overhead, and of course a 100in 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.

在《改變世界的機器》一書中，作者（Womack 等，1990 年）討論了這一概念早在工業 4.0 之前就已存在。為了實現這一目標，精益生產者在組織的各個層面都使用多技能工人團隊，並使用高度靈活、日益自動化的機器來生產各種各樣的產品。

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，"一批一"無非是這種思維方式的推斷。當然，工業尚未達到這種生產靈活性的水平，但這種思維方式的片段已經在更模塊化的生產中出現。其中一個最好的例子是亞馬遜的包裝系統。例如，一位顧客收到了一個由亞馬遜發出的包裹，其中包含了一批混合產品，這些產品是根據他們的具體訂單專門為他/她包裝的。儘管表面上看起來很簡單，但這對顧客來說代表著高度的定制化水平。

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製作。目前有些公司接受您的印刷電路板設計和 BOM，以低成本交付小批量組裝的原型樣品。電子設備的原型製作曾經是一個成本極高的過程，但一些公司已經使他們的生產過程變得非常靈活，以至於能夠快速而可靠地交付。同樣，這是可

能的，因為電子元件本身就是模塊化系統，即使它們具有高度的複雜性。下面的圖片（圖 6：電源適配器電路的示例項目）是一個電子電路的例子，該電路是由這位學生設計並在一周內由 JLCPCB 製造的。

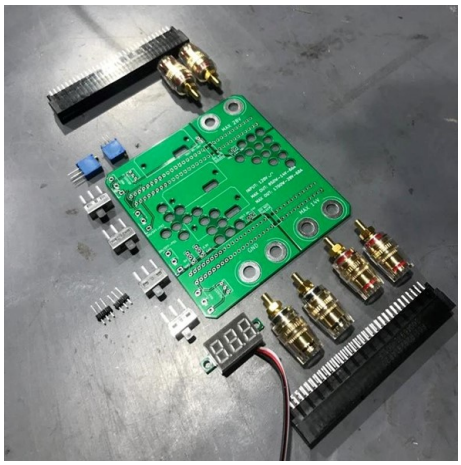

Figure 1: Example project of power supply adaptor

第 6 圖：電源適配器電路的示例項目 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 3 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，這再次引起了對變更控制和管理的更大需求。這意味著實施 PLM-MES 系統將會大有幫助。PLM 將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 將提供即時反應和反饋，以減少可能導致整批損失的錯誤。

3. CHAPTER THE STATE OF THE ART AND THE INTEGRATION OF PLM AND MES

第 3 章最新技術的狀態及 PLM 和 MES 的整合

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. 不幸的是，在 PLM 和 MES 系統整合的問題上，並沒有太多發表的研究。但似乎在該整合的最可能效果方面達成了共識。這些效果包括同步和更嚴格的容忍度。

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 D'Antonio 等人（2015 年）所解釋的，其聚焦於一個涉及航空應用的精密零部件製造的案例研究，監控和控制系統部署所期望的第一個優勢是產品質量的改善：傳感器可以檢測、測量和監控影響過程性能或產品質量的變量、事件和情況。

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 Figure 7. Although it points this out mainly from the perspective of PLM-ERP integration, 4 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.

關於將 PLM 與其他系統整合的一個核心問題是信息的所有權。一個可能的解決方案是依賴於數據庫集成以及系統之間的中間件的使用。正如 Saaksvuori 和 Immonen （2008 年）所述，一個合理的目標是信息應該始終在一個地方更新。其他系統可以直接從 PLM 數據庫中

讀取信息，如果必要，所需信息可以在其他系統的數據庫中複製，如圖 7 所示。儘管它主要從 PLM-ERP 整合的角度指出了這一點，但從 PLM-MES 整合的角度來看，這仍然非常有價值，因為它是一個示例，說明了通過在將不同性質的文件加載到集中式 PLM-ERP 系統中來期望更好的操作。

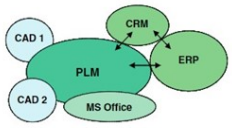

Figure 2: Diagram of PLM integration (Saaksvuori and Immonen, 2008)

第 7 圖 PLM 整合示意圖（Saaksvuori 和 Immonen，2008 年）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，中間件將是一個軟件框架，以用戶友好的方式組織和連接系統數據庫中提供的所有信息。這種應用程序也被稱為集成應用程序，正如 Stark（2015 年）所指出的，這些應用程序使產品信息在 PLM 應用程序之間進行交換（例如，在 CAD 應用程序和 CAE 應用程序之間）。它們還使產品信息在 PLM 應用程序和其他企業應用程序（如 ERP 和 CRM）之間進行交換。

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, 5 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).

在（Ben Khedher 等人，2011 年）中，對這種中間件思維方式進行了更深入的探討。在他們關於實現集成 MES+PLM 的不同系統架構的工作中，他們描述了在 Web 服務架構中使用調解系統。如圖 8 所示，所提出的架構使用基於 Internet 技術的數據交換，幫助公司，尤其是擴展的公司，利用 Web 服務所產生的機遇。”Web 服務” 的概念意味著一個設計用於支持網絡上的可互操作的機器對機器交互的應用程序（程序或軟件系統），根據 W3C 的定義（Ben Khedher 等人，2011 年）。

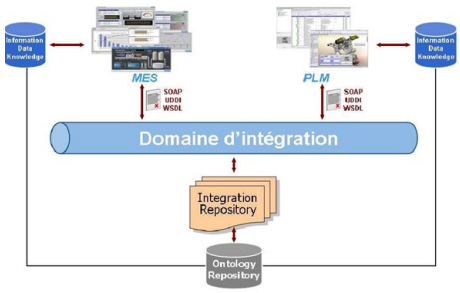

Figure 3: Diagram of Web service architecture (Adapted from Ben Khedher et al., 2011)

第 8 圖 Web 服務架構示意圖（改編自 Ben Khedher 等人，2011 年）

3.1. How would this integration look like in practical terms

3.1 實際上，這種整合會是什麼樣子？

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.

正如在第 2 章中提到的，PLM 的主要理念是管理與產品相關的所有過程中的變化，它主要通過虛擬化來實現。這裡的虛擬化一詞表示將現實世界的物品表示為數字空間中的物品，正如人們可以想象的，有幾個抽象層次可以通過將現實物體或過程表示出來。因此，在 PLM 方面，關於虛擬表示必須多深和/或詳細以達到其目的，沒有確切的共識。

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.

在理想的情況下，這將是最低形式的抽象，基本上就是所謂的數字孿生體，正如第 2 章所解釋的那樣。這是生產周期每個方面的“一對一”數字表示，其中涉及的每個零件都將具有數字表示，不僅包含物品的物理特性，還包含隨時間產生的所有信息。為此，如第 2 章所述，MES 在獲取 DT 所需的實時信息方面起著基本作用，甚至可能是可能的。

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，一台數控機床將具有數字 3D 模型進行仿真，以及一個完全集成的列表，列出了它生產的所有零件，有關其當前生產水平、機械零件的當前磨損情況、所有其他相關的機器、所有受影響的變更和改進的歷史，以及許多其他方面的數據，全部精心打包在一個直觀的圖形用戶界面（GUI）中，以實現最大的互動。

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.

在現實中，我們尚未達到這種虛擬化的水平。獲取和組織信息到這種極細節的水平需要太多的時間和金錢，特別是需要手動輸入的方面，更不用說如何整合和互動這些信息的主觀性。儘管如此，在理想中識別對於這種實現最重要的方面仍然是有用的。

Those are: 這些方面包括：

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.

虛擬化手段 - 用於構建虛擬項目的信息類型。這包括直接附加到項目的元數據和文件。在理想情況下，這將包含有關項目的所有可能信息。

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.

數據輸入手段 - 這些信息是如何載入和組織的。理想情況下，這些信息將尽可能自動地載入系統中，無論是通過 MES 在質量控制期間還是通過使用自動輸入工具如條碼掃描器。

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.

進入手段 - 這是信息向用戶呈現的方式。雖然比之前的方面更加主觀，但這對系統的互動方式非常重要。信息的可用性對 PLM 的核心優勢至關重要。畢竟，即使其他一切都完美無瑕，如果與系統互動的唯一方式是一個命令行界面，使最終用戶難以訪問信息，那一切也將化為烏有。

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.

整合手段 - 這是指項目及其包含的信息如何相互交互並從中受益，即與其他系統和關鍵軟件的集成。例如，如果一個項目可以訪問 CAD 文件，就不需要手動填寫元數據字段。項目如何自動影響其他項目也涉及到這個方面。

4. CHAPTER INTRODUCTION TO THE COMPANY AND PRODUCT

第四章公司和產品介紹

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.

可以想象，這項工作的獨特之處之一是它專注於一個特定的軟件解決方案，這種解決方案在不同類型的業務中實施起來相當靈活。這與大多數 PLM 實施的用例相反，其中業務案例是固定的，系統是圍繞其建立的。儘管如此，為了評估 Odoo 作為 PLM+MES 工具，考慮一個例子是很重要的。這裡的優點在於可以選擇一家虛擬公司來最大程度地展示軟件在模擬中的效果。

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.

考慮到之前提到的所有系統，在示例化的目的上，理論上的公司被組織成了工業 4.0 的模式。這家公司是一家新成立的小型製造公司，其主要生產手段是塑料注塑成型，並將添加製造和快速原型制作作為其業務策略的一部分。正如第二章中所解釋的，這些都是工業正在追求的創新途徑的絕佳示例，其中大量生產變得比產品多樣性和上市時間慢慢不那麼重要。

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

10 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.

為了最大程度地跟踪變化，其大部分業務都是基於主要是自動化的機器進行的低生產批次。這家公司專注於注塑塑料產品的生產，並且在設置生產和原型制作方面非常依賴靈活的機器。考慮到這一點，模擬產品和流程的持續改進應該相當簡單，以達到評估軟件的程度。由於這種不斷變化的生產極度依賴於各種信息管理，因此它必須證明是應用 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，這家公司自成立以來已經實施了 Odoo 軟件，並且已經進行了所有必要的培訓和使用步驟。這消除了對已經存在的業務實施 PLM+MES 系統時常見的界限和限制，即對遺留系統的依賴、管理對變革的抵制或對舊程序的集成。這些顯然很重要，但不在本工作的範圍之內。

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.

該公司的目標是在年底之前生產一種全新的產品。在這樣做之後，公司改進了該產品的生產過程。一旦需要產品改進，也進行了相應的改進。T he following diagram (Figure 9) will be taken into consideration as the path of product development and improvement:

下面的圖表（圖 9）將作為產品開發和改進的路徑加以考慮：

圖 9 開發圖表

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

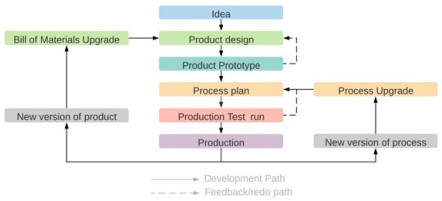

Figure 4: Development diagram

regarding the production process. At the end of this stage initial development is done and the actual production can begin.

該路徑旨在向讀者傳達一種對開發和改進的迭代方法。該想法是為一個產品設計，對其進行原型設計和重新設計的循環直到達到滿意的結果。然後，類似的循環發生在生產過程方面。在這個階段結束時，初始開發完成，實際生產可以開始。

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. 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.

4.1. The products and processes

4.1. 產品和流程

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 12 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.

變化和效果是 PLM+MES 實施的重點，因此變化的主題理想情況下應該是能夠提供合理設計自由度的事物。儘管在嚴格的製造環境中，變化受到極大限制時，良好實施的 PLM+MES 的效果仍然會很顯著，但在一個擅長創新的企業中，系統將會產生更加明顯的變化，因為那裡會有更多的機會來改進系統並獲得反饋。

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，如果將一個由板金沖壓產生的產品（見圖 10）與一個等效的由數控銑削過程產生的產品（見圖 11）進行比較，很容易就能感受到數控銑削產品更適合升級。儘管沖壓是低成本的（相對而言），但它依賴於昂貴的大型高精度金屬模具，這些模具的生產成本極高。這意味著對其實施變更的成本要高得多，因此依賴追蹤變化的系統的效果就變得有限了。

Figure 5: Example of stamped AK74 pattern rifle receiver (Brownnells.com)

圖 10 衝壓 AK74 型步槍機匣示例（Brownnells.com）

圖 11：銑削的 AK74 型步槍機匣示例（來源：sharpsbros.com）

Figure 6: Example of milled AK74 pattern rifle receiver (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.

對於這家虛擬公司而言，已經確定以塑料注塑成型為中心設計產品是展示 PLM+MES 效應的最佳方式。起初可能會覺得考慮這種製造過程有些不合常理，就像之前描述的沖壓過程一樣，因為它在生產過程中也依賴於高精度模具。然而，這兩者之間的主要區別在於原型設計的便利性和升級的成本。

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.

注塑成型是一個廣泛而複雜的工程領域，涉及了各種各樣的材料和方法，其中很少有與本工作相關的。然而，值得指出的是，大部分情況下，注塑成型所涉及的壓力比我們處理鋼

材時低一個數量級；較軟的材料可以用於它們的模具，例如數控銑削的鋁。與此同時，3D 列印技術在塑料部件原型設計方面取得了新的進展，使得塑料零件的原型可以具有更接近注塑成品的物理特性。有時甚至可以使用原型模具（見圖 12）進行低產量測試運行，以進行流程升級。

Figure 7: Example of injection mold made using a 3D printer (thefabricator.com)

圖 12：使用 3D 打印機製造的注塑模具示例（來源：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.

添加製造已成為超靈活生產的不可或缺的工具。特別是在原型設計和迭代設計方面，這種持續改進的思維方式是現代工業中非常重要的精益思維的標誌。

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.

正如前一節所提到的，在這個案例研究中，考慮了一家虛擬公司對新產品及其生產過程的創建。該產品是一款小型塑料電腦機箱，由 3 個不同的零件組成（見圖 13），預計將通過結合添加製造和數控銑削的方式進行設計和原型製作，以達到塑料注塑生產的目標。

圖 13：理論產品的 3D 分解圖

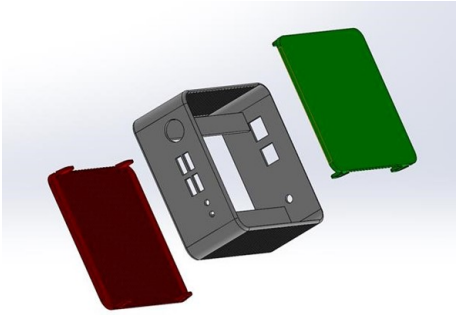

Figure 8: 3D exploded view of the theoretical product

4.1.1. Part A

4.1.1. 部件 A

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（見圖 14）是計算機機箱的核心結構。預計它將包含所有必要的零件，以保證所需小型機箱計算機的正常功能。為此，選擇了原材料 A，即丙烯腈丁二烯苯乙烯共聚物（ABS）。這是一種不透明的熱塑性聚合物，是一種工程級塑料。它通常用於生產電子零件，如電話適配器、鍵盤按鍵和插座塑料護套。