Matrix (T)

Total Relationship Matrix (T)										
Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.3098	0.4992	0.4332	0.4578	0.4506	0.6299	0.6404	0.2639	0.4896	0.3093
B2	0.4033	0.3818	0.4407	0.4741	0.4799	0.6391	0.6242	0.2530	0.5602	0.3229
B3	0.3149	0.3608	0.2733	0.3798	0.3363	0.5254	0.5429	0.2170	0.4192	0.2542
B4	0.3252	0.3969	0.3724	0.3122	0.3711	0.5611	0.5929	0.2284	0.4414	0.2760
B5	0.2667	0.3246	0.2623	0.3150	0.2249	0.4321	0.4391	0.1685	0.2836	0.1973
B6	0.2632	0.2990	0.2964	0.2889	0.2562	0.3243	0.4619	0.1747	0.2964	0.2036
B7	0.3165	0.4051	0.3472	0.3734	0.3473	0.5327	0.4191	0.2097	0.4078	0.2692
B8	0.2668	0.3152	0.2449	0.2594	0.2750	0.4092	0.3929	0.1288	0.3022	0.1985
B9	0.3357	0.4076	0.3893	0.4186	0.3912	0.5436	0.5623	0.2233	0.3441	0.3001
B10	0.3630	0.4460	0.3563	0.3953	0.4296	0.5463	0.5843	0.2532	0.4750	0.2294

With the total relationship matrix established, using the rows of the total relationship matrix to indicate the causal strength and the columns to indicate the effect strength. The total impact (also known as the prominence value) and the relationship value of each barrier can be calculated following step 4 of the DEMATEL method in section 3.4. The impact or prominence is calculated as the combined strength of the cause-and-effect relationships a specific barrier exerts and receives respectively. The relationship value is the difference between the cause-and-effect relationships and is used to determine if a barrier is causal and exerts more influence than it receives or an effected barrier that receives more influence than it exerts.

Table 7. The differences between barrier total impact and relationship value

Total Impact and Relationship Value					
Barrier	Sum of Row (W)	Sum of Column (V)	W + V Total Impact	W - V Relationship Value	Identity
Resistance to Change	3.6281	5.2602	8.8883	-1.6321	Effect
Complexity of Required Configuration	4.5792	3.8361	8.4154	0.7431	Cause
Perception of PLM	2.8647	5.1437	8.0084	-2.2790	Effect
Time Requirement	3.9157	4.0196	7.9353	-0.1039	Effect
Complexity of Systems	4.4837	3.1651	7.6488	1.3186	Cause
Lack of Training	3.8776	3.6744	7.5519	0.2032	Cause
Lack of Knowledge Regarding PLM Solutions	3.6239	3.4160	7.0400	0.2079	Cause
Lack of Knowledge on Current Business Practices	4.0784	2.5606	6.6390	1.5178	Cause
Monetary Cost	2.9140	3.5620	6.4760	-0.6480	Effect
Security Concerns	2.7928	2.1204	4.9132	0.6724	Cause

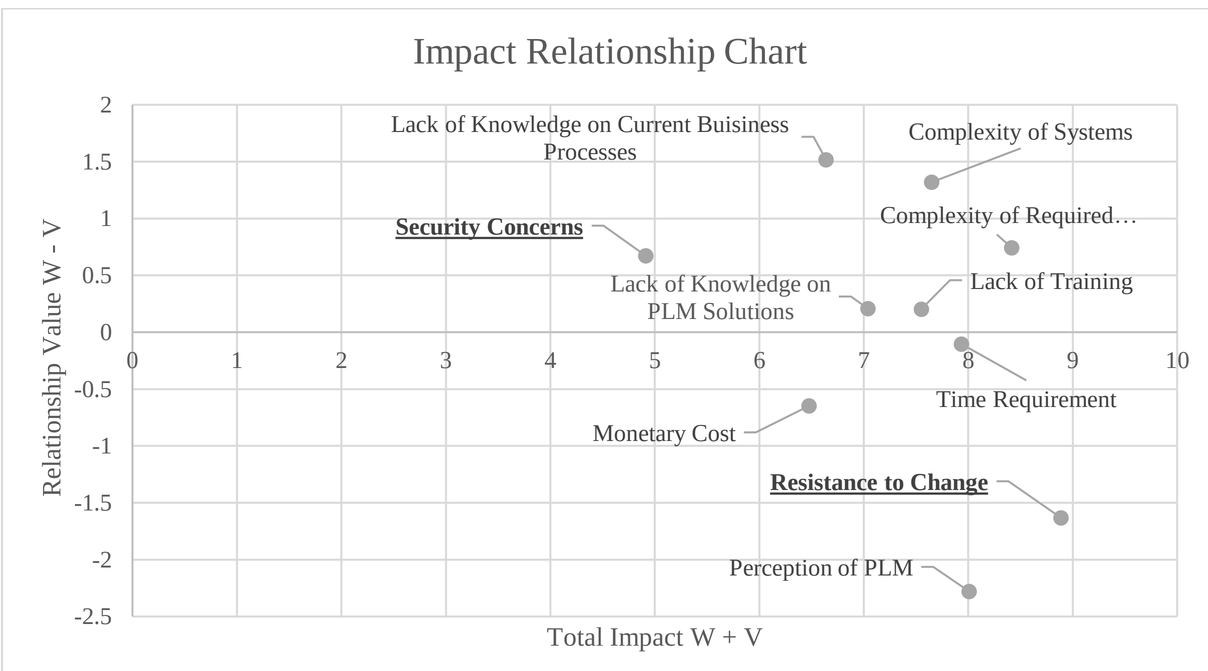

Figure 10. Impact relationship chart showing differences between barrier total impact and relationship value

When reviewing Table 7 and Figure 10, the most impactful or prominent barrier through total impact value was determined to be Resistance to Change, a position that aligns with the ranking given by professions. However as seen by the relationship value, Resistance to Change is an effect barrier that's total impact on PLM implementation is influenced more by other existing barriers than its influence on other barriers indicating that it cannot be solved directly and will have its impact reduced by addressing the barriers that influence it. Conversely the barrier with the second highest total impact value, Complexity of Required Configuration, was determined to be a causal barrier indicating that majority of impact this barrier has on PLM implementation can be addressed without having to first address any of the connected barriers. Matching the sentiment found in Tables 1, 2 and 3, the barrier with the lowest total impact value was determined to be Security Concerns, helping to solidify its position as the least impactful barrier that was confirmed to exist in PLM implementations. Interestingly, three barriers total impact rankings matched their rankings in the impact rankings provided by professionals shown in Table 2. These barriers were Resistance to Change, Complexity of Systems and Security concerns. The barrier largest difference in the impact rankings determined by professionals and those determined using the DEMATEL method was Perception of PLM which jumped from ninth place to third. It can also be seen that three of the top four barriers by total impact value are effect barriers, implying that the barriers with the most impact on the implementation of PLM are not something that can be solved in a vacuum, but without knowing which of the relationships have a critical relationship an effective plan to address the barriers cannot be created.

As shown in Table 6 there is a matrix, containing a set of 100 unique relations among all barriers. These 100 relations may not be equally relevant to the implementation of PLM solutions. Considering this, it is necessary to determine which of these relationships are critical, and by doing so, determine which barriers influence the impact other barriers have on the implementation of PLM solutions. To accomplish as outlined in step 5 in section 3.4, a threshold value is needed.

To calculate the proper threshold value steps, 1 and 2 of the MMDE algorithm discussed in section 3.5 were followed to arrange the total relationship matrix relationship values from largest to smallest with a corresponding dispatch and receive node. This set of ordered triplets is shown in Table 8.

Table 8. Ordered Triplet sets of total relationship matrix relationship values

Ordered Triplet Sets of total relationship matrix elements (T*)											
Di	Re	Value	Di	Re	Value	Di	Re	Value	Di	Re	Value
1	7	0.640443	5	7	0.43911	7	5	0.347314	3	3	0.273271
2	6	0.639077	1	3	0.433223	7	3	0.347171	7	10	0.269177
1	6	0.629869	5	6	0.432123	9	9	0.344134	8	1	0.26684
2	7	0.624215	10	5	0.429605	3	5	0.336258	5	1	0.266671
4	7	0.592924	3	9	0.41919	9	1	0.335685	1	8	0.263917
10	7	0.584325	7	7	0.419133	4	1	0.325242	6	1	0.263176
9	7	0.562275	9	4	0.41857	5	2	0.324604	5	3	0.262308
4	6	0.561061	8	6	0.40924	6	6	0.324336	8	4	0.259366
2	9	0.560228	7	9	0.407846	2	10	0.322949	6	5	0.256202
10	6	0.546342	9	2	0.407593	7	1	0.316513	3	10	0.25423
9	6	0.543559	7	2	0.405095	8	2	0.315176	10	8	0.253178
3	7	0.54295	2	1	0.403312	5	4	0.314986	2	8	0.252996
7	6	0.532708	4	2	0.396945	3	1	0.314915	8	3	0.244857
3	6	0.525414	10	4	0.395261	4	4	0.312162	10	10	0.229422
1	2	0.499173	8	7	0.392943	1	1	0.309767	4	8	0.228401
1	9	0.489609	9	5	0.391229	1	10	0.309269	5	5	0.224856
2	5	0.479895	9	3	0.389304	8	9	0.302175	9	8	0.223253
10	9	0.475027	2	2	0.381777	9	10	0.30013	3	8	0.21705
2	4	0.47407	3	4	0.379802	6	2	0.298961	7	8	0.2097
6	7	0.461863	7	4	0.373429	6	9	0.296442	6	10	0.203635
1	4	0.457776	4	3	0.372422	6	3	0.296439	8	10	0.198501
1	5	0.450633	4	5	0.371061	6	4	0.28893	5	10	0.197308
10	2	0.445967	10	1	0.362966	5	9	0.28356	6	8	0.174705
4	9	0.441381	3	2	0.360842	4	10	0.275971	5	8	0.168468
2	3	0.440723	10	3	0.356314	8	5	0.274954	8	8	0.128761

Then, following step 3 of the MMDE algorithm in section 3.5, the mean de-entropies of the dispatch node set and the receive node set were calculated by taking the first r values at a time, the value of r varies from 1 to 100 as there are 100 relations in the total relationship matrix. Accordingly, the mean de-entropies for the first r values of the dispatch and receive nodes sets have been obtained and shown in Table 9 & 10.

Table 9. Mean de-entropy for dispatch node set

Mean De-Entropy Dispatch Node Set ()							
Number of elements	Mean de-entropy	Number of elements	Mean de-entropy	Number of elements	Mean de-entropy	Number of elements	Mean de-entropy
1	0.00000	26	0.02364	51	0.01348	76	0.00225
2	0.00000	27	0.02602	52	0.01366	77	0.00236
3	0.02832	28	0.02219	53	0.01381	78	0.00189
4	0.00000	29	0.02277	54	0.01360	79	0.00141
5	0.01456	30	0.02098	55	0.01393	80	0.00162
6	0.01416	31	0.01731	56	0.01396	81	0.00133
7	0.01192	32	0.01558	57	0.01228	82	0.00104
8	0.00997	33	0.01721	58	0.00971	83	0.00074
9	0.01730	34	0.01582	59	0.01018	84	0.00060
10	0.01046	35	0.01540	60	0.01040	85	0.00060
11	0.00305	36	0.01493	61	0.00877	86	0.00058
12	0.00727	37	0.01608	62	0.00771	87	0.00069
13	0.00872	38	0.01547	63	0.00765	88	0.00050
14	0.00534	39	0.01598	64	0.00779	89	0.00057
15	0.00671	40	0.01311	65	0.00790	90	0.00063
16	0.01035	41	0.01305	66	0.00817	91	0.00042
17	0.01304	42	0.01340	67	0.00709	92	0.00046
18	0.01226	43	0.01441	68	0.00732	93	0.00048
19	0.01560	44	0.01358	69	0.00575	94	0.00049
20	0.01701	45	0.01330	70	0.00468	95	0.00037
21	0.01954	46	0.01298	71	0.00398	96	0.00025
22	0.02271	47	0.01306	72	0.00356	97	0.00011
23	0.02289	48	0.01344	73	0.00285	98	0.00009
24	0.02107	49	0.01301	74	0.00301	99	0.00005
25	0.02314	50	0.01358	75	0.00229	100	0.00000

Table 10. Mean de-entropy for receive node set

Mean De-Entropy Receive Node Set ()							
Number of elements	Mean de-entropy	Number of elements	Mean de-entropy	Number of elements	Mean de-entropy	Number of elements	Mean de-entropy
1	0.00000	26	0.03211	51	0.00891	76	0.00317
2	0.00000	27	0.02592	52	0.00836	77	0.00221
3	0.02832	28	0.02829	53	0.00818	78	0.00198
4	0.00000	29	0.02488	54	0.00796	79	0.00192
5	0.01007	30	0.02435	55	0.00552	80	0.00827
6	0.02832	31	0.02665	56	0.00388	81	0.00837
7	0.04744	32	0.02316	57	0.00395	82	0.00832
8	0.01579	33	0.02507	58	0.00448	83	0.00839
9	0.05391	34	0.02491	59	0.01137	84	0.00831
10	0.05175	35	0.02140	60	0.01046	85	0.00771
11	0.05461	36	0.01932	61	0.01072	86	0.00557
12	0.06006	37	0.02419	62	0.01046	87	0.00407
13	0.06253	38	0.02341	63	0.00988	88	0.00412
14	0.06680	39	0.02178	64	0.00983	89	0.00372
15	0.07576	40	0.02328	65	0.00951	90	0.00264
16	0.05590	41	0.02157	66	0.00667	91	0.00266
17	0.05828	42	0.01887	67	0.00660	92	0.00186
18	0.05123	43	0.01852	68	0.00469	93	0.00128
19	0.05059	44	0.01756	69	0.00498	94	0.00088
20	0.05383	45	0.01714	70	0.00506	95	0.00062
21	0.04458	46	0.01543	71	0.00470	96	0.00049
22	0.03581	47	0.01442	72	0.00473	97	0.00047
23	0.02748	48	0.01049	73	0.00492	98	0.00020
24	0.02553	49	0.01045	74	0.00358	99	0.00005
25	0.02927	50	0.00944	75	0.00338	100	0.00000

Following step 4 of the MMDE algorithm in section 3.5, the maximum mean de-entropy of the dispatch node set was determined to be 0.02831651 as shown in Figure 11, which took the first three values of the dispatch node set with the corresponding dispatch locations {1,2,1} = {1,2}.

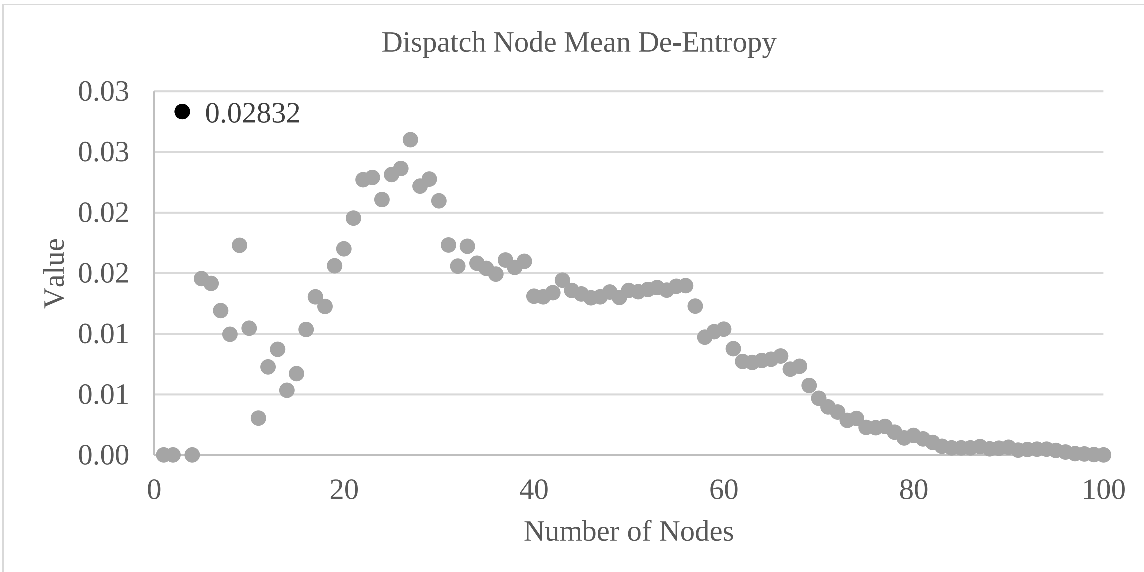

Figure 11. Dispatch Node Mean De-Entropy

Following step 4 of the MMDE, the maximum mean de-entropy of the receive node set was determined to be 0.075759838 as shown in Figure 12, which took the first 15 values of the receive node set with the corresponding receive locations {7,6,6,7,7,7,7,6,9,6,6,7,6,6,2} = {7,6,9,2}.

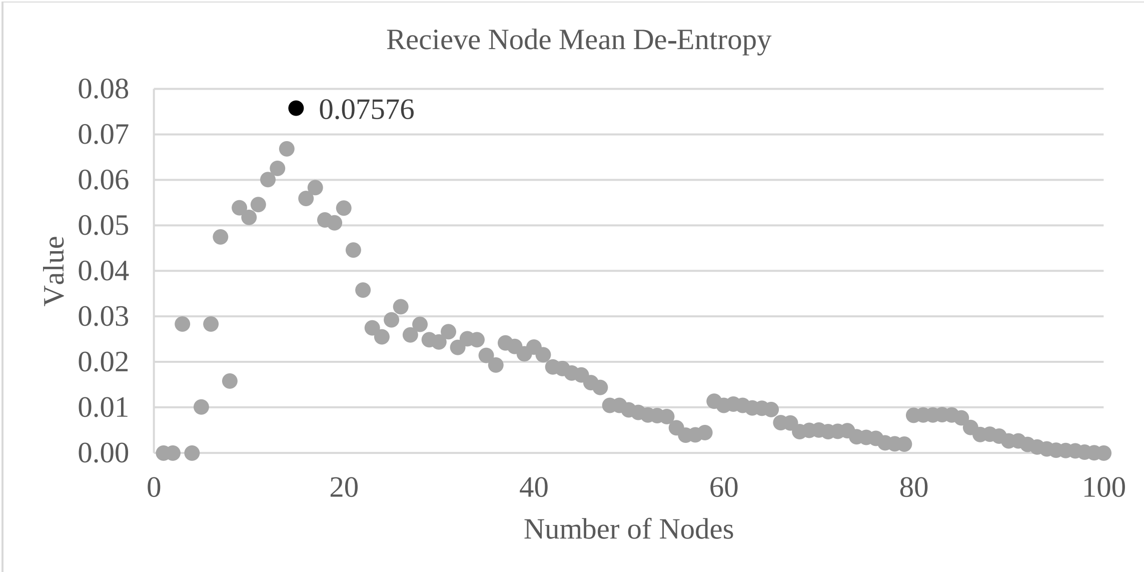

Figure 12. Receive Node Mean De-Entropy

The ordered triplet sets corresponding to the max MDE of the dispatch node sets T_{max}^{Di}: {0.640442833, 1, 7}, {0.63907734, 2, 6}.

The ordered triplet sets corresponding to the max MDE of the receive node sets T_{max}^{Re}: {0.640442833, 1, 7}, {0.63907734, 2, 6}, {0.560228148, 2, 9}, {0.499173222, 1, 2}.

The maximum information set T^{Th}: {0.640442833, 1, 7}, {0.63907734, 2, 6}, {0.560228148, 2, 9}, {0.499173222, 1, 2}.

The threshold value, which is the minimum relationship value of the T^{Th} set was determined to be 0.499173222. Relationship values above the threshold value contain critical information and can be seen in the Table 11.

Table 11. Total Relationship matrix with critical relationships highlighted

Total Relationship Matrix with Critical Relationships										
Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.3098	0.4992	0.4332	0.4578	0.4506	**0.6299**	**0.6404**	0.2639	0.4896	0.3093
B2	0.4033	0.3818	0.4407	0.4741	0.4799	**0.6391**	**0.6242**	0.2530	**0.5602**	0.3229
B3	0.3149	0.3608	0.2733	0.3798	0.3363	**0.5254**	**0.5429**	0.2170	0.4192	0.2542
B4	0.3252	0.3969	0.3724	0.3122	0.3711	**0.5611**	**0.5929**	0.2284	0.4414	0.2760
B5	0.2667	0.3246	0.2623	0.3150	0.2249	0.4321	0.4391	0.1685	0.2836	0.1973
B6	0.2632	0.2990	0.2964	0.2889	0.2562	0.3243	0.4619	0.1747	0.2964	0.2036
B7	0.3165	0.4051	0.3472	0.3734	0.3473	**0.5327**	0.4191	0.2097	0.4078	0.2692
B8	0.2668	0.3152	0.2449	0.2594	0.2750	0.4092	0.3929	0.1288	0.3022	0.1985
B9	0.3357	0.4076	0.3893	0.4186	0.3912	**0.5436**	**0.5623**	0.2233	0.3441	0.3001
B10	0.3630	0.4460	0.3563	0.3953	0.4296	**0.5463**	**0.5843**	0.2532	0.4750	0.2294

The critical relationships were then visualized in Figure 13 to better show the path of influence.

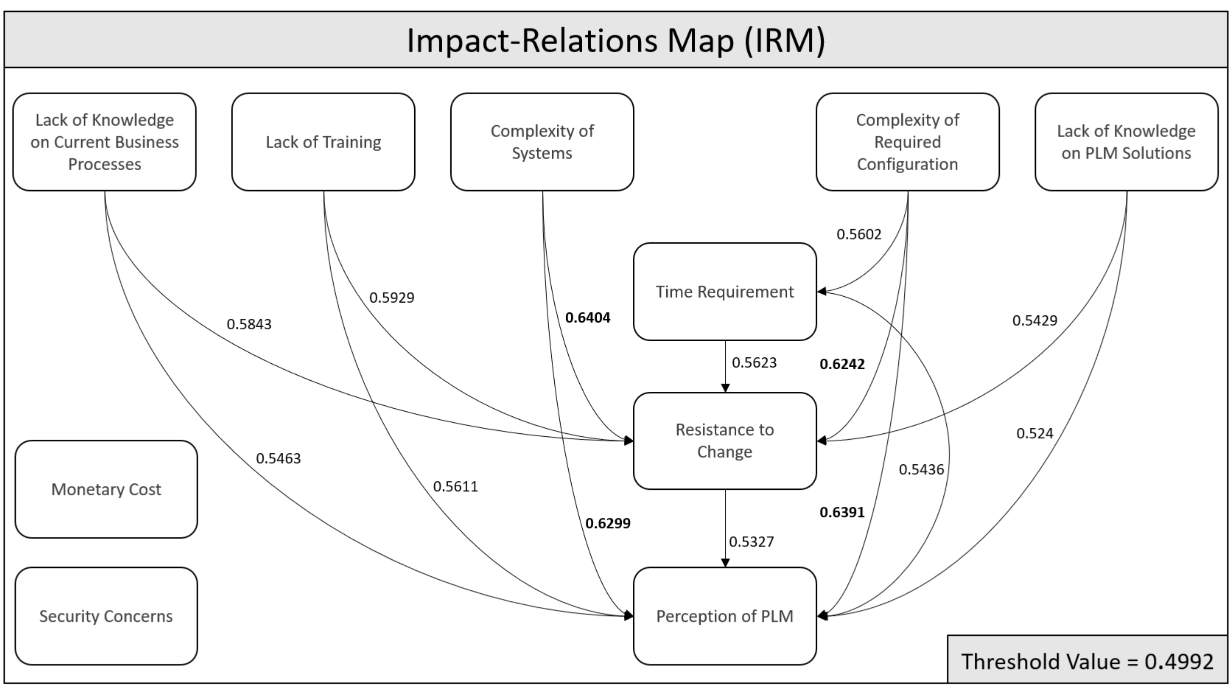

Figure 13. Impact-Relations Map from the DEMATEL method

Analyzing Table 11 and the impact-relations map in Figure 13 the critical relationships between barriers can be identified. From the critical relationships identified, it can be seen that out of the 10 barriers that were confirmed to exist, only 8 have at least one critical relationship, indicating they can be considered important barriers. Barrier criticality, determined using the DEMATEL method, requires an element to be causal and to have at least one critical relationship. Using this definition, five out of the eight important barriers can be considered critical (figure 14). The two barriers that were determined to not have any critical relationships were Monetary Cost and Security Concerns. This indicates that these two barriers cannot be considered important to the implementation of PLM solutions based on the data from this study.

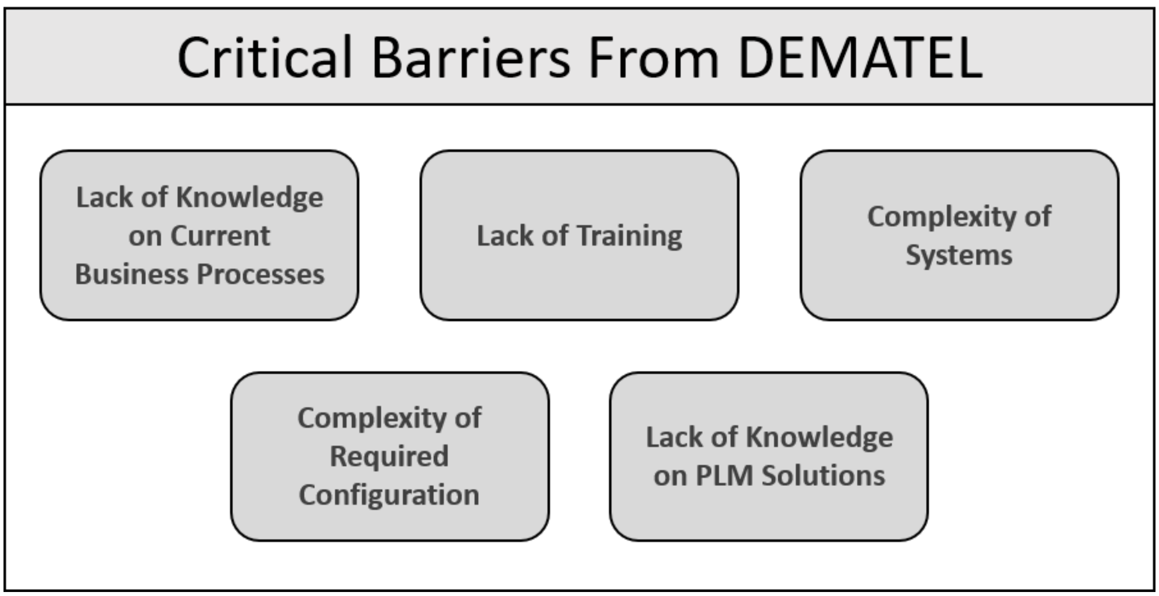

Figure 14. Critical barriers determined from the DEMATEL method

5 DISCUSSION AND CONCLUSION

This section discusses the findings of this study in regard to the research questions outlined in section 1.3. An important aspect of this study to discuss is the participation rate, as the participation rate in this study varied between the two data collection instances and even between questions particularly in the second survey. Recruitment for this study was sent out to industry contacts, professional networks and throughout LinkedIn. Participation in this study was completely voluntary with no direct benefit to any participants. This lack of incentive may have been a contributing factor to the low response rate, as well as a general apathy towards seemingly random survey invitations. The initial survey was sent out to 12 total participants who indicated they were willing to participate in the study. Out of these 12 participants only 10 submitted complete responses to the survey, with the other 2 beginning the survey but not answering any questions. Out of these 10 complete responses only 8 were deemed valid. Interestingly, when accounting for the filler questions the 8 valid participants that have been a part of two or more implementation projects are the same 8 participants that have been involved in the PLM space for five or more years. The secondary survey was sent to the remaining 8 participants, where 7 responses for the first question, investigating the impact ranking of barriers was recorded. The second question in which participants were asked to fill out a relationship matrix recorded 5 complete responses, this reduction in participation may be due to the seemingly complicated nature of a relationship matrix. In another form the matrix would consist of 100 different questions, each explicitly defined. However, this approach would have resulted in a much longer survey that may have caused the same reduction in responses, due to length. This variable response rate could potentially result in an unbalanced comparison, and an incorrect conclusion.

An important area to consider, which was not defined in the literature surrounding the implementation of PLM solutions, is the number of professionals normally utilized during the planning and implementation of a PLM solution. Similar to the results of this study the number of professionals involved may have a large impact on what areas of the implementation process get the most attention, where a low number of professionals involved may result in significant barriers being overlooked. This could also be a source of the variable lists of barriers that were identified in the literature surrounding PLM implementation. While there will always be specific tailoring needed for each PLM solution, a lack of professional input may be the cause for no

The original list of barriers identified in the literature surrounding PLM implementation consisted of nine barriers. These barriers, seen in Figure 4, consisted of Complexity of Systems, Lack of Interoperability, Lack of Knowledge, Lack of Training, Monetary Cost, Perception of PLM, Resistance to change, Security Concerns, and Time Requirement. It is important to note that these barriers were not consistently found within the literature regarding PLM implementation and often each source had a different combination of these barriers. This indicated a need to confirm which of these barriers existed during the PLM implementation process. This conformation took the form of a survey provided to professionals in the PLM space. Through this survey it was determined that the barrier Lack of Interoperability was not believed by a majority of participants to exist in the PLM implementation process. This finding was unexpected, as this barrier was identified in the literature by multiple authors such as Erasmus & Jacob (2015), Saaksvuori (2011) and Silventoinen et al. (2009) who outlined the issues with system interoperability that companies and more commonly SMEs face when working with multiple companies that each have their own system and data management requirements. It is important to note that the exclusion of this barrier may be due to the low sample size of 8 valid responses and a larger sample may have shown professional confidence in its existence.

Building on the original list of barriers, two additional barriers were reported by participants, these consisted of Lack of Knowledge on Current Business Practices, and Complexity of Required Configuration. To add the barrier Lack of Knowledge on Current Business Practices, the barrier Lack of Knowledge was separated into two distinct barriers. The Lack of knowledge barrier was intended to cover knowledge surrounding the PLM solution implementation which included knowledge of business practices as outlined by Garetti et al. (2005) and Johansson et al., (2013). However, through their responses, the participants indicated that they believed there was a need for a distinction to be made. Similarly, to add the barrier Complexity of Required Configuration, the barrier Complexity of Products was be separated into two distinct barriers. Complexity of Products barrier was intended to cover the complexity of commercial PLM systems as outlined by Batenburg et al. (2006), Garetti et al. (2005), Johansson et al. (2013), Kung et al. (2015), Messaadia et al. (2016), and Silventoinen et al., (2009), and any configurations or customizations that were required as outlined by Abramovici (2007). Through their responses, the participants indicated that they believed there was a need for a distinction to be made. The addition of this possibility allowed for the potential configuration, and by extension, customization, of a PLM solution to be separated from the complexity of the base system, as different implementations may need different levels of configuration.

It can be proposed that the set of barriers confirmed may be different between multiple PLM implementation projects. These sets of barriers may include barriers not identified in this study or the removal of barriers used in this study depending on the companies, or focus area being explored. This difference could also take the form of different relationship strengths, potentially leading to impact relationship maps and critical barriers that are implementation specific even when using the same confirmed barriers. This potential difference in confirmed barriers can illustrated in the approaches needed to address implementations in companies with legacy PLM systems and those implementing PLM from a clean starting point. In this study the barrier Lack of Interoperability was not confirmed by a majority of participants, but this finding may be due to the companies that were surveyed, as these companies may be among those that implemented a PLM solution without having to consider connections legacy systems. Whereas a company with a long tradition of utilizing data management systems or previous PLM solution implementations would likely consider Lack of Interoperability to be one of the more important barriers to be considered. It is important to note that the inclusion of these barriers may be due to the low sample size of 8 valid responses, while a larger sample may show different potential barriers such as Lack of Leadership, or Quality of Legacy Data being identified as missing or barriers such as Monetary cost being removed from consideration.

It is important to note that other Multi Criteria Decision Making (MCDM) methods could have been used in a similar way to the DEMATEL method in this study. Some of these methods include the analytic hierarchical process (AHP), grey relational analysis (GRA) or technique for order performance by similarity to ideal solution (TOPSIS). However, as Si et al. (2018) found the DEMATEL method has the following benefits:

- It effectively analyzes the mutual influences (both direct and indirect effects) among different factors and understands the complicated cause and effect relationships in the decision-making problem.
- It is able to visualize the interrelationships between factors via an IRM and enable the decision maker to clearly understand which factors have mutual influences on one another.
- The DEMATEL method can be used not only to determine the ranking of factors, but also to find out critical evaluation criteria and measure the weights of evaluation criteria.

Utilizing any of the methods listed above would not have presented the same findings as these methods do not consider the same aspects when creating a decision-making plan. Especially as these methods do not focus on influences between elements rather, they explore element importance if they were completely separate entities.

In addition to these other MCDM methods there are also variations of the DEMATEL method that could have been used in this study these listed below:

- ANP and DEMATEL
- Fuzzy DEMATEL
- Grey DEMATEL
- Other DEMATEL

These variations of the DEMATEL method may have produced slightly different findings, as they each consider slightly different aspects in addition to the standard DEMATEL method. These considerations include concepts such as participant uncertainty, separately weighted criteria, and separately weighted participants. However, as this study was presented to the PLM community at large there was no way to effectively assign weight to specific participants, and without a concrete list of barriers from literature there was no effective way to assign weight to specific barriers. In the face of these drawbacks the classic version of the DEMATEL method was utilized in this study.

Based on the average impact ranking from the surveyed professionals seen in table 2, the barrier Resistance to Change was identified as the most impactful barrier to a PLM implementation and the barrier Security Concerns was identified as the least impactful barrier. However, the first nine barrier rankings included the most impactful barrier, all of which remained relatively close to the adjacent barriers, indicating there is not a clear consensus between professionals on the impact each barrier has relative to the others. This lack of consensus between professionals on the impact of barriers is reinforced when looking at the standard deviation and variance between the opinion impact ranking results. With the only barrier falling below 1 standard deviation, Security Concerns, also being the only barrier with a comparatively large difference with an adjacently ranked barrier, indicating that there is consensus on its lowest impact ranking. These rankings were then compared to the total impact from the DEMATEL method.

Using the DEMATEL method, the total impact of each barrier was determined. The most impactful barrier was determined to be Resistance to Change, a position that aligns with the impact ranking provided by the surveyed professionals. However as shown by the relationship value, the barrier Resistance to Change is an effect barrier, total impact of which on a PLM implementation is influenced more by other existing barriers than its own influence. This indicates, that while it is the most impactful barrier, its negative effect on a PLM implementation project cannot be solved directly. Instead, a majority of its effect will be reduced by addressing the barriers that influence it. Conversely the barrier with the second highest total impact value, Complexity of Required Configuration, was determined to be a causal barrier indicating that majority of impact this barrier has on PLM implementation can be addressed without having to first address any of the connected barriers. Matching the sentiment found in the professional impact ranking, the barrier with the lowest total impact was determined to be Security Concerns, helping to solidify its position as the least impactful barrier that was confirmed to exist in PLM implementations. The total impact rankings from only three barriers matched their impact rankings provided by professionals: Resistance to Change, Complexity of Systems and Security concerns (representing the first, fifth and last places respectively). This could indicate the industry participants surveyed had some level of accuracy on the impact certain barriers had on the implementation process but were not aligned on every barrier's impact. The barrier with the largest difference in the impact rankings determined by professionals and those determined using the DEMATEL method was Perception of PLM which jumped from ninth place to third. As an *effect* barrier, it can be assumed that this jump is due to the influence exerted on it that was not properly considered by professionals in their rankings. It can also be seen that three of the top four barriers by total impact value are effect barriers, implying that the barriers with the most impact on the implementation of PLM are not something that can be addressed independently of the other barriers, and trying to do so would result in the majority of that barrier's impact remaining. However, without knowing which of the barrier relationships have a critical relationship value, an effective plan to address these barriers cannot be created. To find the threshold value to determine a critical relationship, the MMDE algorithm was used.

Using the threshold value determined by the MMDE algorithm resulted in 8 of the confirmed barriers having at least one critical relationship to another barrier. Using the definition of a critical barrier as having a causal relationship value, showing impact independence, and at least one critical relationship, it was determined that five out of the ten confirmed barriers were critical. these ordered by total impact value, being Complexity of Required Configuration, Complexity of Systems, Lack of Training, Lack of Knowledge on PLM Solutions and Lack of Knowledge on Current Business Practices. Using the definition of an important barrier as having an effectual relationship value and at least one critical relationship, it was determined that three of the ten barriers were important, these ordered in total impact value, being: Resistance to Change, Perception of PLM and Time Requirement. Two of the barriers were determined to be unimportant these, ordered by total impact value, being: Monetary Cost and Security Concerns. These barrier distinctions can be seen in IRM shown in figure 13, where the five critical barriers can be seen at the top of the map acting as a source of impact influence that flows down to the three important barriers below. The two unimportant barriers can be seen off to the side, not having any critical relationships connecting them to the other confirmed barriers.

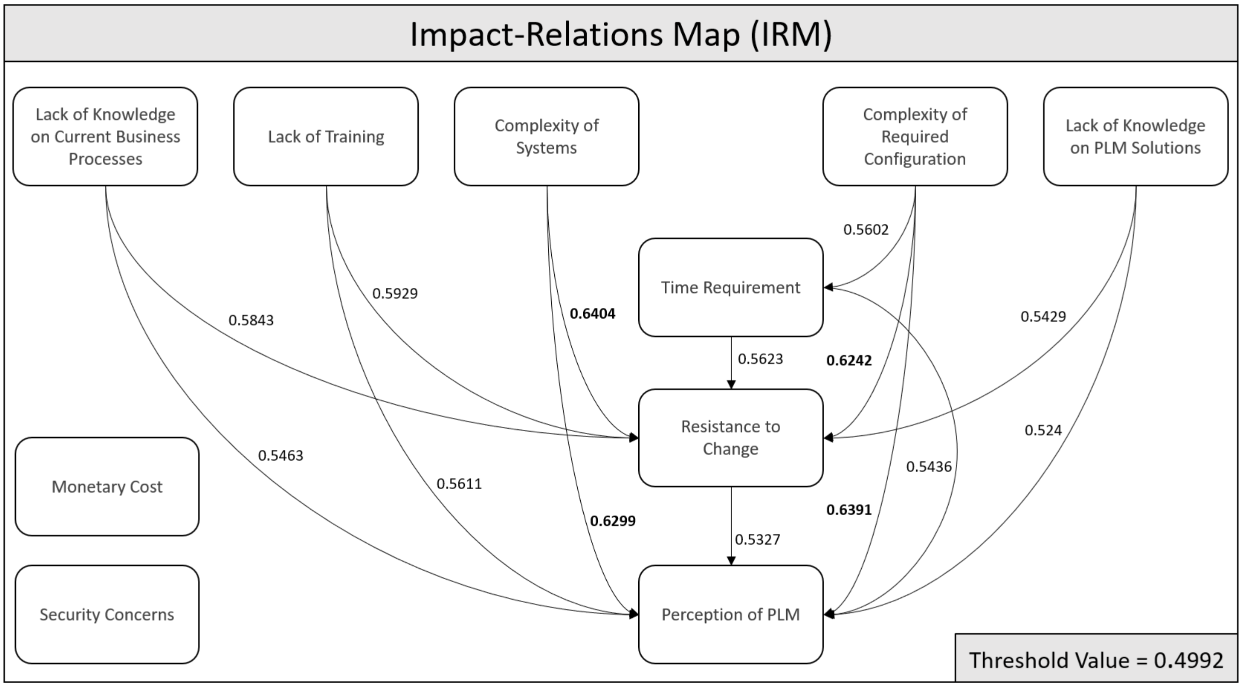

Figure 13. Impact-Relations Map from the DEMATEL method

Following these findings, a general order in which to tackle the confirmed barriers can be seen above in figure 13. With the five critical barriers, shown in order of total impact: Complexity of Required Configuration, Complexity of Systems, Lack of Training, Lack of Knowledge on PLM Solutions and Lack of Knowledge on Current Business Practices being the first barriers to address during an implementation project. It is important to note that these barriers do not need to be addressed in the order described, as they can be considered isolated from each other due to a lack of critical relationships between them. The descriptions of these five critical barriers often refer to a lack of skills or knowledge needed to understand the inherent complexity of a PLM solution. The two critical barriers with the largest and second largest impact are Complexity of Required Configuration and Complexity of Systems both of these barriers directly relate to the PLM systems that companies use to create the digital backbone of their PLM solutions. To address these barriers, the PLM software itself needs to be changed to allow for a greater ease of use: modularity of functions to allow more specialized application of knowledge; a focus on usability during development; or existing system packages receiving easy to understand resources dedicated to teaching how to use the systems from a developmental standpoint. The critical barrier Lack of

Training can be considered in a similar manner, where the best way to address it is to increase access to the resources necessary to learn the required skills. This could also be helped by easier to understand systems in general allowing for more intuitive system usage. The barriers Lack of Knowledge on Current Business Practices and Lack of Knowledge on PLM Solutions need to be addressed in different manners. A lack of knowledge on business practices is an area that needs to be defined and managed by the businesses themselves, and no two businesses are identical so there cannot be a true standard used by all businesses to address this barrier. However, Lack of Knowledge on PLM solutions has a similar solution to a lack of training, an increase in available resources on the concept of PLM and the systems that enable PLM.

The three important barriers, ordered by total impact value, are Resistance to Change, Perception of PLM and Time Requirement. Interestingly, these cannot be addressed in the order derived from largest impact. Instead, the order to address these important barriers following figure 13 is Time Requirement, Resistance to Change, and Perception of PLM. This is due to the flow of influence that can be seen, as Time Requirement critically influences both Resistance to change and Perception of PLM, and subsequently Resistance to Change critically influences Perception of PLM. The time required to implement a PLM solution is highly variable and can change throughout a project, to address this barrier, a more efficient implementation process with more informed frameworks which account for unforeseen problems, may help to better estimate the time required and ensure that there are not unforeseen issues that would contribute to additional required time. The barriers Resistance to Change and Perception of PLM can best be addressed by removing the influences that are exerted on them. This can take the form of the solutions that were suggested for the critical barriers, once those influences are removed the remaining impact may be addressed through better explanation on the benefits of PLM and how it could make a job easier, in addition to extra training resources to ensure that the solution is understood.

Two of the barriers were determined to be unimportant these, ordered by total impact value, being: Monetary Cost and Security Concerns. These barriers not only had the lowest total impact values, but also lacked a single critical relationship. Indicating that they are not important when implementing PLM solutions and can be left till the end of an implementation plan to address. In this regard, the Monetary Costs of the systems are directly related to the size of the implementation and the cost that a provider will charge for the use and support of their system. This is something that only the company implementing, and the providers can directly influence. As for Security Concerns, its impact can be addressed through better access to the knowledge regarding PLM systems and as digital security systems become more robust and easier to utilize this barrier, will diminish.

This study aimed to answer three main research questions outlined in section 1.3, these being:

1. What are the barriers to PLM implementation and is there a difference between those identified in literature and those confirmed by professionals?
2. Is there a difference between barrier impact rankings, based on professional opinion and those determined utilizing the DEMATEL method?
3. What are the critical barriers determined using the DEMATEL method and the MMDE algorithm?

There were three discrepancies found between the barriers identified in literature, and those identified by the study participants. These three discrepancies being a lack of belief in the existence of the barrier Lack of Interoperability and the addition of the two barriers Lack of Knowledge on Current Business Practices and Complexity of Required Configuration. Where the two additional barriers allowed for a more descriptive allocation of barrier influences.

A discrepancy between barrier impact ranked from the opinions of professionals and those results determined using the DEMATEL method was found. It was also observed that the professionals surveyed in this study did not have a clear consensus on the impact that each of the confirmed barriers have on a PLM implementation project. This presents the need for an addition method to accurately determine said impact, and ultimately determine which of the confirmed barriers are critical to the success of a PLM implementation project.

Following the use of the DEMATEL method, supplemented by the MMDE algorithm, out of the 10 confirmed barriers, 5 barriers critical to the implementation of PLM solutions were found. These ordered by largest impact value being Complexity of Required Configuration, Complexity of Systems, Lack of Training, Lack of Knowledge on PLM Solutions and Lack of Knowledge on Current Business Practices. The 3 important barriers were also identified, these ordered by total impact value, are Resistance to Change, Perception of PLM and Time Requirement. The barriers Monetary Cost and Security Concerns were determined to be unimportant to the implementation of PLM when compared to the other 8 barriers.

This study presented the DEMATEL method, supplemented by the MMDE algorithm utilizing the analysis of inter-barrier relationships to better determine the total impact each barrier exerts and to determine which of the confirmed barriers are critical to the implementation of PLM. The highly variable opinion impact assessments can be used as an indication that professional opinion alone is not sufficient to create an effective implementation plan, as resources would be allocated to address barriers solely on highly variable opinion-based impact rankings, resulting in an implementation plan in which critical barriers do not receive enough resources. Ultimately resulting in a PLM solution that fails to meet expected results. Instead, the DEMATEL method, supplemented by the MMDE algorithm can be utilized in existing PLM implementation frameworks to better allow for the allocation of resources to address each of the barriers to the implementation of PLM solution.

5.1 Future Work

This study utilized a two-phase approach to identify the barriers to PLM implementation, a recreation of this study, reaching a larger population size and utilizing a looping approach for barrier identification could result in a more refined list of barriers to be explored. This type of study could potentially be used to create a general framework to address the barriers that are found in the PLM implementation process. It may be the case however that a specialized identification of barriers and the resulting critical barriers may be implementation specific and not applicable in each case. This would require the integration of the DEMATEL or a similar method of multicriteria decision making to be integrated into existing PLM implementation frameworks, allowing a company to begin their PLM implementation with a more detailed plan to address the issues that can present themselves during an implementation process.

There is also a lack of information surrounding the number of professionals normally utilized in PLM implementation projects making the findings of this study difficult to directly compare to realized PLM implementation projects. Future studies could potentially investigate the number of professionals recruited for standard PLM implementation projects and determine if there is a limit to the number of professional inputs that provide value to an implementation project. It may be found that the number of professionals involved in these projects is in line with the number of participants in this study, or it could show that current PLM implementation processes rely on very few professionals when creating their implementation plans.

Although this study presents an overview of the barriers to PLM implementation, each identified barrier may be explored individually in further research. There may also need to be research into the internal factors that affect each barrier.

BIBLIOGRAPHY

Abramovici, M. (2007). Future Trends in Product Lifecycle Management (PLM). In F.-L. Krause (Ed.), *The Future of Product Development* (pp. 665–674). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-69820-3_64

Alemanni, M., Alessia, G., Tornincasa, S., & Vezzetti, E. (2008). Key performance indicators for PLM benefits evaluation: The Alcatel Alenia Space case study. *Computers in Industry*, *59*(8), 833–841. https://doi.org/10.1016/j.compind.2008.06.003

Arendt, L. (2008). Barriers to ICT adoption in SMEs: how to bridge the digital divide? *Journal of Systems and Information Technology*, *10*(2), 93–108. https://doi.org/10.1108/13287260810897738

Barba-Sánchez, V., Martínez-Ruiz, M. D. P., & Jiménez-Zarco, A. I. (2007). Drivers, benefits and challenges of ICT adoption by small and medium sized enterprises (SMEs): A literature review. *Problems and Perspectives in Management*, *5*(1), 103–114.

Batenburg, R., Helms, R. W., & Versendaal, J. (2006). PLM roadmap: stepwise PLM implementation based on the concepts of maturity and alignment. *International Journal of Product Lifecycle Management*, *1*(4), 333. https://doi.org/10.1504/IJPLM.2006.011053

Bedolla, J. S., Gomez, J. M., & Chiabert, P. (2014). A short portable PLM course. *IFIP Advances in Information and Communication Technology*, *442*, 111–120.

Bokinge, M., & Malmqvist, J. (2012). PLM implementation guidelines - Relevance and application in practice: A discussion of findings from a retrospective case study. *International Journal of Product Lifecycle Management*, *6*(1), 79–98. https://doi.org/10.1504/IJPLM.2012.046442

Brown, J. (2016). *PLM License and Deployment Flexibility Puts PLM in Reach The Compelling ROI of PLM*. 1–8.

Cantamessa, M., Montagna, F., & Neirotti, P. (2012). An empirical analysis of the PLM implementation effects in the aerospace industry. *Computers in Industry*, *63*(3), 243–251. https://doi.org/10.1016/j.compind.2012.01.004

Chung-Wei, L., & Gwo-Hshiung, T. (2009). Identification of a threshold value for the dematel method: Using the maximum mean de-entropy algorithm. *Communications in Computer and Information Science*, *35*, 789–796. https://doi.org/10.1007/978-3-642-02298-2_115

CIMdata, Longer, N., & Organizations, L. (2004). *Enterprises of All Sizes Can Benefit from PLM. September*, 1–4.

Duigou, J. Le, Bernard, A., Perry, N., & Delplace, J. (2011). Application of PLM Processes to Respond to Mechanical SMEs Needs. In A. Bernard (Ed.), *Global Product Development* (pp. 319–326). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-15973-2

Erasmus, J., & Jacob, M. (2015). *The drivers and factors influencing PLM adoption and selection*.

Garetti, M., Terzi, S., Bertacci, N., & Brianza, M. (2005). Organisational change and knowledge management in PLM implementation. *International Journal of Product Lifecycle Management*, *1*(1), 43–51. https://doi.org/10.1504/IJPLM.2005.007344

Githens, G. (2007). Product Lifecycle Management: Driving the Next Generation of Lean Thinking by Michael Grieves. *Journal of Product Innovation Management*, *24*(3), 278–280. https://doi.org/10.1111/j.1540-5885.2007.00250_2.x

Grieves, M. (2006). *Product lifecycle management: driving the next generation of lean thinking* [Book]. McGraw-Hill.

Hartman, N. W., & Miller, C. L. (2006). Examining industry perspectives related to legacy data and technology toolset implementation. *Engineering Design Graphics Journal*, *70*(3), 12–20.

Hewett, A. (2010). Product Lifecycle Management (PLM): Critical Issues and Challenges in Implementation. In S. Nambisan (Ed.), *Information Technology and Product Development* (Vol. 5, pp. 81–105). Springer US. https://doi.org/10.1007/978-1-4419-1081-3_5

Johansson, A., Kazemahvazi, S., Henrinksson, B., & Johnsson, M. (2013). Why product lifecycle management should be on every executive' s agenda! *Prism*, *1*, 56–69.

Kärkkäinen, H., Pels, H. J., & Silventoinen, A. (2012). Defining the Customer Dimension of PLM Maturity. In *IFIP Advances in Information and Communication Technology: Vol. 388 AICT* (pp. 623–634). https://doi.org/10.1007/978-3-642-35758-9_56

Koomen, B. (2018). PLM in SME, What Are We Missing? An Alternative View on PLM Implementation for SME. In P. Chiabert, A. Bouras, F. Noël, & J. Ríos (Eds.), *IFIP Advances in Information and Communication Technology* (Vol. 540, Issue July 2018, pp. 681–691). Springer International Publishing. https://doi.org/10.1007/978-3-030-01614-2_62

Kung, K.-H., Ho, C.-F., Hung, W.-H., & Wu, C.-C. (2015). Organizational adaptation for using PLM systems: Group dynamism and management involvement. *Industrial Marketing Management*, *44*, 83–97. https://doi.org/10.1016/j.indmarman.2014.04.018

Lammcr, L., & Bugow, R. (2007). PLM services in practice. *The Future of Product Development - Proceedings of the 17th CIRP Design Conference*, *35267*, 503–512. https://doi.org/10.1007/978-3-540-69820-3_49

Lee, Y.-C., Sheu, L.-C., & Tsou, Y.-G. (2008). Quality function deployment implementation based on Fuzzy Kano model: An application in PLM system. *Computers & Industrial Engineering*, *55*(1), 48–63. https://doi.org/10.1016/j.cie.2007.11.014

Messaadia, M., Baudry, D., Louis, A., Mahdikhah, S., Evans, R., Gao, J., Paquet, T., Sahnoun, M., & Mazari, B. (2016). PLM adoption in SMEs context. *Computer-Aided Design and Applications*, *13*(5), 618–627. https://doi.org/10.1080/16864360.2016.1150706

Messaadia, M., Benatia, F., Baudry, D., & Louis, A. (2017). PLM Adoption Model for SMEs. In J. Ríos, A. Bernard, A. Bouras, & S. Foufou (Eds.), *IFIP International Conference on Product Lifecycle Management* (Vol. 517, Issue 14). Springer International Publishing. https://doi.org/10.1007/978-3-319-72905-3

Nambisan, S. (2010). Information Technology and Product Development. Annals Information Systems. In *Springer*.

Pels, H. J., & Simons, K. (2016). PLM maturity assessment. *2008 IEEE International Technology Management Conference, ICE 2008*.

Penciuc, D., Durupt, A., Belkadi, F., Eynard, B., & Rowson, H. (2014). Towards a PLM Interoperability for a Collaborative Design Support System. *Procedia CIRP*, *25*(C), 369–376. https://doi.org/10.1016/j.procir.2014.10.051

Pol, G., Merlo, C., Legardeur, J., & Jared, G. (2008). Implementation of collaborative design processes into PLM systems. *International Journal of Product Lifecycle Management*, *3*(4), 279. https://doi.org/10.1504/IJPLM.2008.027006

Rangan, R. M., Rohde, S. M., Peak, R., Chadha, B., & Bliznakov, P. (2005). Streamlining product lifecycle processes: A survey of product lifecycle management implementations, directions, and challenges. *Journal of Computing and Information Science in Engineering*, *5*(3), 227–237. https://doi.org/10.1115/1.2031270

Saaksvuori, A. (2011). *PLM vision 2016 and beyond*. 1–37. http://www.plm-info.com/files/PLM vision 2016 C.pdf

Schuh, G., Rozenfeld, H., Assmus, D., & Zancul, E. (2008). Process oriented framework to support PLM implementation. *Computers in Industry*, *59*(2–3), 210–218. https://doi.org/10.1016/j.compind.2007.06.015

Si, S. L., You, X. Y., Liu, H. C., & Zhang, P. (2018). DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications. Mathematical Problems in Engineering, 2018(1). https://doi.org/10.1155/2018/3696457

Silventoinen, A., Papinniemi, J., & Lampela, H. (2009). A Roadmap for Product Lifecycle Management Implementation in SMEs Anneli Silventoinen * Jorma Papinniemi Hannele Lampela. *The XX ISPIM, JUNE*. https://doi.org/978-952-214-767-7

Singh, S., & Misra, S. C. (2018). Core challenges to cloud PLM adoption in large manufacturing firms. *2018 5th International Conference on Industrial Engineering and Applications (ICIEA)*, 141–145. https://doi.org/10.1109/IEA.2018.8387085

Singh, S., & Misra, S. C. (2018). Success determinants to Product Lifecycle Management (PLM) performance. *2018 5th International Conference on Industrial Engineering and Applications (ICIEA)*, 386–390. https://doi.org/10.1109/IEA.2018.8387130

Singh, S., & Misra, S. C. (2019). Exploring the Challenges for Adopting the Cloud PLM in Manufacturing Organizations. *IEEE Transactions on Engineering Management*, 1–15. https://doi.org/10.1109/TEM.2019.2908454

Singh, S., & Misra, S. C. (2019). Identification of barriers to PLM institutionalization in large manufacturing organizations: A case study. *Business Process Management Journal*, *25*(6), 1335–1356. https://doi.org/10.1108/BPMJ-12-2017-0367

Singh, S., Misra, S. C., & Kumar, S. (2019). Critical Barriers to PLM Institutionalization in Manufacturing Organizations. *IEEE Transactions on Engineering Management*, 1–13. https://doi.org/10.1109/TEM.2019.2911574

Srinivasan, V. (2011). An integration framework for product lifecycle management. *Computer-Aided Design*, *43*(5), 464–478. https://doi.org/10.1016/j.cad.2008.12.001

Stark, J. (2015). Product Lifecycle Management. In *Product Lifecycle Management (Volume 1) 21st Century Paradigm for Product Realisation* (Third). Springer International Publishing. https://doi.org/10.1007/978-3-319-17440-2

Subrahmanian, E., Rachuri, S., Fenves, S. J., Foufou, S., Sriram, R. D., Systems, M., & Division, I. (2005). Challenges in supporting product design and manufacturing in a networked economy: A PLM perspective. *Proceedings of the International Conference on Product Lifecycle Management*, *May 2014*, 495–506.

Urbinati, A., Milano, P., & Lambruschini, V. R. (2017). *The PLM implementation challenges in the Power Generation Industry Vito Manfredi Latilla Davide Chiaroni Federico Frattini*. *June*.

Zammit, J. P., Gao, J., & Evans, R. (2017). The Challenges of Adopting PLM Tools Involving Diversified Technologies in the Automotive Supply Chain. In J. Ríos, A. Bernard, A. Bouras, & S. Foufou (Eds.), *IFIP International Conference on Product Lifecycle Management* (Vol. 517, Issue 14, pp. 59–68). Springer International Publishing. https://doi.org/10.1007/978-3-319-72905-3_6

APPENDIX A SURVEY 1 – BARRIER CONFIRMATION

Declaration

RESEARCH PARTICIPANT CONSENT FORM
Determining Critical Barriers to Product Lifecycle Management (PLM) Implementation
Primary Investigator: Nathan Hartman, PhD
Computer Graphics Technology
Purdue University
IRB No. #2021-910

Key Information

Please take the time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask questions to the researchers about the study whenever you would like. If you decide to take part in the study, be sure you understand what you will do and any possible risks or benefits.

What is the purpose of this study?

This research study aims to investigate the barriers that are present when implementing Product Lifecycle Management (PLM) and determine if there is a discrepancy between critical barriers to PLM implementation determined by professionals in the PLM space and those determined through the utilization of the DEMATEL method.

The length of this research project is approximately 2-3 months.

The goals of this study are as follows:

1. Investigate the barriers that exist during the implementation of PLM solutions

2. Determine if there is a discrepancy between critical barriers determined by professionals and those determined by the DEMATEL method.

3. Develop a conceptual model or framework to better identify the critical barriers that will arise during the implementation of a PLM solution.

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You are being requested to participate in this study due to your experience in the implementation and or utilization of PLM within the manufacturing industry. We would like to enroll at least 10 people per organization participating in this study

What will I do if I choose to be in this study?

In this study you will be asked to fill out two surveys regarding the barriers of implementation to PLM using the Qualtrics survey tool, a link to each survey will be shared with you via email.

These surveys can be done remotely and do not require face-to-face meetings or travel.

The first survey will gather data regarding demographic information and professional experience to be used as filter questions to remove any participants that do not meet the requirements to participate in this study and professional opinion on the presence of barriers to PLM implementation that were found within literature around the subject.

The second survey will gather data on the ranked importance of identified barriers and the strength of the relationships between them. This survey's content will be updated based on the responses from the first survey so that it included all barriers that were identified by participants.

We will be using statistical analysis to identify the barriers that are faced when implementing PLM on the data gathered from the first survey.

We will be using statistical analysis and the DEMATEL method to determine which of these barriers are critical based on the data gathered from the second survey.

How long will I be in the study?

This study is expected to take 2-3 months and is split into two different instances of data collection that will be administered at two separate times.

Each survey is expected to take no more than 20 minutes to complete and can be completed at any time until the listed return date.

Each stage of data collection will last 3 weeks, with an additional week being reserved if insufficient responses are collected. The second round of data collection will begin 1-5 days after the conclusion of the first round of data collection, to allow for a modification to the second survey.

What are the possible risks or discomforts?

The risks and discomforts that may be faced during this study are no greater than the participant would encounter in daily life or during the performance of routine physical or psychological exams or tests.

Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

Are there any potential benefits?

There are no anticipated direct benefits to participants, but organizations the participants belong to may benefit from the findings of this study.

Are there costs to me for participation?

There are no anticipated costs to participate in this research.

This section provides more information about the study

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the study sponsor/funding agency, Food and Drug Administration (if FDA regulated), US DHHS Office for Human Research Protections, and by departments at Purdue University responsible for regulatory and research oversight.

All identifiable research records, data, specimens, etc. will only be accessed by the research team.

All data will be stored within Purdue Box data storage, requiring valid login information to access.

Data gathered in this study will be de-identified after the study is completed but will not be destroyed.

Any results disseminated will have any identifying information removed as the identifying information gathered in this study is only used to determine if a participant meets the requirements to participate in this study and are not relevant to the topic being studied.

De-identified data may be used in future studies.

What are my rights if I take part in this study?

You do not have to participate in this research project. If you agree to participate, you may withdraw your participation at any time without penalty.

If a participant wishes to withdraw from this study after completing the first survey, the data they provided can not be withdrawn as it will have been used to update the content found in the second survey and all secondary surveys must be identical to be compared.

If a participant wishes to withdraw from this study after completing the second survey their data from the second survey will be withdrawn without penalty.

Participation in this study may be terminated without the participant's consent if the participant is determined to not have met the requirements to supply valid data for this study.

Who can I contact if I have questions about the study?

If you have questions, comments, or concerns about this research project, please email Kevin J. Del Re at **kdelre@purdue.edu or call (847) 997-0483**.

To report anonymously via Purdue's Hotline, see www.purdue.edu/hotline

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:
Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above.

Please complete this Captcha verification to prove you are not a robot and that you agree to participate in the study described above.

☐ I'm not a robot — reCAPTCHA Privacy - Terms

Demographics

Please indicate your level of work experience in the PLM area.

- ○ Less than one year
- ○ 1 - 2 years
- ○ 2 - 3 years
- ○ 3 - 4 years
- ○ 4 - 5 years
- ○ More than 5 years

Please select the number of PLM implementation projects that you have been a part of.

- ○ 0
- ○ 1
- ○ 2+

Barrier Identification

This section will help to identify the barriers to the implementation of PLM. Based on your experience with PLM in your organization, please share your opinion on the barriers that were identified in the literature surrounding PLM implementation.

Please indicate which of the following barriers you believe exist when implementing a PLM solution.

	Do the following barriers exist in PLM implementation?	
	Yes	No
Complexity of Systems	○	○
Lack of Interoperability	○	○
Lack of Knowledge	○	○

	Do the following barriers exist in PLM implementation?	
	Yes	No
Lack of Training	○	○
Monetary Cost	○	○
Perception of PLM	○	○
Resistance to change	○	○
Security Concerns	○	○
Time Requirement	○	○

Please indicate if there are any barriers to the implementation of PLM that you believe were not included within this survey.

APPENDIX B SURVEY 2 – BARRIER IMPACT & RELATIONSHIPS

Declaration

RESEARCH PARTICIPANT CONSENT FORM
Determining Critical Barriers to PLM Implementation
Primary Investigator: Nathan Hartman, PhD
Computer Graphics Technology
Purdue University
IRB No. #2021-910

Key Information

Please take the time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask questions to the researchers about the study whenever you would like. If you decide to take part in the study, be sure you understand what you will do and any possible risks or benefits.

What is the purpose of this study?

This research study aims to investigate the barriers that are present when implementing PLM and determine if there is a discrepancy between critical barriers to PLM implementation determined by professionals in the PLM space and those determined through the utilization of the DEMATEL method.

The length of this research project is approximately 2-3 months.
The goals of this study are as follows:
1. Investigate the barriers that exist during the implementation of PLM solutions

2. Determine if there is a discrepancy between critical barriers determined by professionals and those determined by the DEMATEL method.

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3. Develop a conceptual model or framework to better identify the critical barriers that will arise during the implementation of a PLM solution. You are being requested to participate in this study due to your experience in the implementation and or utilization of PLM within the manufacturing industry. We would like to enroll at least 10 people per organization participating in this study

What will I do if I choose to be in this study?

In this study you will be asked to fill out two surveys regarding the barriers of implementation to PLM using the Qualtrics survey tool, a link to each survey will be shared with you via email.

These surveys can be done remotely and do not require face-to-face meetings or travel.

The first survey will gather data regarding demographic information and professional experience to be used as filter questions to remove any participants that do not meet the requirements to participate in this study and professional opinion on the presence of barriers to PLM implementation that were found within literature around the subject.

The second survey will gather data on the ranked importance of identified barriers and the strength of the relationships between them. This survey's content will be updated based on the responses from the first survey so that it included all barriers that were identified by participants.

We will be using statistical analysis to identify the barriers that are faced when implementing PLM on the data gathered from the first survey.

We will be using statistical analysis and the DEMATEL method to determine which of these barriers are critical based on the data gathered from the second survey.

How long will I be in the study?

This study is expected to take 2-3 months and is split into two different instances of data collection that will be administered at two separate times.

Each survey is expected to take no more than 20 minutes to complete and can be completed at any time until the listed return date.

What are the possible risks or discomforts?

The risks and discomforts that may be faced during this study are no greater than the participant would encounter in daily life or during the performance of routine physical or psychological exams or tests.

Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

Are there any potential benefits?

There are no anticipated direct benefits to participants, but organizations the participants belong to may benefit from the findings of this study.

Are there costs to me for participation?

There are no anticipated costs to participate in this research.

This section provides more information about the study

Will information about me and my participation be kept confidential?

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All identifiable research records, data, specimens, etc. will only be accessed by the research team.

All data will be stored within Purdue Box data storage, requiring valid login information to access.

Data gathered in this study will be de-identified after the study is completed but will not be destroyed.

Any results disseminated will have any identifying information removed as the identifying information gathered in this study is only used to determine if a participant meets the requirements to participate in this study and are not relevant to the topic being studied.

De-identified data may be used in future studies.

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If a participant wishes to withdraw from this study after completing the first survey, the data they provided can not be withdrawn as it will have been used to update the content found in the second survey and all secondary surveys must be identical to be compared.

If a participant wishes to withdraw from this study after completing the second survey their data from the second survey will be withdrawn without penalty.

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Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
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Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above.

Critical Barrier Identification

Please rank the following identified barriers to PLM implementation from 1 to 10 where 1is the most impactful and 10 is the least.

Complexity of Systems

Complexity of Required Configuration

Lack of Knowledge on PLM solutions

Lack of Training

Monetary Cost

Perception of PLM

Resistance to Change

Security Concerns

Time Requirement

Lack of Knowledge on Current Business Practices

Please complete the following causal relationship matrix table from row to column.

Ranking values from 0 to 4 where 0 is no influence and 4 is very high influence.

EXAMPLE: How the determined barrier "Complexity of Systems" influences the columns adjacent to it.

	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge on PLM solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Business Practices
Complexity of Systems	0									

5/6

	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge on PLM solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Business Practices
Complexity of Required Configuration		0								
Lack of Knowledge on PLM solutions			0							
Lack of Training				0						
Monetary Cost					0					
Perception of PLM						0				
Resistance to Change							0			
Security Concerns								0		
Time Requirement									0	
Lack of Knowledge on Current Business Practices										0

Additional Critical Barriers

Please provide any barriers to the implementation of PLM that you feel this research may have missed

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APPENDIX C INITIAL RELATIONSHIP MATRICIES

Initial Relationship Matrices

1	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge Regarding PLM Solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Buisiness Practices
Complexity of Systems	0	2	0	0	2	3	3	0	2	0
Complexity of Required Configuration	0	0	0	0	2	3	3	0	9	0
Lack of Knowledge Regarding PLM Solutions	0	0	0	0	0	4	3	0	4	0
Lack of Training	0	0	0	0	0	4	3	0	3	0
Monetary Cost	0	0	0	0	0	4	3	0	0	0
Perception of PLM	0	0	0	0	0	0	3	0	0	0
Resistance to Change	0	0	0	0	0	4	0	0	0	0
Security Concerns	0	0	0	0	0	2	0	0	0	0
Time Requirement	0	0	0	0	3	3	0	0	0	0
Lack of Knowledge on Current Buisiness Practices	0	0	0	0	2	3	3	1	3	0

2	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge Regarding PLM Solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Buisiness Practices
Complexity of Systems	0	3	3	4	2	4	4	3	4	2
Complexity of Required Configuration	2	0	1	4	3	4	3	2	4	2
Lack of Knowledge Regarding PLM Solutions	2	2	0	3	2	4	4	2	3	1
Lack of Training	2	2	4	0	2	4	4	3	3	1
Monetary Cost	2	4	0	4	0	2	1	2	1	0
Perception of PLM	2	1	3	2	1	0	4	2	1	1
Resistance to Change	2	3	1	3	1	4	0	3	3	1
Security Concerns	3	3	1	1	2	4	3	0	2	1
Time Requirement	4	4	3	4	2	4	4	2	0	2
Lack of Knowledge on Current Buisiness Practices	3	3	0	0	3	3	4	2	4	0

3	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge Regarding PLM Solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Buisiness Practices
Complexity of Systems	0	4	2	1	3	3	1	1	2	0
Complexity of Required Configuration	2	0	4	2	4	3	1	1	4	0
Lack of Knowledge Regarding PLM Solutions	1	1	0	2	2	2	1	1	2	0
Lack of Training	0	0	1	0	2	2	4	0	2	0
Monetary Cost	1	1	0	2	0	3	4	0	0	0
Perception of PLM	2	1	2	0	0	0	2	1	1	0
Resistance to Change	0	2	1	1	4	2	0	0	3	2
Security Concerns	0	1	0	0	1	2	1	0	1	0
Time Requirement	0	2	2	4	2	3	4	0	0	2
Lack of Knowledge on Current Buisiness Practices	0	3	1	2	4	1	2	1	4	0

4	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge Regarding PLM Solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Buisiness Practices
Complexity of Systems	0	3	4	4	3	2	4	2	2	4
Complexity of Required Configuration	3	0	4	4	3	2	4	1	2	4
Lack of Knowledge Regarding PLM Solutions	4	3	0	4	2	2	4	1	2	4
Lack of Training	4	4	4	0	2	2	4	1	2	4
Monetary Cost	3	3	4	2	0	2	3	1	1	3
Perception of PLM	2	2	4	4	2	0	4	1	2	3
Resistance to Change	3	4	4	4	2	2	0	1	2	4

Security Concerns	2	2	1	2	2	2	3	0	2	3
Time Requirement	3	3	4	4	3	2	4	2	0	3
Lack of Knowledge on Current Buisiness Practices	4	4	4	3	3	2	3	2	2	0

5	Complexity of Systems	Complexity of Required Configuration	Lack of Knowledge Regarding PLM Solutions	Lack of Training	Monetary Cost	Perception of PLM	Resistance to Change	Security Concerns	Time Requirement	Lack of Knowledge on Current Buisiness Practices
Complexity of Systems	0	4	3	3	3	4	4	1	2	1
Complexity of Required Configuration	4	0	3	3	4	4	1	1	2	2
Lack of Knowledge Regarding PLM Solutions	1	1	0	2	1	3	4	2	2	1
Lack of Training	1	3	1	0	3	4	4	2	3	2
Monetary Cost	2	2	1	2	0	2	2	1	1	1
Perception of PLM	2	3	1	1	1	0	4	1	1	1
Resistance to Change	3	4	3	2	1	4	0	1	3	1
Security Concerns	4	4	2	1	2	2	2	0	2	1
Time Requirement	1	1	3	1	1	1	2	1	0	3
Lack of Knowledge on Current Buisiness Practices	3	3	1	3	2	2	3	2	2	0