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ANALYSIS OF THE ODOO SOFTWARE CAPABILITIES REGARDING PRODUCT LIFECYCLE MANAGEMENT, MANUFACTURING EXECUTION SYSTEMS AND THEIR INTEGRATION

ODOO 軟體功能分析產品生命週期管理、製造執行系統及其集成

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ABSTRACT
摘要

ANALYSIS OF THE ODOO SOFTWARE CAPABILITIES REGARDING PRODUCT LIFECYCLE MANAGEMENT, MANUFACTURING EXECUTION SYSTEMS AND THEIR INTEGRATION 。

(ODOO 軟體功能分析產品生命週期管理、製造執行系統及其集成)。

The second half of the 20th century had been marked for the advancements of computer technology in all aspects of production.。

20 世紀下半葉以電腦的進步為標誌生產各個環節的技術

The key feature of that statement is the undeniable truth that alongside the increased complexity allowed by computing power comes an ever increasing production of overwhelming amounts of information. 。

該聲明的關鍵特徵是不可否認的事實，即隨著增加的計算能力所允許的複雜性，帶來了不斷增加的產量與海量資訊。

From separate perspectives of the industrial landscape, several systems were brewed by that sheer necessity for organization, automation and waste reduction focusing on that pool of useful data. 。

從工業景觀的不同角度來看，出於組織、自動化和減少浪費的絕對必要性，一些系統誕生了，這些系統專注於有用資料池。

ERP (from a managerial perspective), MES (from a production perspective) and more recently PLM (from a strategic development/redevelopment perspective) emerged as information solutions tackling this problem from different angles. These solutions, however effective, are always plagued by the fundamental incompatibility between the tools that implement those systems.。

ERP（從管理角度）、MES（從生產角度）以及最近的 PLM（從策略開發/再開發角度）作為資訊解決方案從不同角度解決這個問題。這些解決方案無論多麼有效，總是受到實現這些系統的工具之間根本不相容的困擾。

This paper objectives revolve around analyzing the integration PLM and MES systems from a theoretical perspective and comment on the use of the Odoo software tool to implement said integration.。

本文的目標是從理論角度分析 PLM 和 MES 系統的集成，並對使用 Odoo 軟體工具實現所述集成進行評論。

The Odoo software was described in detail (regarding its use for manufacturing envirorment) icluding how it implements PLM and MES. Then, the software was subjected to the simulation of a fictional firm devised in the molds of Industry 4.0. This company was a fictional recently founded small case manufacturing company that uses plastic injection molding as their primary mean of production and uses additive manufacturing and fast prototyping as part of their business strategy.。

詳細描述了 Odoo 軟體（關於其在製造環境中的使用），包括它如何實施 PLM 和 MES。然後，該軟體對一家按照工業 4.0 模式設計的虛構公司進行模擬。該公司是一家虛構的最近成立的小型箱體製造公司，使用塑膠注塑作為主要生產手段，並使用積層製造和快速原型製作作為其業務策略的一部分。

Keywords: Product Life-Cycle Management, Product Life-Cycle Management, Odoo。

關鍵字：產品生命週期管理、產品生命週期管理、Odoo

Chapter 1

INTRODUCTION

介紹

1.1 Objective 目的

The thesis has the objective of finding out how far PLM+MES system can be implemented by using the readily available Odoo software by analyzing the different concepts and dynamics that would consist said integration and they apply a fictional scenario to determine if and which of those concepts are included within this packaged solution.

本論文的目的是透過分析包含所述整合的不同概念和動態，找出使用現成的 Odoo 軟體可以實現 PLM+MES 系統的程度，並應用一個虛構的場景來確定這些概念是否以及哪些概念包含在此打包解決方案中。

To contextualize, the Odoo software differs from other solutions in the market substantially both in implementation and business model. To summarize, the Odoo software was originated as an open-source ERP software as oppose to a PLM or MES software and as such its availability and modularity are reasonably expanded. It goes without saying that the counter point for this that its usability in the field of PLM or MES is uncertain hence the value of this work.

從具體情況來看，Odoo 軟體在實施和業務模式方面與市場上的其他解決方案有很大不同。總而言之，Odoo 軟體最初是一種開源 ERP 軟體，而不是 PLM 或 MES 軟體，因此其可用性和模組化得到了合理擴展。不言而喻，與之相反的是，它在 PLM 或 MES 領域的可用性是不確定的，因此這項工作的價值。

Specifically, from the perspective of small manufacturing business and startups, the idea of an all-around ERP that implements a PLM-MES system is extremely valuable. Although ERP systems are somewhat available, they rarely venture deep enough into manufacturing to expand into PLM or MES solutions. In addition, the other direction is also relevant since PLM solutions tend to not have the expandability of an ERP which usually means that any integration requires specialized ad-hoc work.

具體來說，從小型製造企業和新創企業的角度來看，實施 PLM-MES 系統的全能 ERP 的想法非常有價值。儘管 ERP 系統在一定程度上可用，但它們很少深入製造業以擴展到 PLM 或 MES 解決方案。此外，另一個方向也相關，因為 PLM 解決方案往往不具備 ERP 的可擴展性，這通常意味著任何整合都需要專門的臨時工作。

Although modifying the software do not fall within the scope of this work, the fact that the software has an open-source community version means that adapting the software even to the most specific cases may prove to be easier and economical barriers for adopting lower,further emphasizing the possible utility of this software in the context of small business.

儘管修改軟體不屬於這項工作的範圍，但該軟體具有開源社群版本這一事實意味著，甚至使該軟體適應最具體的情況也可能被證明是更容易和更經濟的採用更低、更進一步的障礙。強調該軟體在小型企業中的可能實用性。

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Ultimately, the thesis will give theoretical and practical advices on how to further exploit this system. It will also lay the ground for future works on the Odoo software and checks on how the solution is performing by identifying specific key aspects of PLM-MES integration and implementation

最終，本文將為如何進一步利用該系統提供理論和實務建議。它還將為 Odoo 軟體的未來工作奠定基礎，並透過確定 PLM-MES 整合和實施的具體關鍵方面來檢查解決方案的性能

1.2 Structure 結構

This work could be a reference for an actual implementation of the described solution in small manufacturing enterprises and it can be treated as introductory material to PLM-MES and their implementation, as well as first principles and review of the current state of the Odoo software regarding it. To such end, this thesis presents the following structure:

這項工作可以為小型製造企業中所描述的解決方案的實際實施提供參考，並且可以將其視為 PLM-MES 及其實施的介紹材料，以及 Odoo 軟體的首要原則和當前狀態的回顧它。為此，本文提出以下結構：

- Chapter 1 - Introduction to this work and its objectives. Furthermore, it provide a succinct explanation of why this software solution requires this sort of analysis in the first place and how it was be structured.
  第 1 章 - 介紹這項工作及其目標。此外，它還簡要解釋了為什麼該軟體解決方案首先需要進行此類分析以及它是如何建構的。
- Chapter 2 –This chapter introduce the basic theoretical background to PLM, MES, ERP and Industry 4.0. These are presented in order to create the grounds to a meaningful contribution in this kind of analysis as well as providing meaningful context for its implementation in case the reader is a small business representative.
  第 2 章–本章介紹 PLM、MES、ERP 和工業 4.0 的基本理論背景。提出這些內容是為了為此類分析做出有意義的貢獻奠定基礎，並為讀者是小型企業代表的情況下的實施提供有意義的背景。
- Chapter 3 –This chapter is all about the integration between PLM and MES systems as discussed by previous works and as was be analyzed in this work. This is useful to stablish the concepts and dynamics that are the subject when analyzing the Odoo software.
  第 3 章–本章主要介紹 PLM 和 MES 系統之間的集成，如先前的工作所討論的和本工作中所分析的。這對於在分析 Odoo 軟體時確定主題的概念和動態很有用 。
- Chapter 4 –Introduction to the fictional company and products chosen in the molds of Industry 4.0 to be used in the further analysis and evaluation of the Odoo software.
  第 4 章– 介紹在工業 4.0 模型中選擇的虛構公司和產品，用於進一步分析和評估 Odoo 軟體。
- Chapter 5 –The introduction to the Odoo software as well as a more in-depth explanation of its use and functionalities. The description of the experimentation of the Odoo software taking in consideration all the previous chapters.
  第 5 章–Odoo 軟體簡介以及對其使用和功能的更深入解釋。考慮到前面所有章節的 Odoo 軟體實驗描述
- Chapter 7 - Conclusions The last chapter describes the takeaways of the work: how a medium enterprise can improve its processes through an informed use of a PLM+MES system implemented using the Odoo software.
  第 7 章 - 結論最後一章介紹了工作的要點：中型企業如何透過明智地使用使用 Odoo 軟體實施的 PLM+MES 系統來改善其流程。

Chapter 2

THEORETICAL BACKGROUND
理論背景

This chapter is a brief introduction to the different systems that deal with data production collection and processing around the concept of enhancing all aspects of production that are favored by the academic community as well as the current and future state of industry for which these systems should prove to be indispensable.

本章簡要介紹了圍繞學術界所青睞的增強生產各個方面的概念處理資料生產收集和處理的不同系統，以及這些系統應證明的當前和未來的行業狀況成為不可或缺的。

It is important to notice from this part that these are not completely separate information systems. They start from different perspectives and they try to solve different problems but because of broad definitions they unavoidably expand into each other. That represents a problem on its own since from the available literature it becomes difficult to pinpoint where the boundary of a system ends and another one starts.

從這一部分要注意的是，這些並不是完全獨立的資訊系統。他們從不同的角度出發，試圖解決不同的問題，但由於定義廣泛，他們不可避免地會相互擴展。這本身就是一個問題，因為從現有文獻來看，很難確定一個系統的邊界在哪裡結束，另一個系統的邊界從哪裡開始。

The Odoo management software (that is a topic of this work) considers PLM mainly as a tool for tracking change and improvements, while other key characteristics of PLM, like the use of digital items (later detailed at section 2.1), is a base characteristic of the material requirements planning which is a tool utility that also dabbles intoMES..

Odoo 管理軟體（這是本工作的主題）主要將 PLM 視為追蹤變更和改進的工具，而 PLM 的其他關鍵特徵（例如數位專案的使用（稍後在第 2.1 節中詳細介紹））是基本特徵物料需求計劃是一種工具實用程序，也涉足 MES。

2.1 Product lifecycle management 產品生命週期管理

Any information produced by an individual or team is done by an empirical creative process. A task requires either previous knowledge/experience or it will be inevitably plagued by mistakes and corrections, which in turn generates said experience in exchange of time and resources. That experience is, traditionally, embedded in the human resource (employee) that produced the information in the first place.

個人或團隊產生的任何資訊都是透過經驗創作過程完成的。一項任務要么需要先前的知識/經驗，要么將不可避免地受到錯誤和糾正的困擾，這反過來又會產生所述經驗，以換取時間和資源。傳統上，這種經驗嵌入最初產生資訊的人力資源（員工）中。

Product Life-Cycle Management (PLM) is an organizational process that aims to control the flow of information regarding all aspects of a product throughout its life-cycle. As one can imagine, this definition, and its broad scope, does not make understanding PLM any easier. The thing to focus on, for all purposes, is that PLM true value is in what concerns change.

產品生命週期管理 (PLM) 是一個組織流程，旨在控制產品整個生命週期各個面向資訊的流動。可以想像，這一定義及其廣泛的範圍並沒有讓理解 PLM 變得更容易。出於所有目的，需要重點關注的是 PLM 的真正價值在於關注變化。

圖. 2.1: Product lifecycle stages 產品生命週期階段

PLM is above all a connecting technology, not an individual technology islet or information processing system (Saaksvuori and Immonen, 2008). The idea is that every information produced by company personnel holds value equivalent to the time and money invested. Using that information saves money, not using that information wastes money. This is easier to understand when looking to a design process.

PLM首先是一種連結技術，而不是一個單獨的技術島或資訊處理系統（Saaksvuori和Immonen，2008）。我們的想法是，公司人員產生的每個訊息都具有與投入的時間和金錢相當的價值。使用該資訊可以節省金錢，而不使用該資訊會浪費金錢。當查看設計過程時，這一點更容易理解。

E.g. if an engineer designs an electronic circuit, the file holding the CAD drawing has an equivalent value to the time and money invested in it. The problem comes from the fact that in a traditional system only the engineer knows the design process behind the file, the extent of what is inside and its possible uses. While, from the perspective of the rest of the company, that is just a file in the database alongside thousands of others. The result is that, on its own, the information is of limited

例如。如果工程師設計電子電路，保存CAD圖紙的文件與投入的時間和金錢具有相同的價值。問題在於，在傳統系統中，只有工程師知道文件背後的設計過程、內部內容的範圍及其可能的用途。然而，從公司其他部門的角度來看，這只是資料庫中的一個文件，與數千個其他文件一起。結果是，這些資訊本身的用途有限。

If by any chance there is another engineer working in a similar design it will become extremely difficult for him/her to find that file and use it in his own design. Ultimately this results in waste because Engineer2 will have to spend more time and money doing something that wasalready made just because that information was not easily available or well organized.

如果萬一有另一位工程師從事類似的設計，他/她將很難找到該文件並在自己的設計中使用它。最終這會導致浪費，因為第二位工程師將不得不花費更多的時間和金錢來做一些已經完成的事情，因為這些資訊不容易獲得或組織良好。

This scenario is not limited to product design, but also to all aspects of the product lifecycle that produces change over time. Someone had to orchestrate how that piece will be produced , how that piece will be moved,packed , distributed and disposed of. When a problem is found or improvements are possible those changes also produce information and consume resources. If the company cannot take advantage of that existing information about all those phases of the product conception it will waste resources at every single redesign.

這種場景不僅限於產品設計，還包括隨著時間的推移而產生變化的產品生命週期的各個方面。必須有人精心策劃如何生產該作品，如何移動、包裝、分發和處置該作品。當發現問題或可能進行改進時，這些變更也會產生資訊並消耗資源。如果公司不能利用有關產品構思所有這些階段的現有信息，那麼每次重新設計都會浪費資源。

Product Lifecycle Management consists of an information system that allows information and knowledge sharing within and betweenorganizations (Sudarsan et al., 2005) minimizing the waste by controlling and organizing those files with information that would otherwise be carried only by the human resource that produced said files. The way it accomplishes that is by virtualizing all components of the product life-cycle in the form of digital “items” in an object oriented architecture. As explained by (Saaksvuori and Immonen, 2008),an item is a systematic and standard way to identify, encode and name a product, a product element or module, a component, a material or a service.

產品生命週期管理由一個資訊系統組成，該系統允許組織內部和組織之間共享資訊和知識（Sudarsan et al., 2005），透過控制和組織這些文件的資訊來最大限度地減少浪費，否則這些文件只能由產生所述文件的人力資源攜帶。它實現這一目標的方式是在物件導向的架構中以數位「專案」的形式虛擬化產品生命週期的所有元件。如（Saaksvuori 和 Immonen，2008）所解釋的，項目是識別、編碼和命名產品、產品元素或模組、組件、材料或服務的系統和標準方法。

These item objects are, by all means, virtual representations that hold metadata regarding what it tries to represent and allows to connect and link the information. As described by (D’ Antonio et al., 2015) product information should be connected to its production process. PLM allows to link defined processes to the product and to provide constraints on the order of process execution. E.g. a CAD drawing for a circuit schematic is attached to a virtual circuit object that holds basic information about what is contained in the file and all the previous iterations of that file over time as well as links to items representing which bill of materials (BOM) it belongs to, the machines necessary to manufacture it, the processes necessary to assemble it and more importantly how all those items changed over each improving iteration.

無論如何，這些項目物件都是虛擬表示，它們保存有關其試圖表示的內容的元數據，並允許連接和連結資訊。如（D’ Antonio 等人，2015）所述，產品資訊應與其生產過程相關聯。PLM 允許將定義的流程連結到產品，並對流程執行的順序提供約束。例如。電路原理圖的 CAD 繪圖附加到虛擬電路對象，該對象保存有關文件中包含的內容以及該文件隨時間推移的所有先前迭代的基本信息，以及表示其物料清單 (BOM) 的項目的鏈接屬於，製造它所需的機器，組裝它所需的流程，更重要的是所有這些項目在每次改進迭代中如何變化。

This all-around virtualization gives precious context to information otherwise lost on its own complexity. It allows for faster access, easier understanding of the whole and the consequences of what happens when there is change for each part. This is the best way of organizing the existing data for future reference because it allows for structure as well as transparency.

這種全方位的虛擬化為資訊提供了寶貴的背景信息，否則會因其自身的複雜性而丟失。它允許更快地訪問、更容易理解整體以及每個部分發生變化時所發生的後果。這是組織現有資料以供將來參考的最佳方式，因為它允許結構和透明度。

To sum up, PLM as a system aims to track functional change in all aspects regarding the product life, in a way that the company can benefit strategically from it by avoiding informational waste. It does so by virtualizing the real thing in the form of digital items that store the files regarding what the item is supposed to represent. These can in turn be correlated and tracked over time using metadata.

總而言之，PLM 作為一個系統，旨在追蹤產品生命週期各個方面的功能變化，從而使公司能夠透過避免資訊浪費來策略性地從中受益。它透過以數位項目的形式虛擬化真實事物來實現這一點，這些項目儲存有關該項目應該代表的內容的文件。這些又可以使用元資料隨著時間的推移進行關聯和追蹤。

2.2 Enterprise Resource Planing 企業資源規劃

In the early days of information systems, one of the first systems to find wide implementation was the called MRP (Material Requirements Planning). Although not necessarily software based, this system wide implementation was a natural consequence of computing technology and it aimed to solve bottlenecks regarding the material supplying and product output by calculating the material needs for production. As it became more ubiquitous in the enterprise in the late 70' s and early 80' s the system evolved. This gave origin to MRP II (Manufacturing Resource Planning) and, more important to the scope of this paper, ERP (Enterprise Resource Planning).

在資訊系統的早期，最早被廣泛實施的系統之一是 MRP（物料需求計劃）。儘管不一定基於軟體，但這種系統範圍的實施是計算技術的自然結果，旨在透過計算生產的材料需求來解決材料供應和產品輸出的瓶頸。20 世紀 70 年代末和 80 年代初，隨著它在企業中變得越來越普遍，該系統也在不斷發展。這催生了 MRP II（製造資源計劃），以及對本文範圍更重要的 ERP（企業資源計劃）。

For the most part modern Enterprise Resource Planning expands the original MRP function to encompass many other aspects of enterprise operations all while adding modularity to the system.

現代企業資源規劃在很大程度上擴展了原始 MRP 功能，以涵蓋企業營運的許多其他方面，同時為系統添加了模組化功能。

Modern ERP systems are often module based; different modules have different user interfaces and different user groups. For example, Manufacturing module, Procurement module, Logistics module, Financial module, Maintenance module, Sales module. (Saaksvuori and Immonen, 2008). These modules expand across many domains of knowledge but for the most part they do so always from the perspective of Production, Sales and Service. Figure 2 depicts the scope of the ERP system in comparison to other Information systems.

現代 ERP 系統通常是基於模組的；不同的模組有不同的使用者介面和不同的使用者群組。例如，製造模組、採購模組、物流模組、財務模組、維護模組、銷售模組。（Saaksvuori 和 Immonen，2008）。這些模組涵蓋了許多知識領域，但大多數情況下，它們總是從生產、銷售和服務的角度進行。圖 2 描述了 ERP 系統與其他資訊系統相比的範圍。

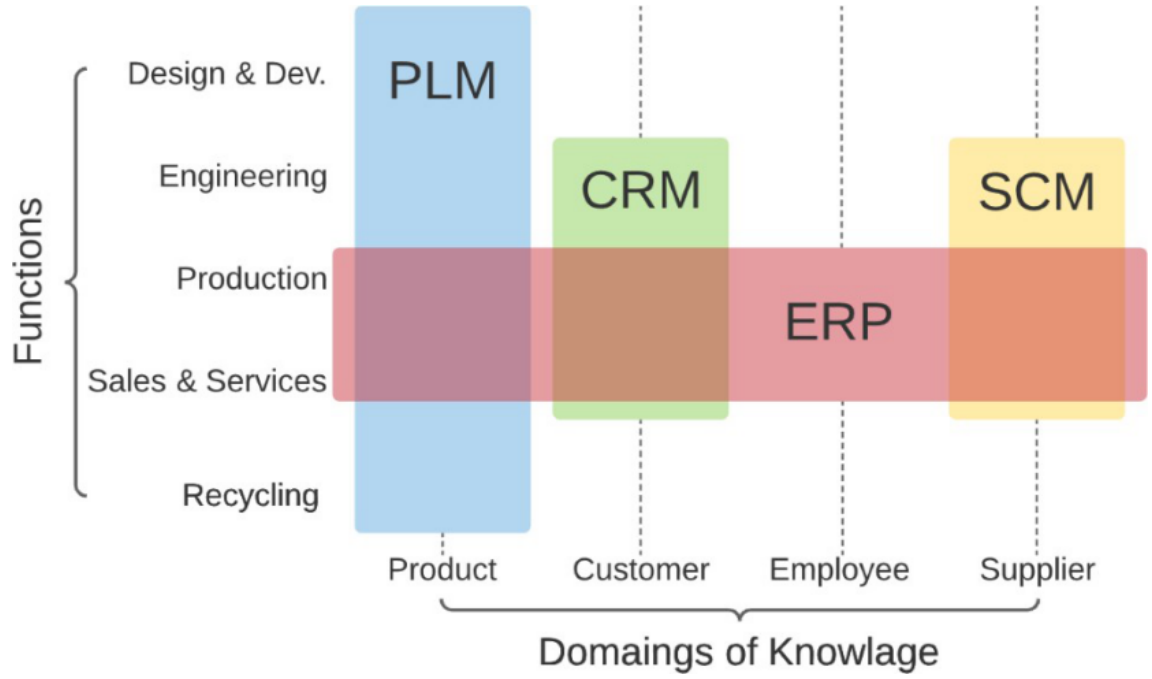

圖. 2.2: Visual representation of the scope of different information systems 不同資訊系統範圍的可視化表示

This sort broad reach across the domains makes sense because the ERP operations, as were in the case of MRP, focus on handling transactions and orders. The focus of the ERP is controlling the change in input, retention and output of resources to the company, be of products, raw materials or packing.

這種跨領域的廣泛影響是有意義的，因為 ERP 操作與 MRP 一樣，專注於處理交易和訂單。ERP 的重點在於控制公司資源（產品、原料或包裝）的輸入、保留和輸出的變化。

From the same image, it is possible to see the theoretical contrast between PLM and ERP even though they are both extremely broad. While ERP expands across the domains of knowledge but limits itself to a few functions, PLM expands across all functions that involve the product. As portrayed by Figure 3, another point of view that represents a good difference between the two is the lack of overlap in what concerns the scale or level of detail in which ERP and PLM affects the industry (i.e. the granularity of the two systems).

從同一張圖中，可以看出 PLM 和 ERP 之間的理論差異，儘管它們的範圍都非常廣泛。ERP 擴展了知識領域，但僅限於少數功能，而 PLM 擴展了涉及產品的所有功能。如圖 3 所示，代表兩者之間良好差異的另一個觀點是 ERP 和 PLM 影響行業的規模或詳細程度（即兩個系統的粒度）方面缺乏重疊。

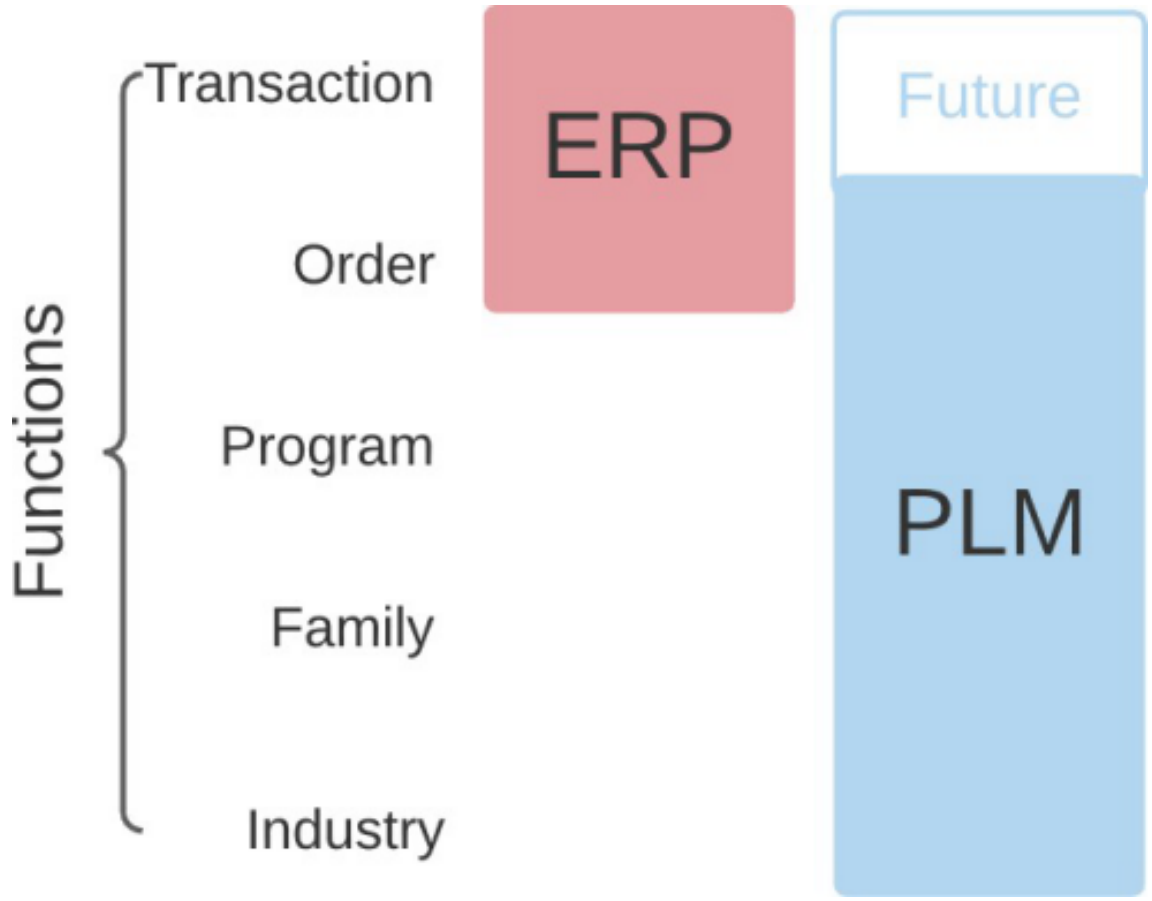

圖. 2.3: Visual comparison of ERP and PLM concerning granularity
ERP 和 PLM 在粒度方面的直觀比較

As we can see, ERP is primarily concerned with the transaction and the order. Once an order is closed out, the ERP system processes the transactions with respect to that order but is not very much concerned with the order beyond that. On the other hand, PLM' s granularity is concerned with the order for the product and extends not only into the program, but into the family and the entire industry .

正如我們所看到的，ERP 主要關注的是交易和訂單。一旦訂單關閉，ERP 系統就會處理與該訂單相關的交易，但不太關心除此之外的訂單。另一方面，PLM 的粒度涉及產品的訂單，不僅擴展到程序，還擴展到家庭和整個行業。

This is particularly interesting because it demonstrates how the two systems can and do complement each other in the field. One of the aspects of ERP that should point out is that it is comparatively easier to integrate with other systems. ERP-MES integration for instance has been widely studied and implemented to the point where standards have been developed for it (ISA 95 - IEC 62264). One argument for this is the modular nature of the ERP system which is discussed further in the paper in (Chapter 5) with the analysis of the Odoo software. That is because the Odoo software evolved originally from an open-source ERP system.

這是特別有趣的，因為它展示了這兩個系統如何能夠並且確實在該領域中相互補充。ERP 值得指出的一方面是它與其他系統的整合相對容易。例如，ERP-MES 整合已被廣泛研究和實施，並已為其製定了標準（ISA 95 - IEC 62264）。對此的一個論點是 ERP 系統的模組化性質，這將在本文（第 5 章）中透過對 Odoo 軟體的分析進行進一步討論。這是因為 Odoo 軟體最初是從開源 ERP 系統發展而來的。

The nature of the ERP system is best summed up by (Umble et al. 2003): ERP provides a unified enterprise view of the business which encompasses all functions and departments, and an enterprise database in which all actions concerning finance, sales, marketing, purchasing and human resources are traced. The aim of this achieving is to expand the customers target and increase customers share in a market that slowly pivots to innovation .

ERP 系統的本質可以這樣概括（Umble et al. 2003）：ERP 提供了一個統一的企業業務視圖，其中包含所有職能和部門，以及一個企業資料庫，其中涉及財務、銷售、行銷、採購和人力資源都被追蹤。實現這一目標的目的是擴大客戶目標並增加緩慢轉向創新的市場中的客戶份額。

2.3 Manufacturing Execution System 製造執行系統

The final key of a fully integrated system would be the Manufacturing Execution System (MES). A MES is a layer of communication between he management and the production levels; it is a software that allows data exchange between the organizational level, usually supported by an ERP, and the shop-floor control systems, in which several, different, very customized software applications are employed (Meyer et al., 2009).

完全整合系統的最後一個關鍵是製造執行系統（MES）。MES 是管理階層與生產層之間的溝通層；它是一種允許組織層面（通常由 ERP 支援）和車間控制系統之間進行資料交換的軟體，其中使用了多種不同的、高度客製化的軟體應用程式（Meyer 等人，2009 年）。

Figure 4 is a nice depiction of how different systems fit within the scope of manufacturing and development.

圖 4 很好地描述了不同的系統如何適應製造和開發的範圍。

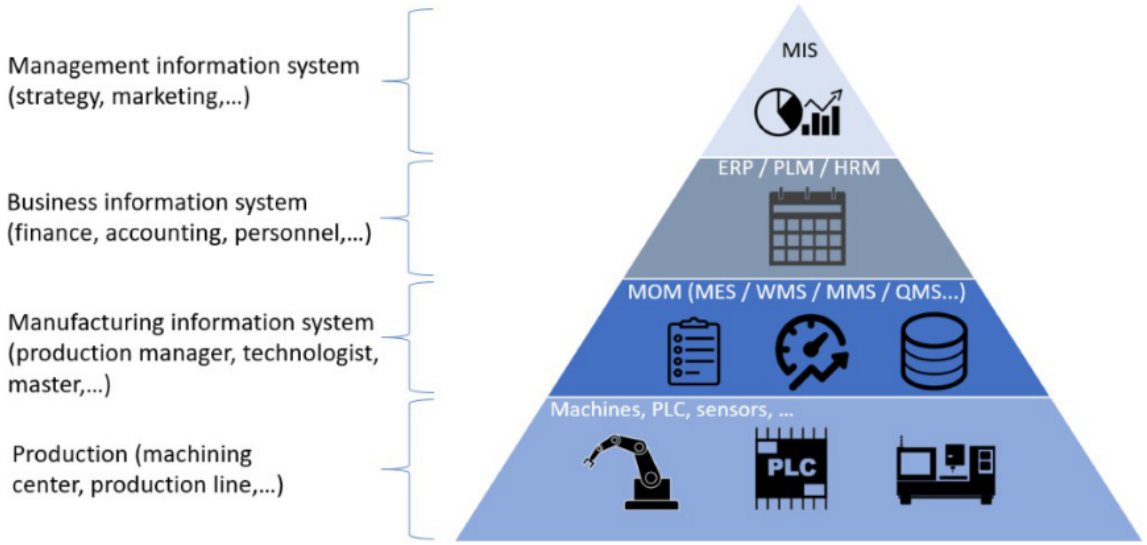

圖. 2.4: Visual representation of the roll of different systems including MES
包括 MES 在內的不同系統的滾動視覺化表示

For all purposes MES main goal is to provide the numbers and data that ultimately is used to ascertain the condition and quality of not only the products but also all the processes that affect production. Machines, sensors, and anything that comes in contact with the product and provides output of any kind, basically, handing said data to the MES for sorting and processing in real time. E.g. if a manager wants to know the instant production numbers or to see a graphical representation of the rejection rate, that data will be available from a MES software.

出於所有目的，MES 的主要目標是提供最終用於確定產品以及影響生產的所有流程的狀況和品質的數字和數據。機器、感測器以及與產品接觸並提供任何類型輸出的任何東西，基本上將所述資料傳遞給 MES 進行即時分類和處理。例如。如果經理想要了解即時生產數據或查看廢品率的圖形表示，則可以從 MES 軟體取得該數據。

Traditionally it is from this sort of information that management will evaluate efforts and make decisions. As mentioned before this sort of data collection fits perfectly to the use of ERP not only because the management of resources can be much more detailed if complemented by real time production data but also because the modularity of ERP usually means a seamless integration. MES (like ERP) has also been proven and implemented for decades and their implementation have already been standardized to a reasonable degree.

傳統上，管理層將根據此類資訊評估工作並做出決策。如前所述，這種數據收集非常適合 ERP 的使用，不僅因為如果輔以即時生產數據，資源管理可以更加詳細，而且還因為 ERP 的模組化通常意味著無縫整合。MES（如 ERP）也已被證明和實施了數十年，其實施已達到合理的標準化程度。

The functionalities of a MES have been grouped in 11 categories by MESA International(1997); furthermore, the tasks for each enterprise layer and, in turn, for each kind of information system are listed in the ISA95 –IEC62264 (2013) standard. This standard also provides definitions for the data structures to be exchanged among information systems aiming to enhance their integration; however, it mainly focuses on ERP-MES-Shop floor integration (D' Antonio et al., 2015).

MESA International (1997) 將 MES 的功能分為 11 類；此外，ISA95–IEC62264 (2013) 標準中列出了每個企業層以及每種資訊系統的任務。該標準還提供了資訊系統之間交換的資料結構的定義，旨在增強資訊系統的整合度；然而，它主要關注 ERP-MES-車間整合（D'Antonio 等，2015）。

PLM studies by comparison are much more recent and PLM-MES integration, a main focus of this work, even more so. The challenge of this sort of integration and the state of the art regarding it was be covered in (Chapter 3) as well as the theoretical structure behind it. For now, suffice to point out that since MES provides the feedback by which changes are orchestrated and results are validated by generating information in the form of files and PLM focus on the tracking change by file organization there sure is value in the PLM-MES

相較之下，PLM 研究是較新的，而 PLM-MES 整合（這項工作的主要焦點）更是如此。（第 3 章）及其背後的理論結構涵蓋了這種整合的挑戰和相關的最新技術。目前，只需指出，由於 MES 提供回饋，透過產生文件形式的資訊來編排變更並驗證結果，而 PLM 專注於按文件組織追蹤變更，因此 PLM-MES 確實有價值一體化。

2.4 Industry 4.0 工業 4.0

The term Industry 4.0 is one mentioned time and time again in modern literature as the next or current step in the evolution of production. It represents what is the 4th industrial revolution where the first was marked the adoption of steam power, the second was marked mainly using electrical power and the 3rd was characterized by the implementation of digital technology. Figure 5 nicely represents the progression of industrial revolutions.

工業 4.0 一詞在現代文獻中被多次提及，被視為生產演變的下一步或當前步驟。它代表了第四次工業革命，第一次工業革命的特徵是蒸汽動力的採用，第二次工業革命的特徵是主要使用電力，第三次工業革命的特徵是數位技術的實施。圖 5 很好地展示了工業革命的進展。

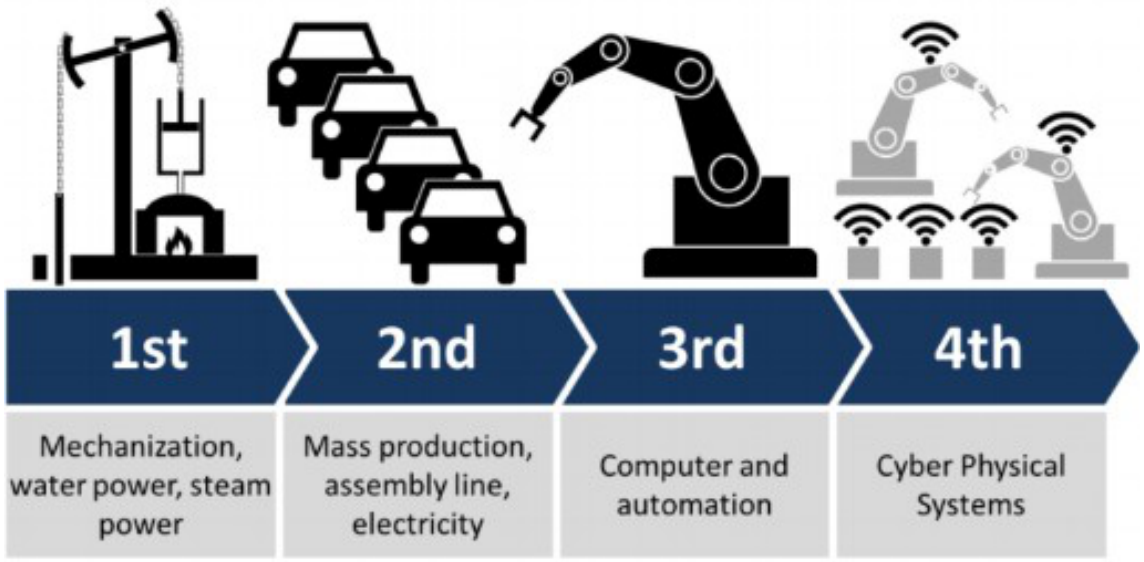

圖. 2.5: The industry evolution 產業演變

In broad strokes the 4th industrial revolution is (or will be) ultimately marked by the full integration between digital connectivity and production. As it is well known that the development of digital networks is the pivotal technology that sustain the modern world. It has changed the way humans interact and do business. However, whether the current level in which it is applied to the industry constitutes an industrial revolution is still uncertain because in all other revolutions have been marked by a violent increase in production that is yet to happen this time around. In fact, we are still to reach a shared definition of Industry 4.0.

從廣義上講，第四次工業革命的最終標誌是（或將）數位連接與生產之間的全面整合。眾所周知，數位網路的發展是維持現代世界的關鍵技術。它改變了人類互動和開展業務的方式。然而，目前它應用於工業的水平是否構成工業革命仍然不確定，因為在所有其他革命中，其標誌都是產量的劇烈增加，而這一次尚未發生。事實上，我們仍然沒有對工業 4.0 達成共同的定義。

What has been widely accepted however is that there are at least 3 technologies that characterize Industry 4.0. Those are the Internet of things (IoT), Cloud computing and the development of Cyber-Physical Systems (CPS), the last of which is particularly important for the context of this thesis.

然而，人們普遍認為至少有 3 種技術可以表徵工業 4.0。這些是物聯網（IoT）、雲端運算和網路物理系統（CPS）的發展，最後一個對於本論文的背景尤其重要。

CPS are systems consisting in a real entity (for example, a machine) and its corresponding virtual model –embedding all the models for mimicking the behavior of the real counterpart –capable to communicate with each other (D' Antonio et al., 2017). The idea is that, if one were to develop a digital twin (DT) of all physical instruments regarding a process in a system that allows for the digital counterparts to interact with each other as well as interacting with the physical world, innovation or change of said process would occur much faster and effectively. E.g., an engineer could simulate a change using the DT' s interaction, then, if successful, apply the change automatically to the production line in real time, execute tests, gather data and feed it back to the system without the need of manual input with all being done through the network.

CPS 是由真實實體（例如機器）及其相應的虛擬模型組成的系統 - 嵌入所有用於模仿真實對應物行為的模型 - 能夠相互通信（D'Antonio 等人，2017）。這個想法是，如果要開發所有實體儀器的數位孿生（DT），涉及系統中的一個過程，允許數位對應物相互交互以及與物理世界交互，創新或改變該過程將發生得更快、更有效。例如，工程師可以使用 DT 的交互來模擬變更，然後，如果成功，則將變更自動即時應用到生產線，執行測試，收集數據並將其反饋給系統，而無需手動輸入所有內容是透過網路完成的。

The main point to be derived from all this is that PLM-MES systems possibly are the first step to achieve a proper CPS since it provides for the virtualization and necessary control to reach something near a virtual twin. The debatable matter is how deep is its current effect in industrial application.

從這一切中得出的要點是，PLM-MES 系統可能是實現適當 CPS 的第一步，因為它提供了虛擬化和必要的控制來達到接近虛擬孿生的效果。值得爭議的問題是它目前在工業應用中的影響有多深。

Nonetheless, the term Industry 4.0 is, if anything, a useful denotation to the increasing application of digital connectivity, network development and the internet to industry.

儘管如此，工業 4.0 這個術語如果有的話，也是對數位連接、網路發展和互聯網在工業中日益增長的應用的有用表示。

Another term often included within the scope of Industry 4.0 is the called Lot Size One or Lot 1. This is the idea of each item customized to the individual specifications of the buyer in a system in which a customer order does not start supply chain equipment moving; it turns on manufacturing machines.

工業 4.0 範圍內經常包含的另一個術語稱為“批量大小一”或“批量 1”。這是在系統中根據買方的個人規格定制每個項目的想法，在該系統中，客戶訂單不會啟動供應鏈設備移動; 它打開製造機器。

The theory behind it is that as production and development becomes more and more flexible as this sort of manufacturing becomes not only viable but also attractive. Having a tailored requested product means that there are no storage requirements, no inventory overhead, and of course a 100percent guaranteed sell. This concept is not new by any means, in fact it predates Industry 4.0 quite a lot. In the book "The machine that changed the world" the authors (Womack et al., 1990) discuss that toward this end, lean producers employ teams of multiskilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in enormous variety.

背後的理論是，隨著生產和開發變得越來越靈活，這種製造不僅變得可行而且有吸引力。擁有量身訂製的需求產品意味著沒有儲存要求、沒有庫存開銷，當然還有 100percent 的銷售保證。無論如何，這個概念並不新鮮，事實上它早在工業 4.0 之前就出現了。在《改變世界的機器》一書中，作者（Womack 等人，1990）討論了為此目的，精益生產者在組織的各個層面僱用多技能工人團隊，並使用高度靈活、自動化程度越來越高的機器來生產大量種類繁多的產品。

In a way 'Lot Size One' is nothing more than the extrapolation of this sort of thinking. Of course, the industry is yet to reach such level of production flexibility, but glimpses of this sort of mentality can already be seem on more modular productions. One of the best examples is amazon packing systems. E.g. a customer receives a package from Amazon containing a mix of products that has been packaged just for him/her according to their specific order. Although superficial in nature, this represents a high level of customization for the customer.

在某種程度上，「批量一」只不過是這種思考的推論。當然，該行業尚未達到這樣的生產靈活性水平，但這種心態已經可以在更模組化的生產中看到。最好的例子之一是亞馬遜包裝系統。例如。客戶收到亞馬遜的包裹，其中包含根據其特定訂單專門為他/她包裝的產品組合。雖然本質上很膚淺，但這代表了客戶的高水準客製化。

Another great example is electronics prototyping. Currently there are companies that take your printed circuit board designs and BOM, delivering small batches of assembled prototypes at a low cost. Prototyping of electronical devices used to be a highly expensive process, but some companies have flexibilized their production to the degree where they are able to deliver it fast and reliably. Again, that is possible because electronics components are inherently modular systems even if of high complexity. The following image (Figure 6 Example project of power supply adaptor circuit) is an example of an electronic circuit that was designed by this student and manufactured by JLCPCB within a single week.

另一個很好的例子是電子原型設計。目前，有些公司會採用您的印刷電路板設計和 BOM，以低成本提供小批量的組裝原型。電子設備的原型設計曾經是一個非常昂貴的過程，但一些公司已經將其生產靈活化到能夠快速可靠地交付的程度。同樣，這是可能的，因為電子元件本質上是模組化系統，即使其複雜性很高。下圖（圖 6 電源適配器電路範例專案）是該學生設計並由 JLCPCB 在一週內製造的電子電路範例。

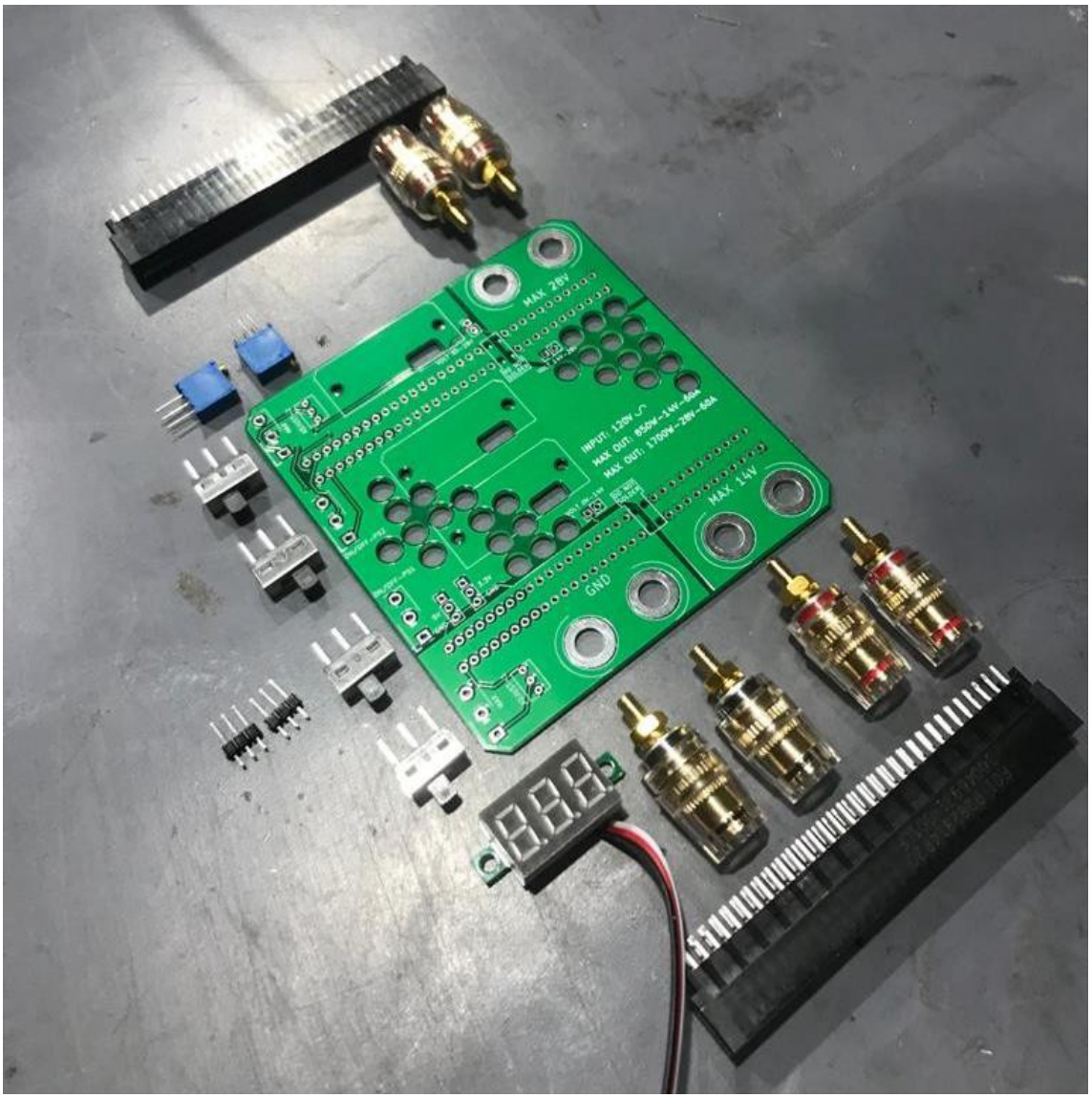

圖. 2.6: Example project of power supply adaptor circuit
電源適配器電路範例項目

All and all, the result is again a greater need for control and management of change. Which means the implementation of a PLM-MES system would be of great help. PLM would be required to manage change and innovation throughout the lifecycle of small batch products and MES would provide the real time reaction and feedback necessary to reduce errors that could cause losing a whole batch.

總而言之，結果再次是對變革的控制和管理的更大需求。這意味著 PLM-MES 系統的實施將會有很大的幫助。PLM 需要在小批量產品的整個生命週期中管理變更和創新，而 MES 將提供必要的即時反應和回饋，以減少可能導致整批產品遺失的錯誤。

Chapter 3

THE STATE OF THE ART AND THE INTEGRATION OF PLM AND MES
最先進的技術以及 PLM 和 MES 的集成

Unfortunately, there are not many published studies in the matter of integration between PLM and MES systems. But there seems to be a consensus in the most probable effects of said integration. Those being synchronization and tighter tolerances.

遺憾的是，關於 PLM 和 MES 系統整合問題的已發表研究並不多。但對於上述整合最可能產生的影響似乎已達成共識。這些是同步和更嚴格的公差。

As explained by D' Antonio et al. (2015), which focus on a case study involving the manufacturing of precision components for aeronautical applications, the first advantage expected by the deployment of the monitoring and control system is product quality improvement: sensors allow to detect, measure and monitor variables, events and situations that affect process performance or product quality.

正如德安東尼奧等人所解釋的。（2015），重點在於涉及航空應用精密零件製造的案例研究，部署監控系統預期的第一個優勢是產品品質改進：感測器允許檢測、測量和監控變數、事件和影響製程性能或產品品質的情況。

One of the central problems regarding integrating PLM with any other system revolves around the ownership of information. A possible solution relies on database integration as well as the use of middleware between systems. As is written in Saaksvuori and Immonen, (2008). A reasonable objective is that information should always be updated in one place. Other systems can read information directly from the PLM databases, and if necessary, the required information can be replicated on the databases of other system, as depicted in Figure7. Although it points this out mainly from the perspective of PLM-ERP integration, it is still very valuable from the perspective of PLM-MES integration because it is an example of how the better operation can be expected by working around systems in which files of different nature are loaded into a centralized PLM-ERP system.

將 PLM 與任何其他系統整合的核心問題之一涉及資訊的所有權。一種可能的解決方案依賴於資料庫整合以及系統之間中間件的使用。正如 Saaksvuori 和 Immonen (2008) 所寫。一個合理的目標是資訊應始終在一個地方更新。其他系統可以直接從 PLM 資料庫中讀取訊息，如果需要，可以將所需資訊複製到其他系統的資料庫上，如圖 7 所示。雖然主要是從 PLM-ERP 整合的角度指出了這一點，但從 PLM-MES 整合的角度來看，仍然非常有價值，因為它是一個範例，說明如何透過將不同性質的檔案載入到集中式 PLM-ERP 系統中的系統來實現更好的操作。

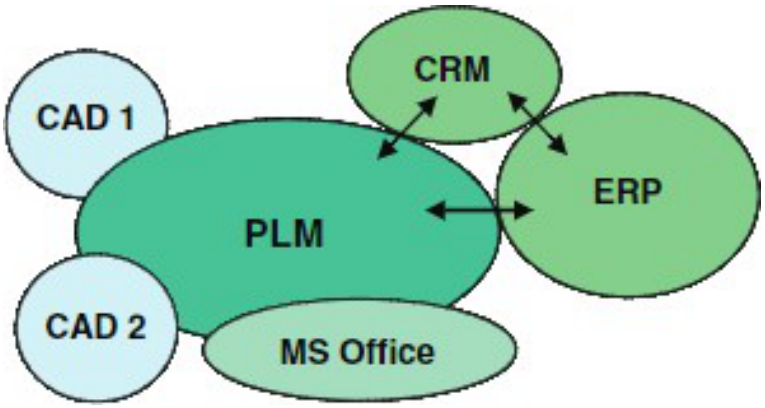

圖. 3.1: Diagram of PLM integration PLM 整合示意圖

The middleware would therefore be a software framework to organize and connect all the information given to the system database in a user-friendly way. This sort of application is also referred to as integration application and, as specified by Stark (2015), these applications enable exchange of product information between PLM applications (for example, between a CAD application and a CAE application). They also enable exchange of product information between PLM applications and other enterprise applications such as ERP and CRM.

因此，中間件將成為一個軟體框架，以使用者友好的方式組織和連接提供給系統資料庫的所有資訊。此類應用程式也稱為整合應用程序，並且根據 Stark (2015) 的規定，這些應用程式支援在 PLM 應用程式之間（例如 CAD 應用程式和 CAE 應用程式之間）交換產品資訊。它們還支援 PLM 應用程式與其他企業應用程式（例如 ERP 和 CRM）之間的產品資訊交換。

In a very relevant fashion, this middleware line of thinking is expanded upon by (Ben Khedher et al., 2011). In their work regarding different systems architectures for the implementation of an integrated MES+PLM they describe the use of a mediation system in web service architecture. As depicted in Figure 8, the proposed architecture uses data exchange based on internet technologies to help companies, especially expanded companies, to take advantage of opportunities generated by the Web Services. The concept of "web service" means an application (program or software system) which is designed to support interoperable machine-to-machine interactions over a network, according to the definition of W3C (Ben Khedher et al., 2011).

(Ben Khedher et al., 2011) 以非常相關的方式擴展了這種中間件思路。在他們關於實施整合 MES+PLM 的不同系統架構的工作中，他們描述了中介系統在 Web 服務架構中的使用。如圖 8 所示，所提出的架構使用基於互聯網技術的資料交換來幫助公司，特別是擴張型公司，利用 Web 服務產生的機會。根據 W3C 的定義，「Web 服務」的概念是指旨在支援網路上可互通的機器對機器互動的應用程式（程式或軟體系統）（Ben Khedher 等，2011）。

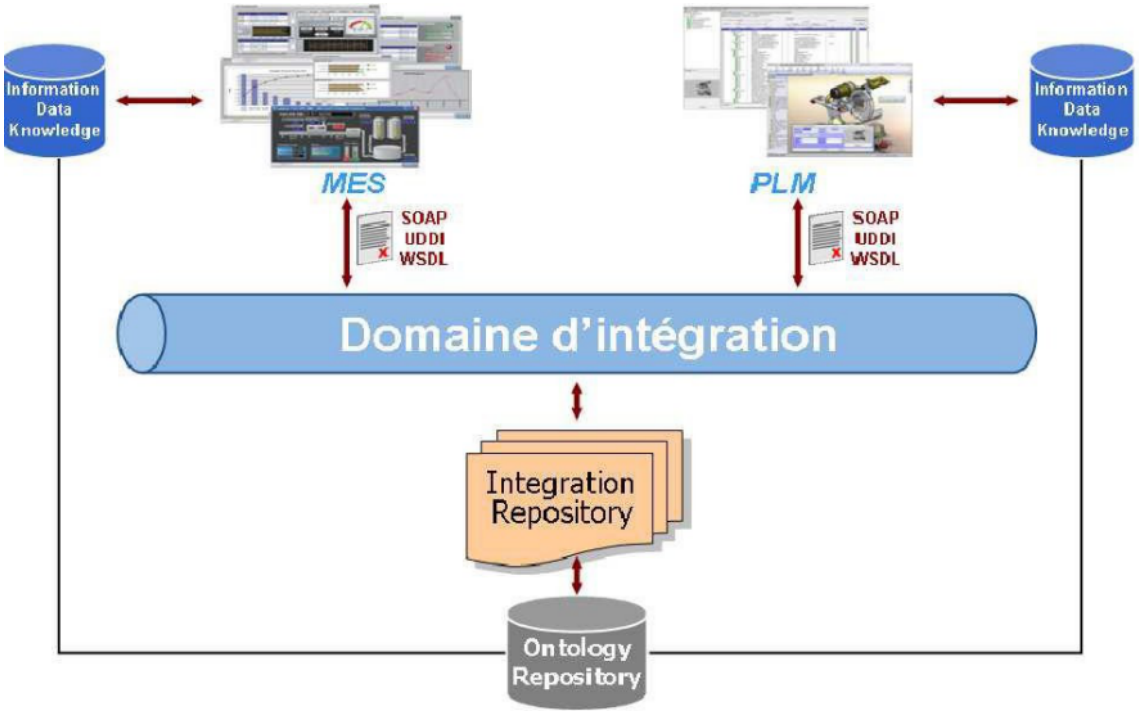

圖. 3.2: Diagram of Web service architecture Web 服務架構圖

The reason this expansion is so relevant from the perspective of this work is that the Odoo software works in a similar fashion through a similar web service architecture. In theory the Odoo software could act as the middleware working through the local network or hosted in the cloud and enacting the layer of integration that was previously mentioned.

從這項工作的角度來看，這種擴展如此相關的原因是 Odoo 軟體透過類似的 Web 服務架構以類似的方式運作。理論上，Odoo 軟體可以充當透過本地網路工作或託管在雲端中的中間件，並執行前面提到的整合層。

3.1 How would this integration look like in practical terms 這種整合在實際中會是什麼樣子

As mentioned in CHAPTER 2 the main idea of PLM is to manage change in all processes related to the product, and it does so mainly through the use of virtualization. The word virtualization here denotes representation of item of the real world to the digital space and, as one can imagine, there are several levels of abstraction through which a real object or process can be represented. As consequence there is no exact consensus regarding PLM of how deep and/or detailed the virtual representation must be to serve its purpose.

如第 2 章中所提到的，PLM 的主要想法是管理與產品相關的所有流程中的變更，它主要透過使用虛擬化來實現。這裡的「虛擬化」一詞表示現實世界的項目在數位空間中的表示，並且正如人們可以想像的那樣，可以透過多個抽象層級來表示真實的物件或過程。因此，對於 PLM 虛擬表示必須有多深和/或多詳細才能達到其目的，還沒有達成確切的共識。

In an ideal world that would be the lowest form of abstraction which, essentially, would come down to a digital twin as explained in the CHAPTER 2. This is a ‘1 to 1’ digital representation of every aspect of the production cycle where every part involved would have a digital representation that not only carry the physical characteristics of the item but also all its information produced over time. To this end, as explained in CHAPTER 2, MES takes a fundamental role in obtaining the real time information required for the DT even be possible.

在理想的世界中，這將是最低的抽象形式，本質上將歸結為數位孿生，如第 2 章所述。這是生產週期各個方面的「1 對 1」數字表示，其中每個部分所涉及的內容將具有數位表示，不僅包含該項目的物理特徵，還包含隨著時間的推移產生的所有資訊。為此，如第 2 章所述，MES 在獲取 DT 所需的即時資訊方面發揮基礎作用，甚至是可能的。

For instance, a CNC machine would have a digital 3D model for simulation as well as a fully integrated list of all the pieces it produces, data regarding its current level of production, the current wear of its mechanical pieces, all other machines it relates to, history of all the alterations and improvements by which it was affected and many other aspects, all well packaged in an intuitive graphical user interface (GUI) that allows for maximum interaction.

例如，數控機床將具有用於模擬的數位 3D 模型以及其生產的所有零件的完全整合清單、有關其當前生產水平的數據、其機械零件的當前磨損情況以及與其相關的所有其他機器、受影響的所有變更和改進的歷史記錄以及許多其他方面，全部都很好地封裝在直覺的圖形使用者介面 (GUI) 中，可實現最大程度的互動。

Outside of fiction, we are yet to achieve such level of virtualization. It takes too much time and money to obtain and organize information to such a level of minutia, specially, the aspects that need to be inserted by hand, not to mention the subjectiveness of how this information can be integrated and interacted with. Regardless of that it is useful to identify, within the ideal, the aspects of most importance for this implementation.

除了小說之外，我們還沒有達到這樣的虛擬化程度。獲取和組織如此詳細的資訊需要花費太多的時間和金錢，特別是需要手動插入的方面，更不用說如何整合和互動這些資訊的主觀性了。不管怎樣，在理想情況下確定對於此實施最重要的方面是有用的。

Those are:
那些是：

- The means of virtualization –What sort of information is used to build the virtual items. This includes the metadata and files that are directly attached to the item. In an ideal fashion this would contain all possible information available about the item.
  虛擬化的手段－使用什麼樣的資訊來建構虛擬物品。這包括直接附加到項目的元資料和文件。在理想的情況下，這將包含有關該項目的所有可能的可用資訊。
- The means of data input - How this information is being loaded and organized. Ideally this information would be loaded into the system as automatically as possible, be it by means of MES during quality control or through the use of automated input tools like bar code scanners.

資料輸入的方式 - 如何載入和組織這些資訊。理想情況下，這些資訊將盡可能自動載入到系統中，無論是在品質控制期間透過 MES 還是透過使用條碼掃描器等自動輸入工具。

- The means of access – How this information is presented to the users. Although more subjective than the previous aspects this is incredibly important to the way the system is interacted with. How intuitive it is the information availability plays right into the core strengths of PLM. Afterall, everything would be for nothing (even if all else would be perfect) if the only way to interact with the system were a command line interface that would make difficult for the end users to access the information.
  存取方式－如何將資訊呈現給使用者。儘管比前面的方面更主觀，但這對於系統互動的方式非常重要。資訊可用性的直覺程度正是 PLM 的核心優勢。畢竟，如果與系統互動的唯一方式是命令列介面，而這將使最終用戶存取資訊變得困難，那麼一切都將毫無意義（即使其他一切都很完美）。

- The means of integration - How items and their contained information can interact and benefit from one another, i.e., the integration with other systems and key softwares. E.g., if an item has access to a cad file, there should be no need to fill in the metadata fields by hand. Hoe items can automatically affect other items also plays into this aspect.
  整合方式 - 專案及其所包含的資訊如何互動並相互受益，即與其他系統和關鍵軟體的整合。例如，如果某個項目可以存取 cad 文件，則無需手動填寫元資料欄位。鋤頭項目可以自動影響其他項目也能發揮作用。

Chapter 4

INTRODUCTION TO THE COMPANY AND PRODUCT

公司及產品介紹

As one can imagine, one of the unique aspects of this work is its focus in one specific software solution that tend to be quite flexible in terms of ease of implementation to different sorts of business. This is contrary to most use cases regarding PLM implementation where the business case is the constant and the system is built around it. Nonetheless, in order to evaluate Odoo as a PLM+MES tool, it is important to consider an example. The advantage here is that a fictional company can be picked for this end maximizing the perceived effect of the software during a simulation.

可以想像，這項工作的獨特之處之一是它專注於一個特定的軟體解決方案，該解決方案在易於實施不同類型的業務方面往往非常靈活。這與大多數有關 PLM 實施的用例相反，在這些用例中，業務案例是不變的，系統是圍繞它構建的。儘管如此，為了評估 Odoo 作為 PLM+MES 工具的能力，考慮一個範例很重要。這裡的優點是可以選擇一家虛構的公司來實現這一目的，從而在模擬過程中最大化軟體的感知效果。

It is considering all those previously mentioned systems that, for the sake of exemplification, the theoretical company was organized in the molds of Industry 4.0. This company is a recently founded small case manufacturing company that uses plastic injection molding as their primary mean of production and uses additive manufacturing and fast prototyping as part of their business strategy. As explained in chapter 2 those are great examples of the path that industry is taking regarding innovation where mass production is becoming slowly less important than product variety and time to market.

考慮到前面提到的所有系統，為了舉例說明，理論公司是按照工業 4.0 的模式組織的。該公司是一家最近成立的小型箱體製造公司，使用塑膠射出成型作為主要生產方式，並使用積層製造和快速原型製作作為其業務策略的一部分。如第 2 章所解釋的，這些都是產業在創新方面所採取的路徑的很好的例子，在這種創新中，大規模生產逐漸變得不如產品品種和上市時間重要。

In order to maximize the tracking of change, most of its business are based on lower production batches on mainly automated machinery. This company focus in the production of injected plastic products and rely heavily in flexible machinery for setting production and prototyping. Having that in mind, it should be simple enough to simulate continuous improvement of both product and process to the extent of the evaluated software. Since this sort of everchanging production is extremely dependent on information management of all kinds, it must prove to be a perfect base for applied PLM+MES.

為了最大限度地追蹤變化，其大部分業務都基於主要自動化機械上的較低生產批次。該公司專注於注射塑膠產品的生產，並嚴重依賴靈活的機械來進行生產和原型製作。考慮到這一點，它應該足夠簡單，可以在評估的軟體範圍內模擬產品和流程的持續改進。由於這種不斷變化的生產極其依賴各種資訊管理，因此它必須成為應用 PLM+MES 的完美基礎。

In this example the company has already implemented, since its recent foundation, the Odoo software and has taken all the necessary training and steps to its proper use. This allow the removal of the boundaries and limitations that are so common regarding implementation of the PLM+MES system to an already existing business, i.e., dependences on legacy systems administrative resistance to change or integration to old procedures. These are obviously important, but it is not within the scope of this work.

在這個例子中，該公司自最近成立以來已經實施了 Odoo 軟體，並採取了所有必要的培訓和步驟來正確使用該軟體。這樣可以消除在現有業務中實施 PLM+MES 系統時常見的邊界和限制，即依賴遺留系統管理對更改或整合舊程式的抵制。這些顯然很重要，但不屬於本工作的範圍。

The company aims to produce a completely new product by the end of the year. After doing so, the company improved the process of production for said product. Once there is the need for product improvement, said improvement was performed as well.

該公司的目標是在今年底前生產出全新的產品。在此之後，該公司改進了該產品的生產流程。一旦產品需要改進，也進行改進。

The following diagram (Figure 9) will be taken into consideration as the path of product development and improvement:

將考慮下圖（圖 9）作為產品開發和改進的路徑：

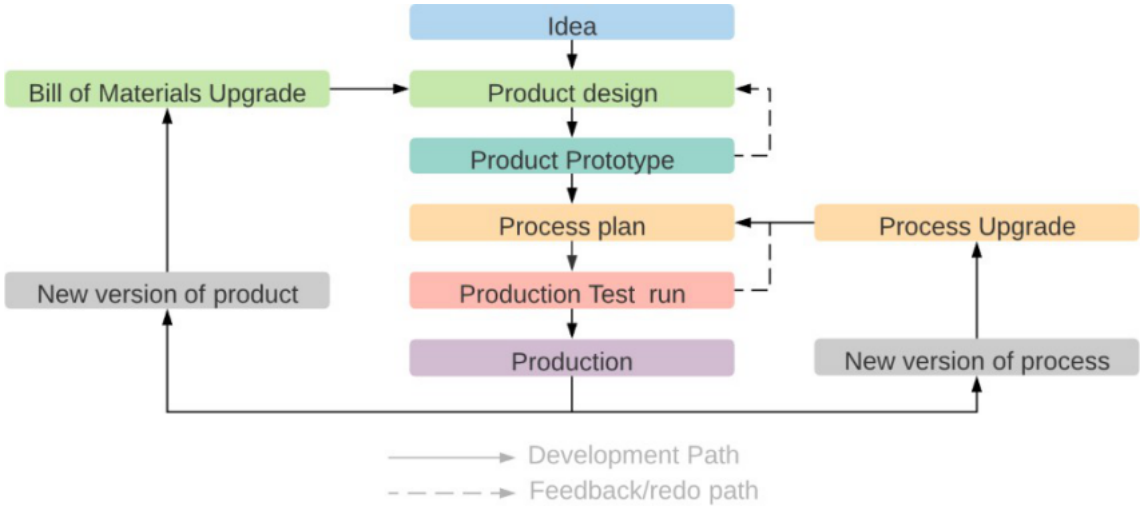

圖. 4.1: Development diagram 開發圖

This path aims to transmit to the reader an iterative approach towards development and improvement. The idea is followed by a product design for which a cycle of prototyping and redesign takes effect until satisfactory result is achieved. Then a similar cycle takes place regarding the production process. At the end of this stage initial development is done and the actual production can begin.

這條路徑旨在向讀者傳達一種開發和改進的迭代方法。這個想法之後是產品設計，原型製作和重新設計的循環生效，直到獲得滿意的結果。然後在生產過程中會發生類似的循環。在此階段結束時，初步開發完成，實際生產即可開始。

It is at this point that ways of stablishing the continuous improvement is important. In the case of this company, we are only considering two main types of upgrade paths, those being, product upgrade and process upgrade respectively.

正是在這一點上，建立持續改進的方法很重要。就這家公司而言，我們只考慮兩個主要的升級路徑，分別是產品升級和流程升級。

4.1 The products and processes 產品和工藝

Change and effect are the focus of the PLM+MES implementation as such the subject of said change would ideally be something that could afford a reasonable amount of freedom of design. Although the effects of a well implemented PLM+MES should be substantial even in rigid manufacturing environments, where the change is extremely limited, the system will produce much more perceivable change in an enterprise that thrives in innovation because there will be more opportunities to improve the system and gain feedback.

變更和效果是 PLM+MES 實施的重點，因此理想情況下，上述變更的主題應該能夠提供合理的設計自由。雖然實施良好的 PLM+MES 的效果即使在變化極其有限的嚴格製造環境中也應該是顯著的，但該系統將在創新蓬勃發展的企業中產生更明顯的變化，因為將有更多的機會來改進系統並獲得回饋。

From the perspective of improvement, if you compare a product that is a result from sheet metal stamping (Figure 10) to an equivalent product that is the result of a CNC milling procedure (Figure 11) it is easy to perceive that the CNC milled product is more welcoming to upgrades. While the stamping is low cost (by comparison) it depends on heavy high precision metal dyes that are extremely expensive to produce. This means that the cost of enacting change to it is much higher and thus the effect of a system that thrives on tracking change becomes limited.

從改進的角度來看，如果將鈑金沖壓的產品（圖 10）與 CNC 銑削加工的同等產品（圖 11）進行比較，很容易看出 CNC 銑削的產品更歡迎升級。雖然沖壓成本較低（相比之下），但它依賴於生產成本極其昂貴的重型高精度金屬染料。這意味著對其進行更改的成本要高得多，因此依靠追蹤更改而蓬勃發展的系統的效果變得有限。

圖. 4.2: Example of stamped AK74 pattern rifle receiver (Brownnells.com) 印有 AK74 圖案的步槍機匣範例 (Brownnells.com)

圖. 4.3: Example of milled AK74 pattern rifle receiver (sharpsbros.com) 銑削 AK74 型步槍機匣範例 (sharpsbros.com)

In the case of this fictional company, it has been determined that the best way to exemplify the PLM+MES effects would be to have products designed around plastic injection molding. It might seem unintuitive at first to consider this manufacturing procedure, like the stamping procedure previously described, since it too depends on high precision molds during production. However, the main differences between the two is regarding ease of prototyping and the cost of upgrading.

就這家虛構的公司而言，我們確定體現PLM+MES效果的最佳方式是圍繞塑膠射出成型設計產品。乍一看，考慮這種製造過程（如前面描述的沖壓過程）似乎不直觀，因為它在生產過程中也依賴高精度模具。然而，兩者之間的主要區別在於原型設計的難易度和升級成本。

Injection molding is a broad and complex field of engineering that involves a huge variety of materials and methods, little of which is of the concern of this work. It is however relevant to point out that for the most part, the pressures involved in the injection molding are one order of magnitude lower than the when we are dealing with steel; softer materials can be used on their molds like CNC milled aluminum. At the same time, new advancements in the field of additive manufacturing have made possible to prototype plastic parts with much closer physical characteristics to the end result of a injected piece. Sometimes even prototype molds (Figure 12) can be used for a lower volume test runs during process upgrades.

射出成型是一個廣泛而複雜的工程領域，涉及各種各樣的材料和方法，但本工作只涉及其中很少一部分。然而，需要指出的是，在大多數情況下，射出成型中涉及的壓力比我們處理鋼時的壓力低一個數量級；模具上可以使用較軟的材料，例如 CNC 銑削鋁。同時，積層製造領域的新進步使得塑膠零件原型成為可能，其物理特性與注射件的最終結果更加接近。有時，甚至原型模具（圖 12）也可用於製程升級期間的小批量試運行。

圖. 4.4: Example of injection mold made using a 3D printer (thefabricator.com) 使用 3D 列印機製作射出成型模具的範例 (thefabricator.com)

Additive manufacturing has become an incredible tool for ultra-flexible production. This mindset of continuous improvement, especially when regarding prototyping and iterative design, is a hallmark of the lean mentality that is so relevant in the modern industry.

增材製造已成為超靈活生產的不可思議的工具。這種持續改進的心態，特別是在原型設計和迭代設計方面，是與現代工業密切相關的精益心態的標誌。

As mentioned in the previous section, in this case study it is considered the creation of a new product and its production process by the fictional company. This product consists in a plastic small form factor computer case, composed of 3 different parts (Figure 13) that are expected to be designed and prototyped considering combination of additive manufacturing and CNC milling towards a plastic injection molding production.

如上一節所提到的，在本案例研究中，它被視為虛構公司的新產品的創造及其生產過程。該產品由一個塑膠小型電腦機殼組成，由 3 個不同的部件組成（圖 13），預計在設計和原型製作時考慮將增材製造和 CNC 銑削相結合進行塑膠射出成型生產。

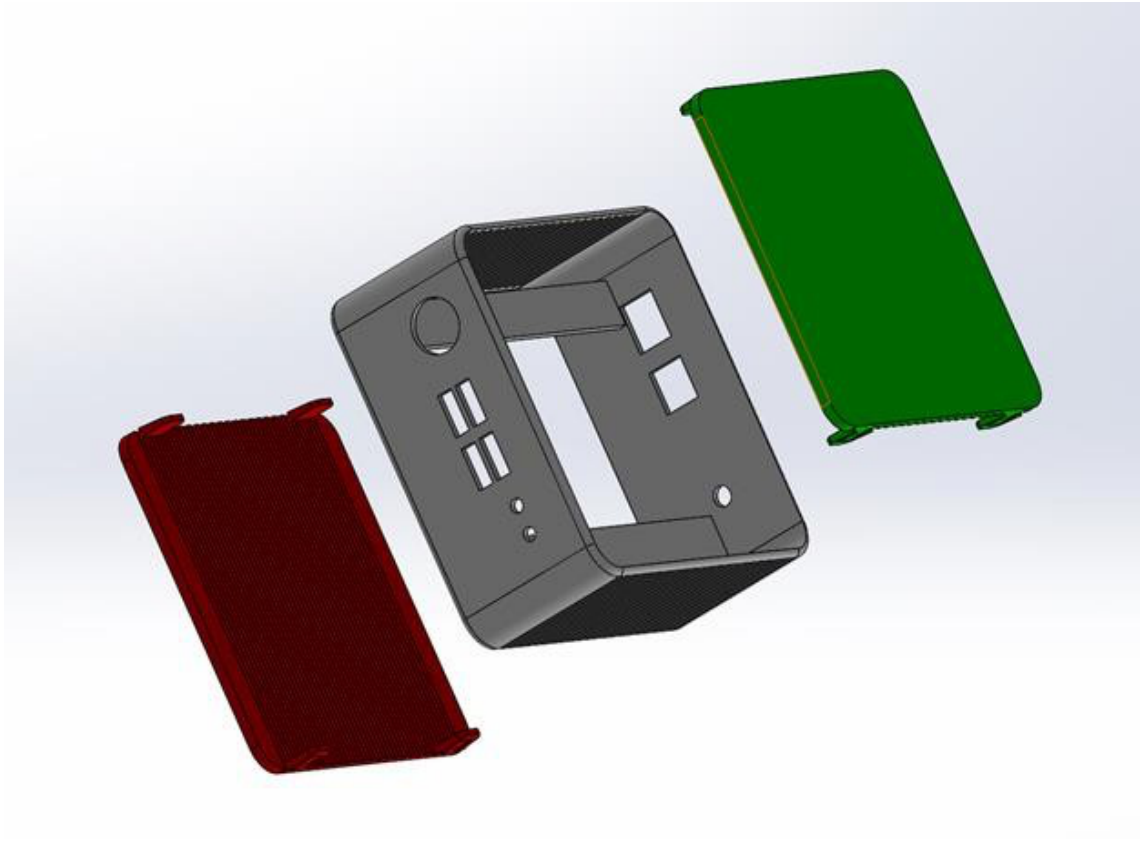

圖. 4.5: 3D exploded view of the theoretical product 理論產品的 3D 分解圖

4.1.1 Part A A 部分

PART-A (Figure 14) is the core structure of the computer case. It is expected to comport all the pieces necessary for the proper function of the small form factor computer in question. To this end a raw material A was selected to be Acrylonitrile Butadiene Styrene (ABS) this is an opaque thermoplastic polymer and an engineering grade plastic. It is commonly used to produce electronic parts such as phone adaptors, keyboard keys and wall socket plastic guards.

PART-A（圖 14）是電腦機殼的核心結構。它預計將配備所討論的小型計算機正常運行所需的所有部件。為此，原料 A 被選為丙烯腈丁二烯苯乙烯 (ABS)，這是一種不透明的熱塑性聚合物和工程級塑膠。它通常用於生產電子零件，例如電話適配器、鍵盤按鍵和牆壁插座塑膠防護罩。

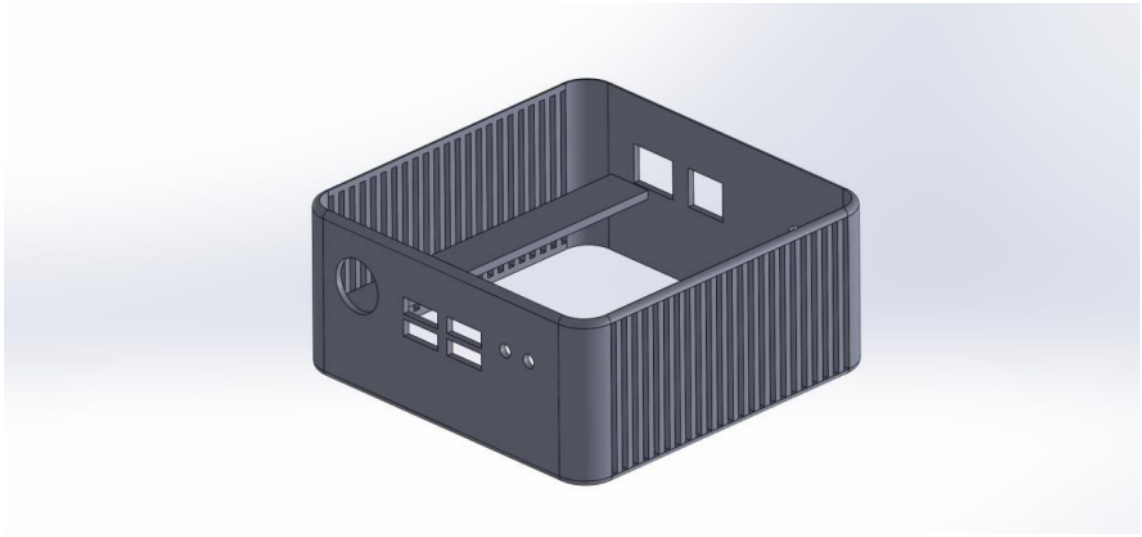

圖. 4.6: Isometric view of Part A A 部分等距視圖

The main reasons for choosing this material specifically are its toughness, its good dimensional stability (resistance to change dimensions after cooling), its high impact resistance and surface hardness. Finally, it is also commonly available in the form of 3D printing filament for extrusion 3D printers which should prove to be quite useful during prototyping.

特別選擇這種材料的主要原因是其韌性、良好的尺寸穩定性（冷卻後不易改變尺寸）、高抗衝擊性和表面硬度。最後，它通常也以用於擠出 3D 列印機的 3D 列印絲的形式提供，這在原型製作過程中應該非常有用。

4.1.2 Part B and C B 部分和 C 部分

Parts B and C are lids that should snap into place, closing the system. These are very simple pieces and require a certain level of elasticity so it can deform to assure a screwless assembly. These two identical parts are going to be made with Thermoplastic Polyurethane (TPU), because of its elastic nature and great tensile and tear strength. This sort of polymer is often used to produce parts that demand a rubber-like elasticity. TPU performs well at high temperatures and is commonly used in power tools, cable insulations and sporting goods. Finally, TPU is also available in the form of filament for 3D printers which, for the simulation, will be used for prototyping.

B 和 C 部分是蓋子，應卡入到位，關閉系統。這些都是非常簡單的零件，需要一定程度的彈性，以便可以變形以確保無螺絲組裝。這兩個相同的部件將由熱塑性聚氨酯 (TPU) 製成，因為它具有彈性、拉伸強度和撕裂強度。這種聚合物通常用於生產需要類似橡膠彈性的零件。TPU 在高溫下表現良好，常用於電動工具、電纜絕緣材料和體育用品。最後，TPU 還可以以細絲的形式用於 3D 列印機，用於模擬，用於原型製作。

圖. 4.7: Part B and C B 部分和 C 部分

4.1.3 Molds 模具

Ideally all molds should be made of steel, for longevity of the mold and product quality. That being said, the injected plastics that are being selected for all parts are not so pressure dependent and their forms are not so complex, so it is assumed that aluminum molds made with a precision CNC machining should suffice to produce said parts.

理想情況下，所有模具應由鋼製成，以確保模具的使用壽命和產品品質。話雖如此，為所有零件選擇的注射塑膠並不那麼依賴壓力，而且它們的形狀也不是那麼複雜，因此假設用精密 CNC 加工製造的鋁模具應該足以生產所述零件。

It is also assumed that all molds are simple enough to be prototyped using 3D printing. Although this is not always true, it was determined representative enough for this simulation. The type of material used in those prototypes is high temperature resign cured using an SLA 3DPrinter. Additionally, the mold will be considered the main physical aspect to be developed when regarding the production process because it something that directly affects the production as well as something that can be produced in house and tracked as a product would.

也假設所有模具都足夠簡單，可以使用 3D 列印來製作原型。儘管這並不總是正確的，但它對於本次模擬來說具有足夠的代表性。這些原型中使用的材料類型是使用 SLA 3D 列印機進行高溫重新固化的。此外，在生產過程中，模具將被視為要開發的主要物理方面，因為它直接影響生產，並且可以像產品一樣在內部生產和追蹤。

4.2 What is analized during the simulation 模擬過程中分析了什麼

Taking into consideration the diagram, shown in Figure 9, as well as the main aspects of a successful integration of PLM and MES as described in the section 3.1, this experiment aims to produce commentary regarding the following relevant questions in Table 1.

考慮到圖 9 所示的圖表，以及第 3.1 節中描述的 PLM 和 MES 成功整合的主要方面，本實驗旨在對錶 1 中的以下相關問題進行評論。

Table 1 Summary of questions to be answered
表 1 需回答的問題總表

Category	Questions
How does the software deals with items?	Are all aspects of the product lifecycle represented?
	How well are each of those items represented?
How easy it is to create a brand-new product?	How the product is depicted
	How does the product integrate and reference relevant files?
	Does changing one affects the other?
How easy it is to create a brand-new production process?	How the process is depicted?
	How does the process integrate and reference the product it produces?
	Does changing one affects the other?
How easy is to improve an existing product	How easy it is to update its metadata
	How easy it is to determine the effects of the change
	How does the software deals with different product revisions?
How easy it is to improve an existing production process	How easy it is to update its metadata
	How easy it is to determine the effects of the change
	How does the software deals with different production process revisions?
How easy is to find data related to product or process?	How easy is find production numbers?
	How does Odoo generate performance data?
	How does the software present performance change as a result of a upgrade?

類別	問題
軟體如何處理物品？	是否代表了產品生命週期的所有面向？ 這些項目的表現如何？
創造一個全新的產品有多容易？	產品的描述方式? 產品如何整合和引用相關文件？ 改變一個會影響另一個嗎？
創造一個是多麼容易全新的生產流程？	其過程是如何描述的？ 該流程如何整合和參考其生產的產品？ 改變一個會影響另一個嗎？
改進現有產品有多容易?	更新元數據有多容易? 確定變更的影響有多容易? 軟體如何處理不同的產品版本？
改進現有生產流程有多容易?	更新元數據有多容易? 確定變更的影響有多容易？ 軟體如何因應不同的生產流程修訂？
尋找與產品或流程相關的數據有多容易？	要找出生產編號有多容易？ Odoo 如何產生效能數據？ 軟體如何呈現效能變化升級？