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# Réconcilier Lean Product Development et Innovation : Une étude de cas dans l'industrie des semi-conducteurs

Maéva Jaffré

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THÈSE

Pour obtenir le grade de

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### Réconcilier Lean Product Development et Innovation : Une étude de cas dans l'industrie des semi-conducteurs

### Reconciling Lean Product Development and Innovation: A case study in the semi-conductor industry

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*À la mémoire de mon oncle, Alain.*

*« Le véritable voyage de découverte ne consiste pas à chercher  
de nouveaux paysages, mais à avoir de nouveaux yeux. »*

- Marcel Proust

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Vous avez changé ma vie sans même chercher à le faire...

À la prochaine mes amis.

# Résumé

Cette thèse explore l'intégration du Lean Product Development (LPD) au sein du département de recherche et développement (R&D) de STMicroelectronics, un géant mondial des semi-conducteurs. Ancrée dans une approche de recherche-action, elle explore la manière dont le LPD peut être adapté pour stimuler l'innovation en R&D, en révélant les nuances nécessaires pour harmoniser les spécificités de ce département avec les principes du Lean.

STMicroelectronics, acteur clé dans le secteur des semi-conducteurs, a été choisi comme terrain d'étude. Son dynamisme et l'impératif constant d'innovation pour rester compétitif dans un marché exigeant en ont fait un cadre propice à l'expérimentation du LPD en R&D.

L'approche méthodologique a été résolument immersive, adoptant la posture de chercheur-acteur au sein du programme d'amélioration continue de la R&D technologique de STMicroelectronics. Cette immersion a permis une observation participante authentique, offrant une perspective unique pour collecter des données et expérimenter les principes du LPD directement sur le terrain.

Les résultats ont offert des indices cruciaux sur les liens entre le LPD et l'innovation en R&D. La question centrale posée par cette thèse était de savoir si le LPD, en tant que démarche, favorise l'innovation au sein des R&D notamment dans le domaine des semi-conducteurs.

La réponse qui a émergé est affirmative, mais conditionnelle. L'adaptabilité du LPD à chaque contexte spécifique est apparue comme une condition sine qua non. L'absence d'un cadre universel a été reconnue non seulement comme une réalité incontestable, mais également comme une force, laissant place à la notion de configuration, mieux apte à appréhender la complexité et la variabilité inhérentes à chaque environnement organisationnel.

Le LPD, en plaçant l'humain au cœur de sa démarche, a été identifié comme un catalyseur potentiel pour l'innovation. L'analyse a souligné le rôle critique des comportements humains, tels que la créativité et l'énergie/motivation, dans ce processus. Cependant, ces comportements ne peuvent être compris de manière isolée de l'operating system (OS) des entreprises.

L'étude a révélé que l'OS, comprenant l'ensemble des outils, des processus, des mécanismes et des activités cadencées d'une organisation, joue un rôle déterminant dans la création d'un environnement propice aux comportements innovants. Plus encore, cet écosystème organisationnel peut agir en tant que levier ou frein, influençant la manifestation de comportements humains favorables à l'innovation.

La réussite de l'intégration du LPD pour stimuler l'innovation dépend donc de la synergie entre la configuration spécifique du LPD adoptée, la reconnaissance du rôle central de l'humain, et la conception réfléchie de l'OS de l'entreprise. Ces éléments interconnectés créent un écosystème favorable, où le LPD et les comportements humains collaborent harmonieusement pour promouvoir l'innovation.

# Summary

This thesis explores the integration of Lean Product Development (LPD) within the research and development (R&D) department of STMicroelectronics, a global semiconductor giant. Rooted in an action-research approach, it explores how LPD can be adapted to stimulate innovation in R&D, revealing the nuances needed to harmonize the specificities of this department with Lean principles.

STMicroelectronics, a key player in the semiconductor sector, was chosen as the study site. Its dynamism and the constant need to innovate in order to remain competitive in a demanding market made it an ideal setting for experimenting with LPD in R&D.

The methodological approach was resolutely immersive, adopting the posture of researcher-actor within STMicroelectronics' continuous technological R&D improvement program. This immersion enabled authentic participant observation, offering a unique perspective for collecting data and experimenting with LPD principles directly in the field.

The results offered crucial clues about the links between LPD and R&D innovation. The central question posed by this thesis was whether LPD, as an approach, fosters innovation within R&D, particularly in the semiconductor field.

The answer that emerged was affirmative, but conditional. The adaptability of the LPD to each specific context appeared to be a *sine qua non* condition. The absence of a universal framework was recognized not only as an indisputable reality, but also as a strength, giving way to the notion of configuration, better able to apprehend the complexity and variability inherent in each organizational environment.

By placing people at the heart of its approach, the LPD was identified as a potential catalyst for innovation. The analysis highlighted the critical role of human behaviors, such as creativity and energy/motivation, in this process. However, these behaviors cannot be understood in isolation from a company's operating system (OS).

The study revealed that the OS, comprising all the tools, processes, mechanisms and cadenced activities of an organization, plays a decisive role in creating an environment conducive to innovative behavior. What's more, this organizational ecosystem can act as a lever or a brake, influencing the manifestation of human behaviors conducive to innovation.

The successful integration of LPD to stimulate innovation therefore depends on the synergy between the specific LPD configuration adopted, the recognition of the central role of people, and the thoughtful design of the company's OS. These interconnected elements create a favorable ecosystem, where LPD and human behaviors collaborate harmoniously to promote innovation.



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# Introduction générale

L'innovation est le moteur de la compétitivité dans l'économie mondiale actuelle, où les entreprises sont constamment en évolution rapide et confrontées à des défis complexes. Au cœur de cette quête d'innovation, les départements de Recherche et Développement (R&D) jouent un rôle central. Ils sont les moteurs de la créativité, de l'ingéniosité et de la capacité d'adaptation d'une entreprise, pour assurer ainsi son avenir (Le Masson et al., 2006).

Cependant, l'innovation en R&D est liée à divers contextes scientifiques et industriels. Elle est profondément enracinée dans les processus, les méthodologies et les cultures organisationnelles qui sous-tendent la R&D elle-même. C'est dans cet espace de convergence entre excellence opérationnelle et innovation que s'ancre notre exploration (Amsden & Tschang, 2003). Cette thèse est dédiée à la compréhension de l'intégration du Lean, en particulier du *Lean Product Development* (LPD), dans les activités de R&D et à son rôle dans la stimulation de l'innovation au sein d'une entreprise de semi-conducteurs, STMicroelectronics (*STMicroelectronics website*, 2023).

Le Lean, une philosophie de gestion d'origine japonaise, a émergé comme une force majeure de transformation dans le monde des affaires, principalement associée à l'amélioration des processus et à la réduction des gaspillages. Cependant, son application à la R&D est un domaine peu stabilisé. Le LPD, une branche du Lean, propose une approche pour repenser la manière dont les entreprises conçoivent, développent et lancent de nouveaux produits et services (Morgan & Liker, 2006; Reinertsen & Shaeffer, 2005).

STMicroelectronics incarne la fusion de la haute technologie et de l'innovation constante, deux éléments cruciaux dans la recherche de l'excellence opérationnelle au service de l'innovation en R&D. STMicroelectronics est également un exemple d'entreprise ayant entrepris la transition du Lean de la production vers la R&D, cherchant à créer un écosystème où l'efficacité opérationnelle et la créativité sont en harmonie.

Au cours de cette thèse, nous explorerons les défis et les opportunités inhérents à cette fusion de l'excellence opérationnelle et de l'innovation en R&D, en mettant en lumière le rôle du LPD dans la création d'un environnement propice à l'innovation. Nous analyserons les impacts sur les comportements humains, les systèmes opérationnels et les résultats d'innovation au sein de STMicroelectronics, tout en offrant des perspectives générales pour d'autres entreprises de haute technologie engagées dans des démarches similaires.

Cette exploration nous guidera à travers un voyage dans l'univers complexe de l'excellence opérationnelle au service de l'innovation en R&D, où le Lean peut devenir un catalyseur de l'innovation, et où STMicroelectronics se dessine comme un laboratoire vivant de cette transformation. Notre objectif est de contribuer à l'évolution de la compréhension des mécanismes qui sous-tendent l'innovation en R&D, en éclairant le chemin pour les entreprises qui aspirent à exceller dans ce domaine en constante évolution.

La présente thèse se propose à explorer en profondeur le lien entre le LPD et l'innovation, en se penchant sur les composantes qui caractérisent cette relation complexe. Nous émettons l'hypothèse que le lien entre LPD et innovation est modulé par les comportements humains au sein des organisations. En d'autres termes, le LPD influence les comportements humains, lesquels à leur tour influent sur le processus d'innovation au sein de l'entreprise (Figure 1). Le LPD influe également l'*Operating System* (OS) d'une organisation en agissant sur les processus, les outils, les activités, et de manière générale, sur tous les éléments caractéristiques de l'OS. L'OS peut à son tour avoir un impact sur les comportements humains. Nous supposons également que cet ensemble d'interactions est impacté par le contexte dans lequel il se réalise.

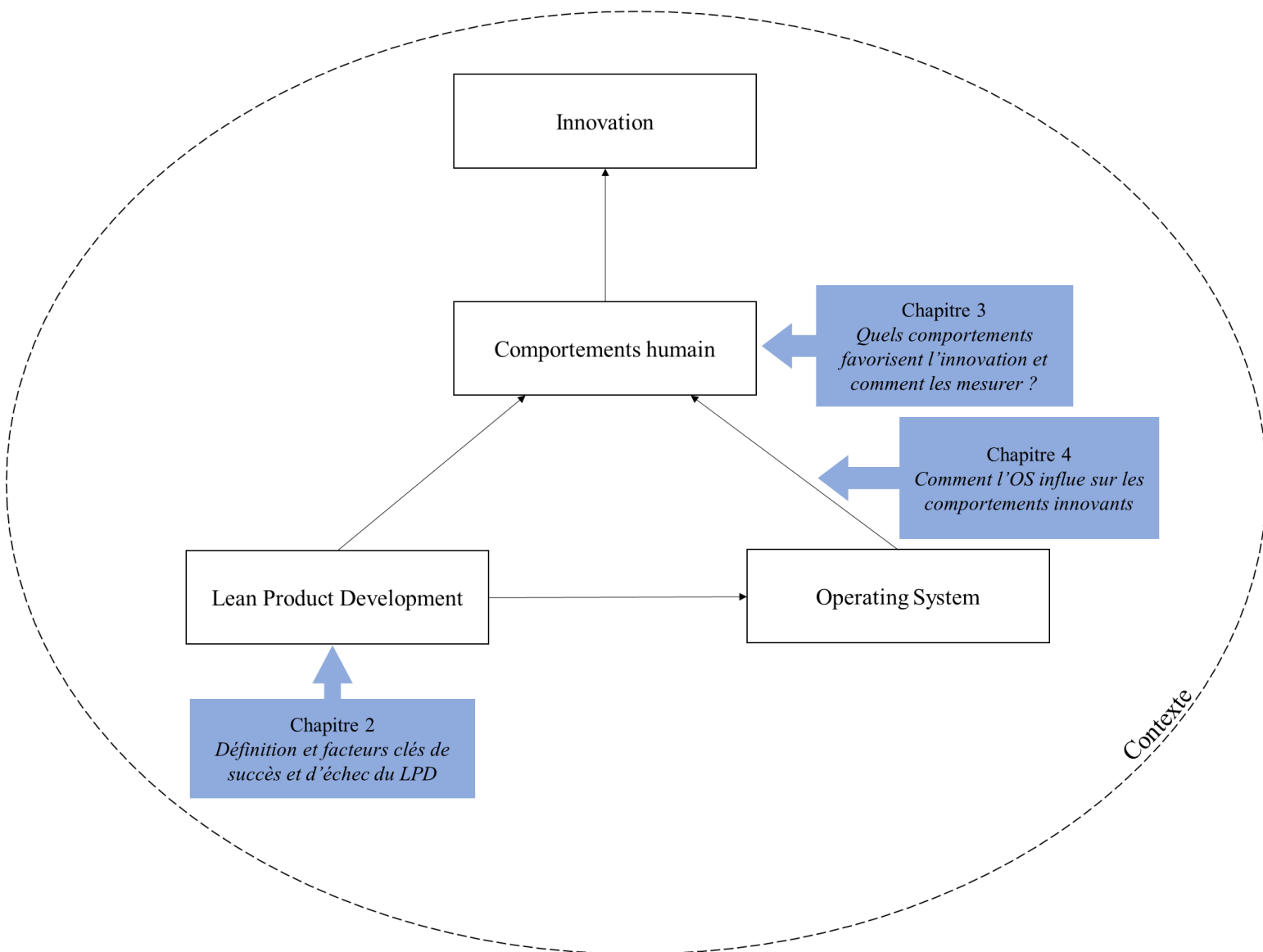


Figure 1 : Lien entre LPD innovation

Le premier chapitre de cette thèse vise à établir le contexte dans lequel cette recherche s'inscrit et à présenter la problématique qui en découle. Nous analyserons l'histoire du LPD, les défis de l'industrie du semi-conducteur et notre terrain d'étude, l'entreprise STMicroelectronics.

Le deuxième chapitre sera consacré à la présentation du concept de LPD. Nous clarifierons sa définition, examinerons les travaux existants dans la littérature et identifierons les facteurs de succès et les barrières à son application réussie. Comprendre les fondements du LPD est essentiel pour établir une base solide permettant d'explorer ses implications sur les comportements humains et, ultimement, sur l'innovation.

Dans le troisième chapitre, notre attention se tournera vers une analyse approfondie des comportements humains dans le contexte de l'innovation. Nous chercherons à définir les comportements propices à la génération et à la mise en œuvre d'idées novatrices.

Enfin, le quatrième chapitre se penchera sur l'impact de l'OS d'une organisation, comprenant ses outils, processus et activités cadencées, sur les comportements innovants. Nous explorerons comment l'OS peut favoriser ou entraver la manifestation des comportements humains propices à l'innovation dans le contexte du LPD.

Cette thèse adopte le format d'une thèse par article. Les chapitres 2, 3 et 4 sont donc également des articles indépendants. Ce choix a été motivé par la volonté de simplifier la gestion des accords de publication des données provenant de STMicroelectronics. Il convient de noter que cette structure peut occasionnellement engendrer une certaine redondance au niveau de la bibliographie

Cette thèse a fait l'objet des publications suivantes :

- Publications dans des revues internationales à comité de lecture
  - Jaffré Maéva, Blanco Eric, Chevrier Pierre, Penz Bernard (2023). The context dependency of Lean Product Development barriers and success factors, a literature review. *International Journal of Innovation and Technology Management* – article soumis après révisions
  - Jaffré Maéva, Blanco Eric, Chevrier Pierre, Penz Bernard (2023). Measuring What Matters: Using Key Behavior Indicators to Drive Innovation. *Journal of Open Innovation: Technology, Market, and Complexity* – article soumis
  - Jaffré Maéva, Blanco Eric, Chevrier Pierre, Penz Bernard (2023). The impact of an organization's Operating System on Innovative behavior, a case study. – article en cours de soumission
- Communication dans un congrès international
  - Jaffré Maéva, Blanco Eric, Chevrier Pierre, Penz Bernard (2023). Favoriser l'innovation par le lean product development: le comportement humain, un indicateur pertinent?. In *CIGI QUALITA MOSIM 2023, Trois-Rivières (Canada)*.



# Chapitre 1 :

## Contexte de l'étude et problématique

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# Chapitre 1

**C**e chapitre explore la transition du Lean, initialement conçu pour la production industrielle, vers le domaine de la Recherche et Développement (R&D). Cette transition offre une occasion unique d'analyser comment les principes Lean s'adaptent à des environnements intellectuels et créatifs, tout en générant des avantages tangibles. Dans cette introduction, nous allons dans un premier temps jeter un regard sur les origines du Lean et dévoiler les distinctions fondamentales entre les domaines de la production et de la R&D. Dans un second temps nous allons présenter notre cas d'étude, STMicroelectronics, un leader mondial de l'industrie des semi-conducteurs. Enfin, nous explorerons la méthodologie adoptée pour cette étude et les questions de recherche qui guideront notre étude.

## 1. Le Lean, de la production à la R&D : la genèse de notre recherche

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### 1.1. Les origines du Lean de la production à la R&D

Le concept du Lean, également connu sous le nom de Lean Manufacturing ou Lean Production, prend son origine au Japon, plus précisément dans l'industrie automobile, avec Toyota comme pionnier. Ses racines remontent aux années 1950, lorsque Toyota s'est lancée dans la création d'un système de production révolutionnaire pour faire face aux défis posés par les ressources limitées et les fluctuations du marché d'après-guerre. Les principes fondamentaux du Lean ont été formellement établis par Taiichi Ohno, l'ingénieur en chef de Toyota, au cours des années 1950 et 1960 (Iuga & Kifor, 2013). L'appellation « Lean » a été introduite en Occident en 1990 grâce à la publication de l'ouvrage « The Machine that changed the World », puis « Lean Thinking » qui ont théorisé, formalisé, décrit et popularisé le processus Lean. Ces ouvrages ont mis en lumière des principes essentiels du Lean, tels que l'élimination du gaspillage et la recherche de la valeur, la recherche continue de l'amélioration et la création d'une culture du respect envers les travailleurs (Womack et al., 1990; Womack & Jones, 1996).

Dans leur ouvrage, Womack et al. (1990) préconisent le déploiement des principes Lean à l'ensemble des opérations des entreprises. Après avoir réussi à améliorer leurs processus de production grâce aux principes du Lean, bon nombre d'entreprises ont constaté que la conception de produits devenait alors un nouveau goulot d'étranglement (Letens et al., 2011; Marodin et al., 2018; Reinertsen, 2009).

Depuis lors, après avoir prouvé ses bénéfices (Melton, 2005; Singh et al., 2010), la méthodologie Lean s'est étendue de l'industrie automobile à d'autres secteurs (Pranav, 2020), tels que la santé, le tourisme, la défense, la construction et les hautes technologies. Cet élargissement des champs applicatifs se manifeste également de la production à d'autres

fonctions de l'entreprise, notamment la finance (Dilton-hill, 2015), les ressources humaines (Jekiel, 2020; Mundth et al., 2020) et la recherche et développement (R&D) (Reinertsen & Shaeffer, 2005).

L'environnement hyper-compétitif des marchés créant une quête constante d'amélioration des performances des entreprises (Ilinitch et al., 1996), le Lean et de plus en plus utilisé dans le contexte de la R&D (Morgan & Liker, 2006).

### 1.2. Différences entre production et R&D

Le passage du Lean de la production à la R&D comporte des différences significatives en raison des caractéristiques intrinsèques de ces deux domaines (Ferreira et al., 2023; Lau et al., 2002). En effet, les processus de production et de R&D présentent des économies et des mécanismes de création de valeur distincts (Reinertsen & Shaeffer, 2005). Les paragraphes ci-après mettent en évidence les principales distinctions à prendre en compte pour penser le Lean en R&D et le Lean en production.

#### 1.2.1. Nature du travail et des processus

Les processus de production et de R&D présentent des différences fondamentales.

En production, les processus sont souvent répétitifs et centrés sur la fabrication de produits existants. Les tâches sont généralement prévisibles standardisées et concernent des objets physiques avec un emplacement unique pour chaque objet à un moment donné (Anand & Kodali, 2008; Thomke & Reinertsen, 2012; Welo, 2011a).

En revanche, la R&D se concentre sur l'innovation et la création de nouveaux produits, impliquant une grande part d'incertitude, d'expérimentation, et de créativité. Au lieu d'être un flux continu, la R&D fonctionne généralement en projets (Cooper & Edgett, 2005). Les projets de R&D sont uniques et comportent souvent une grande variabilité. Il est important de noter que cette variabilité à l'inverse de la production est vue positivement en R&D, car elle est un moyen de générer des connaissances et d'encourager l'agilité (Reinertsen & Shaeffer, 2005). Gudem et al. (2013) mettent également en avant la différence de complexité entre les deux processus : la R&D se concentre sur la génération et l'utilisation d'informations plutôt que sur des biens tangibles.

D'autre part, en production les résultats sont prévisibles et fixes. La durée des tâches est constante, peut souvent être réalisée par des machines et la réduction du nombre de tâches est un signe d'optimisation et d'amélioration (Welo, 2011a).

En R&D les résultats sont imprévisibles et variables. Moins de tâches ne signifie pas nécessairement de meilleures performances, et les tâches étant difficiles à définir complètement, cela rend la prédiction de leurs durées effectives souvent éloignée de la réalité,

d'autant plus qu'elles sont souvent effectuées par des personnes avant des machines (Cooper & Edgett, 2005; Welo, 2011a).

Enfin, les projets de développement de nouveaux produits s'étendent sur plusieurs années contre des secondes, ou tout au plus des jours pour la production.

### 1.2.2. Nature du produit

Une autre différence fondamentale réside dans la nature du produit. En production, le produit est un objet physique, visible, stocké en un seul endroit, avec des exigences de produit définies comme des contraintes. En R&D, le produit consiste en des informations et des connaissances qui nécessitent un réel effort d'organisation afin de les rendre visible et qui sont stockées souvent dans de multiples endroits. Les exigences du produit représentent des opportunités plutôt que des contraintes, ce qui confère à la R&D une plus grande flexibilité dans sa démarche (Welo, 2011a).

### 1.2.3. Personnel et culture

Les caractéristiques des employés dans ces deux domaines diffèrent généralement considérablement. En production, le personnel est généralement composé d'opérateurs et de techniciens avec un faible niveau de qualification, habitués à suivre des procédures et des méthodes établies par d'autres. Ce travail les invite le plus souvent à privilégier la réutilisation de ce qui a fonctionné dans le passé pour gagner du temps et réduire les risques. En revanche, en R&D, le personnel se compose de concepteurs, le plus souvent ingénieurs ou docteurs, avec un niveau de qualification très élevé. Ils sont moins soumis à suivre des règles et des procédures et valorisent l'entrepreneuriat, la créativité, et la prise de risque (Welo, 2011a). Ces différences dans la nature du travail demandé et dans le niveau de qualifications sont essentielles pour comprendre les défis spécifiques de chaque domaine.

### 1.2.4. Notion de valeur et de gaspillage

La notion de valeur et de gaspillage diffère considérablement entre la production et la R&D. En production, la valeur est principalement liée à la qualité, la livraison, et les coûts. Elle se matérialise principalement par un produit physique reçu par un client. Les définitions du gaspillage et de la valeur sont claires et simples, avec des outils prouvés disponibles pour les mesurer. Le gaspillage est plus visible et provient principalement d'activités inutiles. En R&D, il n'y a pas de définitions précises pour séparer la valeur du gaspillage, et la notion de valeur inclut de multiples désirs, préférences et significations des utilisateurs. La plupart des gaspillages ne sont pas facilement visibles et résultent souvent de l'entrée incorrecte d'informations plutôt que d'activités inutiles (Gudem et al., 2013a; Khan, Al-ashaab, Shehab, Haque, Ewers, et al., 2013).

### 1.2.5. Métriques et mesures

En production, les métriques et mesures sont souvent plus claires et basées sur des critères tangibles, tels que la qualité, la quantité produite et les coûts. Cependant, en R&D, les premières étapes de conception sont réputées difficiles à évaluer et à contrôler en raison du manque de livrables physiques, tels que des dessins. Cela rend la mesure de la quantité de travail accompli et restant sur une tâche donnée dans le projet particulièrement complexe (Ballard & Koskela, 1998). Les indicateurs de performance sont souvent moins directs et nécessitent des approches plus flexibles et adaptatives. En outre, la littérature disponible sur la mesure de la performance et des métriques pour les processus d'introduction de nouveaux produits en R&D est limitée, ce qui souligne les défis particuliers liés à l'évaluation de l'efficacité et du progrès dans ce domaine (Haque & James-Moore, 2004). Ces différences mettent en évidence la nécessité d'adopter des méthodologies de mesure spécifiques pour chaque contexte, en tenant compte des particularités de la production et de la R&D (Anand & Kodali, 2008).

### 1.2.6. Des différences mais pas que...

En résumé, au vu de toutes les différences entre production et R&D, le Lean Product Development ne peut pas être une simple adaptation du Lean Manufacturing (Khan, Al-ashaab, Shehab, Haque, Ewers, et al., 2013). C'est pourquoi tandis qu'il y a traditionnellement cinq principes pour le Lean Manufacturing, Morgan et Liker (2006) en ont développé treize spécifiques pour le développement de produits.

Cependant il est important de préciser que le Lean en R&D et le Lean en production partagent des principes de base tels que l'élimination des gaspillages et l'amélioration continue. Ils reposent sur un socle commun de culture, de philosophie et d'états d'esprits partagés. Parmi ces principes fondamentaux, on trouve notamment la vision selon laquelle un problème représente une opportunité d'amélioration, ainsi que la conviction que la collaboration et l'esprit collaboratif sont des éléments essentiels pour réussir dans les deux contextes. En conséquence, l'adaptation du Lean en R&D nécessite une approche flexible qui prend en compte la créativité, l'innovation et la variabilité inhérente aux projets de développement de produits, tout en restant ancrée dans ces valeurs communes (Cooper & Edgett, 2005).

## 2. L'industrie du semi-conducteur

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L'industrie des semi-conducteurs est peut-être le secteur industriel qui illustre le plus la relation d'interdépendance entre innovation et développement économique. Dans cette section, nous allons explorer les aspects clés de cette industrie, en mettant l'accent sur son importance, son évolution, ses acteurs majeurs et les défis qu'elle affronte.

### 2.1. Les semi-conducteurs et leur évolution

Les semi-conducteurs sont des matériaux possédant une conductivité électrique intermédiaire entre celle des métaux et celle des isolants. Ils sont souvent utilisés dans l'industrie pour réaliser des composants électroniques notamment des puces électroniques aussi appelées circuits intégrés. Pour ce faire, ces circuits sont gravés sur des plaquettes appelées *wafers* dont un exemple est montré en Figure 2. Les *wafers* se caractérisent par leur diamètre (200 et 300 mm) ainsi que la finesse de leur gravure.

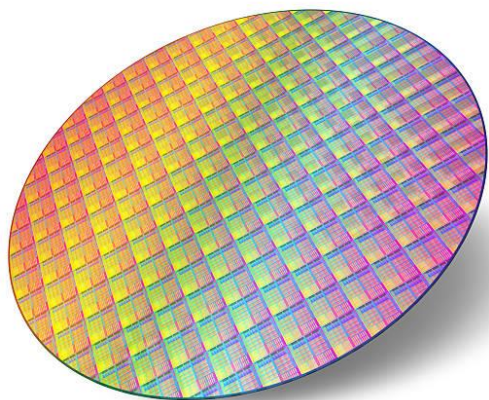


Figure 2: Wafer

L'évolution des technologies associées aux semi-conducteurs a été très rapide. Les principales caractéristiques de ses composants sont qu'ils sont :

- De plus en plus petits (ou à taille égale plus performants)
- De plus en plus rapides
- Ils consomment de moins en moins d'électricité
- Ils sont de moins en moins chers.

Au fur et à mesure du temps, on a donc pu voir le diamètre des *wafers* augmenter et la taille des transistors gravés dessus se réduire. Mais depuis quelques années, il semblerait qu'un « plateau » soit atteint. Ce plateau correspond à la limite de la loi de Moore (Moore, 1965) qui indiquait une constante miniaturisation des circuits intégrés sur les plaques jusqu'à des limites inhérentes à l'architecture système, à la complexité de la conception, aux exigences de la production de masse ainsi qu'aux tests de qualité et de sécurité qui exigeraient un temps trop long. Cependant, un autre facteur limitant de taille correspond aux coûts exorbitants des investissements requis pour surmonter ou repousser ces contraintes (Colin, 2002).

Il existe plusieurs matériaux semi-conducteurs comme par exemple le germanium ou bien l'arséniure de gallium mais c'est le silicium qui est le plus utilisé dans l'industrie car il est présent en abondance sur notre planète et possède des propriétés recherchées (*Semi-conducteur*, 2023).

## 2.2. Les circuits intégrés

### 2.2.1. Les composants d'un circuit intégré

Un circuit intégré est un ensemble de différents composants électroniques reliés de manière bien précise. Il est composé de résistances, de diodes, de condensateurs et principalement de transistors.

Les résistances servent à limiter le passage du courant. Sur la plaque, on en fabrique en créant des zones de Silicium plus ou moins dopées c'est-à-dire plus ou moins résistives. Le courant électrique est ainsi ralenti.

Le condensateur sert à stocker de l'énergie électrique, via un stockage d'électrons. Il est fabriqué avec deux zones conductrices entourant une zone isolante.

La diode quant à elle a pour rôle de laisser passer le courant dans un sens et pas dans l'autre.

Enfin, on trouve principalement deux types de transistors : les bipolaires et les MOS (Métal / Oxyde / Semi-conducteur). Les bipolaires sont utilisés pour réaliser des fonctions analogiques de puissance ou pour travailler à très haute fréquence, tandis que les MOS sont utilisés principalement pour compter ou mémoriser, c'est à dire pour réaliser des fonctions logiques ou binaires. Ils fonctionnent tous deux comme un interrupteur qui serait commandé de façon électrique. De nos jours les transistors MOS sont de plus en plus utilisés quand cela est possible, pour des applications analogiques : ils offrent l'avantage d'une forte miniaturisation, mais ont néanmoins encore de moins bonnes performances que les bipolaires.

### 2.2.2. La fabrication des circuits intégrés

Pour fabriquer des circuits intégrés, c'est-à-dire fabriquer les composants à la surface de la plaquette de Silicium et les relier électriquement entre eux, il n'y a pas une seule succession d'étapes possible. En effet, le processus de fabrication des semi-conducteurs est extrêmement complexe et est composé d'une centaine d'opérations de base qui varient et peuvent se répéter une dizaine de fois dans le cycle de fabrication de ces circuits. De plus, la forte personnalisation des puces rend chaque conception quasiment unique.

Toutes ces étapes ont plusieurs buts et peuvent être regroupées sous différentes catégories selon leur objectif : fabriquer des couches, enlever de la matière, recuire, planariser, dessiner, doper, nettoyer, contrôler, assembler. Nous expliquerons plus bas de manière succincte chaque catégorie afin de mettre en lumière la complexité et la variété des expertises requises dans cette industrie. La diversité des compétences nécessaires rend difficile, voire impossible pour les ingénieurs d'avoir une vision d'ensemble complète.

De plus, à chaque étape, la R&D joue un rôle crucial pour la conception de la puce mais également pour les conditions d'utilisation des machines créant une interdépendance forte entre R&D et production. Contrairement à certaines industries, l'industrie des circuits intégrés exige que la R&D touche à tous les aspects du processus de fabrication. Si l'on prend l'exemple

d'une entreprise de parfums, la R&D se concentre généralement sur la composition du parfum ou bien sur le packaging, mais la chaîne de production et les étapes d'assemblage restent les mêmes et l'impact de la R&D sur la production n'est pas significatif. Dans les semi-conducteurs, chaque innovation en R&D modifie directement l'ordre des étapes de fabrication, le nombre d'étapes ou bien les conditions d'utilisation des machines.

### *2.2.2.1. Fabriquer des couches*

La première catégorie d'étape consiste à fabriquer les couches nécessaires à la construction des circuits intégrés. Cela peut se faire soit en faisant croître une couche d'oxyde de silicium grâce à des procédés à très haute température appelés oxydation sèche ou humide, soit en faisant réagir des espèces chimiques pour former la couche souhaitée (*Chemical Vapor Deposition*). Ces couches peuvent servir de protection contre les agressions extérieures, mais surtout certaines couches servent à isoler électriquement différentes parties du circuit, tandis que d'autres sont conductrices et permettent de relier les composants entre eux.

### *2.2.2.2. Enlever de la matière*

L'enlèvement de matière recouvre les étapes de gravure. La gravure peut-être sèche en utilisant un plasma ou humide.

La gravure humide est purement chimique : elle est très sélective et elle est isotrope, c'est-à-dire qu'elle grave de la même façon dans toutes les directions. Du fait de son isotropie elle est généralement réservée à l'élimination de couches entières, ainsi qu'au recyclage des plaques de silicium.

La gravure sèche quant à elle est réalisée à l'aide d'un plasma. C'est celle qui est le plus souvent utilisée car elle est anisotrope c'est-à-dire qu'elle grave dans une seule direction à la fois. Cela permet de transférer des motifs précis sur une ou plusieurs couches de la plaquette.

### *2.2.2.3. Recuire*

Les recuits servent en début de processus à activer les dopants et à guérir les défauts introduits dans le Silicium lors de l'implantation ionique. Ce sont des recuits qui doivent être réalisés à très haute température et le plus rapidement possible pour éviter la diffusion des dopants dans le Silicium et leur désactivation lors de la redescende en température. Ils peuvent également servir plus tard dans le processus pour densifier, faire réagir et stabiliser les microstructures présentes dans le semi-conducteur ou bien passiver les défauts ou liaisons pendantes des couches déposées précédemment.



### 2.2.2.4. *Planariser*

La planarisation regroupe les étapes de polissage des couches d'oxydes et d'enlèvement d'éventuel surplus de métal. Ces étapes sont de type mécano-chimique. Pour ce faire on envoie un slurry sur les plaques de silicium. Le slurry est un liquide abrasif qui contient des billes de Silice ou de Cérium ainsi qu'un produit chimique (acide ou base selon les matériaux à graver). La partie chimique du Slurry sert à « ramollir » la surface de la plaquette puis cette surface « ramollie » est enlevée par frottement avec les billes du slurry.

### 2.2.2.5. *Dessiner*

Le rôle de l'atelier de Photolithographie est de définir des zones sur la plaquette destinée aux opérations suivantes. En transférant les motifs d'un masque dans la résine, on définit les endroits où il faut graver ou bien les endroits où il faut implanter des dopants. L'opération de Photolithographie se divise en 3 étapes chronologiques :

- L'étalement d'une résine photosensible (aux U.V.)
- L'insolation ou exposition de la résine dans un scanner
- Le développement de la résine, c'est-à-dire que la résine insolée ayant réagi à la lumière est alors dissoute.

Comme on fabrique des composants de plus en plus petits, la lithographie doit être de plus en plus précise pour reproduire avec exactitude les motifs. Pour avoir une bonne définition des motifs c'est-à-dire une bonne résolution, il faut utiliser des U.V. avec une longueur d'onde de plus en plus petite. De même, il faut aussi choisir des résines plus performantes avec une forte photosensibilité et des masques plus performants. Néanmoins, on ne peut pas éternellement diminuer la longueur d'onde des scanners. Une autre alternative pour gagner en résolution pour les scanners de dernière génération est d'introduire un liquide entre la lentille de projection et la plaquette : c'est la technologie dite d'immersion.

### 2.2.2.6. *Doper*

Le silicium doit être dopé afin de lui apporter des électrons (dopage de type N) ou des trous (dopage de type P) supplémentaires selon le dopant utilisé. Le principe consiste à bombarder entièrement la plaquette avec un faisceau d'ions. Les espèces utilisées pour le dopage du Silicium sont le Phosphore (P) et l'Arsenic (As) pour le dopage de type N et le Bore (B & BF<sub>2</sub>) et l'Indium (In) pour le dopage de type P. Ces étapes sont également appelées implant ou implantation ionique.

### 2.2.2.7. *Nettoyer*

Le nettoyage comprend le retrait de la résine, des résidus organiques et la décontamination particulière et métallique. Ces derniers peuvent-être réalisés de façon chimique ou uniquement avec de l'eau sous pression.

### 2.2.2.8. *Contrôler*

Un atelier de métrologie intervient tout au long de la fabrication des circuits intégrés pour faire des mesures après chaque étape clef ou critique pour certifier que le processus se passe correctement. On vérifie que ce qui a été réalisé correspond bien au cahier des charges préalablement défini. On vérifie dans tous les ateliers, la bonne réalisation des procédés, ainsi que le bon fonctionnement des équipements.

Ainsi par exemple on trouvera des mesures :

- D'épaisseur de couches
- De résistances de couches conductrices
- De composition chimique de couches ou de contamination métallique de dimensions critiques
- D'alignement ou d'Overlay
- Des inspections visuelles sur microscope optique
- ...

Des ateliers de défectivité sont également présents afin de réduire le nombre de défauts sur les plaques, pour éviter une dérive, améliorer les rendements et fournir un support à la R&D pour les nouvelles technologies.

Pour ce faire ils utilisent une très grande variété d'équipements pour :

- Détecter : mettre en place les outils, les méthodes pour capter les défauts présents sur les plaques
- Analyser : mettre en place les outils, les méthodes pour analyser les défauts détectés sur les plaques. L'analyse comprend 3 phases : la revue des défauts, la classification des défauts et la détermination de l'origine des défauts.

Enfin, des tests paramétriques sont également réalisés afin de déterminer les paramètres électriques clefs représentatifs des circuits réalisés. Et des tris électriques de plaquettes (Electrical Wafer Sorting) cherchent à vérifier la fonctionnalité électronique de chaque circuit intégré d'une plaquette.

### 2.2.2.9. *Assemblage*

Les circuits sont ensuite découpés individuellement et montés dans des boîtiers plastiques ou céramiques dans des usines dites de « Back-End ».

## 2.3. Le secteur industriel

### 2.3.1. Le marché et son évolution

Les composants électroniques fabriqués à partir de semi-conducteurs sont utilisés dans beaucoup de secteurs qu'ils soient « nouveaux » tels que les ordinateurs ou les smartphones ou plus anciens comme l'aéronautique ou l'automobile. Souvent invisibles mais présent dans quasiment tous les objets qui nous entourent (ordinateurs, consoles de jeux vidéo, smartphones, téléviseurs, voitures, avions, machines à laver, climatiseurs, panneaux solaires, capteurs...) certains en disent qu'ils sont à l'électronique ce que le pétrole est à l'industrie (AP et al., 2021). Pour donner un ordre d'idée, en 2012, une personne utilisait déjà en moyenne 250 circuits électroniques par jour, ce qui équivaut à 5 milliards de transistors par personne et par jour.

Aujourd'hui, avec la demande en intelligence embarquée liée aux objets connectés, à l'industrie 4.0, au télétravail, à la digitalisation des entreprises, et aux innovations dans tous les secteurs, les ventes mondiales de semi-conducteurs représentent environ 580 milliards de dollars comme nous le montre la Figure 3.

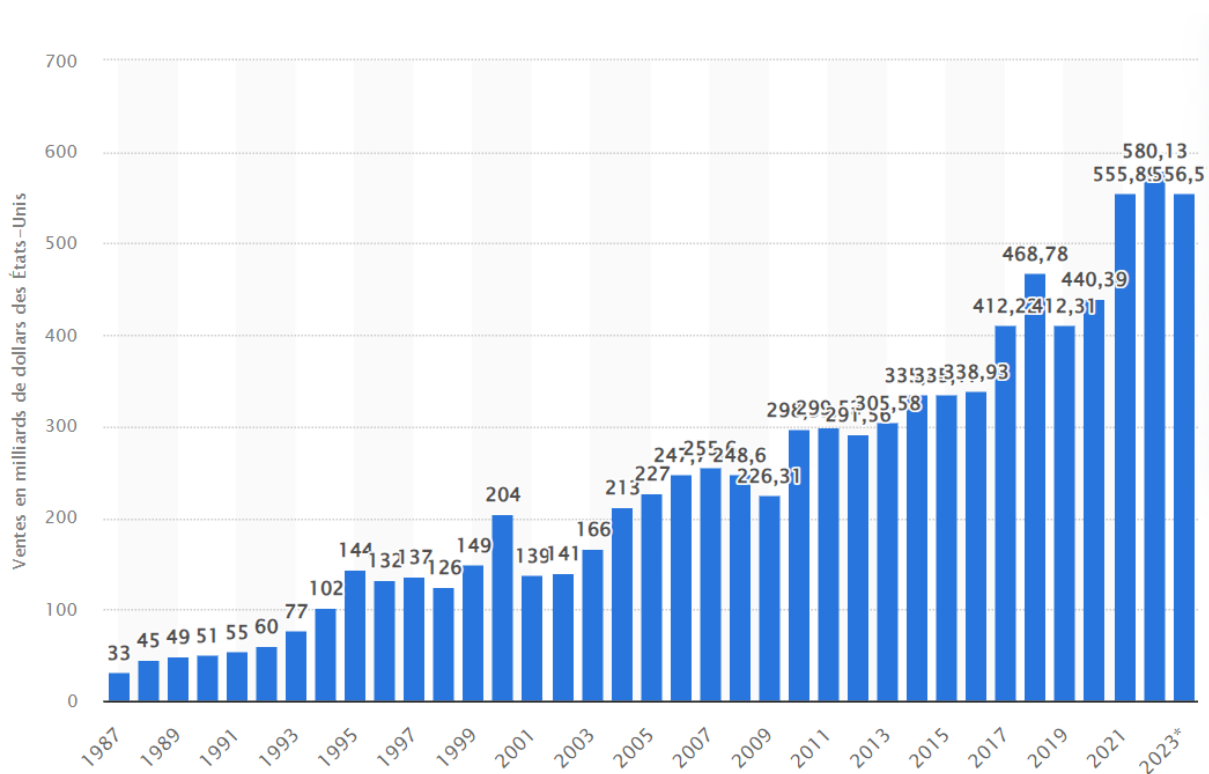


Figure 3: Ventes mondiales de semi-conducteurs en valeur de 1987 à 2023 (Statista, 2023)

En plus d'être un marché important, le marché des semi-conducteurs est en constante croissance (Escande, 2021). La prévision indique que le nombre d'appareils Internet des objets (IoT) dans le monde passera de 15,1 milliards en 2020 à plus de 29 milliards en 2030 (voir Figure 4). Les appareils IoT sont utilisés dans de multiples secteurs industriels et marchés grand public. Parmi les principaux secteurs industriels comptant actuellement plus de 100 millions d'appareils IoT connectés, on trouve l'électricité, le gaz, la vapeur et la climatisation, la distribution d'eau et la gestion des déchets, la vente en gros et au détail, les transports et le stockage, ainsi que le secteur gouvernemental. Le cas d'utilisation le plus important pour les appareils IoT dans le segment grand public concerne les appareils internet et média pour les consommateurs, tels que les smartphones, dont le nombre devrait dépasser 17 milliards d'ici 2030 nécessitant une R&D dynamique pour rester à la pointe des nouvelles technologies mais également une production qui puisse suivre la cadence de cette demande. D'autres cas d'utilisation avec plus d'un milliard d'appareils IoT d'ici 2030 incluent les véhicules connectés (autonomes), l'infrastructure informatique, la traçabilité et la surveillance des actifs, ainsi que les réseaux intelligents (*Semi-conducteur*, 2023).

La constante croissance du marché des semi-conducteurs, stimulée par la demande croissante en intelligence embarquée, objets connectés, industrie 4.0, télétravail, digitalisation des entreprises et innovations tous azimuts, démontre un besoin permanent d'innovations technologiques.

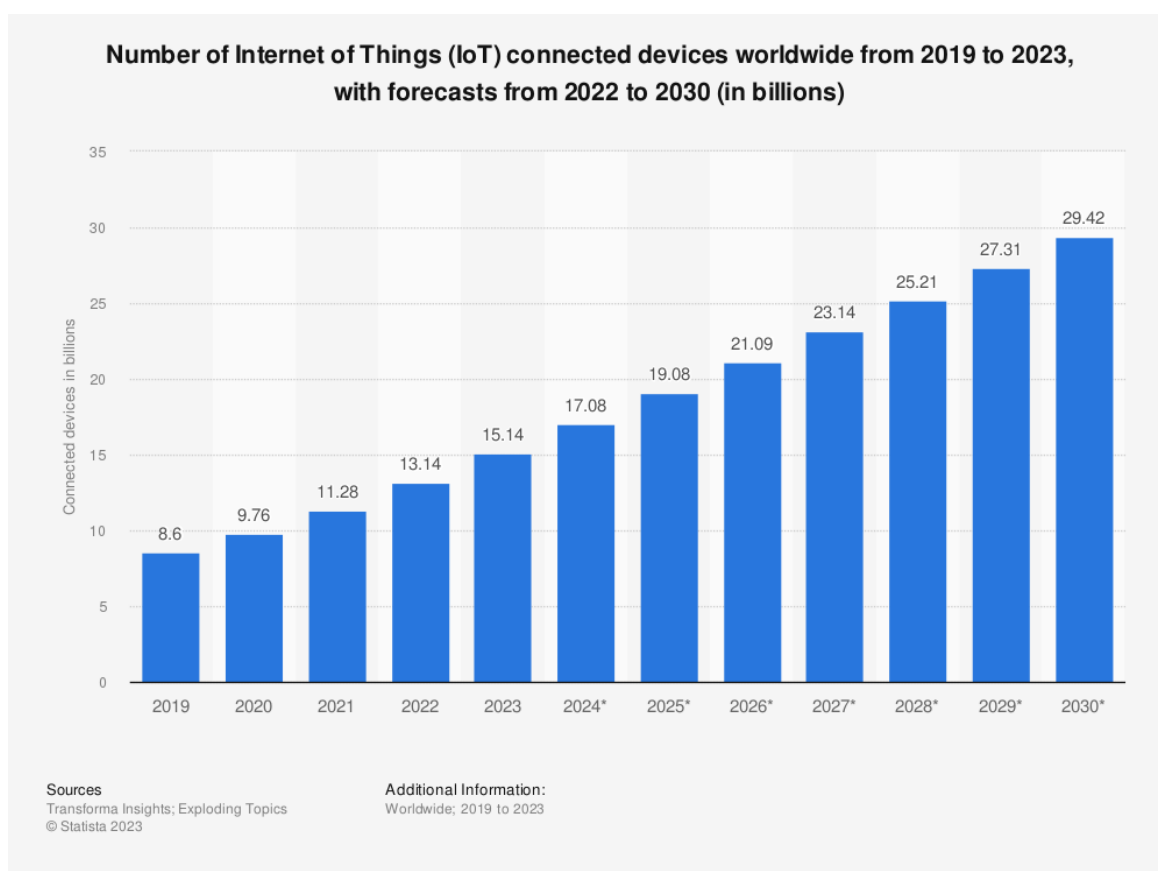


Figure 4: Number of IoT devices worldwide from 2019 to 2030 (Transforma Insights, 2023)

La crise de la Covid-19 a entraîné une pénurie mondiale de semi-conducteurs en 2020 qui a eu des répercussions sur la production et l'approvisionnement de nombreuses industries. En réponse à cet événement, partout dans le monde les gouvernements ont mis en place des initiatives pour éviter de subir à nouveau une pénurie de puces électroniques (Semiconductor Industry Association, 2023). Le 8 février 2022, la Commission européenne a alloué 43 milliards d'euros pour réduire la dépendance de l'industrie européenne vis-à-vis des semi-conducteurs fabriqués en Asie. Ursula von der Leyen, la présidente de la Commission européenne a ainsi déclaré : « *Nous nous sommes fixé l'objectif d'atteindre 20 % du marché mondial d'ici 2030.* » L'Europe reconnaît donc aujourd'hui plus que jamais la microélectronique comme une industrie cruciale. Un nouveau programme appelé IPCEI-ME/CT (*Important Project of Common European Interest in Microelectronics and Communications Technologies*) est en cours de lancement, impliquant 20 États membres. En France, ce programme sera mis en œuvre dans le cadre du programme Électronique 2030, annoncé par le président Emmanuel Macron en juillet 2022, qui couvre l'ensemble des sites français. Emmanuel Macron a également annoncé la décision de la France d'apporter un soutien financier à STMicroelectronics et à quatorze autres chefs de file français participant au PIIEC ME/CT. Toutes ces initiatives indiquent une reconnaissance accrue de la microélectronique comme une industrie cruciale nécessitant des investissements stratégiques.

### 2.3.2. Les acteurs

Le paysage des acteurs de l'industrie des semi-conducteurs a également connu des évolutions significatives au fil des décennies représentées sur la Figure 5. Dans les années 1990, l'Europe, les Etats-Unis et le Japon dominaient le marché mondial. Les pays européens fournissaient alors plus de 40 % des puces électroniques fabriquées dans le monde, les États-Unis 37 % et le Japon près de 20 %.

Aujourd'hui, ces trois régions combinées ne représentent plus que 36% de part de marché. De nouveaux acteurs : la Corée du Sud, Taïwan et la Chine ont pris la tête de la production mondiale. L'Europe subit la plus grosse perte de marché en passant de plus de 40% à 9% en 2020. Cette situation reflète la concurrence intense dans l'industrie des semi-conducteurs notamment au niveau des coûts (Fagot, 2021). L'innovation y est donc indispensable pour rester compétitif.

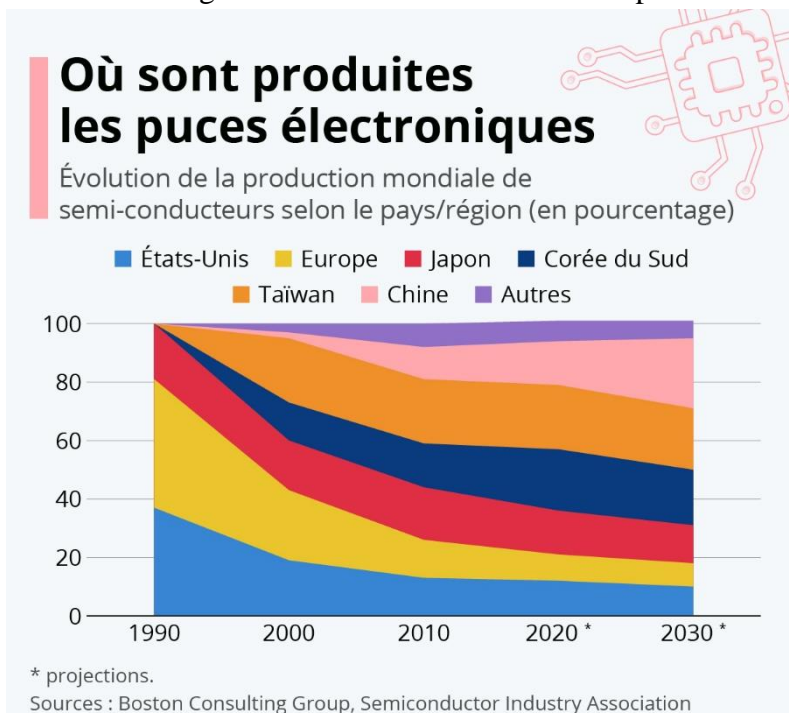


Figure 5: Evolution de la production mondiale de semi-conducteurs (Gaudiaut, 2021)

Par ailleurs, au fil des années, le modèle d'intégration verticale totale suivi par les entreprises de l'industrie des semi-conducteurs depuis les années 1960 a évolué. Les entreprises comme Intel, STMicroelectronics et Samsung Semiconductors, appelées *Integrated Devices Manufacturers* (IDM), effectuaient toutes les étapes de conception et de fabrication des puces, de la R&D aux tests en passant par la production, le conditionnement et la vente. À partir des années 1980, l'explosion des coûts de développement des technologies a remis en cause ce modèle, donnant naissance à deux nouveaux types d'entreprises : les fabless et les fonderies. Les fabless, comme Qualcomm et AMD, se concentrent sur la conception et la vente de puces électroniques, sous-traitant la fabrication des puces à des entreprises spécialisées dans la production de semi-conducteurs en volume, appelées fonderies, ou à des entreprises intégrées. Les fonderies, telles que TSMC (*TSMC*, s. d.), Globalfoundries (*GlobalFoundries*, s. d.) et UMC (*UMC*, s. d.), se consacrent exclusivement à la fabrication en volume de circuits intégrés à partir de plateformes technologiques de semi-conducteurs. Elles assurent la production des puces électroniques pour d'autres entreprises, notamment les fabless. Pour répondre aux coûts élevés de développement des technologies les plus avancées, certaines entreprises s'allient dans des coopérations de R&D dites « précompétitives ». Ces coopérations prennent la forme de consortia temporaires ou d'alliances pour des projets spécifiques, permettant de partager les investissements et les risques.

Pour les entreprises qui sont restées dans le schéma d'intégration verticale comme STMicroelectronics cela leur permet d'avoir le contrôle complet sur l'ensemble de leur chaîne de valeur mais présente également plusieurs défis. Tout d'abord une certaine rigidité peut s'installer. Les entreprises deviennent moins flexibles du fait de leur investissement dans leurs propres installations et processus. Par ailleurs, les entreprises en intégration verticale doivent constamment rivaliser avec des fonderies spécialisées pour rester compétitives en termes de coûts et de technologies.

### 2.4. Défis de l'industrie des semi-conducteurs

L'industrie des semi-conducteurs est confrontée à de nombreux défis. La course à la miniaturisation des composants entraîne des coûts croissants, tant en ce qui concerne les équipements sophistiqués que les investissements en R&D. Les coûts de conception et de développement augmentent également avec chaque nouvelle génération technologique.

La génération technologique ou nœud technologique telle qu'elle est définie par l'ITRS, fait référence à la demi-distance minimale séparant deux plots métalliques sur la première couche locale d'un circuit intégré. Cette valeur représente le pas lithographique à utiliser et traduit la densité de transistor sur une même surface de puce (Molière, 2011).

Par exemple, alors que la conception du nœud technologique 90 nm a coûté environ 500 millions de dollars, l'investissement nécessaire pour le nœud technologique 32 nm est de l'ordre de 1 milliard de dollars. Saunier (2008) souligne que les coûts progressent d'environ 30% par nœud technologique.

D'autre part, les coûts liés à la conception des circuits intégrés augmentent aussi de façon importante, de l'ordre de 50 % pour chaque nouvelle génération technologique (Saunier, 2008). Enfin, le coût des unités de production est lui aussi en augmentation. Entre 2005 et 2008, ce coût a doublé, passant de 1,5 à 3 milliards de dollars. Cette augmentation s'explique en partie par la sophistication croissante des usines de production.

De plus, l'industrie doit faire face à un rythme effréné de renouvellement des technologies, avec des cycles de vie de produits de plus en plus courts. Les investissements deviennent ainsi de plus en plus rapidement obsolètes. Par exemple, les gammes des smartphones évoluent tous les six mois avec un rythme élevé de nouvelles applications. Par conséquent, les pressions pour respecter les délais, accélérer le temps de mise sur le marché et développer de nouvelles technologies tout en augmentant rapidement les volumes de production sont considérables.

### 3. STMicroelectronics comme cas d'étude

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C'est dans ce secteur complexe, en constante évolution, essentiel à l'innovation technologique et à l'économie mondiale, mais confronté à des défis majeurs pour maintenir sa compétitivité et sa pertinence que notre terrain d'étude se positionne.

#### 3.1. La recherche et développement à STMicroelectronics

Aujourd'hui, STMicroelectronics est l'une des plus grandes entreprises de semi-conducteurs au monde avec 10,2 Milliards de dollars de revenus en 2020 ce qui la place comme le leader européen.

Il existe une corrélation entre les investissements en recherche et développement (R&D) et la croissance et pérennité des entreprises visant à être présentes sur le marché des hautes technologies (Aboody & Lev, 2002; Burgelman et al., 1996). Pour maintenir son avantage concurrentiel l'entreprise mise sur la R&D. Chaque année STMicroelectronics investi environ 15% de ses revenus dans la R&D soit 1,5 milliards de dollars par an.

De plus, le groupe possède 16 unités de R&D avancée et 39 centres de conception et d'application présents partout dans le monde comme la Figure 7 nous le montre. Cela représente plus de 8 000 personnes soit 18% des employés de l'entreprise. Ces R&D ont chacune une spécialisation (voir Figure 6). Il existe des R&D dites « produit » qui ont pour mission de réfléchir à l'utilisation finale des puces fabriquées dans l'entreprise. Elles visent à améliorer les produits existants ou à créer de nouveaux produits en utilisant les technologies disponibles. Elles ont une réflexion stratégique sur le marché et travaillent en étroite collaboration avec les équipes marketing pour comprendre les besoins des clients et développer des solutions adaptées. Afin de mieux répondre aux marchés elles sont spécialisées selon des

groupes de produit par exemple les microcontrôleurs, l'automobile ou bien les capteurs. Il existe d'autre part des R&D dites « technologiques » qui se concentrent sur le développement de plateformes technologiques. Ces plateformes technologiques sont un ensemble de composants, de logiciels et de technologies qui servent de base pour la création de puces. Cela inclut des éléments tels que les matériaux, les procédés de fabrication, les outils de conception et les équipements nécessaires pour produire une puce. Si l'on fait l'analogie avec la production de voitures, la plateforme technologique serait une chaîne de montage qui réunirait l'ensemble des équipements, des outils et des processus nécessaires pour fabriquer des voitures. Le constructeur peut ensuite utiliser cette chaîne de montage pour réaliser différentes voitures avec différentes options. Ces R&D sont axées sur l'innovation et la recherche de percées technologiques qui peuvent avoir un impact significatif sur l'entreprise et sur l'industrie des semi-conducteurs. Elles ont pour client les R&D produit et doivent avoir une vision long terme pour maintenir ou établir un avantage concurrentiel pour l'entreprise. A STMicroelectronics les R&D technologiques ont chacune des spécialisations selon le type de technologies qu'elles développent.

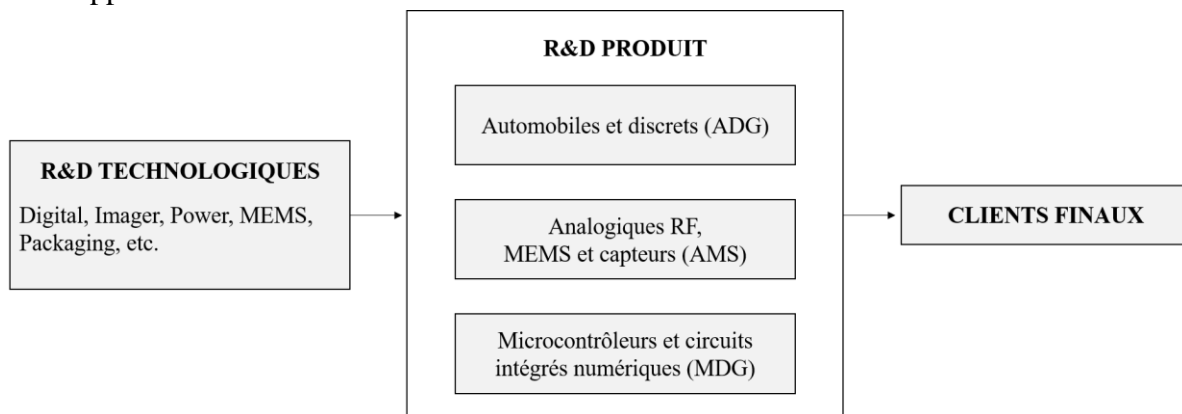


Figure 6: Organisation macro des R&D de STMicroelectronics

Le plus gros site de R&D technologique est situé à Crolles en Isère. Il travaille en étroite collaboration avec Grenoble en Isère, Rousset en Provence, Greater Noida en Inde, Fremont en Californie, Edimbourg en Ecosse et Taiwan. Toutes les équipes sont multi-sites et donc multi-culturelles. Le site industriel de Crolles compte plus de 4 000 salariés, dont environ la moitié est dédiée aux activités de R&D. Cela lui permet d'être d'une importance significative grâce à sa taille, l'ampleur de son personnel dédié à la recherche et au développement ainsi que sa position prédominante en tant que plus grand site de production de l'entreprise en France. Cette envergure lui confère un arsenal de machines performantes et dernier cri qui permettent de réaliser une multitude de tâches, du concept à la conception directement sur place. De plus, le développement de ses projets de R&D s'effectue en coopération avec 37 laboratoires de recherche en France, dont 16 sont localisés en Rhône-Alpes ainsi qu'une dizaine d'industriels du secteur. Sur le site de Crolles, plus de 90 experts techniques et scientifiques et plus de 140 doctorants ont également la charge de concevoir et de développer les technologies de demain.





Figure 7: Présence mondiale de STMicroelectronics

### 3.2. Les processus de la R&D technologique

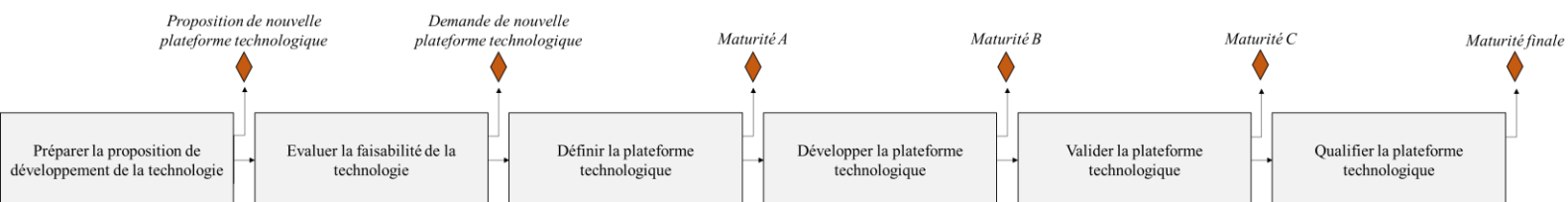


Figure 8: Développement d'une technologie à STMicroelectronics

Le processus de développement de la technologie chez STMicroelectronics peut être décrit comme la succession d'étapes présentées en Figure 8. Tout commence par la préparation d'une proposition détaillée, énonçant les objectifs et les ressources nécessaires. Ensuite, une évaluation approfondie de la faisabilité de la technologie est effectuée, analysant les contraintes techniques et évaluant la viabilité du projet. Suite à cette évaluation, la définition précise de la plateforme technologique est élaborée, établissant un cadre pour le développement. Les ingénieurs passent ensuite à la phase de développement, mettant en œuvre les fonctionnalités spécifiées. Une fois la plateforme achevée, elle est soumise à des tests rigoureux pour valider sa conformité aux normes de performance, de qualité et de fiabilité. Enfin, la plateforme est qualifiée, garantissant sa conformité aux normes industrielles et son aptitude à être intégrée dans des produits finaux.

Ce processus est systématique et robuste. Entre chaque étape un document doit être fourni. Tout d'abord des documents de proposition et de demande de nouvelle plateforme technologique. Puis des documents assurant la maturité globale de la technologie jusqu'à sa maturité finale.

Bien que la description macroscopique puisse donner l'impression d'une progression linéaire, le développement d'une plateforme technologique est en réalité un processus complexe et interconnecté, impliquant de nombreuses interactions entre différents services au sein de l'organisation. La Figure 9 illustre la complexité de ces interactions, soulignant la nature intrinsèquement multifacette du processus. Les ingénieurs, souvent hautement spécialisés dans des domaines spécifiques, peuvent se retrouver immergés dans des aspects détaillés de leur travail sans toujours avoir une vision complète du panorama global. Les multiples interdépendances entre les services peuvent entraîner des défis de communication et de coordination. En conséquence, la conception et le développement d'une plateforme technologique peuvent être perçus comme un ensemble complexe de défis, et la distance entre les ingénieurs et le client final peut parfois entraîner un décalage dans la compréhension des besoins et des résultats finaux. C'est pourquoi la gestion efficace de ces relations interdépendantes et la communication claire entre les équipes sont essentielles pour surmonter ces complexités et créer des solutions technologiques innovantes et cohérentes.

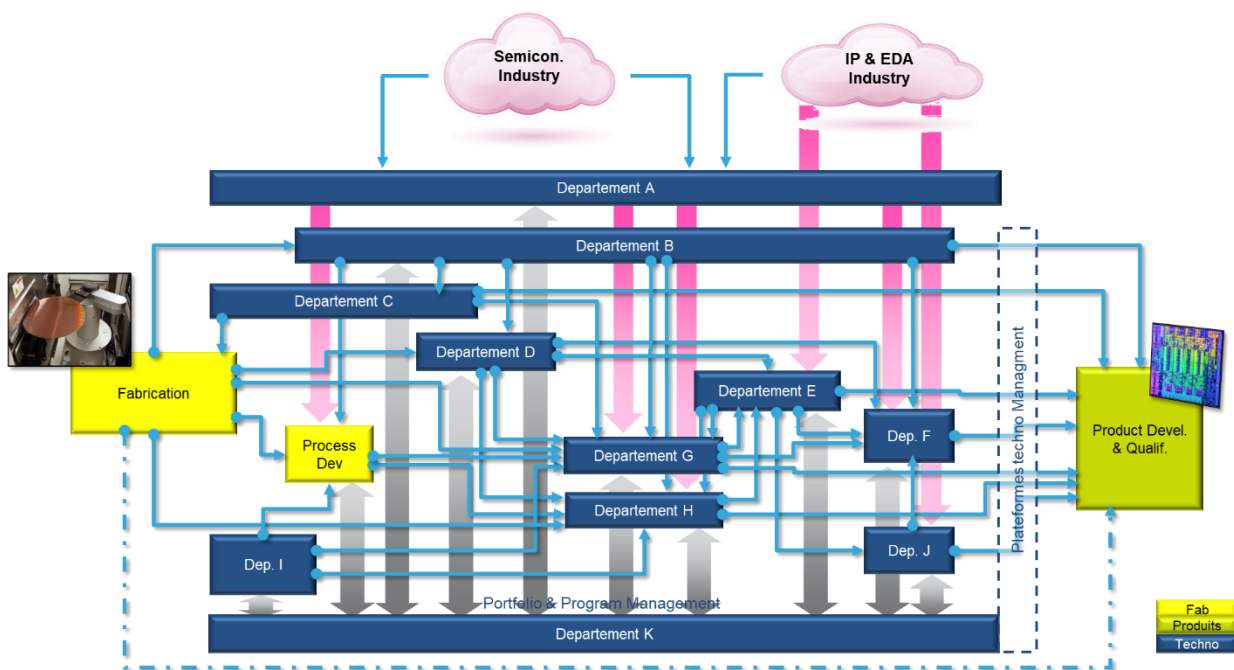


Figure 9: Flux R&D technologique STMicroelectronics<sup>1</sup>

<sup>1</sup> Document anonymisé

## 3.3. Le Lean à STMicroelectronics

### 3.3.1. La construction du Lean à STMicroelectronics

Le déploiement du Lean à STMicroelectronics prend ses racines au sein du département de production.

En 2008, la fonderie de Rousset a commencé à ressentir la pression croissante de la concurrence, qui la surpassait en termes de coûts, de qualité et de délais. Lors de visites chez ses clients, la direction a pu constater les réussites du Lean dans leurs usines. Par ailleurs, la création d'une nouvelle usine sur le site a perturbé les dynamiques sociales en interne. Tous ces éléments ont conduit le directeur des opérations de l'époque à lancer la première initiative Lean chez ST.

Après trois années de déploiement du Lean à Rousset, l'amélioration des performances industrielles et sociales est visible ; le directeur du site et le responsable Lean sont alors transférés vers des fonctions centrales.

À cette époque, ST perd d'importants clients et marchés, ce qui a nécessité une adaptation à la baisse de charge, une réduction des coûts et une adaptation de la production. Afin de gérer cette transformation des pratiques et la diversification de ses produits le Lean est introduit à partir de 2012 dans de nombreux sites de production, notamment à Crolles pour la production de *wafers* de 200 mm.

En 2015, la production de *wafers* de 300 mm à Crolles lance à son tour un programme Lean afin de mieux répondre aux attentes des clients.

En 2016, la R&D rencontre également des défis liés à la diversification de ses produits et technologies et à l'environnement ultra concurrentiel des semi-conducteurs. Elle décide donc de s'inspirer des initiatives du Lean Manufacturing et de mettre en place des outils du Lean en son sein. Grâce à des actions ponctuelles telles que la réalisation de Value Stream Mapping (VSM) (Locher, 2008), la R&D réussit à surmonter certains de ses défis. En 2017, les initiatives Lean évoluent de simples actions ponctuelles à des départements à part entière avec des stratégies et des employés dédiés à son déploiement tout au long de l'année : des programmes Lean « continus » prennent forme. C'est notamment le lancement du programme RISE, rebaptisé BeLight en 2023, au sein duquel cette thèse a été réalisée. Ce programme de transformation a pour principales missions de favoriser l'innovation, et de permettre l'excellence opérationnelle dans les programmes d'exécution en s'appuyant notamment sur les méthodes du Lean. L'intégration de ces deux notions, souvent considérées comme contractidaires, au sein d'une même entité offre un terrain d'étude intéressant pour notre thèse.

Le Lean a ensuite été étendu aux fonctions dites support comme les achats avec la volonté de créer une culture du Lean de manière globale au sein de l'entreprise.

### 3.3.2. Positionnement actuel du Lean Product Development à STMicroelectronics

Aujourd'hui, au sein de ST, plus de 80% des entités réparties sur 28 sites différents ont lancé des initiatives Lean. Cette approche englobe divers domaines, notamment la production, la R&D technologique et produit, les fonctions de soutien (telles que les ressources humaines et les laboratoires), ainsi que les ventes, le marketing, et même des projets de transformation numérique à l'échelle globale.

En ce qui concerne l'organisation, chaque département au sein de STMicroelectronics dispose de son propre service Lean. Cette thèse a été menée au sein de celui du département de R&D technologique nommé BeLight. BeLight est structuré de manière « pieuvre » : une équipe centrale dédiée et des ambassadeurs au sein de chaque service pour faciliter le déploiement.

La stratégie de STMicroelectronics consiste en effet à promouvoir une vision et une philosophie Lean communes au sein de l'ensemble du groupe, d'où ce choix d'organisation.

Cependant, malgré la solide structuration du Lean dans la production, la R&D présente une variété d'approches et d'applications du Lean, reflétant une diversité de pratiques. « Il y a autant d'applications du lean dans nos R&D que de départements voire que de managers » comme a pu le faire remarquer le responsable du Lean à STMicroelectronics.

C'est ce contexte particulier qui a motivé STMicroelectronics à lancer une recherche dans le cadre d'une thèse au sein de la R&D. Dans le but d'analyser la pertinence du Lean dans ce département de R&D technologique et de définir les conditions favorables à son développement optimal, tout en contribuant aux stratégies de déploiement pour une amélioration des performances.

## 4. Cadre méthodologique et questions de recherche

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Comme nous venons de le voir, l'entreprise STMicroelectronics, acteur majeur de l'industrie des semi-conducteurs, industrie compétitive où l'innovation est vitale, est confrontée à un défi important, celui d'optimiser ses processus R&D tout en favorisant l'innovation. Le déploiement d'une approche Lean dans leur département de R&D technologique a été amorcé. Cherchant des réponses et des solutions concrètes pour améliorer ses pratiques, STMicroelectronics a sollicité une collaboration universitaire sous la forme d'un doctorat pour aborder cette question complexe. Cette collaboration a ouvert la voie à une problématique de recherche et ce contexte a aiguillé des choix méthodologiques pour mener les recherches. Ce sont ces deux points que cette partie aborde.

## 4.1. Choix méthodologiques

La méthodologie adoptée pour cette thèse repose sur une approche immersive et interactive, menée dans le cadre d'une Convention Industrielle de Formation par la Recherche (CIFRE) à STMicroelectronics de novembre 2020 à novembre 2023. Cette démarche offre un accès privilégié à une vaste quantité de données de l'entreprise et permet de confronter les résultats théoriques aux réalités empiriques. En tant que chercheur en génie industriel et employé de l'entreprise, notre positionnement s'apparente à celui d'un « chercheur-acteur », comme le décrit Lallé (2004). Cela signifie que notre recherche ne se limite pas à l'observation extérieure, mais nous engage activement dans la vie organisationnelle. Nous participons à l'analyse, à la conception, à la mise en œuvre et à la diffusion des résultats, tant au sein de l'organisation qu'à l'extérieur.

Cette approche peut être qualifiée de « recherche interactive » (Girin, 1986), car elle se caractérise par plusieurs éléments distinctifs :

1. Les données utilisées proviennent essentiellement du terrain, sans influence extérieure ni traitement préalable.
2. Mon travail sur le terrain ne s'est pas conformé à un protocole strictement prédéfini ; au contraire, il s'est adapté aux circonstances changeantes, aux besoins émergents, aux opportunités inattendues et aux contraintes qui ont pu influencer sa trajectoire.
3. J'ai accordé une voix importante aux acteurs locaux, c'est-à-dire aux personnes directement impliquées dans mon domaine d'étude : les employés de STMicroelectronics et toute personne interagissant avec l'entreprise. Leurs perspectives et leurs avis ont été au cœur du processus de recherche.
4. En tant que chercheuse, j'ai été responsable de l'interprétation des données et de l'élaboration théorique, tout en dirigeant l'investigation de manière autonome.

Cependant, comme le souligne Lallé (2004), adopter le rôle de « chercheur-acteur » soulève des questions importantes sur la distance critique et la validité scientifique des résultats obtenus. Afin de garantir la rigueur scientifique, j'ai respecté les conditions minimales pour ce type de recherche (Coenen, 2001; Lallé, 2004):

1. J'ai alterné entre des phases d'immersion dans le terrain et de retrait, permettant de prendre du recul pour une perspective critique. Environ un tiers de mon temps de recherche a été consacré à un travail de tri et d'organisation des données à l'extérieur de l'entreprise, au laboratoire G-SCOP de Grenoble afin de favoriser la réflexivité sur mes actions.
2. J'ai élargi mon champ d'investigation par le biais de recherches bibliographiques et de l'analyse de la littérature. Cette démarche constante m'a permis de confronter mon positionnement et mes résultats aux travaux et théories existants, assurant ainsi la pertinence de ma recherche dans le contexte académique.

Mon rôle au sein de STMicroelectronics a été celui d'expert Lean dans le programme d'amélioration continue de la R&D. Mes missions quotidiennes se sont articulées autour de quatre axes majeurs.

Tout d'abord, en tant que référente Lean, j'ai accompagné les collaborateurs dans des projets d'amélioration continue en les aidant dans la gestion de projet et dans l'utilisation des outils. J'ai par exemple participé à des groupes de travail sur le partage de connaissances ou encadré des chantiers VSM (*value stream mapping*).

En parallèle, j'ai assumé le rôle de formatrice en animant et en créant des formations sur le Lean et ses outils.

Par ailleurs, j'ai endossé un axe de communication en organisant des événements autour du Lean, rédigeant les articles d'une newsletter ou des publications sur les réseaux sociaux professionnels, contribuant ainsi à diffuser les messages liés à cette approche.

Enfin, ma participation à deux groupes de travail sur l'innovation, dont les périmètres étaient la R&D technologique et le site de Crolles, m'a donné une vision globale des initiatives d'innovation au sein de l'entreprise.

### 4.2. Questions de recherche

Dans le cadre de cette thèse, nous adoptons la perspective selon laquelle la science émerge de la formulation de questions pertinentes, comme l'a affirmé Bachelard « s'il n'y a pas de question, il ne peut y avoir de connaissances scientifiques. Rien ne va de soi. Rien n'est donné. Tout est construit » (Bachelard, 1938). Avant même de pouvoir entreprendre une recherche, il est impératif de se poser des questions.

Notre travail de recherche a débuté au sein de STMicroelectronics, où nous avons été affecté au service BeLight le programme de transformation et d'amélioration continue de la R&D technologique. Cette immersion a rapidement soulevé des interrogations quant au rôle du Lean dans ce contexte particulier. Le Lean en R&D se présentait comme un sujet flou, moins structuré et moins palpable que dans le domaine de la production. Parallèlement, la capacité d'innovation est un avantage compétitif essentiel de la R&D. Par conséquent, notre thèse se penche sur la question des liens entre le Lean Product Development (LPD) et l'innovation en R&D. Plus précisément nous nous demanderons **est-ce que des démarches de Lean Product Development favorisent l'innovation dans des entreprises de hautes-technologies**.

Cette question s'avère d'autant plus captivante que le Lean est souvent associé à des notions de standardisation, tandis que l'innovation est généralement liée à la créativité et à l'imagination. Cependant, lorsqu'il est question d'innovation en R&D, il est essentiel d'aborder à la fois la phase d'exploration, où de nouvelles idées sont générées, et la phase d'exploitation, qui vise à développer rapidement les innovations et à améliorer le *time-to-market*, un facteur crucial dans l'industrie. On peut alors se demander ce qu'est exactement le lean dans un contexte de R&D

et ses conditions de succès car pour pouvoir observer ses effets sur l'innovation il faut tout d'abord qu'il soit bien implémenté. Puis nous pouvons nous demander quels sont les attendus lorsque l'on parle d'innovation et comment les observer ? L'industrie des semi-conducteurs ayant des temps de développement très longs et coûteux, peut-être que des indicateurs de tendance seraient une piste à interroger. Enfin, comme se mesurer n'a jamais fait grandir, on peut se demander ce qui dans l'entreprise impacte nos indicateurs et donc par extension l'innovation.

### 4.3. Contributions de la thèse

Comme nous venons de le voir, cette thèse s'attache à savoir si des démarches de LPD favorisent l'innovation dans des entreprises de hautes-technologies. Cette problématique soulève plusieurs questions fondamentales qui guideront notre investigation et contribueront à une meilleure compréhension des interactions entre le LPD et l'innovation dans le contexte particulier de STMicroelectronics. En somme, il s'agit d'analyser comment le LPD peut être un moteur d'innovation au sein de l'entreprise STMicroelectronics, en mettant en lumière les facteurs de succès, les aspects contextuels et l'impact du système opérationnel de l'organisation sur le processus d'innovation.

Notre première question de recherche développée dans le chapitre 2, se demande ce qu'est le LPD et si son efficacité dépend des conditions et du contexte dans lesquels il est appliqué. Ainsi, ce chapitre s'interroge sur les limites et les accélérateurs du LPD, et dans quelle mesure ils dépendent du contexte. Pour aborder cette question, nous avons entrepris une revue de la littérature approfondie, analysant plus de soixante textes. Cette démarche nous a permis de mieux comprendre les principes du LPD et d'identifier des éléments qui peuvent favoriser ou entraver l'efficacité du LPD.

Dans le chapitre 3, afin d'évaluer l'impact du LPD sur l'innovation en R&D, il était nécessaire de disposer de mesures appropriées. Étant donné que les résultats en matière de changement culturel nécessitent du temps, et que les processus d'innovation en R&D se comptent en années nous avons cherché à développer des indicateurs de tendance, en plus des indicateurs post-mortem traditionnels. Notre réflexion nous a conduit à considérer les comportements humains comme des indicateurs potentiels. Notre hypothèse est que des comportements favorables à l'innovation signalent la capacité d'innovation des individus, ce qui peut être un indicateur positif pour l'entreprise. Dans ce chapitre, nous examinons donc comment les comportements humains liés au LPD peuvent favoriser l'innovation, et comment nous pouvons mesurer ces comportements. Pour atteindre cet objectif, nous avons entrepris une triangulation des données, en utilisant les informations recueillies lors de notre immersion dans le service d'amélioration continue comme des entretiens, des comptes-rendus de réunion et de nombreux artefacts organisationnels. Cette triangulation nous a permis de valider l'importance de l'humain dans l'innovation. Puis grâce à des sessions de brainstorming, nous avons identifié des comportements considérés comme favorisant l'innovation chez STMicroelectronics, et nous

avons proposé des indicateurs de comportement clés (*Key Behavior Indicators* - KBIs) associés à ces comportements.

Enfin notre quatrième chapitre s'intéresse à la question essentielle de comment l'*operating system* c'est-à-dire l'ensemble des outils, processus, travail standard, activités cadencées et mécanismes qui constituent les éléments fondamentaux opérationnels d'une organisation (Morgan & Liker, 2018), peut influencer sur les comportements innovants qui favorisent l'innovation. En utilisant une série de cas empiriques récoltés durant les trois années de recherche, nous illustrons les interactions *operating system*-comportements innovants afin d'observer l'impact de l'un sur l'autre.



# Chapitre 2 :

## The context dependency of Lean Product Development barriers and success factors, a literature review

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# Chapitre 2

**T**here is no consensus in the literature on how to apply Lean Product Development (LPD) successfully. This article presents a literature review aiming to fill this gap. The key success factors in and barriers to successful implementation of LPD were gathered and categorized by means of a thematic reading. The question of the context's influence on these factors is also posed, and a proposition is made to prioritize the notion of configurations rather than frameworks. From an academic perspective, this research gives an overview of the LPD implementation's key factors and opens up a discussion on the pertinence of the notion of framework in this field. On the practitioner side, this paper helps organizations to reflect on the main factors to consider when implementing LPD.

## 1. Introduction

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The efficiency of the Lean manufacturing approach in terms of performance and global improvement in manufacturing has been proven (Lai et al., 2019). However, there has been a lot of criticism about its limited applicability outside high-volume repetitive manufacturing environments (Oliveira Vieira & Lopes, 2019).

The literature on Lean in support functions such as Research and Development (R&D) is less mature than that on Lean manufacturing (Salgado & Dekkers, 2017), and despite many successful case studies, there is no consensus on how to apply Lean in R&D successfully (Jasti & Kodali, 2014a). Moreover, while R&D can be mistaken for “a single well-defined thing”, it is in fact multifaceted (Forbes & Wield, 2004). In this paper, R&D will be considered to be the area of an organisation that carries out new product development, and as such the process by which a product is developed (Griffith et al., 2004). This encompasses the process of research and the process of development for manufacturability.

Product development processes are fundamentally different from manufacturing. While manufacturing concerns physical objects, with repetitive tasks, predictable activities and with one possible place at a time for objects, R&D and product development processes have many unique tasks with changing requirements, and outputs can be stored in different places at the same time (Marodin et al., 2018). The variability that is intrinsic to product development can be a source of value while being harmful for manufacturing (Mundth et al., 2020). Furthermore, since product development focuses on the generation and use of information and not tangible goods, both processes need to be approached differently (Gudem et al., 2013).

Therefore, this study can be justified in two ways. From a theoretical point of view, unlike in manufacturing, there is no clear understanding of the success factors and barriers to the implementation of Lean in product development (Ferreira et al., 2023). Studies are scattered, which can create difficulties for practitioners who wish to start a Lean initiative in their R&D. Therefore, conducting a synthesis of the literature is important in order to learn from it.

From a practical point of view, this paper was commissioned by a large semiconductor company that is implementing a Lean approach in its R&D. To help them and others in this journey, this paper aims, by reviewing the literature, to help practitioners by providing a list of the success factors and barriers to the successful implementation of LPD.

This article is organized as follows. Firstly, a brief synopsis of the history of Lean is given. This is followed by a presentation of other literature reviews on Lean in product development and their findings, showing the interest of the review. After introducing the methodology of the research, the results of the review are presented. This results section presents the success factors and barriers to a successful implementation of Lean in product development. This part is followed by a discussion where the limitations of the study are stated and some lines of research are proposed.

## 2. Material and methods

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### 2.1. Lean in R&D: different concepts and their content

The Toyota Production System (TPS), born in the 1950s in Japan, laid down the roots of Lean and is still today looked to as an example (Melton, 2005). The Lean process was then theorized, formalized, described and popularized in “The Machine That Changed the World”, and then in “Lean Thinking” with the five Lean principles: value, value stream, flow, pull, and perfection (Womack et al., 1990; Womack & Jones, 1996).

After its benefits in reducing costs, improving quality and increasing employee satisfaction were proven (Singh et al., 2010), the Lean methodology spread from the automotive industry to other sectors (Pranav, 2020) such as health, tourism, the military, construction, and high technology. It also expanded from production to other functions of a company such as finance (Dilton-hill, 2015), human resources (Jekiel, 2020; Mundth et al., 2020), and R&D (Reinertsen & Shaeffer, 2005). However, the manufacturing processes of the workshop and the product development processes of R&D present many differences. They have different economics and different value creation mechanisms. Firstly, product development is about flows of information, while manufacturing concerns physical flows, which makes product development

a more complex process as it is less tangible (Gudem et al., 2013). There is also more variability in product development processes (Reinertsen & Shaeffer, 2005). Nevertheless, this variability can be seen as a positive in product development, since it is a means to generate knowledge and agility (Welo et al., 2012). Furthermore, there are some characteristics that differ in manufacturing and in product development. Welo et al. (2011) summarize and compare them according to six categories: objective, value-added, product/inventory, tasks, people, and process.

All these differences inevitably led to the adaptation of the Lean methodology to suit its new context. As a result, several derivative concepts emerged: LPD, Lean Design, Lean Engineering, and Lean R&D.

LPD is the application of Lean thinking to product development to achieve a value-oriented, resource-efficient, and fast product innovation process (Hoppmann et al., 2011). Lean Design refers to the principles of Lean applied to the design phase of the development of a new product (Jauregui-Becker & Perry, 2015). However, it is important to note that design is a multifaceted concept, and therefore Lean design can have different meanings and interpretations. It can serve as a synonym of LPD as it refers to the leaning of the processes required to develop and manufacture a product that respond to the market needs (Ward & Sobek II, 2014). It can also be seen as a verb, representing the action of designing in a lean manner (Baines et al., 2006), or as a noun, denoting the object that has been designed in a lean manner (Gautam & Singh, 2008). Lean Engineering, on the other hand, refers to the application of Lean to all activities related to engineering disciplines that an enterprise employs to conceive, design, develop, test, and launch a product (Haque, 2003). The distinction between Lean Design and Lean Engineering can be subtle, with engineering often leaning towards the manufacturability aspect of product development, while design may focus more on its appeal to the end customer and be integrated within the engineering process. Finally, Lean R&D encompasses the application of Lean principles in R&D processes (Reinertsen & Shaeffer, 2005). Given the strong connection between R&D and product development, Lean R&D closely aligns with the concept of LPD.

While the literature traditionally associates the term “product development” with marketing and management concepts (Cooper, 1979), and “design” and “engineering” with the conception and manufacturability of a product, it is apparent that these concepts are interconnected and share common dimensions. Therefore, in this paper, we will consider the terms design and engineering as subsumed within the broader umbrella of product development. As the term LPD is the most widely used in the literature (Salgado & Dekkers, 2017), this term will replace the terms Lean design, Lean engineering and Lean R&D. This unification reflects the intrinsic connections and shared principles between these concepts.

## 2.2. Literature reviews on Lean Product Development overview

To gain a comprehensive understanding of LPD, an initial step involved reviewing the existing literature. This examination uncovered nine literature reviews, each shedding light on different aspects of LPD. These reviews delved into topics such as the definition of LPD, the conditions of its applicability, the associated benefits of this approach, and the concept of added value.

Globally, the oldest reviews focus on the understanding of what LPD is. Baines et al. (2006) focus on the applicability of Lean outside of the factory, while Martinez and Farris (2009) concentrate on a better understanding of the LPD body of knowledge. Leon and Farris (2011) also focus on the understanding of the theoretical content of LPD alongside examining potential implementation challenges. Later, Aggrwal (2013) focusses again on the understanding of what LPD is. On the other hand, Württemberg et.al (2011) also try to summarize and understand what LPD is and what its advantages and disadvantages are. They also study the different LPD tools mentioned in the literature. Furthermore, Fatima and Amjad (2019) present a global literature review on the literature on LPD and discuss the positive and negative impacts of the concept. Moreover, two literature reviews focus on the concept of value and how to create it using a model and a framework (Oliveira Santos et al., 2019; Siyam et al., 2015). Finally, Salgado and Dekkers (2017) question whether LPD is a new practice, a new method, or an encapsulation of already existing methods for new product development.

In this section, we present the key points of these reviews, organized around: the maturity of the concept of LPD and what it is, the notion of waste and value, and the question of innovation.

### 2.2.1. Lean Product Development definition

These reviews all agree that the subject of Lean in the New Product Development (NPD) context is well documented. Nonetheless, the contribution to the subject has been decreasing since 2014 without being able to explain why (Fatima & Amjad, 2019).

Moreover, even though the field is mature, it is still not as well defined and understood as Lean Manufacturing (Salgado & Dekkers, 2017). Some authors define LPD as the application of Lean Manufacturing in Product Development (Tardio et al., 2023), whereas others insist that the mere translation of Lean Manufacturing as Product Development does not always equate to success and means that many organizations struggle with the deployment of LPD (Ferreira et al., 2023). Furthermore, the definition of Lean and Lean thinking is drifting. Indeed, the earliest papers on the definition of these terms were focused on waste and how to reduce it. Then the focus shifted to quality, cost, and delivery and methods to optimize these aspects of

production. Currently, the focus is on value and how to maximize it (Baines et al., 2006; Oliveira Santos et al., 2019).

Examining the literature reveals a noteworthy trend – an increasing intersection between LPD and green initiatives such as sustainability and the circular economy (Kjersem et al., 2022). Scholars are showing a growing interest in how LPD principles can be aligned with environmental stewardship, emphasizing the development of products and processes that are not only customer-centric but also environmentally responsible (Cukor & Hegedic, 2023). This alignment reflects a broader societal shift towards sustainable practices and circular economic models.

Simultaneously, the integration of LPD with Industry 4.0 introduces a new layer of challenges and opportunities. Industry 4.0, marked by the infusion of digital technologies into manufacturing processes, brings complexities that LPD must navigate. Incorporating smart technologies, data-driven decision-making, and the Internet of Things (IoT) poses challenges that demand adaptation and innovation within LPD methodologies. Considerations such as data security, interoperability, and the ethical implications of technology integration become pivotal (Sivolapenko, 2022).

The question of the maturity of the subject is also addressed in these reviews. Although the fields of application of LPD methods are extremely diverse, the majority of the work is largely exploratory and based on qualitative data, driven by interviews and direct observations, and often on small samples (Martinez & Farris, 2009; Toledo et al., 2023). Moreover, most empirical studies on LPD are about Toyota, hence the need for studies that validate the transferability of the methods and theories to other industries and settings (Salgado & Dekkers, 2017).

### 2.2.2. How to define value

These reviews cast additional light on the concepts of waste and value that form one of the core optimizations goals of LPD. The intimate connection between waste and value is evident, with two primary approaches highlighted for maximizing value: eliminating waste and investing in value (Siyam et al., 2015; Würtemberg et al., 2011). Waste, defined as any activity consuming resources without creating customer value, underscores the necessity of a clear value definition. The challenge arises when the definition of value is intangible, making the definition of waste even more elusive, as it inherently derives from value. Notably, many Lean thinking studies concentrate on waste reduction during LPD implementation, often neglecting the equally vital aspect of value augmentation (Oliveira Santos et al., 2019).

This oversight may stem from the inherent difficulty in defining and measuring value in product development, which differs significantly from value in production (Al Hazza et al., 2023). Moreover, establishing a straightforward relationship between defining and measuring value and LPD proves challenging (Salgado & Dekkers, 2017). The integration of these elements into the LPD framework is complex and not easily defined or implemented. Consequently, the scarcity of studies focusing on the establishment of value within Lean thinking persists, reflecting the ongoing complexity of this facet (Oliveira Santos et al., 2019).

### 2.2.3. Innovation and Lean Product Development

The question of innovation is also treated in this corpus. The literature does not take into consideration the novelty of a product when talking about new product development. Yet the degree of novelty affects the way of managing product development and by extension LPD. The application of Lean thinking to new product development is as such based on an incomplete discussion: the concept has not been correlated with incremental and radical innovation. Moreover, there is an antagonism between radical innovation and the elimination of waste that is often linked with standardisation. For some authors, this indicates that LPD can only be applied to recurrent processes through standardisation and simplification (Salgado & Dekkers, 2017).

### 2.2.4. Take away

The key points to understand from these reviews are:

- The notion of LPD is not stabilized and seems to differ from author to author. This is likely due to its interdisciplinary nature which creates challenges in achieving a standardized definition.
- The definition of value is vital in LPD to be able to reduce waste. Yet, practitioners, particularly in complex R&D settings find it challenging. Consequently, many focus solely on waste neglecting the notion of added value.
- There is a tension between a need for radical innovation in R&D and standardization to optimize processes. This can be very confusing for practitioners when trying to decide the best way to proceed. Besides, the question of the novelty of a product or a process is not considered in most of the discussions about LPD.
- Finally, there has not been a clear focus on the failures and success factors in implementing LPD in an R&D context. Würtemberg et al. state that “LPD literature tends to have more to say about what activities the concept includes and what these activities will lead to, than how the activities are going to be performed in order to become successful” (Würtemberg et al., 2011 p6). Moreover Leon and Farris state that



there is a clear need for an “agreement upon the critical few success factors related to LPD performance” (León & Farris, 2011, p43). This review aims to fill this gap and create a clear understanding of the success factors and barriers to the implementation of LPD cited in the literature.

### 2.3. Corpus selection methodology

To conduct this literature review, we started by the identification of a text corpus explicitly dedicated to LPD. Following the guidance of Green et al. (2001) advocating the use of at least two databases, we curated texts containing the keyword “Lean” associated with different usages in the title: “Product Development”, “R&D”, “Research and Development”, “Engineering”, and “Design”. These texts were sourced from Google Scholar, and Scopus databases in November 2023.

After removing the duplicates, 2297 texts were identified, including scientific articles and grey literature from 1995 to 2023. To select the articles to include in this literature review, it was decided to filter the texts according to the following criteria:

- From 1995 to 2010: Selection of papers cited more than 40 times to capture seminal works. The specific value of “more than 40” was determined empirically to ensure the inclusion of articles with significant influence in the field of LPD while narrowing down the number of articles to screen to a realistic number. It was decided that this threshold can be considered meaningful in this context but can be adapted in other study domain.
- From 2011 to 2019: Selection of papers with a citation per year above three (for example a paper from 2015 needs to have been cited 21 times in total while a paper from 2019 needs to have been cited 15 times). This allowed us to select papers with a relative impact on the study field without favoring older publications. As per the previous category, the number of three citations per year was determined empirically.
- From 2020 to 2023: Selection of all papers. Recent papers may not have had the time to be cited so they were all selected in this first sample.

This filter reduced the number of papers down to 451. Then, a thematic reading was carried out to narrow down the corpus based on the following inclusion criteria:

- Inclusion Criterion 1: The paper identifies or mentions the topic of success factors or barriers in LPD.
- Inclusion Criterion 2: The paper identifies or mentions the topic of LPD enablers.
- Inclusion Criterion 3: The paper is peer reviewed (except for books).
- Inclusion Criteria 4: The paper is in English.

These criteria led us to 80 papers being selected comprising our final corpus.

The reporting of this systematic review was guided by the standards of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement (Tugwell & Tovey, 2021). To ensure compliance with PRISMA guidelines, a citation software called Zotero was used, and at each stage the inclusion or exclusion of articles was tracked using a custom Excel spreadsheet.

Figure 10 illustrates the steps of the selection process of the corpus studied.

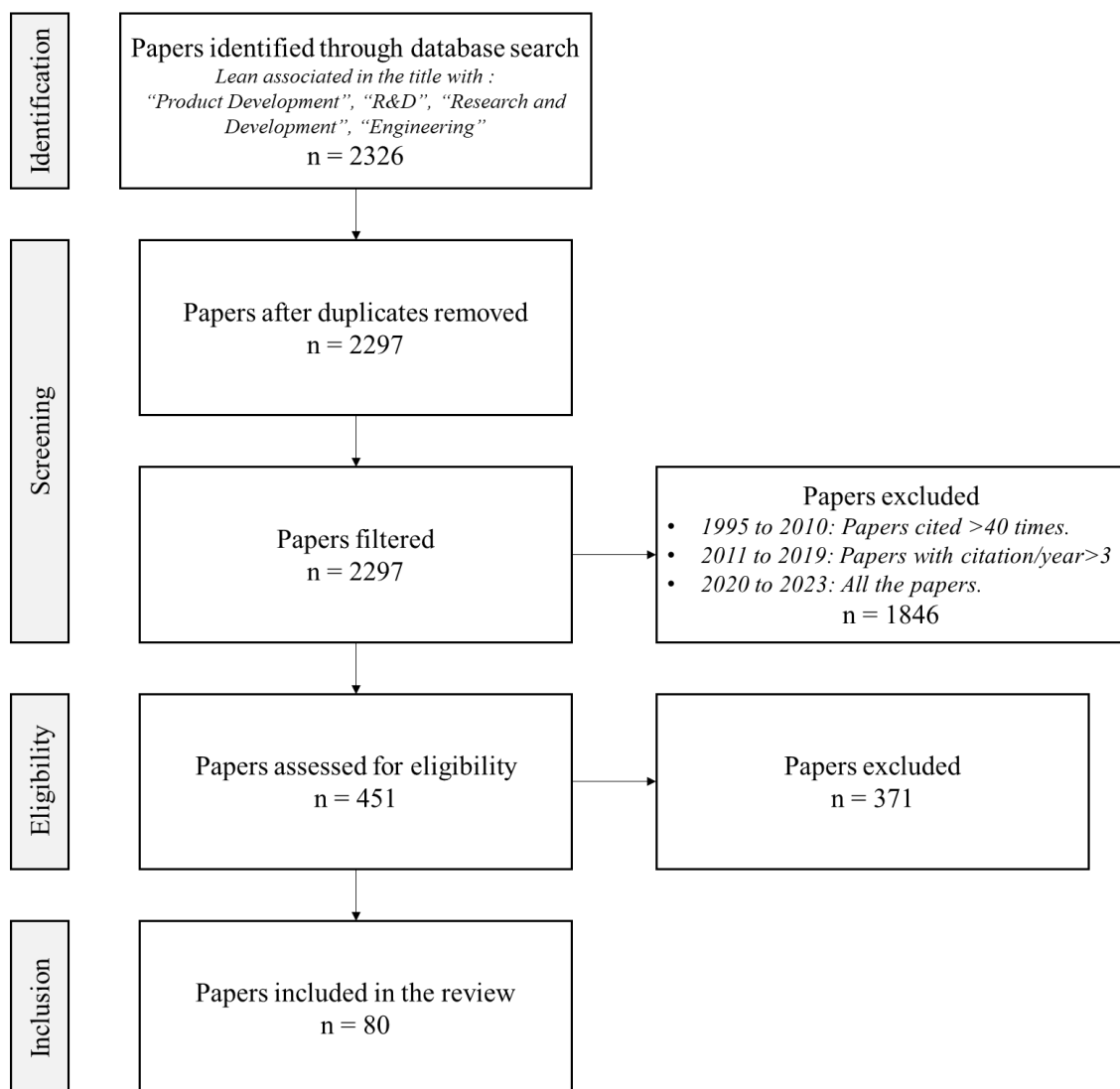


Figure 10: Research methodology

## 2.4. Corpus analysis

The final corpus chosen for this literature review is diverse, as illustrated in

Figure 11. A significant proportion – 42 papers – comes from academic journals, underscoring the scholarly rigor of the selected corpus. Additionally, 18 books contribute to the richness of the literature, emphasizing the importance of seminal work. Conference papers, constituting eight texts, theses, with seven texts and five other types of documents add further dimensions to the corpus.

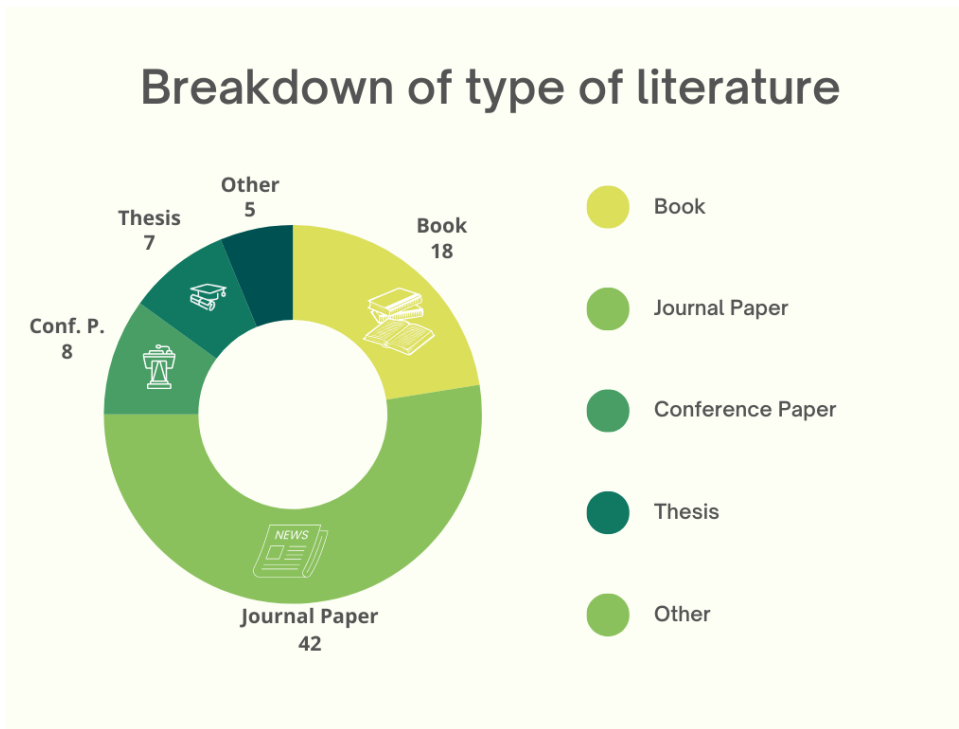


Figure 11: Breakdown of type of literature

A detailed examination of the geographical distribution of the corpus, depicted in Figure 12, offers insight into the global impact and interest of LPD. While North America and Europe, with 32 papers each, dominate the corpus, it is noteworthy that Asia, with eight papers, and South America, with seven papers, also make substantial contributions. The Middle East is represented by three papers, reflecting a global interest and engagement with LPD research across continents. The predominance of Europe and North America may be explained by the fact that North America and Western Europe are the regions of the world with the highest spending on R&D, both in dollars and in percentage of their GDP (UNESCO Institute for Statistics).

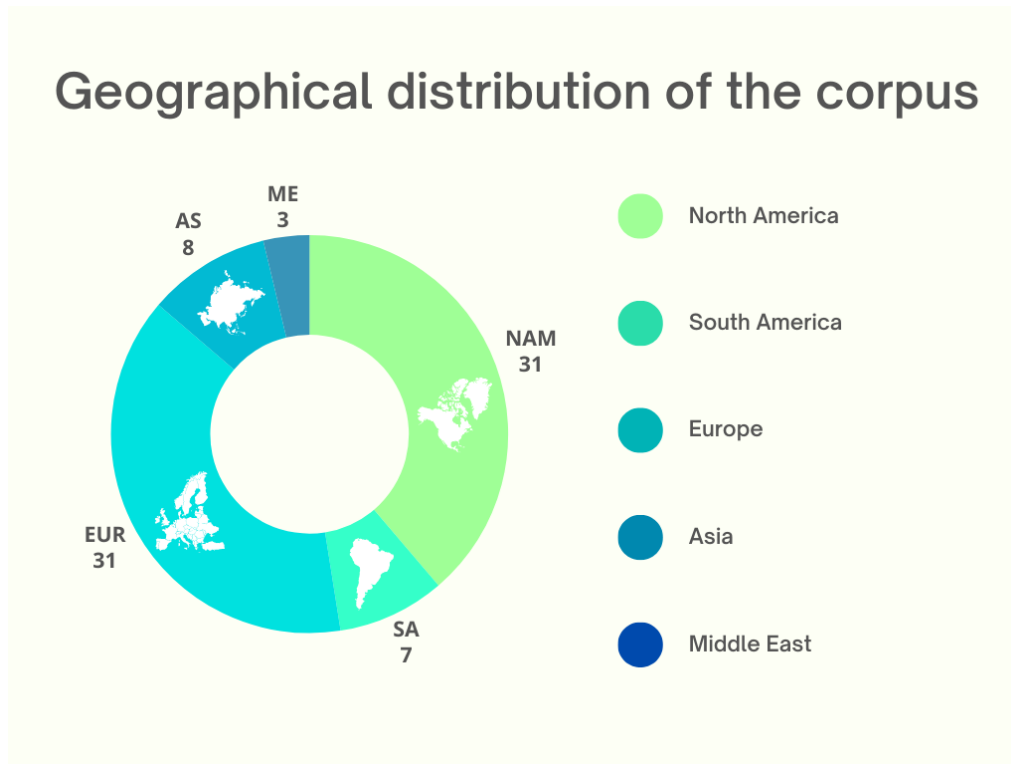


Figure 12: Geographical distribution of the corpus

The type of research was divided in two categories: conceptual contributions and empirical studies. We considered research that involved ideas and concepts based on abstract thinking to be conceptual contributions, whereas results based on observations or experiments were considered as being empirical studies. Within the selected corpus, we identified 26 conceptual contributions and 54 empirical studies, with a predominant focus on case studies. This trend resonates with the findings of Martínez and Farris (2009), affirming that the majority of LPD research is exploratory and grounded in qualitative data.

The analysis of the industry sectors covered in the corpus, as depicted in Figure 13, reveals that the automotive sector, with 23 case studies, constitutes almost 30% of the corpus. This observation reaffirms its historical association with the Toyota roots of Lean principles. The automotive industry is followed by the aerospace sector and the construction sector, with nine and seven papers respectively, showing a significant interest in adapting LPD methodologies to complex projects. High-Tech/Electronics, military, industrial equipment, design and manufacturing and computer sectors contribute with six, six, five, four and four papers respectively, demonstrating the versatility of LPD application. Additionally, 16 papers span other sectors, indicating a broad applicability of LPD concepts beyond traditional industry boundaries.

Furthermore, it is worth noting that all texts in the corpus express a positive perspective on LPD, focusing not on the impact of LPD but rather on successful implementation strategies. The motivation behind these studies lies in the quest for a consensus on defining LPD, the development of frameworks or models, and the assessment of Lean capabilities. The overarching theme revolves around providing answers on how to successfully implement LPD or assess one's LPD maturity level. However, the definition of what constitutes success remains ambiguous.

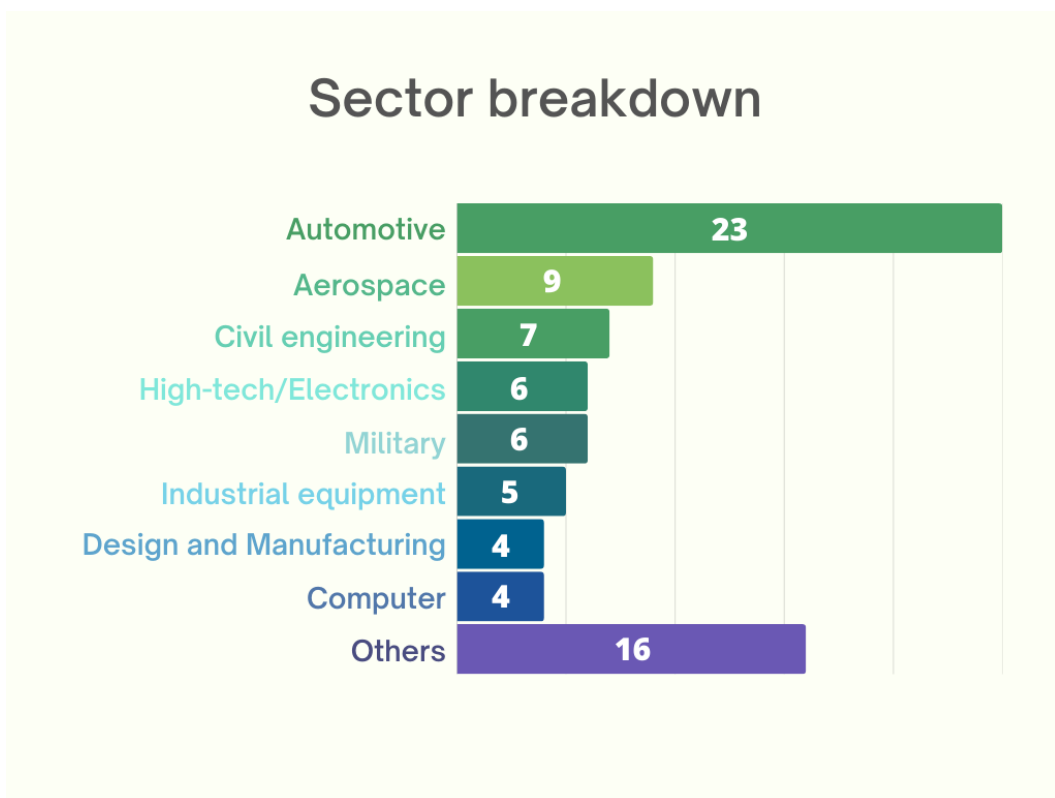


Figure 13: Sector breakdown

The analysis of the corpus highlights the depth and diversity of the chosen texts but also underscores the global reach and applicability of LPD across various literature types and industry sectors.

## 2.5. Methodology for identifying key factors

The prime objective of this work is to comprehensively provide the success factors and barriers to the successful implementation of LPD. By successful, we mean in a way that allows companies to gain a competitive advantage. This could be materialized by an improvement in their development efficiency (a reduced time to market, lower costs, or enhanced customer value) or by more innovation.

In the texts, a success factor was considered to be anything meeting following criteria:

- The factor is explicitly referred to as a success factor.
- The factor is referred to as an enabler.
- The factor is cited as a way to improve the LPD implementation.

The criteria used to select the barriers to the successful implementation of LPD were the following:

- The factor is explicitly referred to as a barrier.
- The factor is cited as hindering the LPD implementation.

To structure our examination of key factors, we initially delved into the existing literature in search of a comprehensive framework to organize ideas. However, we encountered a notable absence of consensus regarding a universally accepted framework for LPD, as highlighted by León and Farris (2011). A literature review conducted later by Jasti and Kodali (2014) emphasized the existence of at least 35 LPD frameworks until 2012, with none emerging as dominant in the domain. This lack of a prevalent and widely acknowledged framework persists, as noted by Van Der Braak et al. (2018) in 2018, who observed the absence of a clear, structured, and comprehensive framework chosen as a reference. Notably, most studies tend to concentrate on tools and techniques rather than adopting an overarching framework.

León and Farris (2011), in their framework inspired by Liker and Morgan's three LPD subsystems (people, process, tools and techniques (Liker & Morgan, 2006)), illustrate the intricate interconnections between various categories within frameworks. This interdependence raises the possibility of alternative categorizations depending on the perspective taken. The complexity inherent in classifying these key points and the multidisciplinary nature of LPD contribute to the proliferation of diverse frameworks without a singular consensus emerging.

The dynamic and interconnected nature of LPD, coupled with its multifaceted dimensions, underscores the challenges in formulating a universally accepted framework. As researchers continue to explore and contribute to the field, the quest for a cohesive and widely embraced LPD framework remains an ongoing endeavor marked by diversity and evolving perspectives. It was decided for this review to organize the success factors and barriers found in the corpus according to their similarities by carrying out a thematic reading that organized the information in a semantic-logical way. Fifteen categories of key elements were created.

All the texts on which we worked use various categories to account for the situations and processes observed. As our purpose was to identify common trends between the various texts studied, we grouped together under a single term, the categories which presented a set of common points. This explains why some of the terms we use sometimes subsume by extension or restriction the semantic fields of the authors we cite. Hence, some of the categorizations, such as the notion of Set-Based Concurrent Engineering (Larman & Vodde, 2010), standardization (Hoppmann et al., 2011), customer focus (Morgan & Liker, 2006), supplier relationships (Haque, 2003), added value focus (Ward & Sobek II, 2014) and management and leadership (Womack & Jones, 1996) were inspired by the literature although their content may vary.

## 2.6. Impact of the context

The different elements found in the corpus were then filtered to study the impact of some contextual parameters on the abovementioned key factors.

The hypotheses we wanted to test were:

- H1: the key factors depend on the time period.
- H2: the key factors depend on the geographical origin.
- H3: the key factors depend on the industrial sector.
- H4: the key factors depend on the complexity of the product.

The analysis of these filters showed no significant pattern. This indicates that the corpus selected failed to prove a correlation between success factors or barriers of LPD and the contextual parameters considered in H1, H2, H3 and H4.

## 2.7. Key factors in the literature

The outcomes of our research are synthesized in tables, providing an overview of both success factors and barriers to Lean implementation. Detailed summaries can be found in the appendices, specifically Table A1 for success factors and Table A2 for barriers. Notably, the question of barriers is comparatively addressed in fewer references than the question of the success factors. This discrepancy may be attributed to the inherent challenge of articulating "what not to do" as opposed to delineating positive guidelines. Additionally, the nuanced nature of barriers may render them less straightforward and challenging to transform into actionable guidelines for practitioners.

The subject also makes it harder to turn barriers into guidelines for practitioners than the success factors. It could also be that barriers are just simply harder to identify and justify than success factors.

Nonetheless, many barriers cited in the literature are simply a lack of key success factors. However, it is important to highlight that barriers are not necessarily the opposite of success factors. The two notions are not symmetrical, the presence of one concept can help a successful implementation of LPD without its absence being harmful to it.

Given the prevalence of success factors in the literature, the key factors extracted from the corpus have been organized in the subsequent section based on their frequency of occurrence, from the most cited to the least cited. Figure 14 and Figure 15 present respectively the list of the success factors and of the barriers sorted according to their occurrence. These figures offer a structured insight into their prevalence within the corpus. This categorization provides a resource for practitioners and researchers seeking a prioritized understanding of the elements influencing the success and barriers of LPD implementation. While the prominence of a factor in these figures does not inherently imply its greater importance, it does signify that these aspects have been extensively explored in the literature. This, in turn, suggests that individuals seeking insights or assistance on these topics may find a wealth of information and support due to their widespread treatment in existing research. The figures thus provide a navigational guide for those delving into LPD, offering a collection of elements that have garnered substantial attention and consideration in literature.



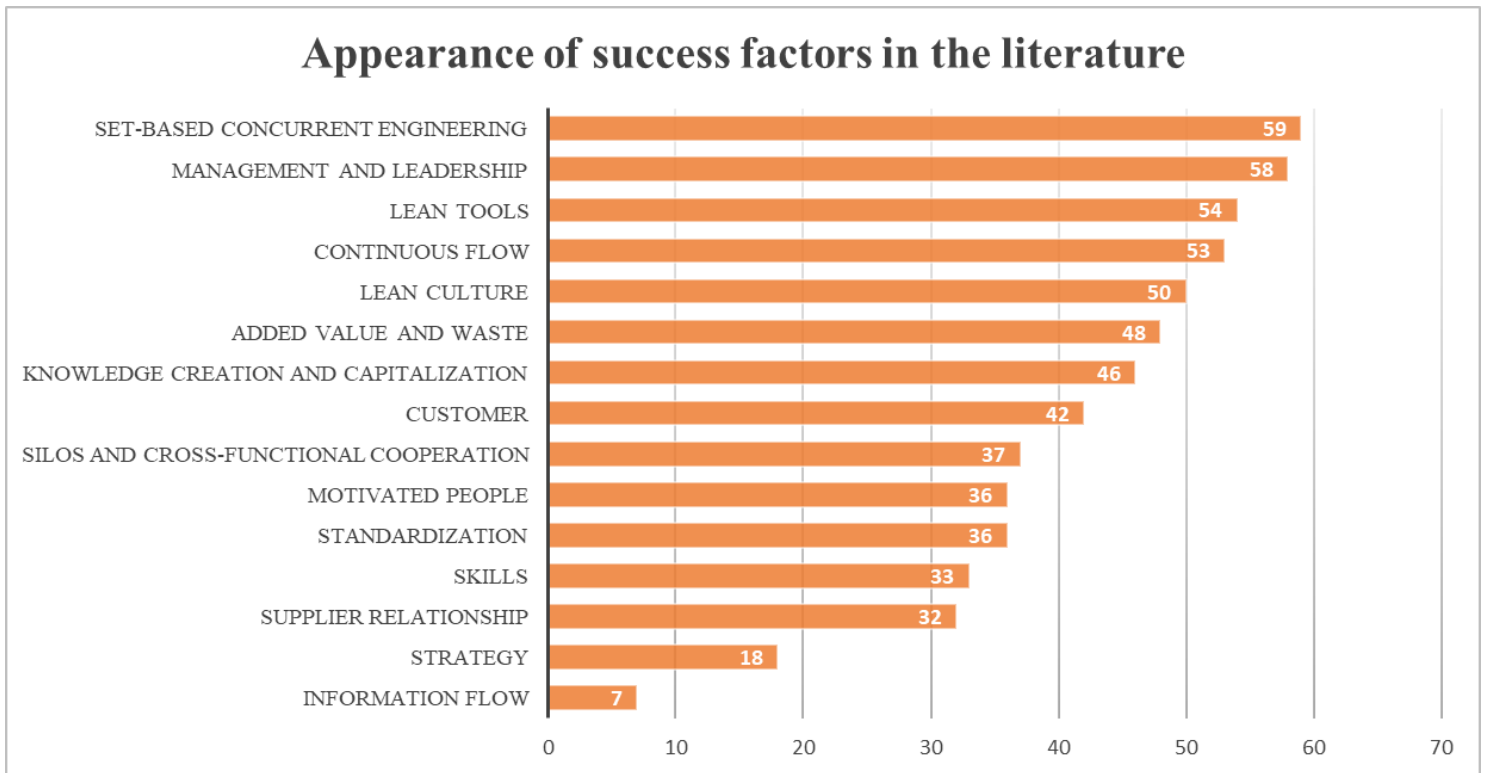


Figure 14: Appearance of success factors in the literature

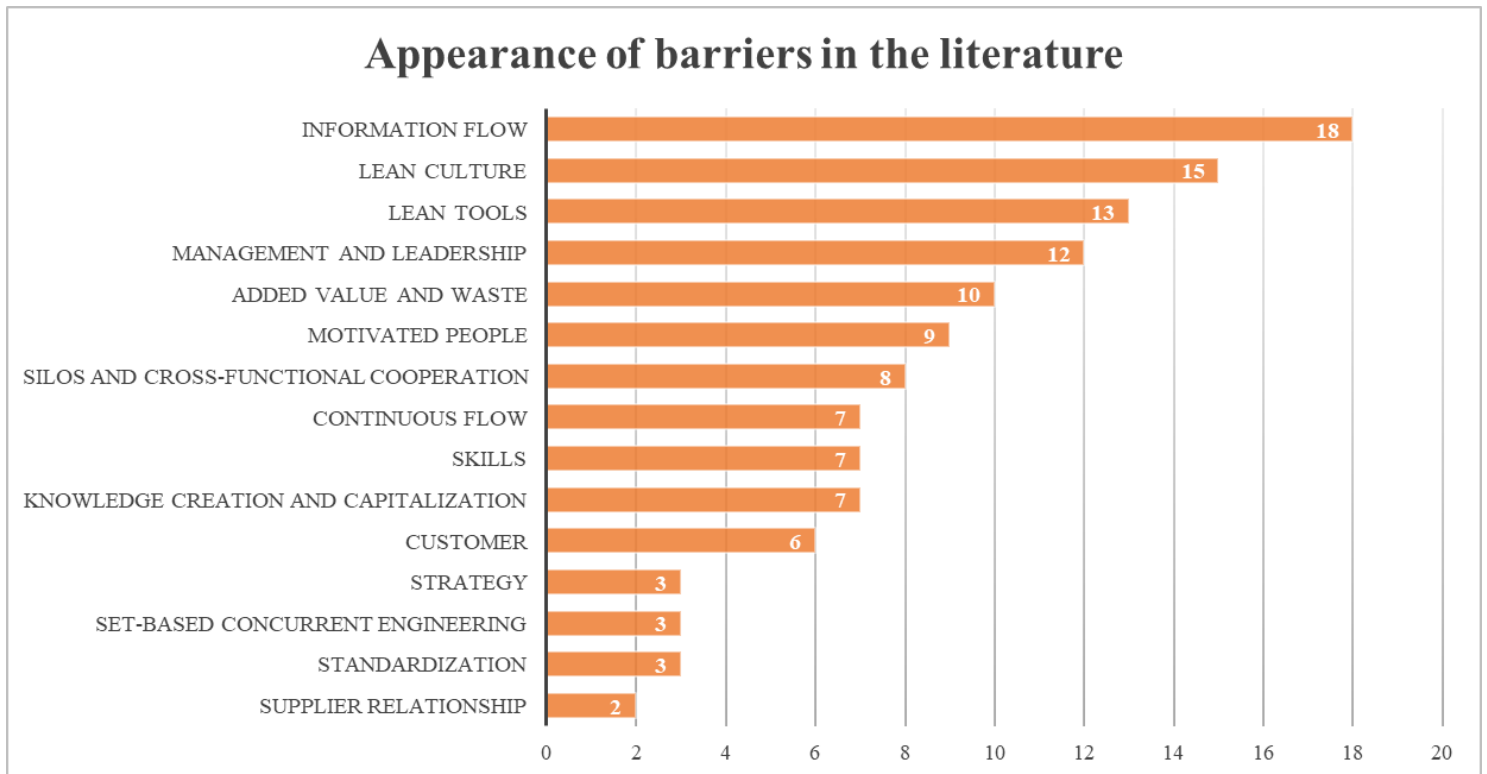


Figure 15: Appearance of barriers in the literature

## 3. Success factors and barriers

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### 3.1. Set-Based Concurrent Engineering

#### 3.1.1. Success factors

Set-Based Concurrent Engineering (SBCE) or Set-Based Design is cited as a key factor in a successful LPD (Larman & Vodde, 2010). It is a cornerstone of Toyota's product development process (Liker & Morgan, 2006) and consists of keeping a set of alternative solutions for as long as possible in a product development process (Synnes & Welo, 2022).

It is sometime referred to as front-loading the product development process (Liker & Morgan, 2006). This helps ensure that customer expectations are fully understood (Al-ashaab et al., 2013). The technical decisions must be based on validated knowledge and made as late as possible but not too late. During the design phase, having a more open mind helps to create innovative solutions. Alternatives are evaluated, trade-offs are made, weaker solutions are eliminated, and new ones are created often by combining components in new ways. This helps to reduce risks by building redundancy into systems (Baines et al., 2006) and it makes it easier to bounce back when an issue or a change of specification occurs by allowing the system to evolve by means of creative combinations of multiple solution sets (Ström, 2022). There is a consensus in the literature that the SBCE approach is superior to the alternative point-based design process which leads to more "rework" costs (Baines et al., 2006).

#### 3.1.2. Barriers

The traditional focus on point designs, which means having a highly specialized solution to a specific problem chosen early in the design process is a barrier to Lean development (McManus et al., 2005). This method prevents teams from exploring set designs and increase the uncertainties of a project (Oppenheim, 2004). While, SBCE is identified as a key success factor in LPD, simultaneous engineering remains paradoxical for engineers and it is hard to get them to endorse this counter intuitive approach (Karlsson & Ahlström, 1996). Moreover, there is a lack of a clear and structured SBCE model in the literature and a lack of clear guidelines on how to implement SBCE in practice. This makes it harder for practitioners to structure and implement it in their context (Al-ashaab et al., 2013).

### 3.2. Management and leadership

#### 3.2.1. Success factors

Firstly, Morgan and Liker (2018) talk about the management system that is for them the product of two elements: leadership behaviour, i.e. the traits and actions that make an individual effective as a leader, and an operating system that includes the tools, processes, standard work, cadenced activities, and other mechanisms that enable the work to be done. To them, all these factors are interdependent, so if one of the factors is weak, the end result will be affected. There

is no operating system that can compensate for incompetent leadership. It is therefore unsurprising that the exemplarity of management is cited as essential in the deployment of LPD. It is crucial to have a management that is committed and that understands the importance of Lean, but that is also a teacher leading the way in adopting Lean (Ferreira et al., 2023; Haraldsson, 2020).

Looking more closely from a project management point of view, others insist on the importance of having a heavyweight team leader or a heavyweight project manager with total project responsibility (Letens et al., 2011; Womack et al., 1990). Toyota goes further and talks about the need for a “chief engineer”. This key actor has a strong leadership and their responsibility is more oriented towards technique, technology and customer value; as such, they must be paired with a project manager that deals with the operational aspect of a project (Synnes & Welo, 2022). However, the chief engineer must be supported by experienced function engineers to have a natural authority, as they do not have any formal or hierarchical authority given to them (Baines et al., 2006; Oppenheim, 2010).

### 3.2.2. Barriers

Similarly to success factors, when managers are not aware of Lean, and when they are not committed and not engaged with the teams on this topic, their attitude hinders the opportunities for the company that this approach could offer (Haraldsson, 2020).

The biggest failure mode for Lean transformations is a senior management that does not believe in Lean or does not understand it (Radeka, 2012). On one hand, managers who do not understand Lean may think that it is just another project with an end. They often do not continually communicate commitment and do not establish a clear vision or clear goals for their teams which makes it impossible to make long lasting change (Kennedy, 2003). On the other hand, some managers fake their support. They say they support Lean initiatives but do not learn what the Lean principles are in depth and how best to apply them. They see Lean from the perspective of “spectators” only merely talk the talk, rather than being examples for others by systematically solving problems and asking others to do so (Haraldsson, 2020). Both cases can be made worse by badly chosen targets and bonuses. For example, if a manager receives a bonus if 50% of their projects have a chief engineer, some regular project leaders may simply be relabelled as chief engineer, without the substance of the role. This simply leads to superficial Lean adoption, game playing, resentment, hidden resistance, and misunderstanding (Larman & Vodde, 2010). On another note, trying to “sell” Lean by hook or by crook to people who are unaware and unconvinced can be a reason for its failure. It is preferable to practise systematic problem-solving skills and show how Lean could help than to force it on employees (Radeka, 2012). Furthermore, when engaging in LPD, halfway measures, such as pilots or small test programmes can be seen as weak commitment and therefore be a

reason for the approach failing. Resources must be allocated to the change process clearly and visibly show a strong commitment (Kennedy, 2003; Toledo et al., 2023).

Leaders who are afraid of showing a lack of confidence (Oosterwal, 2010), or who do not provide coaching because they are scared of confrontation, of causing offence, or of failure, or owing to a lack of time, or perhaps because they have never been coached themselves and have little incentive or accountability to learn to do so, can also hinder LPD (Schulze & Störmer, 2012).

### 3.3. Tools

#### 3.3.1. Success factors

Forty-six texts mention certain Lean tools as key success factors, such as A3, Obeya Room, Kanban, Visual Management, Spaghetti diagrams, VSM, KANO, etc. These tools can be used for standardisation or organisational learning (Aikhuele & Turan, 2018; Paker, 2021; Rauch et al., 2017). However, tools cannot be reduced to so-called “Lean tools”. This key factor should be understood widely and include all tools such as tools for planning, CAO, data management, etc. However, mere possession of tools is insufficient. The corpus underscores the significance of possessing the right tools – ones that are customised and not obsolete (Sivolapenko, 2022). There is this idea that tools and methods need to be adapted to the organisation, and that Lean thinking must be adapted to the environment and to the context. Mascitelli (2011) suggests that thoughtful tool selection can positively transform a firm's culture, emphasising the transformative potential of the right tools. Similarly, Huthwaite (2004) asserts that the effectiveness of product design tools lies in their alignment with the culture they are intended for. Furthermore, an important point is that tools must always be subordinated to people and process, i.e., the technology must be adapted to fit people and processes and not the other way around (Mund et al., 2015). Tools should also be used to improve product development processes by procuring productivity or performance measurement (Dombrowski & Zahn, 2011). However, these measurement systems should be tailored to the specific vision of an organisation and be focused on product quality, customer satisfaction and value definition. This does not necessarily imply creating new metrics, but rather identifying existing metrics that help assess LPD practices (León & Farris, 2011).

#### 3.3.2. Barriers

There are many tools that can be used in LPD. Some of them focus on the structuring or the visualisation of flows, others on problem analysis, others give metrics, among many functions. Marcks von Würtemberg et al. (2011) classify them according to six categories: customer focused tools, knowledge sharing tools, visual management tools, efficiency tools, problem solving tools, and quality assurance tools. The most common mistake made with these tools is to think that they will solve problems on their own (Liker & Morgan, 2006).

Indeed, using Lean tools in a firm that lacks Lean culture, and therefore where people do not have a shared understanding of the vision and of what Lean is, can be disastrous (Synnes & Welo, 2022; Tortorella et al., 2016). Moreover, Lean tools and methods as presented in the literature will not work perfectly for each and every company. They are generic and must be adapted to each specific context (Mascitelli, 2011). However, to be able to adapt these tools, they first need to be understood.

Another issue in LPD is that people use the “wrong” tools or outdated ones, such as old document-centric management tools or 2D drawings instead of 3D ones (Larman & Vodde, 2010; Oppenheim, 2004; Ward & Sobek II, 2014). When an organisation blindly applies tools that are not understood to an ineffective system, the tool may not produce much benefit, resulting in the organisation becoming more reluctant to continue the change process (Oosterwal, 2010). To avoid this, it is advised to start with simple tools such as cards on walls, spreadsheets or wikis (Larman & Vodde, 2010). Furthermore, introducing any automation to the process, such as digital tools, can make a process less efficient if done too early in the maturity of the flow. It is important to pay particular attention to stabilise the product development process first (Welo & Ringen, 2016). On the other hand, the use of the tools can itself be a barrier in successful LPD. Remember, the road to hell is paved with good intentions and one must be careful when using metrics. Indeed, measuring the wrong things can send an inconsistent message to the organisation and even have the opposite effect to the one intended (León & Farris, 2011).

## 3.4. Continuous flow

### 3.4.1. Success factors

Another goal and key factor of LPD is to create a continuous flow (Mund et al., 2015; Synnes & Welo, 2022). To this end, many suggestions on how to manage the process are made in the literature.

Mascitelli (2011) states that to prevent the underutilisation of resources that can result from dedicated teams, and the waste caused by project-assignment overheads, there should be a limited number of projects assigned per person or per team. The optimum number of projects that guarantee the best resource productivity depends on the size and complexity of the projects involved.

Haque (2003) also talks about having a balanced workload. If there is a good balance, this helps to facilitate the flow of value. If there are not enough projects, employees will have idle time, waiting for activities to do. On the other hand, if there are too many projects there is a risk of inefficiency linked to multitasking, as the brain takes time to reset when switching from one project to another. Other key points are working in small batches to avoid long reworking, making queues visible, and prioritising to avoid multitasking (Roche & Delamotte, 2023).

### 3.4.2. Barriers

Firstly, it is important to understand that the mere application of Lean manufacturing to product development will not be fruitful (Ferreira et al., 2023). The principles need to be adapted. Moreover, trying to change a process too fast is not an effective transformation strategy (Mascitelli, 2011).

Resource utilisation and efficiency is an important element that can hinder LPD deployment. Indeed, unused resources can represent losses for a company (Rauch et al., 2015), as can inefficient resource allocation, for example, having the wrong resources allocated to a project or the right resources allocated at the wrong times (Letens et al., 2011). Poorly managed schedules (Oppenheim, 2004) with assumed infinite capacity such as giving teams too many projects with too few resources is not any better (Mascitelli, 2007). For example, having close to 100% of hours booked in advance of a work week for a team does not leave any time to solve unforeseen problems (Welo & Ringen, 2016). Moreover, it has been shown that a lack of resource and workload management can reduce productivity and raise product development costs by more than 20 percent (Hofinger Jünge, 2022). Furthermore, this can create a vicious circle: high workload pressures lead to a lack of time to carry out continuous improvement, which leads to a lack of standardisation, which in turn leads to poor planning and consequent work overload (Hines et al., 2006). Furthermore, multitasking can make a process slower because of the time to switch from one project to another (Haque, 2003; Welo & Ringen, 2016).

Moreover, not having clearly defined, up-to-date processes can be a barrier to the implementation of LPD. In many companies, processes are poorly defined. They may refer to obsolete practices (for example, talking about paper drawing when CAD is used), contain detail that is not relevant to most jobs, or miss out key practices (for example, the appropriate ways to handle new materials or technologies). They may also capture practices that once were critically important, but which have become irrelevant over time (McManus et al., 2005). This ambiguous definition of processes, responsibilities, and working methods lead to improvisation and ineffective actions (Dombrowski & Zahn, 2011). Another barrier is having ad-hoc management or ad-hoc execution (Belvedere et al., 2019; Oppenheim, 2004). In addition, having excess project management, wanting to be too precise in deliverables or in specifications, generating a lot of unproductive meetings and the inexistence of levelled workload (being overloaded with no prioritisation and idleness are commonly observed) are key points considered as barriers in LPD (Hofinger Jünge, 2022). Having gate-controlled governance is also perceived by Mascitelli (2011) as hindering the product development process. Focus should instead be put on achieving a continuous flow. Having a poor operational decision-making process is also an issue. In this case, decisions are superficially analysed by few individuals (Tortorella et al., 2016). Finally, having push- rather than pull-based specifications and requirements can be a source of inefficiencies (Oppenheim, 2004).

## 3.5. Lean culture

### 3.5.1. Success factors

The adoption of a continuous improvement culture is key to the success of LPD (Al-ashaab et al., 2013; Qudrat-Ullah et al., 2012). Also known as a Kaizen culture (Liker & Morgan, 2006; Mascitelli, 2007), continuous improvement is a culture of systematic problem-solving, a never-ending quest for perfection in everything the organisation does. To achieve this continuous improvement, companies must trust employees, who should be at the heart of every improvement. In this continuous improvement culture, there should be a serving-leadership culture that understands that employees spend the most time with their work, so it is them that know best how to improve it, and that managers are not there to solve issues, but to give the support and motivation employees require to do so (Dombrowski & Zahn, 2011). Moreover, this culture should be shared by all in the organisation (Baines et al., 2006; Oosterwal, 2010). It should be a no-blame culture, a culture where people have the right to make mistakes. This means that there is a common acknowledgement that mistakes occur because of systematic error and not intentionally (Dombrowski & Zahn, 2011). In this context, transparency and trust, which are key points in the culture of a Lean organisation, should be fostered and encouraged (Larman & Vodde, 2010; Tribelsky & Sacks, 2011). There should also be an environment of respect for people (Salgado & Dekkers, 2017; Tortorella et al., 2016; Wangwacharakul et al., 2014). Those people, who are an indisputable key element of any organisation, should be put first, over tools and technology (Welo & Ringen, 2016). We can see that the notion of “Lean culture” encompasses many different aspects, and that one signifier includes multiple definitions, which can be confusing.

### 3.5.2. Barriers

There are some factors that constitute barriers to so-called Lean culture. Firstly, there is a lack of understanding of Lean practices and their characteristics, and therefore a lack of Lean thinking when implementing Lean (Aikhuele & Turan, 2018). A special effort needs to be made to increase the awareness and popularity of LPD methods for them to be accepted and adopted (Rauch et al., 2017). Furthermore, some companies do not celebrate success when they make improvements or when they finish a big project. This is a shame because it helps to create a motivating work environment. A strong culture of praise increases engagement, productivity, team spirit, and resilience to challenges that arise in every organisation (Hines et al., 2006).

Moreover, in some companies, the culture is for engineers to immediately say no to “unfeasible” designs. This attitude keeps the company away from innovation and improvement (Liker & Morgan, 2006). It is then harder for researchers to perceive the relevance of addressing the waste generated by their own work, and easier for them to see that generated beyond the scope of their direct responsibilities (Belvedere et al., 2019). Certain cultural barriers can also make it more difficult for companies to apply the Japanese Lean model to

non-Japanese companies. For example, in most western countries, awards bring out the individual competitive spirit of employees, there is less trust in organisations, and communication is often harder (León & Farris, 2011).

On the other hand, the missing transparency regarding project targets and customer values is a frequent cause of wrong decisions and iterations (Schuh et al., 2011). In addition, some companies treat Lean as any other project with a beginning and an end. Therefore, some think that it can be externalised. The problem is that a company must absorb new ideas and methods intrinsically and this learning process begins with knowledgeable internal leadership. Delegating the leadership of the change programme to an external consultant is therefore strongly discouraged (Larman & Vodde, 2010).

One of the biggest obstacles to implementing any new product development tool or method is its impact on the status quo. Many companies spend a lot of time, energy, and money to put in place a formal development process. This is why once in place, and once the management is finally aligned and the teams are well-trained, such a process is tough to change in any significant way (Mascitelli, 2011). Therefore, one of the biggest mistake firms make is announcing that the organisation will undergo some monumental change.

Implementing a Lean culture takes time. Being persistent in a change process is far more effective than being loud once. As Mascitelli (2011, p58) said, “You can fix a person’s overbite either by punching them in the mouth or by putting braces on their teeth”. Instead, companies should choose a few methods and tools and start by using them, and then add others gradually, improving continuously and incrementally. Furthermore, Lean thinking must be translated to fit the specific context of NPD; implementing only a few of its principles is not enough for it to be successful (Salgado & Dekkers, 2017).

## 3.6. Added value and waste

### 3.6.1. Success factors

The question of value and waste is also widely addressed by 41 texts of this corpus. Baines et al. (2006) state that companies need to refocus Lean on the notion of maximizing value rather than minimizing cost and cycle time. In fact, Schuh et al. (2011) state that the majority of financially successful organizations share a common success factor: the early structuring of value and the systematic identification of waste. This is because focusing on value helps companies prevent waste (Roche & Delamotte, 2023).



However, for organizations to be able to focus on value and to reduce waste, these terms must be defined first for each context (Hoppmann, 2009). Waste can be of different types in product development and is closely associated with knowledge (Reis et al., 2021). Although there is not a consensus on the different types of waste, their identification and elimination is considered an important step in the implementation of Lean principles (Belvedere et al., 2019). That said, all the authors drew inspiration from Taiichi Ohno's waste categorization in Lean manufacturing. Locher (2008) reinterprets these as eight types of waste: overproduction, waiting, transportation, processing, inventory, defects (and correction), motion, and underutilized people. Oehmen and Rebertsch (2010) propose eight categories closely linked to the information flow: overproduction of information, over-processing of information, miscommunication of information, stockpiling of information, generating defective information, correcting information, waiting of people and unnecessary movement of people. Finally, Reis et al. (2021) more recently classify waste according to eleven categories: wait, unnecessary transportation, unnecessary movement, excessive processing, inventory, overproduction (or non-synchronized processes), defects, reinvention, lack of discipline, limitations on IT resources and correction of information. A summary table that presents the different types of waste in LPD from the point of view of different authors can be found in Waste in LPD (Oehmen & Rebertsch, 2010). It can be seen that all classifications found in the literature feature more or less the same concepts that are the translations of the Lean Manufacturing waste. The only differences lie in the fact that there are specifications adapted to certain professions. Thus, for example, people in R&D only working with immaterial content should use a classification tailored to information flows, while designers could use one focusing on design works. As we have seen, it is important for organizations to make a clear distinction between value-adding activities and inefficiencies (Belvedere et al., 2019) to be able to eliminate waste from the workflow, and also in order to remove it from the flow of the customer experience (Helmold, 2020), and from the business level as well (Welo, 2011).

For value, it is important to remember that value creation must be a two-headed coin (Paker, 2022). Value should be pulled by the customer (Tortorella et al., 2016), but it can be linked on one side to a customer or a product and on the other side to a process or an enterprise (Al-ashaab, et al., 2013), which is why it should deliver benefit to both the customers and the company (Roche & Delamotte, 2023).

### 3.6.2. Barriers

One key factor of LPD is the definition of added value. The value management approach can only be successful if the value is correctly and mutually identified by the architects, engineers, and customers (Aslam, Gao, and Smith, 2020). One factor hindering this is the fact that defining value is very difficult (Emmitt et al., 2004; Salgado & Dekkers, 2017). Focusing on only one aspect of value is not enough. Focusing on value to the customer, for example, while excluding value to other stakeholders such as the enterprise, employees, shareholders, suppliers, etc., can jeopardize the long-term viability of a firm (Browning, 2000). Moreover, the idea that

increasing value can be done by tackling only one side of the problem which is by decreasing what is not value is not enough. Value can be improved by decreasing costs for example, but it can also be improved by increasing benefits. Therefore, the amount of value added by a product development process can be increased by adding activities as well as by taking them away (Browning, 2000).

## 3.7. Knowledge creation and capitalization

### 3.7.1. Success factors

Knowledge is a key point for a company to keep its competitive advantage. The literature cites knowledge capture and reuse as a clear success factor of LPD (Dal Forno et al., 2016). According to Radeka (2012), companies that understand the process of knowledge creation and that are able to capitalise on knowledge have the ability to be faster, more innovative, and more predictably successful. Having a knowledge-based environment (Nagai & Torres Junior, 2021) or knowledge-based engineering (Aikhuele & Turan, 2018) is crucial for organisations. This means having a company capable of capturing and reusing knowledge on markets, customers, technologies, products and production capacities (Morgan & Liker, 2018). This can be achieved thanks to the recording of lessons learned and the exchange of information, in addition to human abilities (Ström, 2022).

Radeka (2012) emphasises the specific need for contingent knowledge, which she distinguishes from formal knowledge, informal knowledge, and tacit knowledge. Moreover, the creation of knowledge should be spread efficiently throughout the whole organisation. This is what Dal Forno et al. (2016) call cross-project knowledge transfer. However, particular attention should be paid to balancing functional expertise and cross-functional integration (Synnes & Welo, 2022). This means that while having knowledge spread effectively is important, it is also important to have little “islands of expertise”.

The creation of knowledge is also intrinsically linked to people and their abilities, hence why it can be emphasised by the valorisation of employee ideas (Dal Forno et al., 2016). Learning is also pointed to as a key success factor for LPD and is intrinsically linked to knowledge (Salgado & Dekkers, 2017). Companies and people must learn continuously to be able to keep up with the market and create knowledge. According to Ward and Sobek II (2014), knowledge is created through three basic kinds of learning:

- (1) Integration learning, which includes learning about customers, suppliers, partners, the physical environment in which the product will be used, etc.
- (2) Innovation learning, which creates new possible solutions.

(3) Feasibility learning, which enables better decisions among the possible new solutions, avoiding cost and quality problems, and project overruns.

### 3.7.2. Barriers

The most important waste in LPD is knowledge-related waste, such as working with defective information, waiting, lack of knowledge/learning, and ineffective communications (León & Farris, 2011). A lack of knowledge reutilization can significantly hinder a company's product development capacity (Toledo et al., 2023). Previous knowledge is ignored, and current knowledge is not captured or registered (Tortorella et al., 2016). This leads to each programme being started without the legacy knowledge being used, and without learning from past mistakes (Oppenheim, 2004). This can cause a product development department lose a lot of time and money, and results in frustration.

Sometimes knowledge is reused but not well transferred. This can be due to a lack of shared understanding and turnover in project personnel, which results in increased lead-times. This happens when product knowledge is only formally captured near the end of the project. This often leads to conceptual misunderstandings between groups during handoffs in the development process, creating delays and rework to correct resulting errors (Letens et al., 2011). In addition, many companies create component departments to have teams with in-depth technical knowledge on one part of the final product. What needs to be highlighted is that while specialization is good for creating knowledge, increasing productivity and even developing pride in workmanship, single specialization is detrimental. It creates constraints, silos, waste of handoff, and mental communication barriers (Larman & Vodde, 2010). A balance needs to be found.

## 3.8. Customer focus

### 3.8.1. Success factors

To achieve a successful LPD initiative, a focus on customer value is essential (Gutterman, 2023). Value should be pulled by the customer. The focus can be on the needs of external customers, but also on those of internal customers (Dal Forno et al., 2016). In line with evolving methodologies, a growing interest is observed in a novel approach to LPD. This approach explicitly integrates customer development methodology, ensuring that investment in product development is informed by a comprehensive understanding, derived from rigorous hypothesis-driven tests with real customers (Stavig & Stavig, 2022). These tests aim to answer fundamental questions such as identifying the target customers, understanding their problems and needs, assessing their current behaviour, determining which solutions they are willing to pay for, and devising ways to deliver those solutions aligned with customers' decision-making, procurement, purchase, and usage preferences. To operationalise customer-focused LPD, some

key points are given in the literature. Firstly, there should be a good and direct interface between the customer and the teams working on a project or a product (Welo & Ringen, 2016). The teams should meet customers regularly and not just the project managers (Larman & Vodde, 2010). These interactions must continue throughout the entire design process (Koskela & Ballard, 1997).

The goal is to empathize with the customer, to understand their needs before her-him and to eliminate wastes from her-his experience (Helmold, 2020). To achieve this, the customer's voice must be listened to and interpreted through several levels of the organization (Mascitelli, 2007), while keeping in mind that customer values and needs never stop changing (Huthwaite, 2004).

### 3.8.2. Barriers

Not being customer-focused enough is also an issue in LPD. "No amount of efficient lifecycle engineering or engineering process improvement can make up for a product that a customer does not want" (McManus et al., 2005, p2). This can come from insufficient customer empathy (Radeka, 2012), a lack of understanding of customer requirements (Tortorella et al., 2016), or worse, an adversarial relationship with them.

## 3.9. Silos and cross-functional cooperation

### 3.9.1. Success factors

The organizational structure of a company is mentioned as a success factor in LPD (Dal Forno et al., 2016). It is recommended to work in cross-functional teams (Aikhuele & Turan, 2018), to have cross-functional cooperation (Letens et al., 2011; Salgado & Dekkers, 2017), and synchronization (Liker & Morgan, 2006) through meetings, for example. In essence, this approach can be succinctly summarized as the promotion of robust constant communication not only between diverse teams (Cusumano et al., 1998; Mascitelli, 2007; Rauch et al., 2017), but also different functional areas (Mund et al., 2015) and different organization levels (Welo, 2011).

### 3.9.2. Barriers

Having silos is clearly seen as a barrier for LPD (Koskela & Ballard, 1997). There are different types of silos: internal and external. Internal silos result from a silo mentality within the organization, leading to systemic barriers, such as those between Product Managers and R&D. On the other hand, external silos involve isolation from the customer, often more pronounced in larger organizations where a focus on technology and component teams can hinder the visibility of the global product (Larman & Vodde, 2010).

These barriers to communication can take various forms. First, there are some physical barriers, such as distance or incompatible computer formats. There are also social barriers such as corporate “class systems” and management behaviors that prevent communication. Moreover, there are skill barriers, such as individuals not knowing how to turn data into usable knowledge (Ward & Sobek II, 2014).

These silos can be emphasized by organizational complexity. For instance, it is difficult to organize effective communication in a company that has several departments and teams in charge of specific tasks (which can be called organizational complexity by differentiation), or whose activities are highly interdependent (organizational complexity by interdependency) (Belvedere et al., 2019). Moreover, having a cumbersome chain of command that separates working-level engineers from top management is not helpful (Roche & Delamotte, 2023), nor is having a corporate culture of excessive conservatism, bureaucracy, compartmentalization, and poor communications among team members, particularly across departments, divisions, and supplier nodes (Oppenheim, 2004). This lack of communication between all the parties evidently results in little collaboration between key players and therefore less efficiency and fewer new ideas (Aslam et al., 2020). Furthermore, having this separated focus on the R&D department in development creates difficulties in achieving cross-functional integration. Indeed, people tend to think product development is only the responsibility of R&D, and they do not have a lot of time and resources, so they feel like it is not their job to assist in the process of product development (Karlsson & Ahlström, 1996).

## 3.10. Standardization

### 3.10.1. Success factors

The standardization of processes, projects and designs is one of the key success factors to LPD. It is a set of methods defined to avoid reinventing the wheel and to make things simple (Synnes & Welo, 2022). The mix of modularization and standardization plays an important role in LPD by reducing product complexities and variations (Marodin et al., 2018). Moreover, it is also important for the skills of engineering experts to be standardized (Liker & Morgan, 2006). Standardization concerns projects, design, and processes, but also competencies (Dal Forno et al., 2016).

### 3.10.2. Barriers

It is important to keep a trade-off between standardization and flexibility. Too much standardization can stifle creativity and limit innovation, but too little standardization means each project is treated independently to those that have come before it and there is no organizational learning, which can cause a company to lose a lot of time and money by making the same mistakes twice (Liker & Morgan, 2006). Lack of standardized process is also

identified as a barrier to LPD, as it makes it harder to have consistent quality and fast processes (Rauch et al., 2015). Furthermore, despite standardization being identified as a key success factor in LPD, engineers have the tendency to like doing things their way, to find “artisanal” and different ways of doing things. This can lead to great innovation, but it can also be a barrier to standardization (Synnes & Welo, 2022). This is what Belvedere et al. (2019) call the craft mentality of engineers.

## 3.11. Motivated people

### 3.11.1. Success factors

The literature identifies people and their commitment as a key success factor in the implementation of Lean (Rauch et al., 2017). To be the most productive, people should be highly motivated and take pride in the product they are creating (Schuh et al., 2011). To this end, they should feel passionate about coming to work and they should be empowered by feeling like they have the freedom to do what they think is right within the company’s value system (Oosterwal, 2010).

People should also be given individual responsibility (Al-ashaab, et al., 2013), and they should be valorised by being able to be parts of the process and having incentives provided for their ideas and suggestions (Dal Forno et al., 2016).

### 3.11.2. Barriers

The contribution and motivation of every employee is a key success factor in a change approach (Toledo et al., 2023). However, laying down too many conditions or tedious and unrealistic tasks can prevent people from putting their ideas forward. Indeed, if you want a field technician to give their insights, you cannot ask them to do a full business-case analysis beforehand (Mascitelli, 2011). When coaching, it is essential to avoid forcing a Lean approach onto people, as this will result in the exact opposite of what you are looking to do.

Instead, a culture of coaching should be created, and people should be given the freedom to try, think and experiment (Larman & Vodde, 2010). Furthermore, it is important that the incentives and goals given to employees are aligned with the objectives of LPD. There is nothing worse for a company than when a person’s career depends on their paradigm and not on the success of the company (see previous example of the bonus) (Kennedy, 2003). People are usually treated as mere physical assets within most traditional NPD approaches. However, such an often-implicit belief generally weakens most projects’ success rate (Hines et al., 2006).

## 3.12. Skills

### 3.12.1. Success factors

The success of LPD is closely tied to having skilled people. It appears in fact that a great part of Toyota's success may be due to the tacit experience and skills of their well-trained workers (León & Farris, 2011). Firstly, Lean implementation in product development activities is strengthened by employee training specifically tailored to the nuances of Lean-based product development practices (Ferreira et al., 2023). Moreover, the taskforce of engineers should, of course, be competent in their technical domains (Cooper & Edgett, 2005). The same goes for managers, even high-level ones, who should be deeply involved in engineering details, continuously improve their engineering skills, stay abreast of new technologies, remain involved in the creative process, and provide senior managers with in-depth technical knowledge (Schulze & Störmer, 2012). Managers should focus on the customer, the product and the general managers, while also focusing on the management and development of the engineers in the organisation (Wang et al., 2013). Training is hereby identified as very important (Morgan, 2002; Walton, 1999). It helps people to develop technical competence, organisations to grow an expert workforce, and it can also be used to teach critical success factors, such as waste reduction (Larman & Vodde, 2010). Moreover, to give skilled people a means of recognition and to encourage others to follow in their footsteps, a specialist career path must be implemented (Hoppmann, 2009; Rauch et al., 2015; Tortorella et al., 2016).

### 3.12.2. Barriers

Given the importance of having skilled people to the successful implementation of LPD, it is not surprising that a lack of skills among employees is stated as a barrier to a successful Lean approach (Rauch et al., 2017). Moreover, trying to use processes to compensate for a lack of employee skills will be insufficient (Larman & Vodde, 2010). Instead, investing in training the workforce is the best option. Many designers, for example, have never been educated on how to design solutions in a Lean way, or how to avoid certain hidden costs (Huthwaite, 2004).

Conversely, the nonoptimal use of human resources is also a barrier in LPD (Oppenheim, 2004). Using engineers to do certain non-added value tasks can on the one hand be expensive for the company, and on the other hand lead to a lack of employee recognition and motivation (Rauch et al., 2015).

### 3.13. Supplier relationships

#### 3.13.1. Success factors

A key element in an LPD process is having a real partnership between the buyer and the supplier (León & Farris, 2011). This relationship should go beyond commitment to specific contractual specifications. This kind of partnership is achieved through cooperation between the buyer and the supplier. The supplier should be involved and included early on in the product development process (Anand & Kodali, 2008; Franco & Picchi, 2016). In the Japanese automotive industry, for example, relationships were based on trust and rich communication (Cusumano & Takeishi, 1991). At Ford, regular events and technology reviews with the suppliers were held, as well as meetings (both large and small). The Obeya (visit of the shopfloor by management) in the tool shop was also opened for visits by suppliers (Liker & Morgan, 2006).

The choice of suppliers is also crucial in the relationship. Having the right suppliers can make a significant difference. To have a successful buyer and supplier relationship, it is important to achieve the right balance among a supplier's technological capabilities, a buyer's willingness to share information, and the number of suppliers/buyers managed (Liker & Kamath, 1995). On the one hand the buyer has a role of building capability at the suppliers with, for example: knowledge sharing, investment, training, providing the space and facilities for "guest engineers", and supporting suppliers in problem solving. On the other hand, the supplier will benefit the buyer owing to its expertise with, for example, higher quality, lower cost, or shorter development time (Liker & Morgan, 2011).

#### 3.13.2. Barriers

The ability of a company to deliver new products faster and with better quality is strongly correlated with its supplier relationships (León & Farris, 2011). However, there are several points that may turn this key success factor into a hindering factor. Firstly, not creating a partnership with suppliers and not doing simultaneous engineering with them eliminates the positive potentials of having suppliers (Tortorella et al., 2016). Indeed, doing black box engineering where suppliers are responsible for developing complete modules for the product, often without detailed specifications, can lead to a great deal of reworking and mean that great ideas are missed out on (Hoppmann, 2009). Secondly, adopting Japanese supplier management practices without a clear understanding of exactly which practices are most likely to be effective for the given organization may lead to poor investment choices, wrong partnership, and wasted resources, and, as such, supplier involvement may turn into a hindering factor in the implementation of LPD (Liker & Kamath, 1995). Finally, the right number of suppliers must be found. Having too few suppliers results in incentive problems, whereas too many may result in a lack of information sharing and investment, in addition to high administrative costs (Nobeoka et al., 2002).



## 3.14. Strategy

### 3.14.1. Success factors

Business strategy alignment is perceived as another key success factor (Kalinowski et al., 2020). Companies must develop a product portfolio strategy. A select group of senior managers should meet regularly to review and update the product development strategy for the firm. This group must include representatives from all critical functions that impact new product development, including engineering, design, operations, marketing, finance, and potentially others (Mascitelli, 2011). Projects must then be aligned with the product development strategy (Al-ashaab et al., 2013). To achieve this, the vision, the strategy and the values of the company must be shared by everybody at every level in the organisation (Khan, 2012).

### 3.14.2. Barriers

Lacking a product portfolio strategy can lead to a high new product failure rate. Having a lack of alignment between product development strategy and the company business strategy leads to unnecessary development. Furthermore, failure to share a company's vision with employees may lead them to perform their tasks without any sense of common objective or engagement with the business's mission (Tortorella et al., 2016). Not applying the strategy in all projects, or worse, not considering the strategy at all is also a factor that hampers LPD (León & Farris, 2011). In a nutshell, it is crucial to have a coherent strategy followed and understood by everybody.

Conversely, a lack of alignment between product development strategy and the company business strategy can lead to unnecessary development.

## 3.15. Information flow

### 3.15.1. Success factors

There is not one single flow in a company. To put it simply, there are some physical flows of products and people, and also information flows. Information flows are, by definition, much harder to map and understand due to their intangible nature. That said, it is important that they are not overlooked, as they are crucial in product development. There must be a constant and reliable flow of information (Aslam et al., 2020) that should be aligned with the process flow (Hoppmann et al., 2011). Liker and Morgan (2006) argue that organisations can be aligned by means of simple visual communication. A parallel can be made with R&D which mainly comprises flows of information, and the development flow, which is more tangible. Taking into account these two flows, the separation of research from the main workflow (Khan, 2012), also cited as the strategic separation of Research Development and Deployment (Oppenheim, 2004), is also highlighted as a key point in the successful implementation of LPD. Research is highly unpredictable, and its progress and costs are so difficult to schedule that it should be

handled separately from robust mature technology that can be budgeted and rigidly scheduled. This is a way of finding a balance between robustness and flexibility (Oppenheim, 2004).

### 3.15.2. Barriers

The information flow can influence the efficiency of a product development process. Indeed, a poor flow of information can create instability within the product development process and reduce quality (Gomes et al., 2023; Tribelsky & Sacks, 2011). Moreover, having too much administrative information flow can significantly reduce productivity (Mascitelli, 2007), for example, having too many or unproductive meetings (Radeka, 2012).

## 4. Discussion

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Starting this literature review, the goal was to establish a simple and exhaustive table to refer to when implementing LPD. The objective was to be able to provide a checklist for companies to look at to guarantee a successful transformation programme. This review gives practitioners access to a list of success factors and barriers found in the literature to the successful implementation of LPD. We have observed that the concept of barriers in LPD is less well-established and mature compared to that of success factors. Many barriers identified in the literature are essentially the absence of key success factors. Nevertheless, we found it crucial to include them in our analysis, as the two concepts of success factors and barriers are not symmetrical, and barriers do not necessarily stand as the direct opposites of success factors.

In Figure 14 and Figure 15, which respectively display the number of papers citing success factors and barriers in our corpus, we notice variations in the frequency of citation among different factors. For instance, the most frequently cited success factors in our corpus are “Set-Based Concurrent Engineering” and “Management”, while the most cited barriers are “Information flow” and “Lean culture”. It is challenging to pinpoint precisely why these factors are more cited than others, and correlating these occurrences with a measure of importance or relevance is equally challenging. However, what remains certain is that the dynamics surrounding these factors carry significant implications in the realm of LPD, signifying substantial challenges and opportunities for exploration. The notion of SBCE deployment for example is counterintuitive. Cutting costs by developing several projects in parallel is a confusing concept and evidently difficult for management to accept. Information flow has a critical role in product development; it serves as the primary flow, analogous to the centrality of products in manufacturing processes. Moreover, the notion of Lean culture encompasses many different aspects. It can be linked to people with the notions of management, such as trusting people, putting people first, having a serving leadership culture, as well as to process with the notions of Kaizen and continuous improvement. It is a “suitcase word” that is not well

defined and which leads to interpretation. This in turn makes it unclear to understand and implement.

The literature also shows that there is no framework or model that is cohesive or dominant in the domain. In fact, the literature only provides ideas for consideration that depend on other factors. The interconnection between all the factors makes it hard to create a framework that suits everyone. This highlights the systemic dimension of LPD. Hence, whereas the list of key factors presented in this review provides guidance for practitioners, it should not be used blindly without considering the context in which the LPD implementation takes place.

The advent of new technologies, including Industry 4.0 and Artificial Intelligence (AI), introduces a paradigm shift, impacting both practices and products and thus the success factors and barriers of LPD (Lazaroiu et al., 2022; Nica et al., 2021).

This shift can bring about a dual transformation: on the one hand, a metamorphosis of products, marked by increased utilization of electronics and heightened complexity. This can create the need for faster development and the emergence of highly specialized roles. This ultra-specialization can lead to the formation of silos. On the other hand, a transformation of practices is evident, as AI influences the tools employed in the conception process and the Lean tools. The integration of AI enables more sophisticated and data-driven decision-making algorithms. This augmentation enhances the ability to analyze vast datasets, facilitating quicker and more informed decisions at every stage of product development. The real-time insights provided by AI contribute to adaptive planning and streamlined workflows, addressing some barriers in LPD related to slow decision cycles and lack of agility. Furthermore, generative AI can simplify SBCE by systematically comparing diverse approaches.

This dual transformation – both in products and practices – poses challenges and opportunities for the scientific community. This article establishes a framework that can set the basis for exploring the impact of these “4.0” technologies on LPD. While existing literature explores the intersection of Lean principles with various technologies (Rossi et al., 2022), there is a need for a similar examination within the realm of LPD to address the evolving landscape effectively.

Moreover, upon close examination of the interdependence of variables within our corpus, we were unable to discern any consistent patterns or correlations between the key success factors or barriers in implementing a successful LPD process and other contextual variables, such as the time period, geography, industrial sector, or product complexity. This absence of a clear-

cut pattern can be attributed to the nature of LPD itself, which is fundamentally rooted in processes. Processes are inherently dynamic and ever evolving, making them inherently unstable concepts that adapt to the specific contexts in which they are applied. Consequently, rather than discovering a universally applicable, fixed solution, we encounter diverse configurations.

In sociology, the concept of “configuration”, as described by Norbert Elias, characterizes society not as a static substance but as a network of interdependent relations. These relations give rise to sets with a delicate balance that can yield varying outcomes (Elias, 1981). This concept aligns well with the intricate nature of LPD. Notably, contextual variables (such as geography, product, time period, corporate culture, individualities, etc.) can, depending on their configurations, result in either positive or negative dynamics, success, or failure. For instance, LPD seems to be more prevalent in the Japanese automotive industry (Shimokawa, 2010). This could be explained by two factors. First, the automotive industry, where Lean was born, is more mature regarding the subject. The will to implement it and the knowledge of it is therefore greater. Moreover, it may be that the Japanese culture itself is more favorable to a Lean transformation programme. While cultural differences exist between individuals, studies show that there are clear patterns of national cultures (Hofstede et al., 2010). Culture can be seen as a general configuration that is specific to a group of people. On the other hand, LPD is a socio-technical system, i.e. a system with interactions between people and techniques (Fox, 1995).

Implementing Lean entails changing processes, products, philosophies, and people, including individual attitudes, commitment, behavior, and perspectives. Local culture holds significant relevance in this context, and some authors have attempted to decipher the “winning combinations” and assess the impact of different cultures on LPD implementation. Their findings suggest that contextual factors predominantly influence aspects linked to “people” and that these factors must be considered to establish sustainable LPD (Lee et al., 2000; Wangwacharakul et al., 2014).

This conclusion might shed light on why our study could not pinpoint context-dependent key factors. The key factors themselves remain relatively consistent across contexts, but what distinguishes one context from another is the approach to implementing and managing these factors. An exemplar of this adaptability is Volvo, which employs the same LPD model across its global plants. However, the roadmaps to achieve shared objectives differ and are adapted to local conditions, history, and culture (Harlin et al., 2008).

As managers, we were looking for a simple checklist that can answer our questions, but perhaps we approached the problem the wrong way. Instead of searching for a rigid framework, we

might need to delve deeper into the notion of configurations, recognizing that the intricacies of LPD are inherently context-specific and require adaptive solutions.

## 5. Conclusion

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In this article, we focused on identifying and documenting, as exhaustively as possible, the key success factors and the barriers to the implementation of LPD as they are identified and presented in the corpus. This approach can undoubtedly contribute to helping practitioners to reflect on the main factors to consider when implementing an LPD process. In this context, the influence of cultural and sociotechnical contextual elements on these factors, such as the industry, the time period of the programme, the origin of the study, or the type and complexity of the product were then considered. Our literature review focused on 80 texts that were strategically chosen based on their relevance to the topic and their impact on the field. While it seems to us that we have thus opened a page of useful documentation, it may be necessary to combine this broad “top-down” approach with more specific “bottom-up” studies. A literature sample, centered on a specific context, could be chosen to assess whether there are differences with the general key points stated in this text and how to explain them.

Despite this open perspective, our results show that it is difficult to strictly correlate induced effects with key factors implemented in variable and specific contexts. Perhaps the concept of configuration would better suit LPD than the concept of framework often used. However, this study does not show whether differences exist in the acceptance, or in the difficulty of implementing these factors. Future research into the differences of approach for the implementation of these key factors in different contexts could enable the hypothesis made in this review to be validated.

Furthermore, our article has laid the groundwork by introducing a comprehensive framework that provides a foundation for delving into the repercussions of “4.0” technologies on LPD. Despite the existing body of literature investigating the synergy between Lean principles and diverse technologies, there remains a critical gap in understanding how these principles intersect with LPD. Future research should prioritize addressing this gap, exploring the dynamics between LPD and the rapidly evolving technological landscape. This exploration could uncover valuable insights into optimizing Lean methodologies in the context of Industry 4.0 and AI.

It seems that these results open up a set of methodological questions and practical orientations linking research and concrete action within the company. Firstly, from a methodological and research unity point of view, there is a large degree of variation both in survey methods and also in the meaning given to the “concepts” used to define the situations. It is therefore difficult

to build a strict comparative approach between approaches whose differences cannot be reconciled.

Secondly, certain terms, which we ourselves use for lack of anything better, should be clarified. For example, what is a “cultural context”? Is it the language of the actors and the values of commitment to the work that they promote? Is it a local socio-political culture and history building proximity or distance to work and business proposals? Moreover, how do local conditions (material, logistical, family obligations, forms of acceptance of hierarchies, authority and decision-making processes, etc.) influence technical programmes? Real analytical work is undoubtedly essential here.

Finally, there is always a distance between the actor and the system. “Roles, social positions and culture are no longer enough to define the stable elements of action, because individuals do not accomplish a programme, but aim to build unity from the various elements of their social life and from elements they carry within them [translation]” (Dubet, 1994, p.17). In other words, the actors cannot in any way be confused with the functions or choices of a programme. They arrange the proposals, orient them according to their interests, discuss the objectives, etc. This is why LPD cannot be considered merely as a transformation programme. It always corresponds to a process, to a system of dialogue between professional and socio-technical objectives and practices.

In fact, our study questions how specific surveys should accompany the implementation of LPD processes. More than common places based on factorial analyses, we could thus have contextualized analyses allowing us to accurately reconstruct the interfaces between technical choices and social rationales.

## Appendix A. Summary tables of success factors and barriers for LPD

Table A1.: LPD success factors in the literature

	Success factors														
	<i>Lean Tools</i>	<i>Silos and cross-functional cooperation</i>	<i>Added value and Waste</i>	<i>Customer</i>	<i>Knowledge creation and capitalization</i>	<i>Skills</i>	<i>Lean Culture</i>	<i>Motivated People</i>	<i>Management and leadership</i>	<i>Standardization</i>	<i>Supplier relationship</i>	<i>SBCE</i>	<i>Continuous flow</i>	<i>Information flow</i>	<i>Strategy</i>
(Toledo et al., 2023)	x		x	x		x	x	x	x				x		
(Ferreira et al., 2023)	x	x	x		x	x	x		x						
(Gutterman, 2023)				x	x						x		x		x
(Gomes et al., 2023)	x									x		x			
(Roche & Delamotte, 2023)	x		x	x			x	x	x	x		x	x	x	x
(Hofinger Jünge, 2022)			x	x		x	x		x				x		
(Paker, 2022)	x		x			x	x	x	x	x			x		
(Ström, 2022)	x				x				x			x			
(Synnes & Welø, 2022)	x				x		x	x	x	x		x		x	
(Sivolapenko, 2022)	x											x	x		
(Stavig & Stavig, 2022)			x		x		x	x	x	x	x	x	x		
(Paker, 2021)	x	x	x	x			x	x	x	x	x	x	x		
(Nagai & Torres Junior, 2021)			x		x		x		x			x			

Chapitre 2 : The context dependency of LPD barriers and success factors, a literature review

(Reis et al., 2021)	x		x		x	x	x	x		x	x	x	x		
(Helmold, 2020)		x	x	x					x						
(Haraldsson, 2020)			x						x						x
(Sridhar & Wooluru, 2020)			x	x			x						x		
(Kalinowski et al., 2020)						x									x
(Aslam et al., 2020)	x		x	x			x					x	x	x	
(L. H. Forbes & Ahmed, 2020)			x									x			
(Belvedere et al., 2019)			x									x	x		
(Morgan & Liker, 2018)	x			x	x	x	x	x	x	x		x	x		x
(Aikhuele & Turan, 2018)	x	x			x				x		x	x			
(Salgado & Dekkers, 2017)	x	x			x		x		x		x	x	x		x
(Rauch et al., 2017)	x	x	x		x		x	x	x		x	x			
(Tortorella et al., 2016)		x		x			x	x	x	x	x	x	x		
(Welo & Ringen, 2016)			x	x	x		x	x		x			x		
(Dal Forno et al., 2016)	x	x	x	x	x	x	x	x	x	x	x	x			
(Franco & Picchi, 2016)			x		x			x	x	x	x	x	x		
(Mund et al., 2015)	x	x	x	x	x	x	x	x	x	x	x	x	x		x
(Rauch et al., 2015)		x			x				x	x	x	x			
(Ward & Sobek II, 2014)			x		x	x		x	x			x	x		
(Jasti & Kodali, 2014)		x	x		x	x	x		x	x	x	x	x		x
(Wangwacharakul et al., 2014)	x	x	x	x	x	x	x	x	x	x	x	x	x		
(Khan, Al-ashaab, Shehab, Haque, Ewers, et al., 2013)	x	x	x	x	x		x	x	x	x		x		x	
(Al-ashaab et al., 2013)			x	x	x		x		x			x			x
(Wang et al., 2013)	x	x			x				x	x					
(Schulze & Störmer, 2012)	x				x	x	x		x			x			
(Radeka, 2012)				x	x				x			x			
(Qudrat-Ullah et al., 2012)	x	x		x	x		x		x	x	x		x		



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(Khan, 2012)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
(Oehmen et al., 2012)			x		x		x		x	x		x	x		
(León & Farris, 2011)		x	x		x			x	x		x	x	x		x
(Hoppmann et al., 2011)	x	x			x			x	x		x	x	x		
(Liker & Morgan, 2011)	x	x		x		x	x		x	x	x	x			
(Schuh et al., 2011)	x		x	x			x	x	x			x	x		
(Letens et al., 2011)	x		x	x			x		x	x		x	x		
(Mascitelli, 2011)	x				x		x		x			x	x		x
(Welo, 2011b)	x	x	x	x		x	x	x	x	x	x	x	x	x	
(Oppenheim, 2010)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
(Tribelsky & Sacks, 2011)	x		x	x								x	x		
(León & Farris, 2011)	x	x	x	x	x	x		x	x	x	x	x			x
(Dombrowski & Zahn, 2011)	x				x		x	x		x		x	x		
(Letens et al., 2011)	x	x	x	x		x	x		x			x	x		
(Larman & Vodde, 2010)	x	x	x	x	x		x	x	x			x	x		
(Oosterwal, 2010)	x	x		x	x	x	x	x	x			x	x		x
(Reinertsen, 2009)	x							x					x		x
(Hoppmann, 2009)	x	x	x	x	x	x	x		x	x	x	x	x		
(Anand & Kodali, 2008)	x	x						x			x	x	x		x
(Mascitelli, 2007)	x	x	x	x	x	x	x		x	x		x			
(Morgan & Liker, 2006)	x	x	x	x		x	x		x	x		x	x		
(Liker & Morgan, 2006)	x	x		x	x	x	x		x	x	x	x	x		
(Hines et al., 2006)	x		x	x				x		x		x			
(Baines et al., 2006)	x		x		x	x	x		x			x			
(Cooper & Edgett, 2005)	x	x		x	x	x	x	x	x	x		x	x		
(Bindon, 2005)			x										x		
(McManus et al., 2005)	x	x		x		x			x		x	x			
(Oppenheim, 2004)	x	x				x		x	x				x	x	
(Mascitelli, 2004)	x		x	x			x						x		

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(Emmitt et al., 2004)	x		x		x		x	x					x		
(Huthwaite, 2004)	x		x	x	x	x	x	x			x				x
(Kennedy, 2003)		x			x	x		x	x			x	x		
(Haque, 2003)	x			x	x		x		x	x	x	x	x		x
(Morgan, 2002)	x		x		x	x	x		x	x	x	x	x		
(Freire & Alarcó, 2002)					x		x	x		x			x		
(Browning, 2000)	x		x	x									x		
(Walton, 1999)	x	x	x			x	x		x		x	x			
(Cusumano et al., 1998)		x							x		x		x		
(Koskela & Ballard, 1997)				x								x			
(Karlsson & Ahlström, 1996)		x		x		x			x		x	x	x		

Table A2.: LPD barriers in the literature

	Barriers														
	<i>Lean Tools</i>	<i>Silos and cross-functional cooperation</i>	<i>Added value and Waste</i>	<i>Customer</i>	<i>Knowledge creation and capitalization</i>	<i>Skills</i>	<i>Lean Culture</i>	<i>Motivated People</i>	<i>Management and leadership</i>	<i>Standardization</i>	<i>Supplier relationship</i>	<i>SBCE</i>	<i>Continuous flow</i>	<i>Information flow</i>	<i>Strategy</i>
(Toledo et al., 2023)					x		x	x	x						
(Ferreira et al., 2023)													x		
(Gomes et al., 2023)			x				x							x	
(Roche & Delamotte, 2023)	x		x	x			x	x	x	x		x	x	x	x
(Hofinger Jünge, 2022)													x		
(Synnes & Welø, 2022)	x									x					
(Haraldsson, 2020)									x						
(Aslam et al., 2020)		x	x	x	x										
(Belvedere et al., 2019)		x					x							x	
(Morgan & Liker, 2018)									x						
(Aikhuele & Turan, 2018)							x								
(Salgado & Dekkers, 2017)			x				x								
(Rauch et al., 2017)						x	x								
(Tortorella et al., 2016)	x		x	x	x			x	x	x	x			x	
(Welo & Ringen, 2016)	x													x	
(Rauch et al., 2015)			x	x		x	x	x							
(Ward & Sobek II, 2014)	x	x				x									
(Al-ashaab et al., 2013)													x		
(Schulze & Störmer, 2012)									x						

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(Radeka, 2012)				x					x					x
(Liker & Morgan, 2011)		x						x						
(Schuh et al., 2011)								x						
(Letens et al., 2011)					x									x
(Mascitelli, 2011)	x							x	x					x
(Welo, 2011b)			x											
(Tribelsky & Sacks, 2011)														x
(León & Farris, 2011)	x		x		x	x	x		x		x	x		
(Dombrowski & Zahn, 2011)														x
(Larman & Vodde, 2010)	x	x			x	x	x	x	x					
(Oosterwal, 2010)	x								x					x
(Hoppmann, 2009)									x			x		x
(Anand & Kodali, 2008)														x
(Mascitelli, 2007)														x
(Liker & Morgan, 2006)	x													
(Hines et al., 2006)								x	x					x
(Bindon, 2005)			x											
(McManus et al., 2005)				x									x	x
(Oppenheim, 2004)	x	x			x	x							x	x
(Huthwaite, 2004)	x					x								
(Kennedy, 2003)								x	x	x				
(Haque, 2003)														x
(Browning, 2000)			x											
(Walton, 1999)	x													
(Cusumano et al., 1998)									x					
(Koskela & Ballard, 1997)		x												
(Karlsson & Ahlström, 1996)		x											x	x

# Chapitre 3 :

## Measuring What Matters: Using Key Behavior Indicators to Drive Innovation

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# Chapitre 3

**I**nnovation is widely regarded as a key driver of organizational success, particularly in today's rapidly changing business landscape. However, fostering innovation can be a challenging endeavor for many organizations. One way to be able to promote innovation is by tracking and measuring the right factors that are indicative of innovative activity within the organization. A lot of studies focus on key performance indicators of innovation but other factors such as the human dimension of innovation cannot be directly measured with these tools. Some authors believe that promoting human factors and especially behaviors represent a differentiating capability of an innovative company. This article delves into the significance of human capital in driving innovation within organizations. It aims to address the question of "how to foster innovation by promoting behaviors using indicators?". By looking at the role of behaviors and employing key behavior indicators (KBIs), we seek to shed light on the path to measuring and evaluating these behaviors, unraveling the connection between human capital and innovation outcomes.

To explore how key behavior indicators can be used to foster innovation in an organization, the study begins with a comprehensive literature review on measuring innovation and identifying key behaviors that are associated with innovative activity. A case study is then conducted at STMicroelectronics, a leading semiconductor company, to overcome the limitations of existing literature, to establish a stronger theoretical foundation and to gain insights into the specific behaviors that are shown to foster innovation within the company. The methodology is a triangulation of data complemented by interview analyses and brainstorming. As a result of this study, an analytical grid of indicators is proposed to provide practical guidance towards a more accurate understanding of the human factor in organizational innovation.

## 1. Introduction

---

In the ever-evolving landscape of organizational innovation, the pivotal role of human capital has garnered significant attention. Companies worldwide strive to cultivate an environment that fosters groundbreaking ideas, pushing the boundaries of what is possible (Building & Of, 1998; Gault, 2013). At the heart of this pursuit lies the intricate interplay between human behaviors and the realization of innovation (Panayides, 2006).

Fostering innovation can be a challenging endeavor for many organizations. One way to be able to promote innovation is by tracking and measuring the right factors that are indicative of innovative activity within the organization (Patterson, 2003). A lot of studies focus on key performance indicators of innovation but other factors such as the human dimension of innovation cannot be directly measured with these tools (Dziallas & Blind, 2019). Some

authors believe that promoting human factors and especially behaviors represent a differentiating capability of an innovative company but measuring it remains a challenge (Adams et al., 2006).

In this article, we present an examination of innovation measurement and the tracking of behaviors within the context of STMicroelectronics by addressing the question of “how to foster innovation by promoting behaviors using indicators?”. Our aim is to contribute to the existing body of knowledge by addressing the importance of people's involvement in driving innovation and the development of Key Behavior Indicators (KBIs) as a means of evaluating and fostering innovative behaviors.

To achieve this, the paper is structured as follows. We systematically explore various dimensions of innovation measurement, including economic, organizational, and human indicators. Then, we delve into the identification and measurement of specific favorable behaviors that drive innovation, along with the implementation challenges and benefits associated with KBIs. Through a field study conducted at STMicroelectronics, we employ a rigorous methodology involving data triangulation and a mixed-methods approach that is explained in the third section. Finally, the results are showcased in a fourth section. Our analysis provides valuable insights into the significance of people's involvement for innovation within the organization and offers practical guidance for the implementation of KBIs. The ensuing discussion highlights the limitations of our study and opens up new avenues for future research and application of KBIs in fostering innovation.

## 2. Measuring innovation

---

### 2.1. Innovation capability and innovation capacity

Innovation capability refers to an organization's ability to consistently deliver innovative products, services and processes that meet customer needs and drive business growth. It is about the potential to create innovations (Saunila & Ukko, 2014).

In today's fast paced environment, the innovation capability of a company is crucial in its success (Battor & Battor, 2010; Sivadas & Dwyer, 2000). There seems to be a direct and positive correlation between innovation and superior performance (Calantone et al., 2002; Hult et al., 2004; Panayides, 2006).

As researchers and practitioners recognize the significance of assessing an organization's ability to innovate, the measurement of innovation capability or capacity has become a focal point in the literature.

Innovation capacity refers to an organization's potential to generate and implement innovative ideas, solutions and processes. However, the conceptualization of innovation capacity varies across studies, with some focusing only on product or process innovation, neglecting other essential aspects such as behavioral changes and processes. To address this complexity, researchers have called for measuring innovation capacity as a multidimensional construct that reflects the overall capacity of the firm. While there is no complete agreement on the dimensions of innovation capacity, commonalities can be identified, such as product, market, process, behavioral and strategic innovativeness. (Mehrabani & Shajari, 2012)

Innovation capability is the actual ability of an organization to carry out innovative activities effectively and consistently. It is a dynamic capability that the organization builds to compete effectively in a rapidly changing environment. Innovation capability involves processes that enable the organization to respond to a changing business environment and create dynamic capabilities essential for success. It is a means to link existing knowledge in new ways, combining elements that were previously disconnected, and creating new knowledge that leads to innovative outcomes. This capability is crucial for organizational growth and renewal, as innovation is a key mechanism for driving the organization forward. The development of innovation capability involves integrating, building, and reconfiguring internal and external competences to support innovation activities effectively. (Mendoza-Silva, 2021; Parashar & Singh, 2005)

Overall, innovation capacity focuses on the potential to innovate, while innovation capability emphasizes the practical ability to execute and deliver innovative outcomes. Innovation capacity sets the stage for innovation, encompassing various dimensions, while innovation capability represents the organization's dynamic capability to effectively implement innovation and respond to changing market conditions.

The questioning of innovation indicators can be traced back in the United States to the 1980s when Hill et al. tested nearly forty possible indicators of innovation to add to the traditional R&D spending, patents and bibliometrics (Hill et al. 1983).

However, because innovation capability and innovativeness are a composition of a lot of different activities and factors (Rogers, 1998), and because there is a lack of commonly agreed definition, no universal way to define or measure innovation has been found (Välimäki et al., 2004).

There are several types of innovation indicators – economic, organizational and human – and several approaches to the measurement of innovation in literature. Some authors focus on measuring the inputs, ie what is necessary for a company to be innovative, while others focus



on the outputs, measuring instead the innovativeness of a company. In both cases the factors considered relevant for innovation can be internal or external, “soft” or “hard”.

## 2.2. Economic indicators

Economic indicators for innovation are often outputs and have been mainly based on bibliometric data such as R&D expenditures, patent filings and other “hard” indicators linked to the development of new products (Välimäki et al., 2004). Some proposals suggest monitoring the number of times patents are used or cited, as simply counting patents may not consider their value (Trajtenberg, 1990). Other indicators are linked to new products reaching a market and include for example the number of new products launched, the percentage of sales attributable to new products, and the time to market of new products (Adams et al., 2006; Dziallas & Blind, 2019; Mohnen et al., 2002). However, some other aspects are harder to monitor like the innovation in processes and this aspect is often ignored in studies (Adams et al., 2006; Cordero, 1990)

There are also some economic indicators in the “input” category that are related to the amount of support an organization receives or uses on innovation activities. Some can be financial resources, financial support from the government (Sulistyo & Siyamtinah, 2016), amount of money spent on innovation activities (Gault, 2013), research and development budgets and investments or the availability of resources (Välimäki et al., 2004).

## 2.3. Organizational indicators

Organizational indicators include the company's culture and values that may have a significant impact on innovation capacity. Indeed, companies that promote employee engagement and provide opportunities for collaboration and experimentation not just internally but also with external parties (customers, suppliers, competitors, financial institutions, R&D institutions, industry associations) tend to have higher levels of innovation capacity (Sulistyo & Siyamtinah, 2016). Also, a company's willingness to take risks, experiment, and learn from failure can boost its innovation capability (Sulistyo & Siyamtinah, 2016).

A strong innovation strategy that aligns with the company's overall goals and objectives is also essential, and so is a company's ability to manage innovation processes effectively, its access to new technology and information, its level of customer intimacy.

Some authors argue that a new product has better chances of success if the incubation of innovation is done separately from the organization (Christensen, 2013). Other studies highlight the need for a better integration of the new initiatives with the rest of the organization since new initiatives can benefit from the established processes, management and capabilities of a larger entity (Govindarajan & Trimble, 2005).

## 2.4. Human indicators

Finally, some indicators are more “human oriented” such as the quality of leadership.

Having a strong inspiring leadership is essential to creating a culture that values innovation and provides the necessary support and resources for it to thrive. The level of employee engagement, the presence of a skilled and diverse workforce with a deep understanding of the company's industry and of its customers are also key factors in a company innovation capability.

Romijn and Albaladejo (2000) highlight in their study that the level of education and the technical skills of manpower plus the investment in training and human resource development are determinants of organizational innovation.

Some studies also emphasize the correlation between entrepreneurship and a company's innovation capability (J.-S. Lee & Hsieh, 2010). An entrepreneurial spirit, defined as the ability to take initiatives, or the ability to take risks and always be proactive, must be shared by each member of an organization to encourage business growth and performance (Sulistyo & Siyamtinah, 2016).

## 2.5. Take away

The innovation capability of a company is critical to its success in today's fast-paced environment. However, there is no universally agreed-upon definition or way to measure innovation nor way to define a successful organization. An approach is to measure the outputs of an organization such as the number of patents, new products launched, or percentage of sales attributable to new products. Another approach is to measure the inputs, that can be economic such as financial resources, organizational like a company's willingness to take risks, or human oriented such as employee engagement or competences. This last category found in the literature confirms the importance of measuring “human factors” in innovation and is what we will focus on in this paper.

# 3. Tracking behaviors in innovation

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## 3.1. Favorable behaviors

We just saw that a company innovation capacity can be measured and defined by many factors that can be economic, organizational or human. Among all these factors, we must keep in mind that the capability of a company to innovate depends, to a large extent, on its intangible assets, knowledge and ability to mobilize them (Subramaniam & Youndt, 2005). These intangible assets are commonly called intellectual capital and most papers establish that it consists of three elements: human capital, structural capital and relational capital (Bontis, 1996, 1998; Edvinsson & Malone, 1997).

In our hypercompetitive reality, human capital and specifically favorable behaviors are one of the most important factors for innovation and organizational competitiveness (Mariz-Pérez et al., 2012). Mariz-Pérez et al. (2012) include in human capital competencies, the knowledge, creativity, capacity to resolve problems, leadership and personal compromise and Carson et al. (2006) include tacit knowledge, communications skills, entrepreneurship and other personal attributes such as the disposition or aptitudes for lifelong learning.

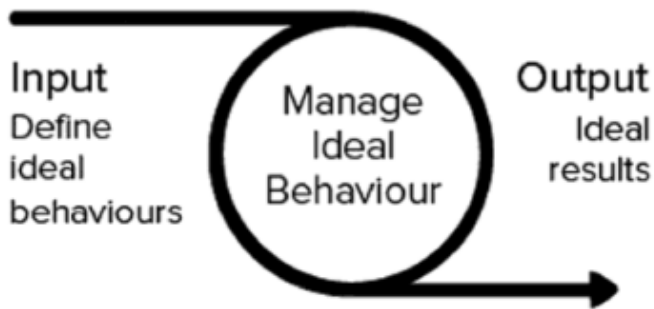


Figure 16: Ideal Results Require Ideal Behaviors (Butterworth et al. 2021)

Butterworth et al. (2021) stated that “ideal results require ideal behaviors” (see Figure 16). They define ideal results by a sustainable long-term excellence in financial, social, personal and environmental perspectives. For them, the success of an organization depends on the way its people behave, and ideal behaviors must be expected from and evident to every collaborator.

When discussing behaviors, it is important to remember that there can be varying degrees involved: the behaviors of an individual, the behaviors of a group of individuals and the overall behavior of an organization (Bauer & Erdogan, 2012).

Although each level can be studied alone, they cannot be separated as they influence each other (George & Jones, 2014). For example, the behavior of an individual within an organization is influenced by how the organization responds to her/his behaviors. And the behavior of senior managers and leaders can determine organizational behavior as a whole (Jones et al., 2023).

Studies have shown that the healthiest organizations are those with a strong and shared definition of the characteristics of ideal behavior that help guide employees towards the desired direction (Bauer & Erdogan, 2012).

### 3.2. Measuring behaviors, the KBIs

Measuring and tracking human capital and more specifically behavior is critical for innovation because it provides valuable insights into what drives success. By identifying and measuring the behaviors that are associated with innovation, organizations can gain a deeper understanding into how their innovation process is performing and make data-driven decisions to improve it. Measuring and tracking behavior can also help companies identify areas where they need to make improvements, such as increasing collaboration, enhancing communication, investing in training or fostering creativity. By measuring the right behaviors, organizations can create a culture that values innovation and continuously improves their innovation performance and therefore ultimately remain competitive in today's rapidly changing business environment.

Considerable attention has been given to the inclination of individuals to innovate, but measuring it remains challenging (Adams et al., 2006). Kirton (Kirton, 1976) developed a questionnaire composed of 32 items to determine where an individual falls on an “adaptor–innovator” spectrum. Scott and Bruce (S. Scott & Bruce, 1994) evaluated a six-item “innovative behavior measure” that management uses to evaluate subordinates. Finally, the Innovation Potential Indicator (Patterson, 2003) is a measurement tool that investigates individual behaviors that may promote or impede innovation in the workplace. This measurement tool is based on four dimensions: an individual's motivation to change, challenging behavior, preferred work approach, and preference for conventional methods over innovation.

As previously noted, the challenge with managing human capital lies in measuring it because it encompasses various individual factors such as education, work experience, capability, motivation, etc. Additionally, just like any other asset, its obsolescence must be considered, but it is surprising that very few studies have taken this into account (Fournier et al., 2015). Obsolescence in human capital refers to the diminishing value or relevance of an individual's skills, knowledge, or competencies in the context of evolving technology, changing market demands, or industry transformations. It occurs when the skills or knowledge that an individual possesses become outdated or less valuable in comparison with newer or emerging skills required in the workforce. There are several factors that can contribute to human capital obsolescence: technological advancements, industry shifts or disruption, knowledge and research advancements, globalization and market competition. According to de Grip and Van Loo (2002), when considering skill for example, there are two types of depreciation from an economic perspective: technical depreciation pertains to the decrease in human capital value due to physical deterioration, such as skill erosion resulting from inactivity, unemployment, low motivation, and lack of new skills. On the other hand, economic depreciation is related to the decrease in the market value of employee qualifications, mainly due to specific skill obsolescence, caused by rapid technological advancements, changes in sector structure, and inadequate organizational skill adaptation.

A common way of measuring success is by using Key Performance Indicators (KPIs). However, these indicators do not work well with behaviors. A more effective way to measure human capital is to use Key Behaviors Indicators (KBIs) (Butterworth et al., 2021).

While the concept of KBIs is not new, they are typically more challenging to define and quantify than KPIs because they often have a qualitative nature rather than a quantitative one. For instance, instead of focusing on the frequency of top managers' meetings, KBIs may assess the effectiveness of such meetings (Jones et al., 2023).

### 3.3. Pros and cons of KBIs:

As any measurement tool, KBIs have both advantages and disadvantages when assessing innovation progress. On the positive side, KBIs provide a clear and measurable way to track progress towards innovation goals. They also focus attention on the behaviors that lead to innovation, rather than just the outcomes. Additionally, KBIs can help identify areas for improvement and provide insights into the factors that drive innovation. Moreover, they can facilitate communication and collaboration among team members and stakeholders and align innovation efforts with overall business objectives while prioritizing innovation initiatives. However, there are also drawbacks to using KBIs. For instance, they may not capture all the factors that contribute to innovation success. They can also be difficult to measure, requiring significant resources to track and analyze. Additionally, KBIs may be subject to bias or misinterpretation, leading to incorrect conclusions about innovation progress. They can also create a culture of “box-ticking”, where teams focus on meeting KBI targets rather than genuine innovation. Finally, they may incentivize short-term thinking and discourage long-term innovation efforts or even lead to the opposite result of what was intended (Stentoft, 2019).

Moreover, studies showed that results and impact of KBIs vary and depend on measurement method (self-ratings vs. independent ratings) and measurement level (individual vs. team) (Hulsheger et al., 2009).

Overall, KBIs can be a useful tool for tracking innovation progress and driving innovation efforts. However, they should be used with caution and in conjunction with other innovation metrics and methods. It is essential to ensure that KBIs are aligned with overall business objectives and that they do not inadvertently create unintended consequences that undermine innovation efforts.

### 3.4. Take away

Innovation capacity is influenced by intangible assets and favorable behaviors within organizations. Intellectual capital, comprising human, structural, and relational capital, plays a vital role in driving innovation and competitiveness. Measuring and tracking behaviors at various levels—individual, group, and organizational—provide insights into improvement opportunities. Key Behavior Indicators (KBIs) offer a more effective way to measure innovation progress, focusing on behavior rather than just outcomes. However, using KBIs has challenges, such as capturing all factors and has potential bias. Careful integration with other metrics is necessary to align KBIs with business objectives and promote genuine innovation efforts.

## 4. A field study and its methodology

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### 4.1. Need for a case study

To answer the question of how to foster innovation by promoting behaviors using indicators we decided to work on a real-life study. A case study approach is justified in this research due to the complexities and limitations identified in the existing literature. Indeed, it lacks clarity and precision in defining key concepts and variables. Some concepts are vague and not stabilized such as “culture” for example, which encompasses diverse realities from different geographic regions and contexts. This lack of a standardized vocabulary and theoretical framework hinders analytical perspectives and makes it challenging to draw definitive conclusions from theoretical studies alone.

Additionally, existing work commonly acknowledges the significance of the human factor in organizations (Mariz-Pérez et al., 2012), but this variable remains largely unanalyzed and is treated as a black box. Merely stating that the human factor is important is insufficient to gain an understanding of its impact on innovation. Thus, returning to the field through a case study allows for theoretical assertions to be grounded in the real world and provides an opportunity to delve into the logic and behaviors of the individuals involved.

By conducting a case study, the research aims to address these limitations and to fill the gaps identified in the literature. It seeks to go beyond vague assertions about the importance of the human factor by developing an analytical grid of indicators to measure specific behaviors. This approach will provide a more nuanced and context-specific understanding of how human behaviors contribute to innovation within an organization.

Through a case study methodology, the research aims to explore the complex dynamics of human behavior in the specific context of a highly innovative firm, STMicroelectronics. It allows for in-depth data collection, triangulation of information from multiple sources, and a comprehensive analysis of behaviors and their impact on innovation outcomes. By examining real-world practices and interactions, the case study approach facilitates a more robust and practical understanding of the role of human factors in driving innovation. (Swanborn, 2010)

## 4.2. Choice of the field

We chose to focus on the topic of innovation at STMicroelectronics, and more specifically within its central technology R&D department.

The choice of this fieldwork was made for several reasons:

1. First of all, STMicroelectronics operates in the global semiconductor market, which has been driven by a technology push since its inception in the 1950s, as evidenced by the famous “Moore’s Law”, a heuristic formula designed by Intel’s former founder Gordon Moore (1929-2023) predicting the evolution of computer chip density (and therefore performance per circuit area) over time. The relentless race for innovation results in considerable financial and human efforts invested by the company (nearly US\$2 billion and 8,000 R&D engineers in 2022). We can therefore assume that technological innovation is an important issue for this company.

2. The company is global and has the particularity of having departments and teams located on several continents. Cultural and contextual influence can therefore be observed directly in an R&D context.

3. In 2016, the first Lean initiatives were launched in STMicroelectronics’ R&D in the form of Obeya and VSM (Morgan & Liker, 2006). As these local initiatives were well received by the teams, in 2017 the creation of the continuous improvement department in R&D took place, with the stated aim of increasing innovation capacity. The company therefore has some historical perspective on using methods to foster innovation, which provides a diachronic view of the situation. Today, the continuous improvement department is organized as an “octopus”. A central team is fully dedicated to continuous improvement and one engineer is further designated as “lean ambassador” for each technical department in this 1000-people strong R&D organization. The ambassadors have the mission of deploying the lean approach inside their departments and of bringing back to the central team the daily issues encountered in the field.

4. Finally, from a bibliographic point of view, STMicroelectronics is often cited as a company with a human approach to indicators (Butterworth et al., 2021). Indeed, it is one of the precursors that uses behavioral indicators, KBIs.

### 4.3. Methodology

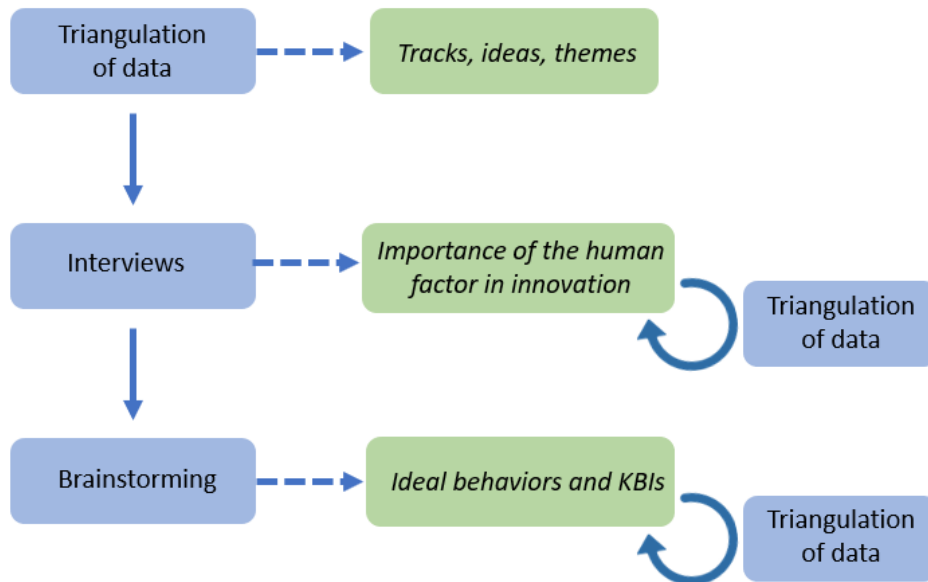


Figure 17: Research methodology

The methodology employed in this study uses a mixed-methods approach, incorporating both qualitative and quantitative data collection and analysis techniques. The following steps presented on Figure 17 and developed later were undertaken to gather and analyze the data:

1. **Triangulation of data:** To ensure data reliability and validity, a triangulation approach was adopted. Data was collected from multiple sources. This comprehensive data collection step first allowed for finding tracks, ideas and themes for our research. Then, it helped for cross-checking and comparing information from different sources, enhancing the credibility and robustness of the findings at the other steps (Silverman, 2019).
2. **Individual interviews:** A total of 17 semi-directive interviews were conducted with employees from various levels within STMicroelectronics. These interviews provided valuable insights into the importance of the human factor in driving innovation within the organization. Through in-depth discussions and open-ended questions, the perspectives and experiences of the employees were captured, shedding light on the behaviors that contribute to innovation.
3. **Brainstorming:** A working group consisting of relevant stakeholders involved in innovation within the organization participated in brainstorming sessions. The first aim was to identify ideal behaviors for innovation at STMicroelectronics. Then to translate the identified ideal behaviors into specific Key Behavior Indicators (KBIs) that can be used to measure and assess the presence of these behaviors. Through collaborative



discussions and idea generation, the working group proposed KBIs that align well with the identified ideal behaviors. This process ensured that the KBIs were contextually relevant and practical for implementation within STMicroelectronics.

### **1. Triangulation of data:**

To ensure data reliability and validity, a triangulation approach was adopted in this study. Multiple sources of data were collected over a period spanning from November 2020 to May 2023. These diverse data sources provided a comprehensive understanding of the subject matter.

The first source of data was obtained through 17 individual interviews conducted from January to May 2021. These interviews allowed for in-depth discussions and capturing the perspectives and experiences of employees regarding innovation within STMicroelectronics.

Furthermore, the study had access to the results of annual employee satisfaction surveys conducted in 2020, 2021, and 2022, which garnered nearly 1000 responses each year from the R&D department. These survey results provided additional insights into employee perceptions and experiences related to innovation within the organization.

In addition, day-to-day organizational artifacts were collected from November 2020 to July 2023. These artifacts included approximately 200 meeting minutes, internal communication elements such as 72 newsletters, various yammer posts, and emails. Access to 16 working groups and the topics of 88 groups was also obtained. Moreover, data from 37 training sessions and their corresponding feedback, as well as evaluation documents, were gathered.

The combination of data from diverse sources and time periods provided a comprehensive and holistic understanding of the factors influencing innovation within STMicroelectronics' central R&D organization.

### **2. Individual interviews:**

We conducted 17 interviews.

The purpose of these semi-structured interviews was to:

1. Understand the representation of innovation, of mere improvements and of other categories of change.

2. Collect a set of innovation experiences as experienced by employees.
3. Identify the positive and negative factors of innovation and change as perceived by employees.
4. Collect the information on how this desire to innovate aligns with the professional trajectories of these employees.

The duration of the interviews varied from 1 hour to 1.5 hours and a transcription was produced afterwards.

These interviews were analyzed with Liz Cristaldo (2022). The panel was composed of 17 individuals from different hierarchical levels of R&D. These individuals were selected based on their spontaneous inclination for innovation. While it may have introduced a potential bias, it also allowed the study to benefit from a diverse range of perspectives and experiences on the topic of innovation, thus ultimately enriching the discussions and contributions. The criterion used was that they regularly participated in innovation forums or were involved in various ways in innovation initiatives in their department.

The objective of these semi-structured interviews was to find out, from their point of view, the factors promoting or limiting innovation within STMicroelectronics.

After transcribing these interviews, qualitative and quantitative analyses were performed. The answers have been divided into 227 comments then classified and compiled into three categories: “supporting factors” and “limiting factors” for innovation, for comments referring to elements, circumstances, or influences that contributed adversely or positively to innovation, and “other” for the comments which were neither expressing a detractor nor a support factor. Then, it was observed that within each of the two lists, certain relationships existed between the comments, either because they presented similarity in meaning, or because they referred to the same circumstances. The comments were so grouped into the following subcategories (see Figure 18 that details the subcategories) (Saldana, 2021):

- Leadership behavior: The behaviors exhibited by leaders to achieve organizational goals. Leadership differs from management, with managers organizing, planning, controlling and leaders inspiring and motivating people to follow them (Morgan & Liker, 2006).
- People involvement: Behaviors driven by individuals themselves in carrying out their work. People are crucial for successful product development, providing skills, energy, and creativity (Morgan & Liker, 2018).
- Operating system: The collection of tools, processes, and standard work that enables effective execution of tasks. It serves as the leader's toolkit for achieving goals (Morgan & Liker, 2018).

- Prioritization and visibility of innovation projects: How project priorities are established and ensure sufficient resources for successful execution. Ownership, understanding, and agreement among the team are crucial for project prioritization, while visibility within the organization is vital for project health (Mascitelli, 2011).
- Resources for Innovation: Elements that enable innovation, whether available or not. The company's context influences its ability to mobilize and concentrate resources required for overcoming innovation barriers. Allocating resources at the individual level, considering unique skill sets, is essential for success (Christensen, 2013; Mascitelli, 2011).

To help strengthen the results, two observers did the thematic text analysis individually and a triangulation through multiple analysts was performed (Ritchie et al., 2013).

Subcategory	Support factors codes	Subcategory	Limiting factors codes
Leadership behavior	Support	Leadership behavior (Lack of)	Middle management
	Mentoring network		Pyramid organization
	Management support		Sense of safety (don't want to step out of their comfort zone)
	Sponsor	People involvement (Lack of)	People who have no desire
	Supportive leader		People who don't try to understand
People involvement	Entrepreneurial mindset		Individual brakes
	People who want to do stuff		Lack of consciousness (about the definition of innovation)
	Individual people		People with less inclination to ask themselves questions
	Involved people		Learn that ideas can be rejected
	People that have ideas	Don't feel in the right mood	
	The vitality of the employees	Operating system (Lack of)	Not enough implementation of a good emulation
Operating system	Innovation forum		Innovation contextualization
	Share what is being done to give meaning to innovation		Not enough establishment of a good environment
	Meetings		Heavy administrative processes
	Workgroups		Rigid organization
	Physical structures		Work under pressure
	Different environment		Financial or non-financial recognition
	Discussions	Resources for innovation (Lack of)	Resource time
Prioritization and visibility of innovation projects	As important as other projects		Time to create
	Displayed as priority		Time to imagine
	Management visibility		Time spent on innovation
Resources for innovation	This means that can be granted		Not much time
			Head in the handlebars
			Work in a very busy environment
			Self-censorship (because of bandwidth)
		Very busy people	
		Financial resource	

Figure 18: Support and limiting factors subcategories along with their corresponding codes (Cristaldo, 2022)

### **3. Brainstorming:**

The data collected from interviews and other sources were analyzed to identify recurring themes and patterns related to ideal behaviors for innovation. Through a process of data triangulation and comparison with existing literature on innovation, categories of ideal behaviors were developed. This involved synthesizing and organizing the data to derive a comprehensive understanding of the behaviors that foster innovation within the context of STMicroelectronics.

To further refine the understanding of ideal behaviors, a brainstorming session was conducted with a working group consisting of five volunteers who were passionate about the topic of innovation. The group was entirely composed of STMicroelectronics engineers from the R&D. The first step in this process was to define the ideal behaviors for innovation at STMicroelectronics.

The first step was to define ideal behaviors for innovation at STMicroelectronics.

To do so we collected and analyzed data from 37 training courses on lean product development and creativity. These courses were attended by the R&D population at STMicroelectronics. The data collection process involved multiple sources, including survey feedback, verbatims collected during the training sessions, and brainstorming tables that have been organized and compiled into a structured dataset. Then a thematic analysis was performed on the collected data to identify recurring themes, patterns, and insights related to innovative behavior within the organization. To ensure the validity and reliability of the findings, five engineers from a working group about innovation were involved in the process and discussions among the analysts were conducted to reach consensus on the identified themes and character traits. To enrich the analysis and provide a broader context, a literature review was conducted. The work of Standing et al. (2016) was specifically referenced and compared to the identified themes from the training course data. This step helped validate the findings and establish connections between the organization-specific insights and the existing knowledge in the field. By synthesizing the findings and aligning them with relevant literature, we identified six key character traits that can promote innovation: expertise, creativity, attention to technology trends, entrepreneurship/risk-taking, and energy/motivation. These traits provide insights into the specific characteristics that drive innovation within the organization.

These character traits were then sent to the 1000 employees of STMicroelectronics technological R&D in order for them to vote for the most impactful characteristics.

For each prioritized characteristic, specific behavioral indicators were defined by conducting another brainstorming with the five members of the innovation working group. This brainstorming generated a list of potential behavioral indicators that align with each characteristic. The results were then narrowed down after evaluating the feasibility and

objectivity of each of them as well as the alignment with the organizational context thanks to a vote system in the same working group.

#### 4.4. Take away

This part presents a field study conducted in the technology R&D department of STMicroelectronics to explore the issue of fostering innovation by promoting behaviors using indicators. The choice of this fieldwork was motivated by STMicroelectronics' presence in the semiconductor market, where innovation plays a vital role. Additionally, the company's global operations and historical experience with lean concepts provided a rich context for studying the influence of cultural and contextual factors on innovation. Furthermore, STMicroelectronics' reputation for employing behavioral indicators added to its suitability for the study. Then, the section describes how by employing a mixed-methods approach including triangulation of data, individual interviews, analysis of existing literature, and collaborative brainstorming, a comprehensive understanding of the human behaviors influencing innovation and the development of relevant KBIs were achieved. This methodology allowed for the integration of diverse perspectives and sources of information, enhancing the rigor and validity of the study's findings.

### 5. Results and analysis

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In today's fast-paced and competitive business environment, fostering innovation has become a crucial imperative for organizations aiming to thrive and stay ahead in the market. We have observed that recognizing the pivotal role of people in driving innovation is crucial and companies like STMicroelectronics have placed a strong emphasis on cultivating a culture that nurtures and harnesses the innovative potential of their workforce. However, implementing and sustaining an innovation-focused culture requires more than just setting goals, communicating them and providing resources; it requires a deeper understanding of the desired behaviors that contribute to innovation and the challenges associated with effectively measuring and evaluating these behaviors.

The first section explores the fundamental importance of individuals within the innovation process at STMicroelectronics. By examining the key role played by employees, teams, and leaders, we will uncover the underlying dynamics that make people an essential component in driving innovation. Understanding the importance of people will serve as a foundation for developing strategies that foster a supportive environment for innovation and encourage the desired behaviors.

The second section focuses on defining the desired behaviors that contribute to a culture of innovation at STMicroelectronics. Recognizing that innovation is not limited to specific job roles or departments, we will explore the essential behavioral dimensions that encompass creativity, collaboration, risk-taking, and adaptability. By defining these behaviors and their associated competencies, we can provide a clear framework for employees to align their actions with the organization's innovation goals.

While defining desired behaviors is a crucial step, effectively monitoring and measuring progress towards these behaviors presents its own set of challenges. The third section of this chapter delves into the obstacles and complexities of implementing Key Behavioral Indicators (KBIs) to evaluate innovation-related behaviors. We will address issues such as subjectivity, data collection, interpretation, and the integration of KBIs into existing performance evaluation systems. By acknowledging these challenges, we can better strategize and develop solutions to ensure the accurate assessment and recognition of employees' innovation contributions.

## 5.1. Importance of people for innovation at STMicroelectronics

Our first goal was to assess whether the human factor was important for innovation in the context of STMicroelectronics.

We analyzed the 227 comments extracted from the 17 interviews. As shown on Figure 19, over half of them (121 comments) highlight the significance of “people involvement” as a factor that supports innovation or the “lack of people involvement” as a hindrance to innovation.

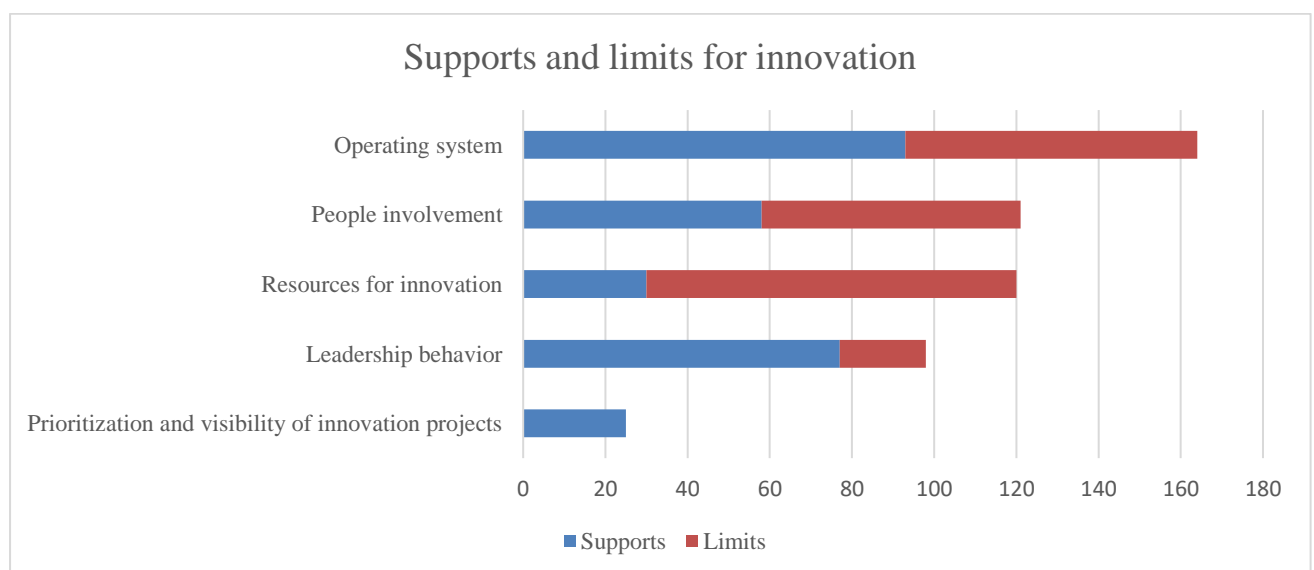


Figure 19: Supports and limits for innovation

Managers and engineers emphasize the value of motivated individuals working on innovative projects and the need to listen to people with ideas. The presence of creative minds and employees who are dedicated to their company's success is seen as a crucial asset for fostering innovation. *“What promotes innovation is motivated people who work on innovative projects”* (Manager, individual interview, 11/01/2021) says for example a manager *“For me, the support for innovation is first and foremost the employees [...]. There are a lot of people who get involved in their company. There are a lot of people who have ideas and a lot of people who want to implement and do things, who would be willing to spend time, even at home.”* (Manager, individual interview, 5/24/2021) tell us another one. Finally, a last manager stated during the interviews *“a company like ours do not lack creativity and bright people. We have plenty of them around, and that's a great asset for innovation.”* (Manager, individual interview, 5/24/2021).

On the other hand, some managers express the challenges of taking risks, managing fear of failure, and the cultural complexities associated with embracing innovation. *“I think the biggest bottleneck that we have from a cultural perspective is that fear of failure”* (Manager, individual interview, 5/24/2021) stated one manager during the interviews. These observations highlight the importance of addressing cultural barriers and encouraging a mindset that embraces innovation and risk-taking.

The analysis also reveals a strong ideological consistency within this specific group no matter the hierarchical grade, emphasizing that innovation is perceived as an individual human capacity. This finding aligns with existing studies that support the predominant role of the human factor in a company's innovation capacity (Camacho-Miñano et al., 2013).

Given the challenges of measuring the human factor in innovation using traditional performance indicators, STMicroelectronics has implemented “human” behavior indicators, known as KBIs. These indicators aim to capture important aspects such as regular Gemba walks by managers to connect with teams and understand their challenges, as well as employees actively sharing technical problems and demonstrating teamwork.

By incorporating KBIs, STMicroelectronics seeks to measure the involvement of motivated employees and provide trend indicators rather than relying solely on post-mortem results from traditional key performance indicators (KPIs). This approach is expected to encourage an organization's capacity for innovation and could be scientifically valuable in identifying behavioral indicators that support innovation.

In addition to the analysis of interview data, the study also drew insights from various internal sources within STMicroelectronics, including meetings' minutes, training verbatims, indicator tables, and internal communication. These sources provided valuable corroborating evidence that confirmed the findings derived from the interview analysis.

By examining the minutes of meetings or training sessions and verbatims, we gained access to discussions and interactions among employees regarding innovation. These records shed further light on the significance of people involvement and the challenges associated with embracing innovation. The analysis of minutes or verbatims highlighted recurring themes and patterns that reinforced the importance of motivated individuals, creative minds, and teamwork in driving innovation within the organization. *“We need to trust people when they have ideas in order not to lose motivation.”* (Project Meeting minutes 10/04/2022). *“ST employees went to the job dating event only to see the demos of our products to be inspired”* (Engineer, meeting, 13/10/2022), *“Since I finished my PhD I am no longer encouraged to be innovative, I have too much work and no space to innovate even if I deeply want to. I am losing motivation”* (Engineer, creativity training, 22/02/2023), *“In Lean and innovation we need to think also about human, we need to help people grow.”* (Speaker, Lean forum, 30/03/2023)

We also examined indicator tables within STMicroelectronics. These tables provided quantitative data and insights into the organization's performance and progress in fostering innovation. We can observe that in 2023, the innovation thematic appeared in these tables. Indeed, experts now have an objective in their individual MBO (management by objectives) dedicated to innovation. Their bonuses are impacted by their innovation capacity. By cross-referencing these indicators with the interview findings, it highlights the growing concern and interest on individual innovation capacity.

By incorporating these additional sources of data, the study ensured a triangulation of data, strengthening the validity and reliability of the findings. The consistency between the interview analysis and the insights derived from these internal sources further reinforced the significance of people involvement as a crucial factor in driving innovation at STMicroelectronics.

In summary, the analysis underscores the significance of people involvement in driving innovation at STMicroelectronics. While the lack of people involvement presents challenges, the implementation of human behavior indicators offers a promising approach to measure and encourage innovation within the organization.

## 5.2. Defining KBIs

After confirming the importance of human behavior for innovation at STMicroelectronics, we focused our research on the ideal characteristics of these collaborators.

We saw that organizations with a shared definition of the characteristics of ideal behavior are the healthiest since it helps guide employees to the desired direction (Bauer & Erdogan, 2012).



To share the characteristics of ideal behavior related to innovation and thereby have a more innovative organization, we should characterize innovative behavior in our context.

The definition of possible ideal behavior was done through data triangulation and thematic analysis. Particularly, the analysis of internal communication within STMicroelectronics contributed to the overall understanding of the organization's approach to innovation and the role and qualities expected of individuals in this process. Internal communications, such as memos, newsletters, or announcements, provided additional perspectives and context that complemented and helped set the ground for these discussions. For example, the leadership model was used. It is described by the company's CEO as "*a set of common behaviors across the organization that capture our identity and our values of People, Integrity and Excellence. The Model also prepares us for the challenges of the future [...] it captures the behaviors that will drive ever-increasing levels of performance and continue to build our culture*" (Jean-Marc Chery, STMicroelectronics' CEO, internal website).

The results of the thematic analysis led to the identification of six key character traits that can promote innovation within STMicroelectronics: expertise, creativity, attention to technology trends, entrepreneurship/risk-taking, and energy/motivation. These traits provide insights into the specific characteristics that drive innovation within the organization. The traits identified in this study align with the existing literature on innovation and organizational behavior, providing further support for their significance in driving innovation outcomes. Notably, the traits identified closely resonate with the nine innovative work behavior items proposed by Janssen (2000). Our six key character traits align with several of Janssen's innovative work behavior items, such as generating new ideas for difficult issues (idea generation), searching out new working methods, techniques, or instruments (idea generation), and transforming innovative ideas into useful applications (idea realization). While our study focused on a specific organizational context, the alignment between the identified traits and Janssen's framework suggests a common understanding of the behaviors that drive innovation within STMicroelectronics. This convergence strengthens the validity and reliability of our findings and reinforces the importance of these character traits in fostering innovation within organizations.

To further validate and rank the impact of these character traits, 231 responses were collected from the 1000 employees of STMicroelectronics' technological R&D division. Figure 20 illustrates the results, showing that creativity and energy/motivation were the most impactful characteristics according to the employees' votes, receiving 205 out of 231 and 194 out of 231 votes, respectively. The remaining items received between 18 and 108 votes.

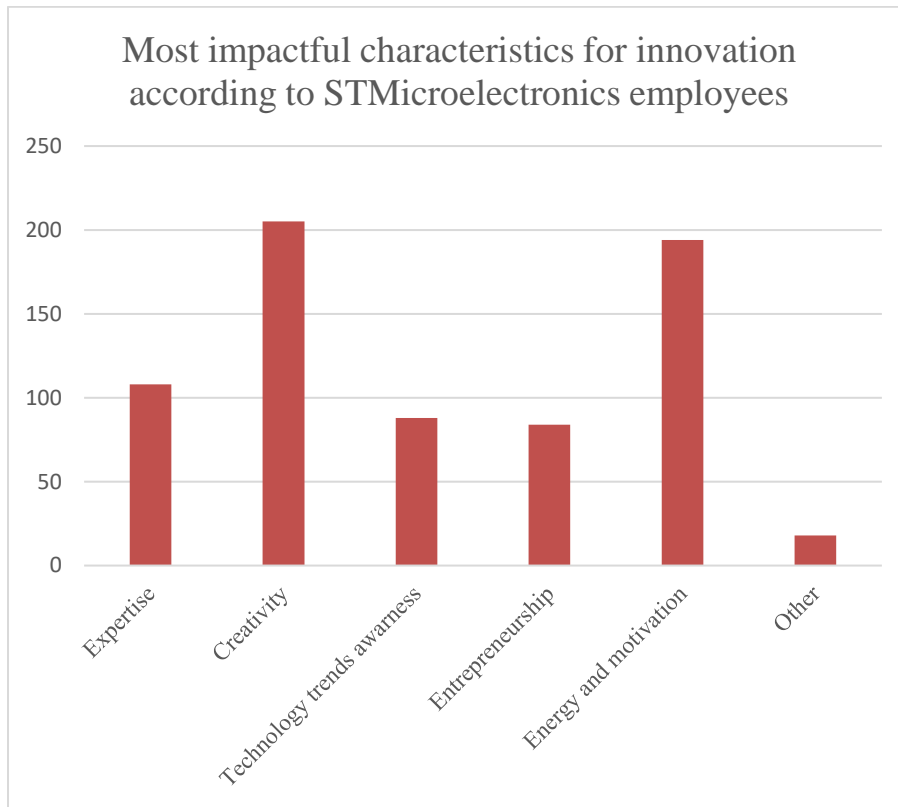


Figure 20: Most impactful characteristics for innovation according to STMicroelectronics employees

For each prioritized characteristic, specific behavioral indicators were defined by conducting a brainstorming with the five members of the innovation working group. This brainstorming generated a list of potential behavioral indicators that align with each characteristic.

To ensure that the KBIs are not merely abstract concepts, but tangible metrics that can be tracked, communicated, and integrated into performance management systems, the deployment of the KBIs is crucial after defining them. By translating the KBIs into actionable measures at the personal, team, and organizational levels, organizations can effectively assess individual and collective performance, identify areas for improvement, and align their efforts towards fostering an environment of innovation. To do so, each KBI have been translated into practical and measurable actions. At personal and team levels, the KBIs and their measurement can be integrated into the performance evaluation frameworks or used for individual development plans. At an organizational level, the KBIs can help guide strategic decision-making and provide insights into the overall innovation culture and performance. They can be integrated into performance management systems, employee engagement surveys, or innovation audits.

Table 1 proposes the translation of the ideal model of behavior favorable to innovation into KBIs and measurement propositions. The table comprises four columns: Characteristics, representing the identified ideal behaviors for innovation; Level, indicating the assessment levels (person, team, organization); KBIs, which translate the characteristics into indicators at each level; and Measurement Proposition, providing concrete methods for measuring each KBI. Although not exhaustive, this table can serve as inspiration for practitioners.

## Chapitre 3 : Measuring What Matters: Using Key Behavior Indicators to Drive Innovation

Characteristic	Level	KBIs	Measurement proposition
Expertise	Person	Actively pursues professional development opportunities, attends relevant workshops or conferences, and acquires new knowledge or skills in their field of expertise.	Measure the individual's participation in relevant training programs, certifications, or workshops. Keep track of completed courses or certifications.
	Team	Encourages knowledge sharing and collaboration among team members, conducts regular technical knowledge exchange sessions or peer-to-peer learning activities.	Conduct surveys or interviews to gauge team members' perception of knowledge sharing and collaboration within the team.
	Organization	Supports and provides resources for employees to engage in continuous learning and skill development, recognizes and rewards individuals who demonstrate high levels of expertise in their respective areas.	Monitor the participation rates in professional development activities and track the acquisition of new skills or knowledge by employees.
Creativity	Person	Actively seeks out new ideas and perspectives, contributes innovative suggestions or solutions to problem-solving discussions or brainstorming sessions.	Evaluate the individual's contribution to idea generation or problem-solving sessions through qualitative assessments, such as peer reviews or expert evaluations.
	Team	Facilitates regular brainstorming sessions or ideation workshops, encourages team members to explore unconventional approaches and embrace creative thinking.	Assess the quantity and quality of ideas generated by the team during brainstorming sessions or innovation workshops.
	Organization	Establishes a culture that fosters and rewards creativity, promotes cross-functional collaboration to facilitate the exchange of diverse ideas and perspectives.	Collect feedback from employees on the organization's support for creative thinking and the presence of a culture that encourages and values innovation.
Attention to Technological Developments	Person	Regularly stays updated on the latest advancements and trends in their field, actively follows industry publications, attends relevant webinars or seminars.	Monitor the individual's engagement with industry publications, attendance at relevant conferences or seminars, and participation in webinars or training sessions on technological advancements.
	Team	Allocates time for team members to explore emerging technologies and trends, encourages knowledge sharing regarding technological advancements and their potential impact.	Keep track of the team's awareness and utilization of emerging technologies in their projects, assess the team's ability to adapt and integrate new technologies into their work.
	Organization	Establishes mechanisms to capture and disseminate information on technological developments, encourages cross-functional collaboration to leverage emerging technologies for innovation projects.	Gather information on the organization's mechanisms for capturing and disseminating information about technological developments and assess the level of engagement and knowledge uptake among employees.
Entrepreneurship/ Risk-taking	Person	Demonstrates a proactive attitude towards taking calculated risks, initiates and leads projects with innovative ideas, displays a willingness to challenge the status quo.	Evaluate the individual's involvement in initiating and leading innovative projects, assess their willingness to challenge existing norms or take calculated risks through self-assessment or performance reviews.
	Team	Encourages experimentation and supports the testing of new concepts or approaches, fosters a culture that values calculated risk-taking and embraces learning from failures.	Measure the team's success in implementing innovative ideas and their ability to learn from failures and adapt their approaches.
	Organization	Establishes mechanisms to identify and support entrepreneurial initiatives, provides resources and autonomy for employees to pursue innovative projects, recognizes and celebrates successful risk-taking endeavors.	Track the number and success rate of entrepreneurial initiatives, collect feedback from employees on the organization's support for risk-taking and entrepreneurial behavior.
Energy/Motivation	Person	Displays enthusiasm and drive in their work, takes initiative to go above and beyond their assigned responsibilities, maintains a positive and proactive attitude.	Conduct surveys or assessments to measure individual motivation, engagement levels, and self-reported energy or enthusiasm towards work.
	Team	Promotes a supportive and inclusive team environment, fosters a sense of purpose and meaningfulness in the work, encourages team members to set and achieve ambitious goals.	Evaluate team dynamics, morale, and indicators of high energy levels such as proactive problem-solving, high participation rates, or positive feedback from team members.
	Organization	Implements initiatives to foster employee motivation and engagement, recognizes and rewards exceptional performance and dedication, promotes work-life balance and employee well-being.	Monitor employee satisfaction and engagement surveys, assess employee turnover rates, and measure indicators of employee well-being and work-life balance.

Table 1: Proposition of KBIs for innovation

In Table 2, we focus on the two characteristics ranked as most impactful for STMicroelectronics employees: Creativity and Energy/Motivation.

At the team level, the KBI for Creativity entails facilitating regular brainstorming sessions or ideation workshops and encouraging team members to explore unconventional approaches while embracing creative thinking. The measurement proposition involves assessing both the quantity and quality of ideas generated by the team during these brainstorming sessions or innovation workshops.

For Energy/Motivation at the individual level, it is reflected in an employee's enthusiasm, drive, and initiative. Going above and beyond assigned responsibilities while maintaining a positive and proactive attitude are indicative of high motivation. To measure motivation at the person's

Characteristic	Level	KBIs	Measurement proposition
Creativity	Person	Actively seeks out new ideas and perspectives, contributes innovative suggestions or solutions to problem-solving discussions or brainstorming sessions.	Evaluate the individual's contribution to idea generation or problem-solving sessions through qualitative assessments, such as peer reviews or expert evaluations.
	Team	Facilitates regular brainstorming sessions or ideation workshops, encourages team members to explore unconventional approaches and embrace creative thinking.	Assess the quantity and quality of ideas generated by the team during brainstorming sessions or innovation workshops.
	Organization	Establishes a culture that fosters and rewards creativity, promotes cross-functional collaboration to facilitate the exchange of diverse ideas and perspectives.	Collect feedback from employees on the organization's support for creative thinking and the presence of a culture that encourages and values innovation.
Energy/Motivation	Person	Displays enthusiasm and drive in their work, takes initiative to go above and beyond their assigned responsibilities, maintains a positive and proactive attitude.	Conduct surveys or assessments to measure individual motivation, engagement levels, and self-reported energy or enthusiasm towards work.
	Team	Promotes a supportive and inclusive team environment, fosters a sense of purpose and meaningfulness in the work, encourages team members to set and achieve ambitious goals.	Evaluate team dynamics, morale, and indicators of high energy levels such as proactive problem-solving, high participation rates, or positive feedback from team members.
	Organization	Implements initiatives to foster employee motivation and engagement, recognizes and rewards exceptional performance and dedication, promotes work-life balance and employee well-being.	Monitor employee satisfaction and engagement surveys, assess employee turnover rates, and measure indicators of employee well-being and work-life balance.

Table 2: Zoom on Creativity and Energy/Motivation

level, conducting surveys or assessments is proposed. These surveys can gauge an individual's level of motivation, engagement, and self-reported enthusiasm towards their work. It can help understand the individual's dedication and contribution to the organization's goals.

### 5.3. Overcoming challenges of KBIs implementation

Implementing KBIs in organizations can be a challenging task. The main challenge is obviously identifying the right set of KBIs that align with the organizational goals and objectives. But finding the right set of indicators is not enough.

The collection of accurate and reliable data to measure these KBIs can also be a challenge since they are often composed of intangible data. Striking the right balance between the energy expended in gathering these indicators and the value they bring is also primordial. Moreover, it can be difficult to gain buy-in from all stakeholders, particularly employees who may

perceive KBIs as an additional burden (Butterworth et al., 2021). KBI may be perceived as yet another form of control, which is somewhat counterproductive in freeing up creative energy. In STMicroelectronics, for example, the management staff decided that KBIs were interesting but that they were not actionable at their level because the balance measure-added value wasn't probative (Internal Document, 2023). This shows that the choice of the means of measure is a key factor in the success of KBIs. It can also be indicative of a mistrust in the concept or in the ability to deploy it practically at all levels. Mistrust that is shared by others, during a training an engineer said "*KBIs are nonsense. They are just here to please management.*" (Engineer, 03/02/2023).

To address these challenges, organizations need to establish clear communication and engage employees in the KBI development process. They should also invest in technology and training to support data collection and analysis. Additionally, organizations should provide incentives and recognition for employees who perform well on KBIs to ensure their active participation and commitment. Finally, regular evaluation and feedback can help identify any gaps or areas of improvement, which can be addressed through further training and development initiatives (Butterworth et al., 2021; George & Jones, 2014; Jones et al., 2023).

Considering the challenges at hand, it is crucial to adopt a careful and strategic approach when implementing KBIs. To ensure a focused and smooth change management process, we propose the selection of two key behaviors for promotion: "creativity" and "energy and motivation". These behaviors have been determined as the most impactful for driving innovation within STMicroelectronics, as evidenced by the results depicted in Figure 20.

By limiting the number of key behaviors, we aim to prevent overwhelming and confusing collaborators, enabling them to concentrate their efforts on the essential aspects of their work. To provide clarity and align expectations, the indicators associated with these behaviors will be displayed on the indicator monitoring page, which is directly linked to monetary incentives such as bonuses. This strategic focus ensures that employees have a clear understanding of the desired behaviors and the potential rewards tied to their performance.

This approach not only fosters accountability and motivation among employees but also seamlessly integrates the KBIs into the existing performance management system at STMicroelectronics. It also guarantees that the company will set goals for each indicator and regularly monitor them. By leveraging the established structure, we create a cohesive framework that harmonizes the pursuit of innovation with the organization's overarching goals and values.

## 6. Discussion, Limits and Perspectives

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This study sheds light on the significance of human capital in driving innovation within organizations by focusing on behaviors and employing key behavior indicators (KBIs). The research provides insights into measuring and evaluating these behaviors in the context of STMicroelectronics' R&D department. Through data triangulation and a collaborative brainstorming process, specific behaviors that contribute to fostering innovation were identified, and a set of KBIs based on these behaviors was proposed.

However, the implementation of KBIs may pose challenges for companies. Careful planning, stakeholder engagement, and continuous monitoring and adjustment are necessary to ensure the effectiveness and sustainability of KBI systems. This research contributes to the existing body of knowledge by offering practical guidance and by highlighting the importance of integrating human capital considerations into innovation strategies. Further research is needed to refine and validate the proposed KBIs and explore their impact on organizational innovation outcomes.

In addition to the discussion on KBIs, several lines of thought emerge from the confrontation between bibliography and fieldwork. Firstly, the absence of a common definition of a successful innovative organization poses challenges in measuring innovation. The definition of innovation varies depending on how it is understood by different organizations. Establishing a clear and stable definition of innovation at STMicroelectronics would enable better assessment and measurement of the company's innovation capacity. One issue is that novel ideas are known to be innovations only after the fact: when the business has materialized (years later). This issue can be resolved by requesting from inventors that they identify a “path to business” for their inventions, which then gets qualified as “innovation”.

Furthermore, translating individual behaviors into collective behaviors is a complex process. While individual ideal behaviors are important, they may not guarantee the emergence of collective ideal behavior. The dynamics of groups and organizations can be influenced by contextual factors, and understanding the interplay between local cultural inclinations, values, and professional behaviors is crucial for facilitating different types of innovations. Exploring the concept of reflexivity at the individual and organizational levels presents an intriguing avenue for future research.

The study also acknowledges the limitations and perspectives for future research. Individual employees' unique logic and preferences may interfere with the manifestation of ideal behaviors within an organization, suggesting the need for a nuanced understanding of behavior

dynamics. Additionally, the broader management system, including control systems, strategies, incentives, and organizational culture, significantly influences ideal behaviors and should be further investigated. Involving a more diverse range of stakeholders in the process of identifying KBIs can lead to a more inclusive and readily accepted set of indicators. Careful selection of a manageable set of KBIs is crucial to prevent information overload and maintain their effectiveness. Finally, exploring the factors and mechanisms that contribute to human capital obsolescence over time would provide valuable insights for organizations aiming to enhance their innovative capabilities.

# Chapitre 4 :

## The impact of an organization's Operating System on Innovative Behavior, a case study

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# Chapitre 4

**T***his chapter delves into the dynamic between an organization's operating system and innovative behaviors by presenting a comprehensive case study of STMicroelectronics. Drawing upon diverse data sources, including interviews, annual surveys, organizational artifacts, training sessions, and performance indicators, our research aims to provide a holistic depiction of STMicroelectronics' operating system.*

*A framework developed from Morgan and Liker (2018) definition of the operating system is proposed. It is composed of tools, processes, standard work, cadenced activities, and mechanisms. The study employs empirical cases to illustrate the practical nuances within various categories of the operating system grounding our theoretical framework in real-world context.*

*Our findings reveal delicate balances to find for practitioners between - for example - standardization and flexibility, or in the impact of incentives on creativity and motivation. We explore how STMicroelectronics leverages its operating system to drive innovation.*

## Introduction

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The relationship between an organization's operating system and its ability to foster innovative behaviors is a topic that has garnered limited attention within literature. While several studies acknowledge the importance of management systems and their impact on organizational effectiveness, there remains a gap in the understanding of how specific aspects of an operating system can influence innovative behaviors.

This study helps us to understand what impacts innovative behaviors and more specifically creativity and motivation. It helps practitioners understand how to design a system that naturally steers behavior towards the desired outcomes. Drawing from Butterworth et al. (2021), we acknowledge the interconnectedness of systems and behaviors: “systems and behaviors are two sides of the same coin”. This study explores the synergy between a well-designed operating system and favorable behaviors, to create a cycle of innovation.

## 1. Literature Review

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Before delving into the interconnexions between the operating system of an organization and innovative behavior it is important to understand what stands behind those terms and what the body of literature gathers around them.

## 1.1. Operating System

First, we need to define what is an operating system. Morgan and Liker (2018) present a comprehensive perspective of the operating system within an organization. They conceptualize the operating system as the tools, processes, standard work, cadenced activities, and mechanisms that facilitate the execution of tasks. However, the literature lacks a clear and unified framework for analyzing the components of an operating system in the context of innovation.

However, some specific elements of the operating system have drawn more attention than others.

The impact of performance incentives on operating systems and innovation is a recurring theme. Larman and Vodde (2010) emphasize that poorly chosen targets and bonuses can lead to superficial adoption of innovation practices, causing resentment and misunderstanding among employees. However, the literature also suggests that the same incentives, when strategically applied, can shift from negative to positive outcomes. Transforming individual-based rewards to team-based goals may reduce competition and enhance cooperation (Larman & Vodde, 2010). This dynamic highlights the importance of aligning incentives with desired innovative behaviors.

The impact of an organization's structure and culture on innovation has also been widely acknowledged. Research by Amabile et al. (1996) and Ekvall (1996) suggests that the perceived work environment, encompassing both structural and cultural elements, significantly influences innovation levels. Mathisen and Einarsen (2004) emphasize the role of the work environment in promoting creative and innovative behaviors. Organizations are found to create environments that either encourage or hinder innovation, with a focus on balancing freedom for creative exploration and control for effective management (Dougherty & Cohen, 1995; Tidd & Bessant, 2020). This dichotomy often leads to the need for a polychronic organizational approach, often called “ambidexterity”, where organizations oscillate between a loose and tight structure to facilitate innovation (S. W. Becker & Whisler, 1967).

As well as the operating system of an organization can shape and influence behaviors, the largely invisible set of stimuli and pressures in the environment, outside the operating system can influence whether an organization emphasizes certain types of behaviors. Ghoshal and Bartlett (1997) highlight the role of context as an influential factor in shaping organizational behaviors. This contextual influence underscores the need to consider external factors when designing an operating system that supports innovation.

The interplay between operating systems and behaviors is a central theme in understanding innovation. Deming's assertion that “a bad system will defeat a good person every time” highlights the significance of a supportive operating system in nurturing desired behaviors (Butterworth et al., 2021). The relationship between systems and behaviors is reciprocal, with both components reinforcing each other. Butterworth et al. (2021) emphasize that a good system with poor behavior leads to decay, while a poor system with good behavior results in

excess effort and waste. Thus, an effective operating system not only complements but also shapes innovative behaviors.

## 1.2. Innovative behavior

Scholars have proposed various frameworks to categorize and understand the nature of innovative behaviors. One such framework is offered by Janssen (2000), who delineated nine distinct innovative work behavior items. These items encompass the entire spectrum of the innovation process, including idea generation, idea promotion, and idea realization. They cover actions such as generating new ideas, seeking novel working methods, mobilizing support for ideas, and evaluating the utility of innovations. This framework highlights the multifaceted nature of innovative behaviors within organizations.

Scott and Bruce (1994) contribute to the understanding of innovative behaviors by emphasizing the significance of a “psychological climate for innovation”. This psychological climate, composed of resource supply and support for innovation, provides fertile ground for fostering innovative behaviors. The presence of necessary resources and a supportive environment encourages employees to engage in behaviors that contribute to innovation. This perspective underscores the importance of both internal and external factors in facilitating innovative actions within organizations.

## 1.3. Theoretical Framework

After a comprehensive literature review, we realized a lack of unified theoretical framework for defining the operating system. We chose to use the definition of Morgan and Liker (2018) of the operating system as the tools, processes, standard work, cadenced activities, and mechanisms that facilitate the execution of tasks. Table 3 presents our proposition of what is gathered behind these terms. The items in the table were developed by scrutinizing literature and empirical insights to ensure clarity and precision for readers. It was then reviewed and validated by experts to validate the reliability and practitioners to ensure the easiness of understanding.

Tools are the physical or digital resources and instruments used by employees to perform their tasks effectively. These can include software applications, equipment, hardware, and communication devices that support various functions within the organization. Tools enable employees to achieve their objectives more efficiently and contribute to the overall effectiveness of processes.

Processes are the structured series of steps or actions that are taken to achieve a specific outcome or goal. They define how work is carried out within an organization, guiding employees in executing tasks efficiently and consistently. Processes can encompass workflows,

procedures, protocols, and guidelines that govern various functions, from project management to customer service.

Standard work refers to the established best practices, guidelines, and documented procedures that are consistently followed by employees in their roles. It provides a baseline for how tasks should be performed to ensure consistency, quality, and efficiency. Standard work helps maintain a level of predictability and uniformity in an organization's operations.

Cadenced activities are regular, scheduled actions or events that occur within an organization. These activities follow a set rhythm or pattern, often on a specific time frame (e.g., daily, weekly, monthly, quarterly, annually). Cadenced activities help ensure consistency, routine, and accountability in various processes and operations, such as regular meetings, performance reviews, or reporting cycles.

Mechanisms refer to the association of established systems, procedures, and tools that facilitate various aspects of an organization's functioning. They are the structured ways in which certain activities or interactions are managed to achieve specific goals.

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Categories	Includes	Examples
Tools	Software tools	Various software applications and platforms used for different aspects of the company's operations, such as project management software, financial software, etc.
	Hardware tools	Physical equipment and devices used, such as computers, machinery, communication devices, etc.
	Communication tools	Tools that facilitate internal and external communication, including email, video conferencing, instant messaging, etc.
	Analytical tools	Software used for data analysis, reporting, and business intelligence to make informed decisions.
	Collaboration tools	Platforms that enable employees to work together on projects and share resources seamlessly.
Processes	Workflow processes	Sequential steps followed to complete tasks and projects, ensuring efficient and consistent execution
	Quality control processes	Methods for monitoring and ensuring the quality of products or services.
	Change management processes	Strategies for implementing changes smoothly and minimizing disruption.
	Supply chain processes	Processes related to sourcing, procurement, inventory management, and logistics.
	Customer service processes	Protocols for interacting with customers, addressing inquiries, resolving issues, etc.
	Financial processes	Accounting, budgeting, financial reporting, and other financial management procedures.
	Human resources processes	Procedures for hiring, onboarding, performance evaluations, and employee development.
Standard work	Standard Operating Procedures (SOPs) + Local Operating Procedures (LOPs)	Detailed documents outlining the specific steps to perform tasks consistently and efficiently.
	Best practices	Established methods that have been proven to yield favorable outcomes and are followed as benchmarks.
Cadenced activities	Regular meetings	Scheduled meetings such as team check-ins, project updates, and performance reviews.
	Performance metrics review	Scheduled evaluations of key performance indicators (KPIs) to assess progress and identify areas for improvement.
	Training sessions	Periodic training sessions to update employees on new tools, processes, or skills.
Mechanisms	Feedback loops	Systems for collecting and responding to feedback from customers, employees, and stakeholders to drive improvements.
	Escalation procedures	Protocols for escalating issues or decisions to higher levels of authority when necessary.
	Incentive mechanisms	Strategies for motivating employees through performance-based incentives and rewards.
	Risk management mechanisms	Processes for identifying, assessing, and mitigating risks that could impact operations.

Table 3: Operating system framework detailed

Building upon the preceding information and zooming out, we can conceptualize the intricate relationships among key elements by visualizing them as illustrated in Figure 21. The figure outlines a dynamic interplay involving the Operating System, Innovative Behaviors, Innovation, and External Context.

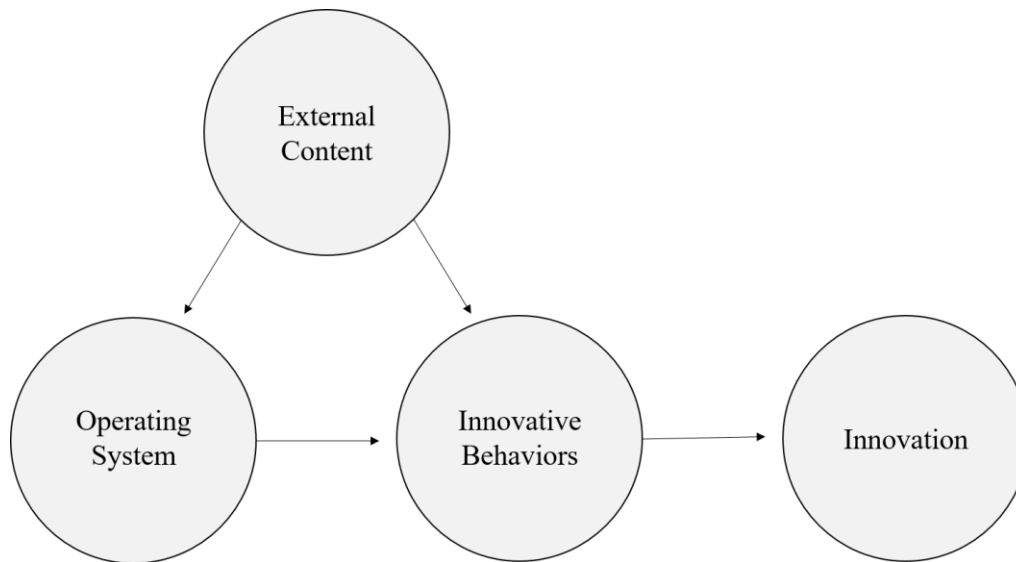


Figure 21: Organized Interactions

In this schematic representation, the Operating System serves as the foundational layer, exerting a profound influence on Innovative Behaviors. Its impact on Innovative Behaviors implies that the foundational organizational structure significantly influences the way individuals and groups approach and engage in innovation.

Simultaneously, Innovative Behaviors play a pivotal role in driving the process of innovation. The arrow connecting Innovative Behaviors to Innovation signifies the transformative effect of these behaviors on the creation and implementation of novel ideas, processes, or products. This implies that the cultivation and encouragement of innovative behaviors within the established Operating System are crucial for fostering innovation.

Moreover, the figure acknowledges the presence of External Context which includes various factors such as market conditions, socio-economic trends, geographical localization and individuals' logics. Both the Operating System and Innovative Behaviors are subject to the influences of this external layer. Changes in the external context can impact the effectiveness of the Operating System and either stimulate or impede Innovative Behaviors.

Growing from this framework we decided to look closely at the link between the Operating System and Innovative Behaviors. In this article we will wonder **how the Operating System (OS) of an organization can impact Innovative Behaviors?**

## 2. The field

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### 2.1. Choice of the field

We chose to analyze the operating system of the technology R&D department of STMicroelectronics for two reasons: (1) the technological landscape and innovation drive of STMicroelectronics, (2) its human-centric approach to performance metrics.

1. STMicroelectronics' prominence in the global semiconductor industry positions it as an exemplary case for study. The semiconductor domain, since its inception in the 1950s, has been steered by a relentless pursuit of technological advancement, evident through "Moore's Law." Formulated by Intel's founder Gordon Moore (1929-2023), this heuristic formula prognosticates the trajectory of computer chip density, and consequently, performance per circuit area, across temporal dimensions. The commitment to innovation is visibly manifest in the substantial financial and human resources earmarked by the company, with investments reaching nearly US\$2 billion and a dedicated workforce of 8,000 R&D engineers as of 2022. Consequently, it is reasonable to posit that technological innovation occupies a primary place within STMicroelectronics.

2. The bibliographic narrative surrounding STMicroelectronics underscores its distinctive orientation towards performance indicators. Notably, the company's utilization of behavioral indicators, specifically Key Behavioral Indicators (KBIs), emerges as a pioneering endeavor (Butterworth et al., 2021). This ethos, marked by a pronounced emphasis on behavioral assessment, positions STMicroelectronics as an exemplar of an organization attuned to human dynamics. Thus, the proclivity of the company towards behavioral evaluation evokes the premise that its strategic pursuits may be inherently intertwined with fostering innovative behaviors.

### 2.2. STMicroelectronics innovative behavior

In a previous study, we established a nuanced understanding of the pivotal human behaviors underpinning innovation at STMicroelectronics. Our findings unveiled a set of desired character traits that form the bedrock of innovative behaviors within the organization: expertise, creativity, technology trends, entrepreneurship, energy and motivation (Jaffré et al., 2023).

Subsequently, a validation phase ensued: a vote involving the 1000 employees of STMicroelectronics' technological R&D division. We collected 231 answers from this voting process. The results were that within the STMicroelectronics' ecosystem, creativity and energy/motivation emerged as the preeminent drivers of innovative behaviors (Jaffré et al., 2023).

In this study we will focus on the operating system of STMicroelectronics.

### 3. Methodology

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The intricate interplay between an organization's operating system and the emergence of innovative behaviors among collaborators is inherently contextual. To understand this multifaceted relationship, the study utilizes a case study approach. The primary data source for this research is a set of data gathered from STMicroelectronics from November 2020 to November 2023 thanks to a researcher-actor approach. By analyzing data from diverse sources and time periods, we aim to present a comprehensive and holistic depiction of the STMicroelectronics operating system.

We employ empirical cases to illustrate the tensions and dynamics within each category of the operating system. These cases not only highlight the practical nuances but also serve to justify the significance of our research by offering real-world context to our theoretical framework (Dorais, 1993). Empirical data are used to analyze the reasons for action of the actors and how segments of the various professions situate themselves in relation to innovation proposals and related issues.

Our data collection efforts encompassed a diverse array of sources. We employed a multifaceted approach, which included the utilization of signs, traces, and cues (Ginzburg, 1980) dispersed throughout diverse sources.

- Individual Interviews: Seventeen individual interviews were conducted from January to May 2021, providing qualitative insights into the subject matter.
- Annual Survey: The STMicroelectronics' annual survey, consisting of 62 questions categorized into 11 distinct areas.
- Organizational Artifacts: A trove of day-to-day organizational artifacts was amassed, spanning from November 2020 to July 2023. These artifacts comprised approximately 200 meeting minutes, internal communication elements such as 72 newsletters, various Yammer posts, and emails. Access to 16 working groups, along with insights into the topics of 88 groups, enriched our data pool.
- Training Sessions: Insights from 37 training sessions, accompanied by corresponding feedback and evaluation documents, were meticulously gathered.
- Performance indicators: We had access to the list of key performance indicators (KPIs) used to assess individual performance.

Integrating these diverse data sources, we seek to provide a robust and comprehensive analysis of STMicroelectronics operating system.

These data materials are inherently discontinuous, originating from various stages of the research process and representing interfaces between theoretical models and observed, real-world practices. The significance of having observed and experienced these practices during this researcher-actor approach without preconceived theoretical conditioning or the constraint



of a specific framework lends validity to our research. This approach allowed us to identify and examine phenomena without being beholden to hypotheses (Passeron, 2011).

The value of these empirical cases also lies in the fact that they provide a contextual understanding of how the operating system functions within a genuine organizational environment. They offer a practical lens through which readers can appreciate the intricacies of real-world organizational operations. Our corpus is therefore composed of diverse materials, all analyzing similar questions. It is this recurring theme, albeit discussed differently, that allows us to bring together in a single discourse what might seem to belong to different sets (H. S. Becker, 2016). Then, in contrast to relying solely on abstract concepts and theories, these cases offer tangible examples that readers can readily relate to. This facilitates the connection between theoretical frameworks and tangible, observable outcomes. Besides, while each case is unique, patterns and insights emerging from multiple cases can contribute to broader generalizations. These cases serve as foundational blocks for a more comprehensive understanding of how operating systems influence innovation in diverse contexts.

In summary, the inclusion of empirical cases in this article serves as a vital bridge between theoretical constructs and real-world applications. These cases add depth and authenticity to the research, unveiling hidden motivations and behaviors and by this way offer a real-world context for understanding how an organization's operating system influences creativity and motivation.

## 4. Results – STMicroelectronics' operating system

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STMicroelectronics provides an insightful context for examining the impact of an organization's operating system on innovative behavior within the theoretical framework proposed by Morgan and Liker (2018). In this part we will look more closely at STMicroelectronics' operating system and examine empirical cases. We will examine recurring themes related to five core elements that constitute the foundation of any operating system: (1) tools, (2) processes, (3) Standard work, (4) Cadenced Activities, (5) Mechanisms. On these key themes that structure the company, we will describe the contradictions that can hinder their implementation. Simultaneously, we will explore the behavioral logics that explain them or shed light on the actions of the stakeholders.

### 4.1. Tools: Balancing utilization logics and technical innovation

STMicroelectronics acknowledges the pivotal role of a comprehensive toolkit in fostering a creative and motivated R&D environment. This toolbox, a fusion of cutting-edge hardware and software resources, is designed to empower innovation. By providing an array of tools, including the Office suite for streamlined documentation and communication, the company

aims to offer its workforce the means to excel in their innovation endeavors. However, the interplay between the tools provided and their actual utilization by employees reveals a nuanced dynamic.

Consider, for example, the provision of state-of-the-art hardware and software resources. On the surface, it seems like an ideal way to bolster innovation. But as we delve deeper, we uncover the potential paradox. While STMicroelectronics equips its employees with top-notch resources, the ever-increasing demands placed on them might inadvertently lead to a saturation point. Overwhelmed by constant notifications and interruptions, some employees may reach a state of digital fatigue. They may no longer pay attention to their notifications or become so engrossed in their work that they disconnect from communication channels. This tug-of-war between the tools' intentions and the practical utilization by employees illustrates a delicate balance that needs to be maintained.

To illustrate that, STMicroelectronics places significant emphasis on digital platforms for communication and collaboration. Company-specific social media platforms like Yammer and SharePoint, as well as ideation platforms like HIVE, are introduced to foster knowledge sharing and global brainstorming. Communication is a catalyst for innovation, and while the introduction of these tools marks a move towards swift and informal communication, it also introduces challenges. The constant stream of messages and notifications can potentially disrupt focused work, making it essential for employees to manage their digital presence. For instance, some employees disable notifications to maintain productivity, change their availability status or create “fake meetings” on their calendar. The intention behind these digital tools is to enhance communication, but the practical utilization necessitates a careful balance to prevent them from becoming counterproductive.

The introduction of SharePoint, HIVE, or Microsoft Teams offers a prime example of how intentions and utilization can diverge. While some employees seamlessly integrate these tools into their daily workflow, others encounter difficulties, perceiving them as counterintuitive. For example, a lot of ideation campaigns on HIVE did not receive as many ideas as intended because employees do not use the platform. As an illustrative example, a HIVE campaign launched in October yielded only four ideas over a span of five weeks, even after directly encouraging individuals to contribute their thoughts on the platform. Given that the campaign was aimed at 1000 employees, this outcome was deemed unsuccessful. The wide range of employee reactions highlights the necessity of not only providing tools but also ensuring that training and support are available to help employees maximize their effectiveness.

Furthermore, recent facility upgrades, like flex offices and coworking spaces, are aimed at breaking down physical barriers to encourage collaboration and innovative thinking. These changes reflect the company's commitment to creating an environment that fuels creativity and motivation. These flexible spaces serve as hubs for cross-functional interactions, encouraging the cross-pollination of ideas and perspectives. Feedback from training sessions indicates that the new collaborative spaces have made a positive impact on creativity during brainstorming sessions. While these new collaborative spaces have received positive feedback for enhancing

creativity during brainstorming sessions, they also shed light on the complex relationship between space and innovation. As with tools, there is a duality in play. The intention behind these open, collaborative spaces is to stimulate cross-functional interactions and the cross-pollination of ideas. However, the balance between these aspirations and the practical implementation – ensuring these spaces do not become distracting or overcrowded – remains an ongoing challenge. Some employees find it difficult to focus in an open environment with noise and visual distraction, which can hinder their productivity and create frustration. The open design of such spaces often lacks the acoustic privacy needed for deep concentration, making it challenging for individuals who require a quiet workspace. Furthermore, the appeal of these spaces sometimes extends beyond the immediate workforce. People from other buildings or departments may try to enter these areas in search of a more vibrant work environment or to escape their regular spaces, inadvertently overcrowding them and diluting the intended cross-functional collaboration. The issue of access to these open spaces can also be a sensitive one. Employees from manufacturing departments, for instance, do not have the same level of access to these areas as those from other departments, which can lead to feelings of exclusion, inequality and the message that creativity is not expected from them. Addressing this disparity and fostering a sense of inclusivity in open workspaces becomes a challenging task for organizations, as they strive to balance the benefits of collaboration with the need for privacy and fair access.

In light of these observations, we can almost liken this phenomenon to what we might term “iatrogenic processes.” Just as iatrogenic diseases emerge from the medical environment itself, these dynamics arise within the realm of innovation. The very tools and innovations that are intended to promote creativity and motivation can sometimes inadvertently lead to burnout or diminished productivity. Therefore, it is clear that striking the right balance between providing tools and enabling their effective utilization is a complex endeavor, crucial for maintaining the harmony between intention and practicality in an innovation-driven organization.

## 4.2. Processes: Between creativity and validation processes

Regarding “Processes” STMicroelectronics demonstrates a structured approach. Being a big hierarchical company (more than a thousand people work in the R&D), workflow processes sometimes involve complex approval processes, while other flatter structures offer more streamlined workflows. And it is understandable as in the semiconductor industry, maintaining rigorous quality control standards is really important. STMicroelectronics places great emphasis on these processes to ensure that its products meet the high standards demanded by the industry and this commitment to quality implies more bureaucratic and rigid tasks. While quality assurance remains a top priority, the rigid hierarchical structure presents challenges in terms of fostering creativity and maintaining employee motivation.

The multilayered hierarchy often impedes the flow of innovative ideas. The journey from lower-level employees to upper management entails multiple filtration points, potentially leading to the loss of valuable insights. Employees describe their experience as being filtered out before their innovative ideas reach higher levels of decision-making. One employee voiced their frustration: *“There are so many filters between your boss, your boss's boss, and the boss of your boss's boss that, in the end, someone who might be motivated higher up is already filtered out. If we aim for something efficient at this level, there are too many filters, and these filters are linked, so it never reaches the top, where someone could potentially decide to invest in it. [translation]”* (Interview, Engineer, 06/01/2021).

Another significant concern arises from the extensive effort required by technical experts to validate their ideas, especially when dealing with colleagues who lack domain knowledge. This bureaucratic process can be both exhausting and discouraging. Building trust in the expertise of technical specialists is an essential aspect of fostering innovation. *“The second thing to improve is that, in fact, the technical expert must always prove that what he has in mind is a good idea. When you see the sometimes-necessary steps to motivate someone who doesn't necessarily understand the domain and doesn't rely solely on the opinion of the technical expert, it can be exhausting and frustrating to go to such lengths and put in so much effort to try to convince people when technically, the expert is already convinced. The management should trust technical experts more than they already do within the organization,”* explained an employee (Interview, Engineer, 01/06/2021).

In parallel, STMicroelectronics acknowledges the need to remove barriers to innovation and empower employees to take initiative. Programs such as EvereST and Inn'Spire, designed for local and global innovation fostering, and BeLight, a continuous improvement department, seek to transform the organization. BeLight, for example, instills values and principles collected from employee interviews and encourages a structured approach to improvement and innovation. These programs motivate employees by offering a framework for contributing to the organization's innovation agenda, creating channels for innovative ideas to bypass excessive layers of approval. This empowers employees to contribute their creative insights directly.

However, it is crucial to note that the reception of the BeLight initiative varies among employees. This divergence in reception raises questions about how these initiatives are perceived and appropriated within the workforce. It highlights the complexity of employee engagement and understanding. The diversity in employee reactions, as evidenced by feedback from the annual survey and a series of interviews, calls for further examination of factors influencing engagement with these innovation initiatives. Moreover, it prompts broader inquiries into organizational change and the challenges associated with implementing innovation-driven programs, emphasizing the need for organizations to tailor their initiatives to accommodate diverse perspectives, ultimately fostering a more inclusive approach to innovation.

One reason given during interviews for this mixed reception is the feeling of inefficiency of the processes put in place. For example, STMicroelectronics has instituted a process known as External Paper Validation, facilitated through dedicated software, for the approval of any scientific publication within the organization. However, my experience has shown that, despite submitting several papers over a three-year period, none of them progressed beyond the initial stage of validation. On one hand, this process serves positively in terms of preserving confidentiality and ensuring corporate endorsement of published work. It also contributes to knowledge sharing, as the organization remains informed about the research output, facilitating connections between individuals. Nonetheless, the persistent lack of progress in this validation process raises questions about its utility. It prompts us to consider whether the disappointment stemming from a non-functional process is more detrimental than the absence of a process altogether. In my own experience, I have resorted to bypassing this process by directly emailing colleagues for more expeditious responses. This workaround, however, raises concerns about credibility and whether circumventing established processes undermines their intended purpose.

### 4.3. Standard work: Building efficiency while embracing context

STMicroelectronics, committed to Standard Work practices, relies on Standard Operating Procedures (SOPs) and Local Operating Procedures (LOPs) to ensure efficiency and consistency across various functions. While these best practices serve as guiding principles for operational excellence, a paradox exists within the organization. STMicroelectronics often operates like a consortium of independent startups, each adapting global initiatives to fit their specific context. This observation underscores a challenge related to establishing a global standard within the organization. When an innovative initiative is introduced in one location, each site or department tends to customize and adapt it to their specific cultural or organizational contexts. While this approach can be advantageous by tailoring solutions to local nuances, it also raises questions regarding the necessity of such adaptations, which at times may appear more habitual than strategic. For instance, following the successful development and implementation of RnDyneo, a lean training program for R&D teams in Crolles, Grenoble and Edinburgh, the Italian R&D department and the Rousset site (located in the south of France) opted to modify the program before its implementation. In Rousset, compared to the initial version, a two-round game about silos was spread across two different days. Other games were switched to introduce the notion of Scrum and A3. Similarly, the Italian site made alterations to the standard set of games. Specifically, they integrated the two rounds on silos and the notion of Obeya and VSM into an A3 framework. Additionally, they introduced a structured brainstorming session for defining solutions after the first round and removed the final game involving quizzes and cards. The Italians also enhanced a Kano exercise spending more time on it.

The intent of all these changes was to tailor the training program to address specific needs within each organizational context. However, one might question the necessity of all these changes and whether they indicate an incohesive organizational approach especially since they have been made arbitrarily before deploying the initial training. Such modifications may raise concerns about potential challenges and unintended consequences. For instance, the allocation of resources used for customization, and implementation could be seen as a duplication of effort and thus an inefficiency. Then, the original program has been carefully designed, and there is a risk that too many modifications may dilute its effectiveness. The long-term sustainability of customized approaches may be questionable, especially if key individuals responsible for the modifications leave the organization. Finally, changes made at the local level may not align with the broader organizational goals and strategies. It is crucial to acknowledge that one of the major objectives was to share the 'Mindsets' of Lean in R&D. However, it appears counterproductive not to align these mindsets throughout the entire organization. Without this alignment, the modifications might inadvertently steer teams away from the overall vision and objectives, causing misalignment within the organization.

While standard work provides structure and clarity, there can be perceptions that it stifles creativity. Striking the right balance is a perpetual challenge, as both excessive standardization and complete lack thereof can have consequences.

One illustrative example of this balance is reflected in the activities of the process integration team, where there isn't a standardized dedicated software platform. As a result, team members are free to choose the software that best suits their needs. On one hand, employees express that this freedom fosters a sense of empowerment and creativity. They perceive it as a demonstration of trust, which, in turn, enhances motivation. On the other hand, “newcomers to the team often find themselves overwhelmed by the multitude of software options available [translation]” (interview process integration manager, 11/06/2023). And the process integration manager even sees standardization as a way of giving autonomy to its team to allow them to be more creative.

The lack of standardization can complicate workflows, potentially leading to inefficiencies. It is evident that finding the right balance between standardization and flexibility is both challenging and essential. This balance becomes the prerogative of each manager, recognizing that in some areas, standardization is critical for efficiency and consistency, while in others, freedom and flexibility may boost creativity and motivation.

#### 4.4. Cadenced activities: balancing discursive production and endogenous innovation processes

Cadenced activities are integral to STMicroelectronics' operating system, with regular meetings, project kick-offs, Obeya sessions, and performance metrics reviews, including key behavior indicators (KBIs), all serving as mechanisms to drive innovation.

These cadenced activities are crucial as they set the rhythm for collaboration, allowing teams to engage in meaningful discourse while ensuring that the innovation pipeline remains dynamic and responsive. The cadenced approach establishes a framework where regular discussions, idea generation sessions, and reflective pauses harmonize with the ongoing innovation processes. This intentional rhythm promotes a healthy flow of ideas and encourages collaboration.

However, it can be challenging to install and some drifts may emerge. For instance, a high frequency of cadenced activities without proper consideration for workload and capacity may lead to fatigue among employees, diminishing their creative and innovative capacities. This is typically the main complaint continuous improvement project leaders have in STMicroelectronics. "I already have too many meetings, it was too much to add one meeting every week for the continuous improvement project" (interview, project leader, 03/04/2021).

If the cadenced activities introduce excessive administrative overhead, it can impede the natural flow of creativity and innovation. Striking a balance between structure and agility is key. Recently, the continuous improvement department of STMicroelectronics worked on its framing document to simplify it. People complained they would spend too much time on documentation leaving them with less time for the project.

Cadenced activities may inadvertently exclude voices from diverse teams or departments, limiting the range of perspectives and ideas. Inclusivity is crucial to harness the full creative potential of the entire organization. For instance, there is an event within the R&D department where only managers and recognized experts are invited to participate. This exclusive approach can unintentionally create feelings of resentment among other employees. On the last event, the goal was to find energy efficiency innovative ideas. A subsequent global brainstorming was then organized to hear the voice of other groups of collaborators. Unfortunately, the response was lackluster. This may be partly due to the fact that many employees did not feel integrated from the outset, leading to a sense of disconnection and apathy. This scenario highlights the importance of inclusivity from the inception of cadenced activities to ensure that diverse voices are heard, perspectives are valued, and the entire organization feels a sense of ownership and relevance in contributing to innovative endeavors.

The effectiveness of cadenced activities hinges on clear and efficient communication channels, crucial for collaboration and the smooth integration of innovative ideas into existing processes. This necessity is exemplified in various organizational contexts. For instance, innovation forums, designed to foster creativity, can inadvertently amplify the dominance of voices already comfortable with innovation. An interview highlights the tendency for these forums to become platforms where the same individuals, already at ease with innovation, dominate discussions "*often in discussion forums, it's always the same people talking: it's people who are comfortable and don't need a forum to be innovative, they already are [translation]*" (interview, manager, 20/05/2021). The challenge, therefore, lies in ensuring that such forums authentically involve a diverse range of voices, including those less naturally inclined towards innovation. Similarly, in project advancement meetings, individuals monopolizing discussions

on unrelated topics disrupt the flow and hinder progress, as noted in another interview “*the biggest difficulty I had was with people who monopolize the floor for more than an hour, no matter how hard you try to cut them off, it doesn't work, because they want to solve another super-important problem, which has nothing to do with the subject, but which must be solved right away. Now they're off for an hour of discussion, nothing to do with the subject or the schedule [translation]*” (interview, project leader, 12/01/2021). This underlines the critical importance of maintaining focus and relevance during such gatherings to optimize communication and collaboration.

It is also important to highlight that performance metrics reviews are an essential component of STMicroelectronics' cadenced activities. These reviews offer a structured approach to assess progress, identify areas for improvement, and recognize exemplary contributions. STMicroelectronics takes care to align these metrics with innovation goals. Thereby the organization provides a clear framework for measuring innovation performance.

## 4.5. Mechanisms: Innovation proposals VS stakeholder interests

The mechanisms embedded within STMicroelectronics' operating system encompass a diverse array of tools designed to drive innovation and motivate employees. These mechanisms include feedback loops, escalation procedures, and an array of incentive mechanisms such as recognition, bonuses, awards, and Key Behavior Indicators (KBIs). However, it is crucial to explore how the genuine interests of stakeholders can interfere with the initial goal of these mechanisms.

For example, STMicroelectronics utilizes an annual survey structured around affirmations, where respondents provide feedback on a Likert scale. The survey is a valuable feedback mechanism that offers employees an opportunity to voice their opinions on various aspects of the organization. Remarkably, the survey has evolved over time, responding to specific departmental needs. For example, prompted by the quality department's request for quality-related questions, relevant items were added. This adaptive approach to the survey reflects STMicroelectronics' departments' commitment to capturing employee perceptions and organizational dynamics. However, it is essential to highlight that the survey's utilization varies across the organization. Some managers employ it as a tool to gauge team sentiment and perception, while others may not integrate survey data into their decision-making processes.

STMicroelectronics ties bonuses to the results of the annual survey, creating a dual-edged impact on innovation and motivation. On one hand, such bonuses incentivize managers to improve their teams' working conditions and overall job satisfaction. This can serve as a powerful driver for enhancing the employee experience. However, it can also introduce challenges. For instance, when survey results related to lean practices were less favorable, the



focus shifted to addressing perceived issues with the survey questions. This situation illustrates how the presence of bonuses can inadvertently steer attention away from genuinely addressing critical areas, potentially undermining innovation.

Another striking case is the Employee Suggestion Scheme (ESS), a process and tool introduced in STMicroelectronics to recognize and reward improvements, irrespective of their source. ESS empowers employees, including those whose voices might not typically be heard, to contribute their ideas and improve motivation. This mechanism has the potential to foster creativity by tapping into a broader pool of creativity within the organization. However, it is worth noting that the introduction of ESS also brought unintended consequences. Some employees, who would have previously taken immediate action to address issues, now rely on the platform to report problems. For example, an engineer stated during a return on experience meeting *“there's a non-glass door that swings in both directions, posing a safety hazard as people might collide with it. In the past, individuals would have put up a "dangerous" sign themselves. However, now, no one puts up a sign because they submit the idea to ESS, hoping to receive a reward [translation]”* (meeting, engineer, 09/07/2023). This shift in behavior underscores the importance of striking a balance between incentivizing contributions and maintaining individual initiative.

## 5. Discussion

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The examination of how STMicroelectronics' operating system impacts creativity and motivation reveals a complex interplay of mechanisms, actions, and unintended consequences. Our field research confirms that the operating system indeed affects creativity and motivation, aligning with Butterworth's et. al statement (2021). Moreover, it supports the claims that performance incentives impact innovation and that the work environment plays a crucial role in innovation (Larman & Vodde, 2010; Mathisen & Einarsen, 2004).

The existing theoretical framework of OS developed by Morgan and Liker is too broad and falls short when it comes to qualifying the specific impact of each constituent element on innovative behavior within organizations. Recognizing this limitation, there arises a clear need for a more refined framework that can provide nuanced insights into the interplay of elements. In this article we propose a more detailed framework that specify what is gathered under the terms “tools”, “processes”, “standard work”, “cadenced activities” and “mechanisms”. Such refined proposition is essential to establish the groundwork for future studies, fostering a shared foundation for comprehensive exploration and analysis. By delving into the nuances of these elements, our aim is to contribute to a more precise and insightful assessment of their impact on fostering innovative behavior within the organizational context.

To delve deeper into the theoretical aspect, it would be valuable to measure the impact of each element of the operating system on specific innovative behaviors. While we can't provide a comprehensive characterization e.g., stating that “tools” have a universally positive or negative

impact, we can develop a questionnaire to observe the correlation between types of tools and specific behaviors. A quantitative study could help qualify the impact of each element.

Moreover, it is essential to recognize that all elements of the framework are interdependent, which adds complexity to understanding the implications of one on the other, as multiple interactions likely exist.

Then, we couldn't explore the impact of external and contextual factors, which could be an intriguing avenue for further research.

Beyond the theoretical validation, these findings carry practical implications that could benefit organizations seeking to enhance creativity and motivation within their workforce.

First and foremost, it is evident that addressing the barriers and breaks within an organizational system is paramount. However, the approach to dealing with these obstacles should not necessarily entail their complete removal. Rather, it calls for a thoughtful and strategic adaptation of these impediments to ensure they have a different, more constructive impact. Take, for instance, the case of bonuses and targets. While these mechanisms may have unintended consequences when used indiscriminately, the key lies in a nuanced selection and implementation of bonuses that align with innovation objectives. This underscores the need for organizations to carefully evaluate which incentives are most conducive to fostering creativity and motivation.

One pertinent question that emerges from this analysis is whether the facilitators and barriers within an operating system can be managed in any order or if a specific sequence is more effective. The answer lies in recognizing that the order of management depends on the specific context of the organization. While addressing barriers is fundamental, it doesn't necessarily imply their immediate suppression. Instead, organizations should consider adapting these impediments to harness their potential for positive influence. This adaptive approach aligns with the idea that not all breaks need to be eliminated; rather, they can be transformed to contribute to innovation.

To gain a deeper understanding of the impact of an operating system on innovative behaviors, we suggested that future research explore the use of meticulously tailored questionnaires. Such surveys could be very helpful also in the industrial world to address and assess the various aspects of the operating system and their correlations with specific innovative behaviors. By conducting rigorous data analysis and correlation calculations, organizations can uncover more nuanced insights and personalized audit into the intricate relationship between their operating systems and innovation outcomes.

Furthermore, if we narrow the scale of analysis concerning the acceptance or appropriation processes of innovations, we observe a multitude of responses based on the specific situations of the actors involved. Simply put, professionals' reactions depend on factors such as age, gender, remaining time in the company, promotion expectations, job position, and more. This approach revisits the question of "innovative behaviors" such as commonly used and asks if the notion of "polysemic behaviors" wouldn't be more appropriate. Therefore, practitioners need

to enhance their approach by focusing on the observation of actions and situations, analyzing the diversity of stakeholders' discourse to identify recurring themes, and examining how technical innovations are embraced by these stakeholders. This process begins with “Genba” observation, which can be prepared in advance but also shared with the workers. Timing is critical, and involving employees in making these observations can promote greater reflection. The bottom-up process we recommended earlier isn't just about giving a voice to the people, it is not that simple. It requires a process of self-reflection on one's actions, which is not something natural but rather stems from reflective analysis. This means that innovation is not just a project within the company; it is an ongoing process of introspection about the organization itself. By helping individuals contemplate their practices and granting them the autonomy to define what innovation means to them, we acknowledge the company as a distributed entity and view its stakeholders as possessing capabilities. This concept aligns with the principles of Lean thinking and continuous improvement. In essence, this approach entails taking Lean and continuous improvement seriously, going beyond treating them as mere slogans and instead applying them in a tangible and meaningful way. It is not just a toolbox; it is a fundamental philosophy that drives organizational progress.

## Conclusion

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In conclusion, our examination of various aspects of the operating system within the company, exemplified by STMicroelectronics but reflective of broader corporate dynamics, sheds light on the complex interplay between innovation, operating system, and the role of individual actors.

First, tools introduced with the intent to enhance connectivity or foster innovation often confront varying levels of adoption. The critical question arises: Can we develop tools in isolation from the users' perspectives and needs?

Second, the evaluation of processes reveals that stringent quality standards, while commendable, can lead to unintended consequences, hampering innovation. Striking the right balance between creativity and rigorous validation processes is crucial, as is understanding how these processes are received by the workforce.

Third, the notion of standard work highlights the challenge of harmonizing freedom for creativity and motivation with the necessity of standardization for quality and efficiency.

Fourth, the concept of “cadenced activities” illustrates the need to reconcile discursive production and endogenous innovation processes, emphasizing the importance of a well-calibrated approach.

Fifth, understanding the mechanisms within the organization exposes the impact of employees' individual interests on innovation proposals and intentions, necessitating a thorough examination of how these interests may intersect with organizational objectives.

Our exploration has underscored the intricate connection between the operating system and innovation as stated by Butterworth et. al (2021) but further into the innovative behaviors of creativity and motivation and the actors who evolve in the organization. The links between the operating system elements and the innovative behaviors are complex to characterize because they are interconnected but also because human individual logics of doing make it harder to propose a one-fit-for-all strategy. From a distant view, the overarching logic differs from the intricate processes of appropriation by individual actors. There are interactions on an individual level as well as on a collective one. A need for a quantitative study is therefore evident to qualify better these complex relationships. It is only through a comprehensive understanding of these multiple layers of influence that we can hope to drive innovative behavior and transform organizations. Effective innovation relies on fostering a sense of ownership among these actors. In this context, we do not question the fact that effecting change within an organization – especially a multinational - necessitates a top-down approach. However, the vitality of the bottom-up perspective cannot be overstated, as the dynamics at different scales are not uniform (Revel, 1996).

# Conclusion et perspectives

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# Conclusion et perspectives

**D**ans cette conclusion nous proposons de mettre en évidence les principaux résultats de recherche de notre thèse. Tout d'abord, nous mettrons en exergue les contributions théoriques et empiriques que notre recherche a apportées. Nous expliquerons comment ces contributions éclairent la gestion d'un LPD favorable à l'innovation en R&D.

Ensuite, nous aborderons les limites inhérentes à notre recherche, en accordant une attention particulière aux aspects méthodologiques, à la construction théorique et à l'étude empirique. Comprendre ces limites est essentiel pour contextualiser nos résultats et reconnaître les zones où des recherches futures pourraient être nécessaires pour approfondir notre compréhension du Lean en R&D.

Enfin, nous concluons ce chapitre en jetant un regard vers l'avenir, en proposant des pistes prometteuses pour de nouvelles recherches. Ces perspectives aideront à orienter les futurs travaux académiques et professionnels dans le domaine de l'excellence opérationnelle et du management de l'innovation tout en maintenant le cap sur l'objectif ultime d'améliorer la performance et la compétitivité des organisations industrielles dans un monde en constante évolution.

## 1. Conclusion

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### 1.1. Principaux résultats

Ce chapitre de conclusion marque la fin d'un voyage intellectuel passionnant à travers les méandres du *Lean Product Development* (LPD) au sein de l'environnement complexe de la R&D de STMicroelectronics. Pour mieux appréhender le contexte de cette thèse, il est important de revenir brièvement sur les éléments clés qui ont conduit à cette recherche.

Dans le chapitre initial de cette thèse, nous nous sommes intéressés aux origines du Lean, une méthodologie de gestion de la production qui a connu une transformation remarquable, passant de son utilisation traditionnelle dans la production à une tentative d'application dans le domaine de la R&D. Cette évolution a été motivée par la reconnaissance des différences fondamentales entre les processus de fabrication et les processus de recherche et développement, créant ainsi la nécessité d'adapter le Lean pour répondre aux besoins spécifiques de la R&D.

Notre étude a pris pour terrain d'exploration STMicroelectronics, une entreprise de renommée mondiale dans le secteur des semi-conducteurs. Ce marché dynamique et exigeant exige une

innovation continue pour rester compétitif. La décision de l'Europe d'investir massivement dans STMicroelectronics en vue de produire des semi-conducteurs indépendamment de l'Asie a placé l'innovation au cœur de l'entreprise. En 2008, STMicroelectronics a initié avec succès l'implémentation du Lean dans ses opérations de production. En 2016, l'entreprise a étendu ses actions Lean à la R&D, puis en 2017, elle a lancé le programme Lean « BeLight » (*voir chapitre 1*). C'est au sein de ce programme que cette thèse a été menée, cherchant à comprendre comment le Lean pourrait être adapté pour stimuler l'innovation en R&D.

La méthodologie de cette thèse a été ancrée dans une approche de recherche-action. En tant que chercheur-acteur, j'ai été immergée au sein de l'entreprise, travaillant en tant qu'ingénieur au sein du programme BeLight. Cette immersion a favorisé une réelle « observation participante » (Olivier de Sardan, 2008) qui m'a permis de recueillir des données de manière authentique et d'expérimenter les principes Lean directement sur le terrain.

En fin de compte, au fil des mois et des travaux, notre thèse est devenue une réflexion sur la question cruciale des liens entre le LPD et l'innovation en R&D. Notre recherche a révélé des indices essentiels sur la manière dont les principes Lean peuvent être adaptés et mis en œuvre avec succès dans un environnement de R&D, tout en favorisant l'innovation. Nous avons démontré que le Lean peut être une approche pertinente, mais qu'il nécessite des ajustements spécifiques pour s'aligner aux besoins d'une R&D.

Durant cette thèse nous voulions répondre à la question suivante : **est-ce que des démarches de Lean Product Development favorisent l'innovation dans des entreprises de hautes-technologies** ? Une réponse affirmative se dessine, mais elle est conditionnelle et subordonnée à divers facteurs. En premier lieu, l'adaptabilité du concept de LPD à chaque contexte spécifique émerge comme une condition sine qua non. L'absence d'un *framework* universel (*voir chapitre 2*) apparaît non seulement comme une réalité incontestable, mais également comme une force, laissant place à la notion de configuration, qui s'avère plus apte à appréhender la complexité et la variabilité inhérentes à chaque environnement organisationnel.

Le LPD, en plaçant l'humain comme l'un de ses piliers, a été identifié comme un catalyseur potentiel pour l'innovation. Notre analyse a mis en évidence le rôle critique des comportements humains dans ce processus, soulignant leur capacité à favoriser l'émergence d'idées novatrices. Cependant, ces comportements ne sont pas isolés de l'*operating system* (OS) des entreprises.

Au cours de notre recherche, nous avons observé que l'OS, comprenant des outils, des processus, et des activités cadencées, joue un rôle déterminant dans la création d'un environnement propice aux comportements innovants. Plus encore, cet écosystème organisationnel peut agir en tant que levier ou frein, influençant la manifestation de comportements humains favorables à l'innovation.

Ainsi, la réussite de l'intégration du LPD pour stimuler l'innovation dépend de la synergie entre la configuration spécifique du LPD adoptée, la reconnaissance du rôle central de l'humain, et la conception réfléchie de l'*operating system* de l'entreprise. Ces éléments interconnectés créent

un écosystème favorable, où le LPD et les comportements humains collaborent harmonieusement pour promouvoir l'innovation.

## 1.2. Contributions du chapitre 2

Dans le chapitre 2 de cette thèse, une revue de la littérature sur le LPD a été réalisée. Cette contribution a permis de mettre en évidence les principaux facteurs de succès et les obstacles à une mise en œuvre réussie du LPD. En outre, la thèse a abordé la question de l'influence du contexte sur ces facteurs, proposant ainsi une perspective qui privilégie la notion de configurations plutôt que de cadres rigides. Sur le plan académique, cette recherche a offert une vue d'ensemble des facteurs clés de la mise en œuvre du LPD et a ouvert une discussion sur la pertinence du concept de cadre dans ce domaine. Du côté des praticiens, cette contribution a fourni aux organisations des éléments de réflexion sur les principaux facteurs à prendre en compte lors de la mise en œuvre du LPD.

**Apports Théoriques :** Cette contribution enrichit la compréhension des facteurs de succès et des obstacles liés au LPD, tout en remettant en question la notion traditionnelle de cadre dans ce contexte. Elle ouvre la voie à une réflexion plus nuancée sur la mise en œuvre du LPD. Notre revue systématique de la littérature, a souligné que le signifiant LPD recouvrait de multiples signifiés et désignait des situations techniques, économiques et culturelles extrêmement variables. De ce fait il est difficile d'isoler des variables explicatives des éventuels changements observés. C'est pourquoi nous soulignons que progresser dans la compréhension de l'impact du LPD demanderait des études comparatives usant des mêmes « outils conceptuels » et travaillant sur des dimensions semblables.

**Apports Managériaux :** Cette contribution offre aux gestionnaires et aux praticiens une meilleure compréhension des défis et des opportunités liés à la mise en œuvre du LPD, les aidant ainsi à prendre des décisions éclairées lorsqu'ils envisagent d'adopter cette approche dans leurs organisations. Notre étude ne peut aucunement donner des « recettes ». Toute entreprise est complexe et spécifique, et toute innovation correspond à une négociation entre l'ancien et le nouveau, bouscule des acquis et des routines souvent rassurantes pour les acteurs. Cependant nous proposons une sorte de catalogues des possibilités d'innovation ainsi que des variables à prendre en compte pour réaliser in situ et concrètement des actions ainsi que pour les évaluer avec rigueur.

## 1.3. Contributions du chapitre 3

Le chapitre 3 de cette thèse se concentre sur l'importance du facteur humain dans l'innovation et propose des indicateurs de comportement pour mesurer ce facteur. Cette contribution met en lumière l'importance de promouvoir des comportements favorisant l'innovation au sein des organisations. Elle vise à répondre à la question de « comment favoriser l'innovation en promouvant des comportements grâce à des indicateurs ? » en se penchant sur le rôle des



comportements et en utilisant des indicateurs clés de comportement (KBIs). Cette recherche s'attache à éclairer la voie vers la mesure et l'évaluation de ces comportements, établissant un lien entre le capital humain et les résultats en matière d'innovation.

Nous soulignons que la notion de « facteur humain » est complexe et doit être déconstruite pour être analysée. En effet ce terme polysémique recouvre des questions portant sur des identités culturelles déterminant des manières d'être au travail (Berger, 2006; D'Iribarne, 1989), l'histoire de l'implantation d'une entreprise dans une région spécifique, les modes de gestion, les rapports de genre dans l'entreprise, etc.

Ici encore nous ne conservons ce terme que par convention, mais nous soulignons combien il se présente comme une « boîte noire » qu'il convient d'explorer si l'on souhaite comprendre l'adhésion ou le refus de certaines innovations.

**Apports Théoriques :** Cette contribution élargit la compréhension du rôle crucial du facteur humain dans le processus d'innovation au sein des organisations. Elle introduit également un cadre pour mesurer et évaluer les comportements liés à l'innovation.

**Apports Managériaux :** Cette contribution permet à STMicroelectronics de connaître les comportements favorisant l'innovation au sein de sa R&D dont les deux principaux semblent être « créativité » et « énergie/motivation » et donne un exemple et un élément de comparaison aux autres praticiens.

## 1.4. Contributions du chapitre 4

Le chapitre 4 examine l'influence de l'*operating system* (OS) d'une organisation sur les comportements favorisant l'innovation, tels que la créativité et la motivation. Cette contribution se base sur une étude de cas approfondie menée chez STMicroelectronics, qui a permis de préciser un cadre conceptuel de l'OS comprenant des outils, des processus, des normes de travail, des activités cadencées et des mécanismes. Les résultats révèlent par exemple les subtilités pratiques de l'équilibre délicat entre la standardisation et la flexibilité, ainsi que l'impact des incitations sur la créativité et la motivation.

Les questions de la « créativité » et de la « motivation » ou sans doute « des » motivations bien que centrales dans la gestion des entreprises sont encore trop peu étudiées et souvent réduites à des questions salariales et de temps de repos. Pourtant, les nouvelles attitudes envers le travail montrent que le sens de son activité, la façon dont les acteurs ressentent leur adéquation à diverses priorités sociétales comme l'écologie sont au cœur des choix professionnels et des recrutements. Nous espérons avoir éclairé l'importance de ces dimensions sociales. L'acteur n'est jamais uniquement un producteur. Ses motivations correspondent aussi aux champs des représentations qui semblent socialement légitimes.

**Apports Théoriques :** Cette contribution élargit la compréhension de la relation entre l'*operating system* d'une organisation et les comportements innovants. Elle introduit un cadre

conceptuel affiné qui éclaire cette dynamique et met en lumière des balances nécessaires et subtiles à trouver pour chaque élément.

Si les études usent du terme de « comportement » notre travail s'interroge si la notion de conduites polysémiques ne serait pas plus adéquate pour analyser les pratiques des acteurs. En effet, si l'on réduit l'échelle d'analyse des processus d'acceptation ou d'appropriation des innovations on peut constater une multitude de réponses selon les situations des acteurs. Pour le dire simplement, la réponse des professionnels dépendra de leur âge, genre, temps de travail restant à effectuer dans l'entreprise, espérance de promotion, poste de travail, etc. C'est ici reprendre la question des échelles d'analyse, ainsi illustré par Leibniz : « le sujet ne perçoit pas le bruit de chacune des gouttes d'eau qui composent la vague. En revanche, il perçoit, comme un tout, le bruit que fait la vague » (Leibniz, 1990). En ce domaine notre étude souligne l'intérêt qu'il y aurait à user d'enquêtes précises pour comprendre pourquoi, à échelle humaine, certaines innovations sont acceptées et d'autres refusées.

**Apports Managériaux :** Cette contribution offre aux praticiens, par le biais de cas empiriques, des idées sur les éléments de leur *operating system* pouvant influencer sur la créativité et la motivation au sein de leur organisation.

## 2. Limites et perspectives

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### 2.1. Limites

#### 2.1.1. Limites du chapitre 2

Bien que le chapitre 2 ait permis d'identifier les facteurs clés de succès et les obstacles à la mise en œuvre du LPD, certaines limites subsistent. Tout d'abord, la recherche se base principalement sur une analyse de la littérature existante, ce qui peut ne pas refléter entièrement la diversité des pratiques et des contextes organisationnels, il serait intéressant d'explorer d'autres sources de données telles que des entretiens avec des praticiens de l'industrie ou des enquêtes terrain. De plus, l'impact du LPD sur l'innovation peut varier en fonction de la nature spécifique de l'industrie et de l'entreprise, ce qui nécessite des recherches futures pour approfondir ces différences contextuelles.

#### 2.1.2. Limites du chapitre 3

Le chapitre 3 a mis en lumière l'importance des comportements humains dans le contexte de l'innovation, mais il présente également certaines limites. La mesure des comportements liés à l'innovation à l'aide d'indicateurs reste un défi complexe, la mise en œuvre d'indicateurs de comportement clés (*key behavior indicators*, KBIs) peut présenter des défis pour les entreprises. Ces défis peuvent inclure la planification minutieuse, l'engagement des parties prenantes et la nécessité d'un suivi continu et d'ajustements pour garantir l'efficacité et la

durabilité des systèmes KBI. Par ailleurs, les indicateurs proposés ne couvrent peut-être pas l'ensemble du spectre des comportements innovants. De plus, la recherche a été menée dans le contexte spécifique de STMicroelectronics, ce qui limite la généralisation des résultats.

### 2.1.3. Limites du chapitre 4

Le chapitre 4 a analysé l'influence de l'*operating system* sur les comportements favorisant l'innovation, mais il présente également certaines limites. L'étude de cas a une fois de plus été réalisée dans le contexte spécifique de STMicroelectronics, ce qui limite la généralisation des résultats à d'autres organisations industrielles. De plus, nous nous sommes attardés sur l'exploration des comportements de créativité et de motivation, mais il existe d'autres comportements liés à l'innovation qui méritent également une attention. Il serait donc intéressant de conduire des recherches supplémentaires pour évaluer comment les organisations peuvent adapter leur système opérationnel de manière plus précise pour promouvoir une culture de l'innovation. Il serait également bénéfique d'explorer comment les incitations et les mécanismes du système opérationnel peuvent être ajustés pour encourager des comportements innovants spécifiques.

Par ailleurs, il est essentiel de noter les limitations rencontrées dans la réalisation de l'étude. Premièrement, en raison de contraintes de confidentialité, il n'a pas été possible de lancer un questionnaire directement auprès des employés ou d'accéder aux données et résultats du sondage annuel de l'entreprise. Cette limitation a restreint la capacité de collecter des données spécifiques sur les comportements liés à l'innovation et à l'*operating system* au sein de l'organisation. De plus, le sondage annuel de l'entreprise ne couvrait pas suffisamment de questions spécifiques liées à l'innovation et à l'*operating system*, ce qui a limité la possibilité de mener des analyses de corrélation approfondies entre ces variables. Ces questions spécifiques sont essentielles pour comprendre les liens entre l'*operating system* de l'entreprise, les comportements favorisant l'innovation et les résultats en matière d'innovation.

## 2.2. Perspectives

Des limites de notre recherche, identifiées précédemment, naissent des perspectives de recherche.

### 2.2.1. Perspectives du chapitre 2

Pour aller plus loin que le chapitre 2, il serait intéressant d'explorer davantage comment les organisations peuvent adapter le LPD en fonction de leurs besoins spécifiques, en intégrant des approches flexibles tout en préservant les principes fondamentaux du Lean. La recherche future pourrait se concentrer sur la création de modèles de management qui tiennent compte de ces facteurs de succès et d'obstacles, tout en intégrant des approches plus flexibles pour s'adapter aux spécificités de chaque organisation. Il serait également pertinent d'explorer comment les

entreprises peuvent évaluer leur propre contexte et déterminer quels facteurs de succès sont les plus pertinents pour leur situation particulière.

### 2.2.2. Perspectives du chapitre 3

Aux vues des conclusions du chapitre 3, une recherche plus poussée pourrait explorer comment les organisations peuvent mettre en œuvre et ajuster ces indicateurs de comportement pour encourager l'innovation. Il serait également intéressant d'explorer les liens entre les comportements humains et d'autres aspects de la gestion de l'innovation, tels que la culture d'entreprise et la structure organisationnelle.

Il est nécessaire de continuer à affiner et à valider les KBIs proposés, en s'appuyant sur des données empiriques supplémentaires. Il serait également intéressant d'explorer davantage l'impact des KBIs sur les résultats d'innovation organisationnelle. En outre, il serait bénéfique d'approfondir la compréhension des mécanismes qui contribuent à l'obsolescence du capital humain au fil du temps, ce qui pourrait aider les organisations à maintenir et à améliorer leur capacité à innover.

Une autre piste de recherche pertinente consiste à examiner comment les comportements individuels se traduisent en comportements collectifs au sein des organisations, en tenant compte des facteurs contextuels. La notion de réflexivité, à la fois au niveau individuel et organisationnel, représente une opportunité prometteuse pour explorer davantage les dynamiques comportementales et leur impact sur l'innovation.

Des enquêtes réflexives réalisées par les acteurs, seraient aussi d'un réel apport pour les entreprises en permettant à chacun de mieux se situer dans une longue chaîne de production et en comprenant les contraintes de chacun des autres maillons de la production.

### 2.2.3. Perspectives du chapitre 4

Enfin, dans le but de combler les lacunes du chapitre 4, il serait intéressant de proposer un questionnaire complémentaire ou intégré au sondage annuel de l'entreprise, axé spécifiquement sur les questions liées à l'innovation et à l'*operating system*. Ce questionnaire pourrait inclure des questions conçues pour évaluer les comportements des employés en lien avec les pratiques du LPD, la créativité, la motivation et d'autres aspects liés à l'innovation. De plus, il serait bénéfique d'inclure des questions sur la perception des employés concernant l'*operating system* de l'entreprise et son impact sur leur capacité à innover. L'analyse de corrélation entre les réponses à ces questions permettrait de mieux comprendre les relations entre les différentes variables, notamment la manière dont l'*operating system* influence les comportements des employés en matière d'innovation. Les résultats de cette analyse pourraient offrir des perspectives précieuses pour orienter les efforts de management de l'innovation au sein de l'entreprise.

En définitive, l'intégration de nouvelles questions dans le questionnaire existant ou la création d'un questionnaire complémentaire pourrait constituer une approche prometteuse pour mieux évaluer les interactions complexes entre l'*operating system*, les comportements favorisant l'innovation et les résultats d'innovation au sein de l'organisation. Un questionnaire plus complet, interrogeant sur des éléments concrets de l'*operating system* et des manifestations des comportements voulus pourrait permettre une analyse de corrélation et obtenir des données quantitatives. Cela permettrait d'obtenir des données plus précises et informatives pour orienter les décisions stratégiques et les actions managériales.

De plus, le terme de « comportement » humain n'est peut-être pas le plus adapté car limité. La terminologie de « conduites » offre une alternative plus riche et polyvalente. La notion de « conduites » offre une polysémie qui va au-delà de la simplicité du mot « comportement ». Elle embrasse la diversité des actions, des réactions et des interactions humaines. Chaque individu est le chef d'orchestre de ses propres conduites, façonné par un ensemble de facteurs intriqués, tels que les influences sociales, les expériences personnelles, les motivations profondes, et même les paramètres biologiques. En adoptant le terme « conduites », nous reconnaissons la multi-dimensionalité inhérente à l'expression humaine. Les conduites sont des phénomènes qui ne se limitent pas à une simple réponse à un stimulus externe, mais résultent d'une combinaison complexe de variables internes et externes. En étudiant les conduites, nous ouvrons la porte à une compréhension plus nuancée et holistique des logiques d'action des acteurs. L'utilisation de « conduites » souligne également l'aspect dynamique et évolutif des actions humaines. Elle invite à explorer les processus de prise de décision, les motivations changeantes, et les réponses adaptatives aux contextes variés. Les conduites, par leur nature multifactorielle, reflètent la flexibilité inhérente à l'expérience humaine qu'il serait intéressant d'approfondir (Biehl et al., 2007; Mapel, 1977; Passeron, 2011).

### 2.3. Autres intérêts, autres perspectives de recherche

Au-delà des limites spécifiques à chaque chapitre, des perspectives plus générales se dessinent. Tout d'abord, il est essentiel de reconnaître que le LPD ne peut pas être simplement considéré comme un programme de transformation standard. Il représente un système complexe de dialogue entre des objectifs professionnels et sociotechniques, et sa mise en œuvre doit être étroitement liée aux contextes spécifiques de chaque organisation. Les organisations, y compris STMicroelectronics, peuvent envisager de mettre en place un cadre de management de l'innovation intégrant le LPD, les comportements humains et l'alignement de l'*operating system*. Cela pourrait inclure la création d'indicateurs de performance innovants qui mesurent l'impact des comportements sur les résultats de l'innovation. De plus, une culture d'entreprise encourageant la créativité, la collaboration et l'apprentissage continu pourrait être promue. Les organisations pourraient également explorer des mécanismes d'incitation et de reconnaissance qui renforcent les comportements innovants. Enfin, la flexibilité et l'adaptabilité dans la mise en œuvre du LPD et dans la configuration de l'OS pourraient être encouragées pour répondre aux besoins changeants du marché et aux défis de l'innovation.

Pour STMicroelectronics, en tant qu'entreprise internationale avec des équipes multisites et des activités diversifiées, explorer des éléments contextuels tels que la culture d'entreprise locale et les logiques sociales devient essentiel pour comprendre leur capacité d'innovation. Face à cette complexité organisationnelle, une première étape cruciale serait de définir clairement ce qu'ils entendent par « innovation ». Cela permettrait d'éviter que le terme ne devienne une expression générique, tout en établissant une base solide pour évaluer l'impact de ces divers éléments sur leur approche de l'innovation. Cette définition précise fournirait un cadre essentiel pour la compréhension interne, favorisant ainsi une gestion plus efficace et stratégique de l'innovation au sein de l'entreprise.

La recherche future pourrait également se concentrer sur des enquêtes plus ciblées, en examinant des contextes spécifiques pour évaluer la pertinence des facteurs clés identifiés dans cette thèse. Il est important de reconnaître que ces facteurs peuvent être les mêmes, mais leur mise en œuvre et leur gestion peuvent varier en fonction du contexte.

En fin de compte, la recherche et la gestion de l'innovation dans le contexte du LPD nécessitent une approche nuancée qui tienne compte des interactions complexes entre les éléments humains, les processus organisationnels et les contextes spécifiques. En combinant une compréhension approfondie des facteurs de succès et d'obstacles avec une flexibilité adaptée au contexte, les organisations, y compris STMicroelectronics, peuvent renforcer leur capacité à innover sur le long terme.

### 3. Le mot de la fin

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Le voyage à travers cette thèse a été enrichissant à bien des égards. Il nous a permis de mieux comprendre les défis et les opportunités qui se présentent lorsqu'on tente d'introduire le LPD dans un environnement de R&D. Il a également mis en lumière l'importance de l'adaptabilité et de la flexibilité dans la recherche de solutions Lean pour l'innovation en R&D.

En fin de compte, cette thèse contribue à l'enrichissement du corpus de connaissances sur le LPD et son application dans des contextes variés. Elle offre des pistes de réflexion pour les organisations engagées dans une quête constante d'amélioration de leurs processus de R&D tout en maintenant un niveau élevé d'innovation.

En tant que chercheur-acteur, j'ai eu le privilège de vivre cette aventure aux côtés de mes collègues de STMicroelectronics, et je reste optimiste quant à l'impact positif que cette recherche pourra avoir sur les futures initiatives Lean en R&D et sur l'innovation au sein de l'entreprise.

L'exploration continue, les défis persistent, mais avec une compréhension plus approfondie des synergies possibles entre le LPD et l'innovation en R&D, nous sommes mieux préparés à relever ces défis et à façonner un avenir plus innovant.

En conclusion, cette thèse ne fait pas que proposer des réponses, au contraire elle ouvre la porte à de nouvelles questions, de nouvelles explorations et à la recherche continue de l'équilibre entre efficacité et innovation en R&D. Elle invite à poursuivre la réflexion sur la manière dont le Lean peut être un catalyseur de l'innovation, contribuant ainsi à la compétitivité des entreprises dans un monde en perpétuelle évolution.

Au début de ma recherche j'aurais été déçue de ne pas apporter de réponse claire et définitive à toutes ces questions. Mais s'il y a une chose que j'ai comprise durant ces trois années de thèse c'est que la recherche, par nature, ne se contente pas de résoudre des énigmes, mais qu'elle génère également de nouvelles questions. En fin de compte, chaque réponse éclaire de nouvelles zones d'ombre, ouvrant ainsi la voie à un dialogue ininterrompu et à une quête inlassable de compréhension. La thèse émerge ainsi comme une étape dans ce processus continu de questionnement et d'exploration. Si, à travers ces quelques pages, j'ai réussi à susciter en vous le désir d'explorer de nouvelles questions, la soif insatiable de connaissances approfondies, et même la frustration face à des interrogations demeurées sans réponse, alors je peux affirmer que je contribue enfin modestement à l'effervescence perpétuelle qui caractérise le monde de la recherche.

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