



**Faculty of Business & Law
International Strategy & Business**

Student Name:
Moncef Salmi

Student ID:
17427019

**MBA
STRM-044**

**Modeling and Simulation Software Industry:
Potential Solutions for a Better Deployment
from a Marketing Perspective**

Assignment 2: Business Research Project (50 credits)

Assignment word count: 14664

Lecturer Name / Supervisor: Dr Rani Kaur / Tom Moore

Submission Date: 07/02/19

Acknowledgments

This work is the result of the support of numerous contributors that made it possible. I'm convinced that this experience will have a deep impact in my life from both personal and professional points of view. In fact, it was the opportunity to confirm to myself that I am considerably interested by both acquiring and applying effective business skills in order to resolve interesting and compelling strategic challenges. This is particularly true when the target business research is about modeling and simulation industry. Indeed, this is the field where I evolve since more than 10 years. It's the field where I performed my engineering and doctoral studies. I also taught this field in the university and worked as a technical expert of it in the industry during the past decade. Consequently, the current experience is a golden opportunity for me to complement a deep technical knowledge of this domain by a business insight into it.

In this framework, I acknowledge all the teaching and technical staff of the University of Northampton that made this experience possible. I acknowledge particularly Dr Deniz Meric and Dr Rani Kaur who are the lecturers for the current final stage of this MBA program. I also thank particularly Tom Moore for his advices and for being my supervisor for the final business research project.

Finally, I bless my lovely family for being always the main source of my successes and accomplishments. I praise my parents for planting into my spirit invaluable beliefs that push me always at aiming higher and accomplishing more. Endless thanks go to my lovely wife Rim for being the best partner and my best half. My most tender thoughts and grace go to my beloved and cherished babies Emna and Assil. You are simply the most beautiful gift that life has ever gave to me...

Executive Summary

Modeling and Simulation (M&S) can be defined as the realm of replacing a real experimentation by a virtual one through the implementation of applied mathematics models into advanced software solutions. This gives an idea of the value that such technologies can bring to the market. In fact, it gives the opportunity to optimize new designs without building any real prototype. It allows also to shorten the time to market of new products. In addition, it allows to replace harmful and non-ecofriendly processes by virtual ones. Consequently, the added value of such technologies can be highly important to its adopters. On the other hand, the market research of the M&S industry shows that the latter has relatively low market value. This is the major pain point that is tackled by the current study. This pain point is particularly addressed from a marketing point of view. In this framework, the study starts by performing a literature review regarding M&S industry. This research has 3 main objectives: First is to define the M&S industry and the value that it brings to its adopters. Second is to identify the major hurdles for a better deployment of M&S in the industry from a marketing point of view. Third is to identify the main leverages that can help M&S for a better deployment in the industry. The next step consists in verifying and validating the major outcomes of the literature review through a primary and quantitative data research. In this framework, a survey is designed and conducted and the major outcomes are quantified and analyzed. Afterwards, the performed business research study leverages the main results of the performed primary and secondary data research in order to provide M&S marketers with actionable recommendations. In this framework, 2 M&S market segmentations are adopted: from end users point of view and from geographical point of view. Finally, a discussion chapter compares and criticizes the outcomes of the different research sources in order to summarize in a synthetic and concise way the major takeaways of the conducted study.

Table of Contents

I.	Introduction of the framework and main objectives.....	7
1.	M&S Definition.....	7
2.	M&S Added Value and Main Features	9
3.	M&S Market size	10
4.	Market Segmentation	12
5.	Main objectives of the conducted study.....	14
II.	Literature Review	15
1.	Commonly Used Marketing Analysis Tools	15
a.	SWOT Analysis	15
b.	PESTEL analysis	16
c.	Porter's 5 Forces Analysis	17
d.	BCG Matrix Analysis	17
e.	Product Life Cycle Analysis	18
2.	Main Marketing Hurdles for Modeling and Simulation Industry.....	19
a.	Lack of Transparency and Clarity.....	19
b.	Weak Networking	20
c.	Senior executives reluctance	21
d.	Lack of Input Data and Complexity of Usage.....	22
e.	Lack of M&S Qualified resources	24
f.	Lack of Verification and Validation (V&V)	24
g.	Lack of Maturity Regarding some M&S Applications	25
h.	Miscellaneous Challenges.....	27
3.	Main Marketing Leverages to Modeling and Simulation Industry.....	27
a.	Market Dynamism and High Competitiveness	28
b.	M&S historical presence in the market	29
c.	Fundamental Research Revolution	29
d.	Digital Revolution.....	30
e.	Increasing Global Ethical Awareness	32
III.	Research Methodology	34
1.	Adopted Research Methodology at a Glance	34
2.	Research Methodology for Primary Data.....	34
3.	Limitations and Difficulties of the Adopted Research Methodology.....	35
a.	Limitations	35
b.	Difficulties	36
IV.	Primary Research Survey.....	37
V.	Summary of the Main Findings and Discussion	44

1.	Marketing Recommendations Based On The Main Findings	44
a.	From an End-Users Perspective:	44
b.	From a Geographical Perspective:	46
2.	Discussion	48
VI.	Conclusions and Open Questions.....	51
VII.	References.....	53

Table of Figures

Figure 1: Global R&D relative investments worldwide (Industrial Research Institute 2016).....	10
Figure 2: M&S Market Size (Mordorintelligence 2018).....	11
Figure 3: M&S Vs PLM Market Size (Market Research Future 2019).....	12
Figure 4: Main employers of M&S experts (SIAM 2012)	13
Figure 5: Number of Researchers per Million People (UNESCO 2019).....	14
Figure 6: M&S SWOT Analysis	16
Figure 7: M&S PESTEL Analysis.....	16
Figure 8: M&S Porter’s 5 Forces Analysis.....	17
Figure 9: M&S BCG Matrix Analysis.....	18
Figure 10: M&S Product Life Cycle Analysis	19
Figure 11: Transistor Economic KPIs (Holt 2015).....	32
Figure 12: Survey Results Question1: Use of M&S in Daily Job	37
Figure 13: Survey Results Question2: M&S Training in the University	38
Figure 14: Survey Results Question3: M&S Training in the Current Job.....	38
Figure 15: Survey Results Question4: M&S Market Size Feedback.....	39
Figure 16: Survey Results Question5: M&S Importance	40
Figure 17: Survey Results Question6: M&S Main Added Value.....	40
Figure 18: Survey Results Question7: M&S Strength.....	41
Figure 19: Survey Results Question8: M&S Weakness	42
Figure 20: Survey Results Question9: M&S Opportunity.....	42
Figure 21: Survey Results Question10: M&S Threat.....	43

I. Introduction of the framework and main objectives

This first section aims at introducing the main objectives of the conducted study. In this framework, the current investigation starts with defining its main focus which is Modeling and Simulation (M&S) software industry. Afterwards, the market features of the considered field as well as its added values are outlined. Finally, based on the gathered findings, the main questions of the conducted study are exposed.

1. M&S Definition

Modeling and Simulation (M&S) industry can be found in the literature with different labels such as: Applied mathematics, computer aided design, computer aided engineering or virtual manufacturing to name a few. M&S in the current report should be understood in its broad meaning, hence corresponding to all these terms interchangeably. Based on the different consulted literature resources, giving a unique definition of M&S has always been a tedious task that authors never succeeded to overcome through a unique consensus. This is true since few decades ago. In fact, Pritsker (1979), is one of the first authors that tried to provide several definitions of the studied field. More recently, Mittal (2017) provided hundreds of definitions of simulation. Several authors like Law (2007) attempted to provide a holistic definition of M&S by presenting it as a modeling of an animated process over time and space.

An additional important notion that is closely related to M&S, especially in its modern implementation, is certainly Monte Carlo simulation. According to Rubinstein and Kroese (2008), this notion is related to uncertainty quantification and reliability analysis which are essential added values brought by M&S to the industry. It consists of assessing virtually the reliability that can be affected to a given product that is evolving in a given environment. This definition of the authors focusses on a very specific aspect of M&S and can't be considered as a generic or complete definition of it. Macal (2013) defines M&S through its practitioners by stating that simulation is merely what simulationists do. The latter are defined as the engineers, scientists and more generally as any stakeholder involved in the usage of computers as applied mathematics based software aiming at mimicking and reproducing virtually the target physical phenomena. Consequently, Macal (2013) defines the activity through its practitioners. Even if it provides interesting details regarding the main aspects and goals of M&S, this approach

adopted by the author for defining M&S can be confusing to the reader since it can be considered as an infinite loop of definitions.

According to Glotzer et al (2009), M&S is nowadays ubiquitous and continues to invade different types of industries. The author outlines that M&S is used today by stakeholders as a complementary investigation and design tool to traditional methodologies such as experimentation and real prototyping. There are even critical technologies and discoveries that will not be able to be further developed without M&S. Some examples for the latter are the design of more efficient materials for energy storage or the research regarding the genesis and the evolution of the universe.

Among the different attempts for defining M&S in the literature, one of the simplest and most pragmatic can be the one provided by SIAM (2012). The authors provide an exhaustive view of M&S status in the modern industry. On the other hand, the authors take clearly the position of M&S enthusiasts which make them focus on the strengths and opportunities of M&S and omitting to investigate its weaknesses and threats. In the framework of defining M&S, the authors of SIAM (2012) state that: M&S are mainly applied mathematics tools that are implemented through industrial technologies in order to be applied in the field of virtual engineering. The authors take the specific example of several of the most popular terms in the field that are business analytics or business intelligence and data science. These terms are only trendy expressions for activities that exist since decades. This is why the authors state that applied mathematics are still very present and very important in today's industry, it's only that it exists in different new labels. The authors prefer to use the term applied mathematics instead of M&S. In fact, the former exists in the industry since the 1950s. At that time, the US Air force used mathematical approaches to resolve complex issues in the field of logistics.

Based on all these definitions from the literature, the one that will be considered in the current study defines Modeling and Simulation (M&S) as the realm of replacing a real experimentation by a virtual one through the implementation of applied mathematics models into advanced software solutions.

2. M&S Added Value and Main Features

Lockney (2018), who is Technology Transfer Program Executive at NASA, states that software in general and M&S in particular has played and will always play a key role in NASA core activities ranging from aeronautics to data processing passing by materials.

In the same framework, Kadanov (2004) states that there are 3 main added values brought by simulation which are to:

- Make new discoveries that are unattainable by using conventional experimental approaches.
- Solve fully established issues.
- Try virtually numerous design choices and end up with the most optimized version at an optimized cost. In fact, all the “what if” analysis are made virtually, hence at a fraction of time and price of the real prototypes.

On the other hand, according to Hayes (2008), the major output that one can expect from M&S is: A deep insight into the studied system through exhaustive output data bringing a new and unique interpretation for new scientific challenges as well as for old ones.

In addition, M&S is seen in the industry as a decision making tool. In this framework, M&S discipline is also called “Business Intelligence” or “Business Analytics”. The main idea behind is to have M&S tools that are able to find the major pattern in a big amount of data in a fully autonomous manner by using the “Artificial Intelligence” technology or more precisely the “Machine Learning” tools. In this framework, Lohr (2011) reports that the biggest technology companies such as Microsoft, IBM and Oracle spent together more than \$25B in the acquisition of specialized startups in this field.

Regarding M&S features, SIAM (2012) conducted a survey on M&S professionals in different sectors and at different levels in the industry. The results of the survey reflects 3 main features of the M&S industry: First, M&S experts are increasingly demanded by the market. In fact they have a first order impact on the performance of their corporations. Second, M&S experts in the industry are expected to have entrepreneurial

skills in addition to their technical skills. In fact, in addition to their ability to model and implement creative new ideas, M&S experts should also convince their executives and stakeholders of the added value that their models are bringing on the table. The third main outcome of the study is that M&S experts should have excellent teamwork skills. In fact, M&S is a very interdisciplinary field where different stakeholders from different backgrounds should interact at different levels.

3. *M&S Market size*

According to Page (2017), it's very difficult to evaluate accurately the global investment levels in M&S, hence to evaluate its market value. This is due to 2 main reasons: First, M&S is spread into different disconnected disciplines ranging from finance to healthcare passing by system design and engineering. Secondly, the M&S does not have yet a clear visibility among the corporations. In fact, it's generally closely embedded to Research and Development (R&D) departments. Consequently, a qualitative consideration would be to track the R&D general trends and projecting the similar ones to M&S. According to Valvida and Clark (2015), the global R&D spending in the US can be evaluated at about \$100B. At a more global scale, Industrial Research Institute (2016) evaluates the worldwide R&D investment at \$2T. This global investment amount is divided as shown by Figure 1 among the major protagonists. In this framework, China and North America represent more than $\frac{2}{3}$ of the global R&D investment.

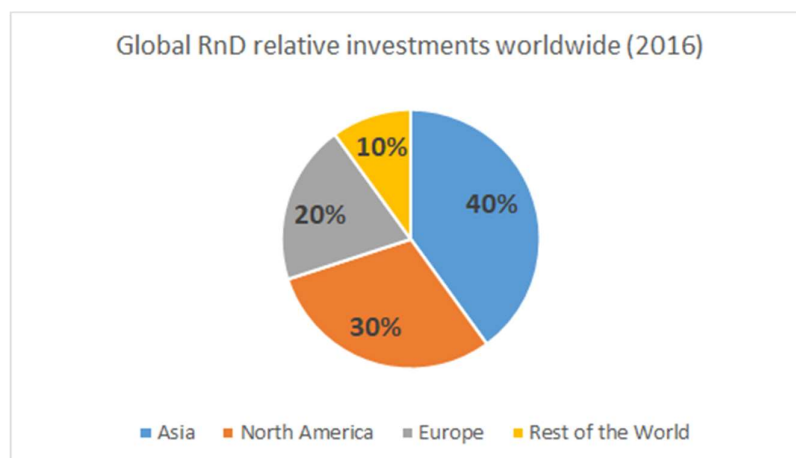


Figure 1: Global R&D relative investments worldwide (Industrial Research Institute 2016)

Different sources from the literature try to evaluate the global worth of M&S industry. Even if the range is still wide, the global order of magnitude can be caught. Figure 2 reports an estimation of the M&S market size between 2017 and 2023. According to Mordorintelligence (2018), the M&S market size is evaluated in 2017 at \$6B and expected to grow at a CAGR of 15.1% until 2023 to reach a global value of \$14.5B. Even if the economic growth of M&S is promising, it's current worth is still relatively low by comparison to the added value that it brings to its users.

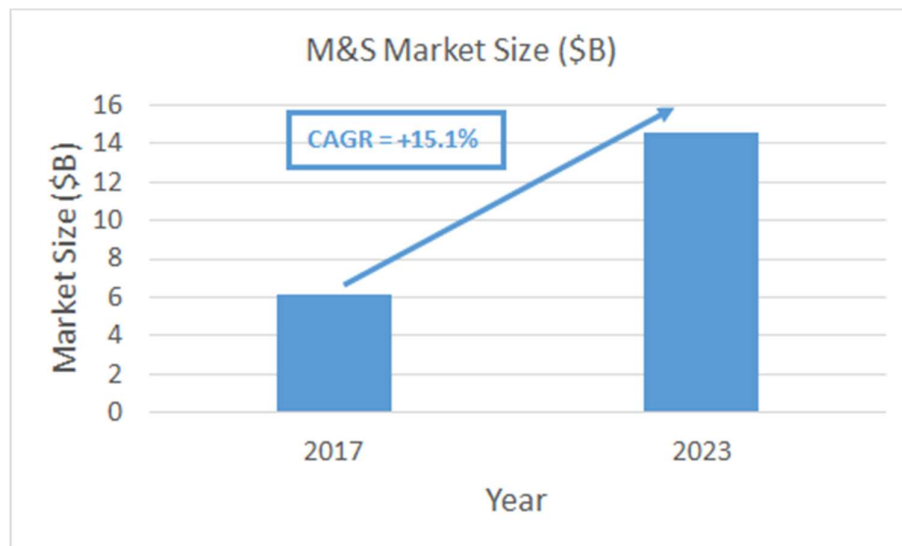


Figure 2: M&S Market Size (Mordorintelligence 2018)

In fact, M&S industry is part of Product Lifetime Management (PLM) industry. According to Market Research Future (2019), in 2017, the M&S represents about 15% of the PLM industry. This ratio is expected to reach 23% in 2023. This increasing market share is due to a fast CAGR of M&S by comparison to the CAGR of PLM as reported by the Figure 3.

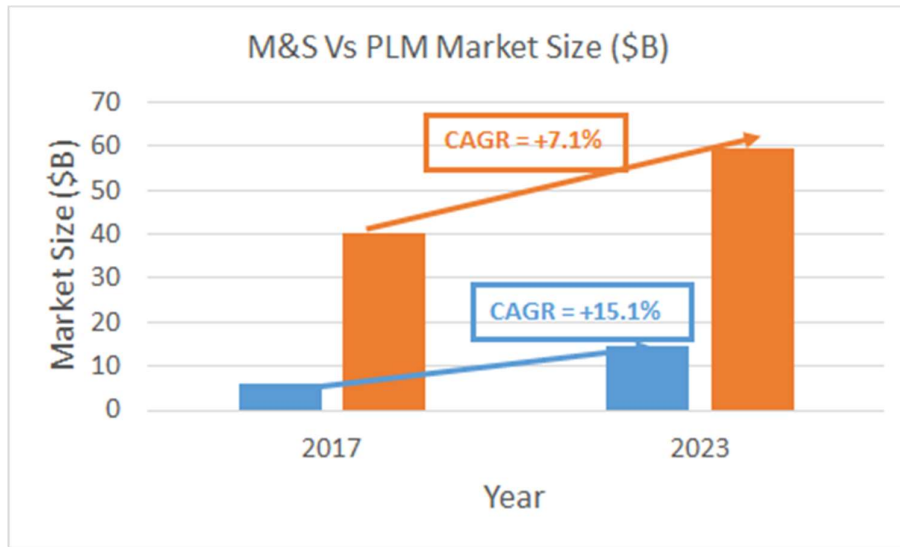


Figure 3: M&S Vs PLM Market Size (Market Research Future 2019)

Based on these evaluations, it can be seen that at best, M&S industry represents 1% of the global R&D spending worldwide. This means that more than 99% of R&D is still fulfilled by a non-simulation based R&D activity. These numbers bring us to the major question of this report which is: Why despite of the high added value brought by M&S in the industry, its financial weight is still low by comparison to its market potential ? This report aims at investigating on the reasons resulting in this reality. This is performed with a special focus on the marketing aspects.

4. Market Segmentation

Segmentation is a classical yet effective marketing strategy. In fact, this technique allows addressing each group of target prospects by adapted marketing action plan. This section provides a market segmentation of the M&S industry from 2 different perspectives.

The first segmentation is performed from an end user point of view. This segmentation is inspired by the major industries that need M&S technologies. In this framework, Figure 4 reports the partition of the major sectors employing M&S experts. In fact, this kind of data is a valuable indicator regarding the industries that need M&S the most. The major 3 areas recruiting M&S experts are in decreasing order: Finance and insurance then pharmaceuticals followed by general software industry.

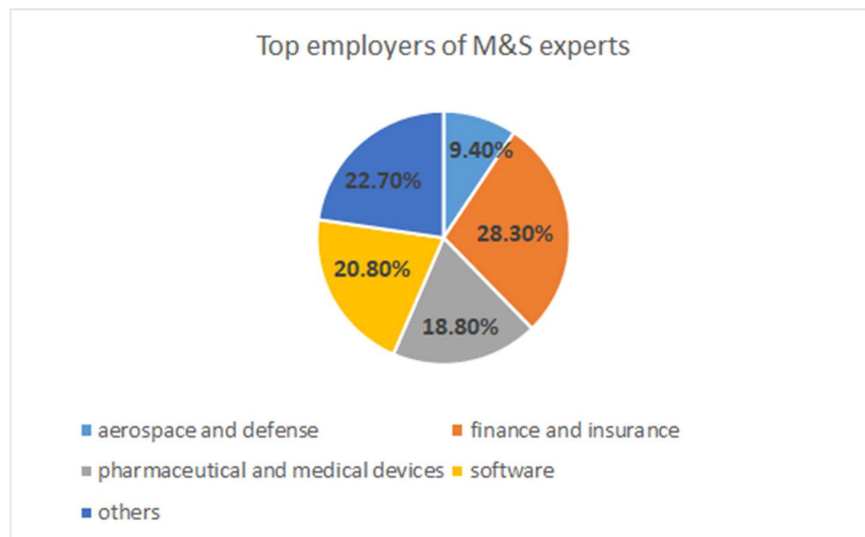


Figure 4: Main employers of M&S experts (SIAM 2012)

The second segmentation is performed from a geographic point of view. In this way, the M&S marketer knows how to deal with a potential prospect based on his background from both technical and geographical points of view. In fact, any marketing deployment is highly dependent on the considered end-user. In addition, M&S is more or less well developed on some specific geographic areas and it has specific difficulties to be deployed in other areas. This segmentation is adopted upon the study of the major geographic zones that are investing on M&S. In this framework, Figure 5 reports the number of R&D researchers per million people among the considered geographical segments. This data is a significant indicator regarding the M&S geographic segmentation since the latter is heavily correlated with the R&D sector as stated previously. Figure 5 shows that Europe has the most important R&D researchers in terms of number per million people, followed by North America. Surprisingly, China has low statistics in this field. This result should be considered with care. In fact, the reported numbers are normalized and expressed in terms of per million people. Obviously, China has more number of total people than the other considered areas. Hence the absolute number of researchers should be of the same order of magnitude between the 3 major R&D areas which are: Europe, North America and China.

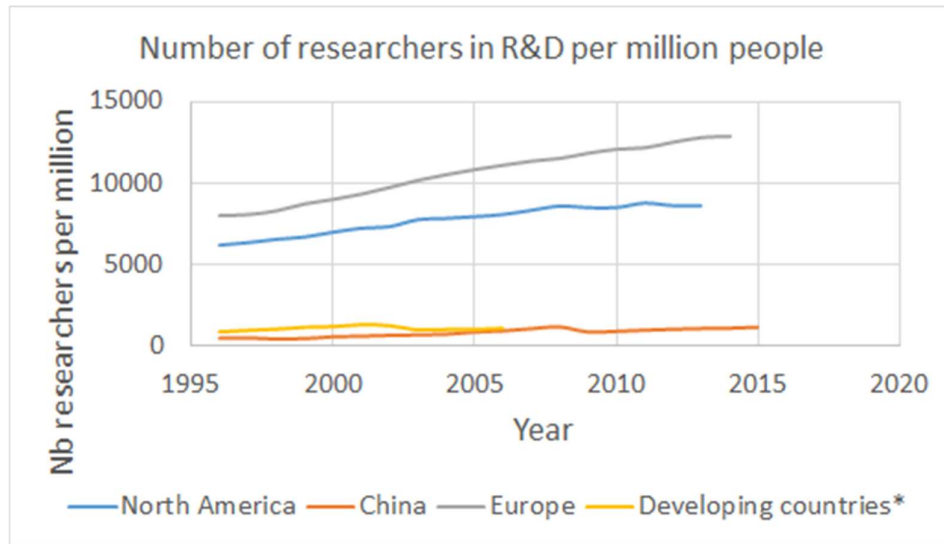


Figure 5: Number of Researchers per Million People (UNESCO 2019)

*Brazil, India, South Africa and Pakistan

5. Main objectives of the conducted study

This report focuses on the industry of Modeling and Simulation (M&S) software from a marketing point of view. In fact, despite the high potential value that it brings to the market, M&S industry is still having the image of being more as a Research and Development (R&D) activity than as an industrial standard. In addition, at the best estimations, M&S represents a very small fraction among the global R&D investments worldwide. In this framework:

- What are the major hurdles to an effective deployment of the M&S in the industry?
- What are the major leverages to an effective deployment of the M&S in the industry?
- How can M&S editors adapt their marketing strategy for a better deployment in the industry?

II. Literature Review

After introducing the framework of the study and its main objectives, the current section aims at studying the exposed questions from a literature review perspective. In fact, the idea is to collect the major thoughts that can be found in the state of the art regarding the main pain points exposed previously. In this framework, different literature resources are consulted in order to identify both the main hurdles and leverages that M&S is encountering in the market from a marketing perspective. The objective is also to make the link with the previously exposed marketing analysis tools. The conducted literature review is also used for designing the quantitative primary data survey of the next section. Afterwards, the major findings of the conducted survey are discussed through a confrontation to the main outcomes of the following literature review.

1. Commonly Used Marketing Analysis Tools

Based on the first literature findings regarding the M&S definition and main features presented in the former chapter, the current section aims at building the classical market analysis tools. The commonly used market analysis tools allow the marketing strategist and researcher to have an organized idea about the tackled market. This is true from internal and external points of view. From internal point of view, the proposed analysis tools allow to identify clearly the inner marketing features of the studied subject. From external point of view, these market analysis tools provide a strategic overview on the environment of the studied topic from different perspectives. This effort provides valuable information for structuring effectively the conducted research activity.

a. SWOT Analysis

The performed literature review can be seen as a detailed SWOT analysis gathered from the different resources. In the current section, the M&S SWOT features are summarized as reported by Figure 6. This summary allows the M&S marketer to access to the different aspects of M&S industry at a glance. In addition, it allows building the online survey that will come in the next section as it will be detailed later. Each of the components of the SWOT analysis will be detailed in the upcoming literature review.

<ul style="list-style-type: none"> > Unique added value (replacing real manufacturing by virtual one) > Historical presence in the market and former success stories > Continuously improving Strengths	<ul style="list-style-type: none"> > Blurred image, not very well known as a technology > Very complex to master > Lack of standardization (poor compatibility with other softwares) > Lack of accuracy and efficiency > Lack of maturity regarding some advanced applications > Lack of a solid networking Weaknesses
<ul style="list-style-type: none"> > World digitalization momentum > Cloud computing > Market dynamism and high competitiveness Opportunities	<ul style="list-style-type: none"> > Not always accepted by executives especially seniors > Oversold by some marketers > Nationalism and border closure regarding data and resources exchange Threats

Figure 6: M&S SWOT Analysis

b. PESTEL analysis

The PESTEL analysis is also provided. This is a powerful marketing and strategic tool that the M&S marketer should take into account during the construction of the marketing strategy. In fact, the PESTEL analysis provides a detailed study of the M&S global environment and conditions as reported by Figure 7. In this framework, the performed analysis reports that from a political point of view, the global situation is stable, especially in developed countries, which is favorable to this industry. Regarding economy, the situation is also favorable since both the recession and the global economic crisis are over and the world is globally living in an economic prosperity. From a social point of view, the M&S technologies lack popularity and visibility by non-experts and it didn't reach yet the status of an industrial standard. Regarding environment, the global ecological awareness can be a serious opportunity to M&S since the latter replaces non-ecological activities by virtual testing. On the other hand, legal aspects should be managed with a particular care. In fact, data exchange policies are becoming increasingly complex which is not favorable to M&S industry. Finally, the current technological environment is very favorable to M&S through the highly powerful digital momentum that the world is living since 2 decades.

Political Good global stability	Economic Favorable: help in cost reduction	Social Lack of popularity
Environment Favorable: replace harmful processes	Legal Warning: data exchange, VISA policies	Techlonogy Very favorable digital momentum

Figure 7: M&S PESTEL Analysis

c. Porter's 5 Forces Analysis

Porter's 5 forces analysis can also be built as reported by Figure 8. In this framework, the provided analysis shows that the main marketing and strategic advantages to M&S is the high entrance barrier to this field. In fact, editing M&S software is a highly complex and tedious process. Hence, the already established corporations have a considerable strategic advance by comparison to the new entrants. This is also why the competition level is not set to a very high level, even if it is still non negligible. In addition, the bargaining power of the buyers is low which is very favorable to M&S industrials. On the other hand, the bargaining power of suppliers is high, hence it's not favorable to M&S industrials. In fact the M&S experts are still rare to find in the market. Finally, the threat of substitutes should be considered with particular care. This is represented mainly by copy protection issues that M&S industry is facing. Even if this threat is very important, it will not be detailed in this study. In fact, this threat falls into the technical side more than into the marketing side. The latter is the major focus of the current study.

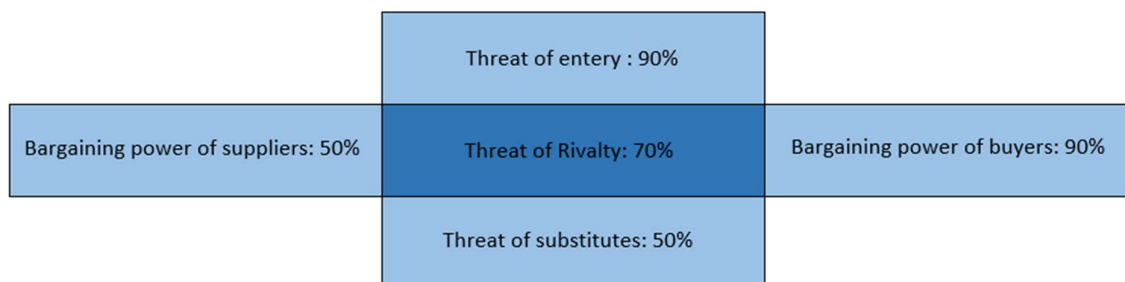


Figure 8: M&S Porter's 5 Forces Analysis

d. BCG Matrix Analysis

The BCG Matrix places the M&S software industry as a "Question Mark" product as reported by Figure 9. In fact, based on the economic status of M&S in the industry provided in the former chapter, it's outlined that even if M&S has an important growth rate, its market share is still relatively low. The major purpose of the current report is to provide some insight regarding the potential solutions for a better deployment in the industry by focusing on the marketing aspects. This aims at moving the M&S products to the "Stars" cell of the BCG matrix.

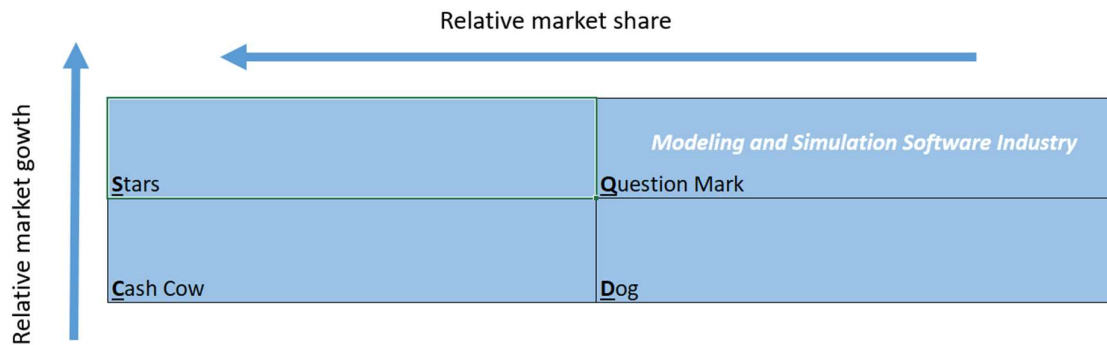


Figure 9: M&S BCG Matrix Analysis

e. Product Life Cycle Analysis

Figure 10 reports a typical product life cycle analysis of M&S products. Since the financial values as well as the time line differ considerably depending on the considered M&S application, the axis values are normalized. The provided figure reports an estimation of the classical 4 stages of a product life cycle starting by the introduction of the product and ending by its decline and passing by the growth and maturity stages. Let's remind that the typical life cycle of a software is highly cyclic since it depends on the recently introduced versions to the market. The provided analysis should be understood at its macroscopic level without taking into account the embedded elementary cycles. In this framework, the most sensitive stage is the introduction stage. In fact, during this step, the M&S software is under development. Consequently, the M&S editor focuses the investments mainly in creating the tool and introducing it in the market. Once the M&S software is well established, the next stages are growth and maturity. These are the most profitable stages until the decline of the M&S software. M&S marketers play key roles at the 4 stages in different manners.

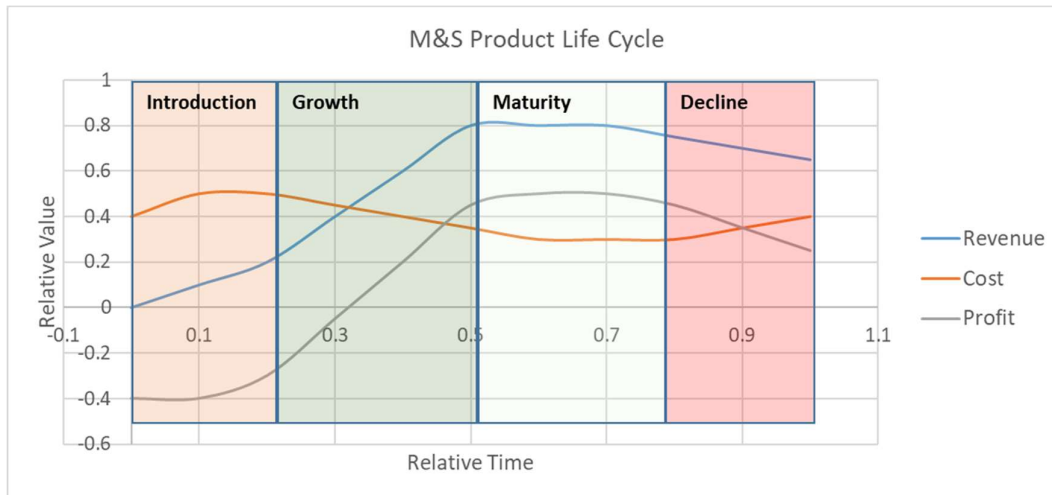


Figure 10: M&S Product Life Cycle Analysis

2. Main Marketing Hurdles for Modeling and Simulation Industry

After exposing the definition of the M&S industry as well as its main features, first questions rose up. In fact, despite the clear value brought by M&S in the industry, it is still have a relatively tiny portion of the global R&D spending worldwide. In this framework, this section aims at bringing some answers to the question: What are the main hurdles for M&S that prevents it from being an indisputable standard tool by designers, manufacturers and executives ? A special focus on the marketing aspects will be provided.

a. Lack of Transparency and Clarity

In the framework of having the brand image of being an unknown black box, Hofmann (2011) outlines the importance of communicating clearly on what is behind the scenes of a given M&S solution. In other terms, the developers of M&S tools should answer clearly to the questions: What's modeled and How it's modeled. Obviously the image of being considered as a black box does not reassure the M&S users and this is particularly true for the potential new prospects. In this same framework, Yilmaz (2012) emphasizes on the importance on what he calls the transparency of the M&S tools.

In addition, there are few or inexistent stakeholders that provide exhaustive and accurate advice regarding the final choice that should be made for a given M&S solution or another. In this framework, the potential customers in general and the industrial users in

particular find themselves facing a complex dilemma. This also represents a non-negligible hurdle for smooth M&S deployment in the industry. In this framework, Gupta (2010) outlines this major difficulty faced by potential M&S prospects and provides a simple, yet scientific and objective tool, for classifying the potential M&S solutions based on a particular need. The selection methodology consists of scoring the different solutions based on different selection criteria. The different M&S solutions are then classified based on their scores. Even if the method is simple to implement and optimistic, it contains several limitations. The first is that it's too simplistic especially for complex systems and M&S solutions. The second is the subjectivity of the scoring evaluation that may differ considerably from one user to another even for the same application.

b. Weak Networking

Let's take the particular example of M&S technologies applied to the material modeling industry. According to De Baas (2014), the research roadmaps in this field are rare or even nonexistent. The authors also outlines the lack of structured organizations and networks that should manage effectively the relationships between the different stakeholders of M&S.

In fact, laboratories and companies develop and implement new models based on fundamental research request or based on punctual and short term industrial need without always having a long term strategic vision. There is a lack of consistency in the sustainable development of the M&S in this field. In addition, the business research and reports are lacking in the field of M&S. The author outlines even a more dangerous aspect which is the absence of an organized M&S organization that represents all the M&S stakeholders from editors until final users passing by the collateral participants. This is particularly true in Europe. In this framework, the author calls for the creation of a M&S "Leadership Council". This entity will have the role of linking all the different M&S communities together.

In addition, the author emphasizes on the fact that the most difficult aspect of M&S is an efficient communication between the different stakeholders. In fact, on the one hand, the M&S software builders are mainly applied mathematicians and software engineer

that have their own technical syntax and ecosystem. On the other hand, their tools can be used in a tremendous bunch of applications coming from widely different fields ranging from military to financial and healthcare sectors. The M&S users have their own cultural ecosystem that is generally very different from the M&S culture and ecosystem. Consequently, there is obviously a missing ring between those two words. In this framework the author emphasizes on the vital need for “Translators”. These translators correspond to key actors in the whole chain that have the mission of understanding deeply the industrial challenge to be tackled then translate it very clearly to the M&S developers.

c. Senior executives reluctance

Based on the literature review as well as on several direct interviews, one of the major challenges for a better deployment of M&S tools is the reluctance of several executives regarding the usage of virtual tools for designing and validating their products. This is especially true for Senior managers.

In this framework, SIAM (2012) suggests for decision makers in both governments and industries to foster openness and rich exchange between major M&S stakeholders who are: government, industry and academia. This would be a valuable opportunity for major M&S editors to come up with real success stories to be shared with the community and especially with the reluctant executives. It should be avoided at this stage to oversell the M&S capabilities and to adopt an objective and balanced demonstration instead. As stated by Barnett (2003), M&S technologies should be presented as complementary tools for classical industrial standards such as lean management or Six Sigma solutions. Consequently, M&S tools should be seen as an opportunity for enriching the classical industrial standards and not as a competitive replacement to them. This approach aims at reducing the entrance barrier to reluctant senior executives that are generally very attached to the classical industrial standards.

Page (2017) emphasizes on the fact that an effective M&S industrial deployment is viscerally linked to convincing senior executives of the importance of the role that M&S can play in the future of their corporations. On the other hand, the author is aware of the reluctance that senior executives have against M&S solutions. He states that this is

mainly related to the ignorance of executives of the potential value that can be brought by such tools and suggests some solutions accordingly. First, the author states that complexity of M&S is the major hurdle. Consequently, the author suggests to begin by preparing a pedagogical and simplified representation of M&S to the reluctant audience. This can be performed through what is called metamodeling in the glossary of M&S. Metamodeling is the fact of replacing a complex model, called high fidelity model, by a simplified and lighter one. This metamodel can be represented through a simple spreadsheet or even a set of mathematical equations. It's trivial that metamodels are not as accurate as high fidelity models but they are enough to represent qualitatively the major outcomes of the real M&S tool. By adopting such approach, the senior executive can realize in real time the added value of such tools.

The second solution proposed by Page (2017) is to use new technologies such as immersive visualizations while communicating the M&S results. This process is generally highly impressive for their users and constitutes a powerful pedagogical tool. In fact, it offers the possibility to interact in real time with the modeled system, such as the new designed machine or car for example that do not exist yet in the real world. This has a deep impact on its users and constitutes one of the most spectacular and promising M&S tools for designers and engineers.

Chick (2013) outlines that there are not enough metrics showing the real added value of M&S as a decision making tool. In this framework, the author suggests a pragmatic solution for a better deployment of M&S as a decision making tool. His idea is to make a direct link between the M&S results and its direct impact on the final net present value (NPV) of a given project conducted by the corporation. In this way, the executives have a quantitative and scientific evidence of the efficiency of M&S as a decision making tool especially for reluctant audience. In the same framework, Fowler and Rose (2004) introduce senior executives reluctance as the biggest challenge that is facing M&S deployment in the industry.

d. Lack of Input Data and Complexity of Usage

According to Khan (2013), the major challenge for M&S is the high level of complexity related to its usage. The complexity is even higher when dealing with more complex

systems to be modeled. This particular challenge is called the composability grand challenge by Morse et al (2004).

Effective user interface is one of the best candidate solutions for reducing the complexity of M&S usage in the industry. In this framework, Morse et al (2004) claim that there is still need for more efforts regarding the delivery of efficient and user friendly user interfaces. In addition, visualization tools should be put as first priority by M&S developers. In fact, effective industrial deployment of M&S implies that it will be used by different players coming from many backgrounds. These users will not be all experts in setting up models nor in interpreting the final results. Hence, it's important to have effective M&S user interfaces.

Let's also notice that one of the major feedbacks received by M&S editors is the lack of efficient post processing tools that optimize the exploitation of M&S output. In this framework, Nelson (2013) reminds that M&S solutions provide amazing tools for performing investigations and generating important amounts of data. On the other hand, these tools generally do not give enough importance to the effective post processing of this data. In some cases, the situation is even worse. In fact, the output data is sometimes misunderstood, hence misinterpreted by its users which makes the whole M&S process a heavy waste of time and budget. In this framework, the author emphasizes on the need of providing the user with sophisticated tools for leveraging the results of the M&S activity. These tools should play the role of embedded experts that identify the most relevant results to be taken into account during the decision making process.

Fowler and Rose (2004) outline the necessity for reducing the complexity of M&S lifecycle. In fact, M&S have the image of being a very tedious and complex process at the different stages starting from input data collection until running the simulation and collecting and analyzing the output data. As a remedy to this, Chance et al (1996) provide rules of good practice for M&S project management. Fowler and Rose (2004) outline also the computational heaviness of the major current M&S solutions. In fact, these models run generally in several hours or even days from an order of magnitude point of view especially for complex systems.

De Baas (2014) outlines also an additional point which is the need for an easy to use M&S tools at the industrial level. In fact, in some cases, the technical M&S solutions exist for a given industrial challenge but it cannot be used effectively by industrials. This is generally due to a non-user friendly M&S software that needs particular skills and deep knowledge to be used. On the other hand, industrials need easy to use solutions and they need to be fully autonomous in their usage. In this framework, a better deployment of M&S solutions should inevitably be linked to the edition of “plug-and-play” M&S solutions that can be easily used by industrials. This M&S philosophy is also known as Integrated Computational Engineering (ICE).

e. Lack of M&S Qualified resources

Another major bottleneck for a better deployment of M&S in the industry is that it's not taught well enough to its current users. Consequently it's often misused and leads erroneously to unsatisfactory performance which curbs its usage both by the old users and the new ones. In fact, according to Barnett (2003), several M&S users overestimate the capabilities of such tools and build exaggeratedly complex simulations by trying to model all the physical phenomena without spending any effort in finding the good trade-off between complexity and efficiency. This trade-off is what makes the difference between an expert and a non-expert M&S practitioner.

On the other hand, the author outlines the hurdle but doesn't provide a deep insight among the reasons that are causing it nor provides potential solutions for it. In fact, the lack of M&S experts can be considered as a result of other challenges like the M&S model complexity and the lack of an efficient network among the M&S community. In this framework, several solutions for this M&S deployment hurdle can be addressed: First, the previously introduced “Leadership Council” can play a major role in the education of former and new M&S users for an optimal usage of these tools. Second, the “Translators” introduced previously can also play a major role in this area.

f. Lack of Verification and Validation (V&V)

Box (1976) has a famous quotation saying that “All models are wrong but some are useful”. Even if it was said few decades ago, modern authors are still stating similar

quotes. This is for example the case of Law (2007) who states that simulation should be used only in the domain where we can trust the model. These 2 statements remind that the effort of evaluating the validity domain of a given M&S activity should not be neglected by the user. This is unfortunately not the case in many M&S applications today. This is emphasized by L'Ecuyer (2013) who highlights the importance of accompanying the M&S activity by a complete evaluation of the corresponding uncertainty and error.

De Baas (2014) outlines the lack of standardization and validation of the M&S tools regarding both new and already existing products. The author states that this is one of the main requests of the industry for a wider usage of M&S tools. In fact, standardization and validation procedures give more confidence on the tools to be used. It can also reduce the entrance barrier of M&S to new industries by increasing their confidence in this technology.

According to Wilson (2006), current M&S software are not tested nor validated enough by their producers. One of the main reasons to this is that software developers of M&S solutions are not pure developers originally. Indeed, they are generally coming from different applied mathematical areas instead. Consequently, M&S developers spend a tremendous amount of their time in debugging the software and reinventing the wheel of building efficient methodologies for software development. As a major result, they have little time left for testing and validation.

Mesirov (2010) as well as Fomel and Claerbout (2009) outline the current carefree attitude regarding verification and validation (V&V) process. This is particularly appropriate among the M&S academic research community. This is due to the widely spread mindset of what is called “Publish or Perish” among the academic ecosystem. In fact, the current academic researchers from all generations, are submitted to a high pressure regarding the quantity of the articles that they should publish each year. Unfortunately, quantity does not mean quality. Consequently, several researchers choose to publish their models and results even if they lack V&V.

g. Lack of Maturity Regarding some M&S Applications

In several highly complex applications, M&S show some technical limitations and lack of maturity for resolving such issues. Examples of complex systems to be modeled that require sophisticated computational chains include the detailed simulation of the behavior of a biological cell as described by Karr et al (2012). Another complex challenging application is the study of the causes of environmental change as stated by Sokolov et al (2005) or the complex modeling of human anatomical behavior from a biomechanical point of view as reported by Lloyd et al (2011).

Morse and Schloman (2011) as well as Naseer et al (2008) focus particularly on the strategic application field of healthcare. The authors report that there is no clear evidence regarding the value of M&S in this field. The authors explain this reality by the fact that producing models in the healthcare industry needs a flexible technological solution. In fact, healthcare deals by nature with a high versatility of cases to be treated and needs accordingly an easily adaptable solutions. In this framework, Taylor et al (2013) propose a potential solution for M&S deployment in the healthcare industry. The authors suggest a generic software that consists of different building blocks that are platform and software independent. These building blocks can be arranged in a customized manner for a given new case. This tool should be as easy to use as a spreadsheet. It should be also flexible and accurate. Even if the proposal of the authors is fully consistent with the existing need, it's probably considered to be too simplistic and excessively optimistic by M&S editors.

Lehtinen and Kuorikoski (2007) focus on the particular example of M&S in the field of economics. In fact, even if applied mathematics are widely used by economists since few decades ago, the most modern and sophisticated M&S tools such as agent based simulation or artificial intelligence, are still shun by this community. The statements provided by the authors can be considered as overgeneralized and contradicts some statistical and historical market evidence. In fact, as reported by Figure 4, the economic sector is the first employee of M&S experts with 28% of the total hired workforce in 2016 according to SIAM (2012). Consequently, the statements provided by the authors should be considered with care.

h. Miscellaneous Challenges

SIAM (2012) outlines an additional important hurdle for M&S industrial deployment which is the increasingly border closure to foreign skills. In fact, as stated previously, M&S is mainly an innovative R&D activity. On the other hand, innovation goes in hand with openness since it's by definition a mixture of new ideas and creativity. Consequently, the recent trend towards nationalism and very difficult VISA policies makes the innovation process, hence the M&S global ecosystem, increasingly chained and blocked. Countries that are betting on new technologies in general, and on a general deployment of high adding value activities like M&S in particular, should revise their immigration policies accordingly.

Zander et al (2011) outlines an additional challenge for M&S industrial deployment which is scalability. Scalability stands for being able to implement a single M&S solution that can be used by different customers in order to solve similar design issues. Scalability is a grant for any industrial deployment success. According to the author, there is still some work to do by scientists in order to reach scalability of M&S tools.

Mourtzis et al (2014) tackle the challenges faced by M&S in the industry in an original manner. In fact, instead of concentrating on the current challenges, the authors project themselves in the future challenges that M&S would face in the next few years. The main outlined issue by the authors is the low performance that M&S technologies exhibit regarding the execution time, hence their low compatibility with new technologies like augmented reality. In fact the latter technology requires computation performance of the order of micro-seconds whereas the current M&S performance can reach several hours or days for some complex applications.

3. Main Marketing Leverages to Modeling and Simulation Industry

Let's remind that the major objective of the current research is to sketch a marketing oriented strategy towards a more effective industrial deployment of M&S in the industry. In this framework, this research can be considered as a detailed SWOT analysis of M&S in the industry. Hence, after exposing the weaknesses and threats of the studied field, the current section focuses on its strengths and opportunities. In this

way, the M&S strategist can identify clearly the major points to be corrected and avoided as well as the major features to be emphasized and leveraged.

a. Market Dynamism and High Competitiveness

Let's remind that the major characteristic of today's industry is continuous change that is mainly due to an extreme volatility of the market. The latter itself is due to a more requiring customer who enjoys the drastic competition on the market. This high market dynamism is also due to the continuous and high pace technological development that offers to corporations endless opportunities to improve their products. In this framework, the main challenge in this highly competitive race is to reduce the time to market by optimizing processes and leveraging highly innovative solutions such as M&S tools.

In fact, the classical design and manufacturing cycle consists in testing and optimizing the product performance by repeating a heavy and costly optimization chain. This chain consists in producing a prototype then modifying it before reproducing it again. This endless chain is avoided when adopting the virtual manufacturing process using M&S technologies. In fact, in this case, all this iterative chain is performed at a fraction of the time and cost. In this framework, Gupta (2010) outlines the power of M&S tools for enabling scientists and engineers to perform quantitative observations and proof of concepts of potential products that does not exist yet in the real world.

In this same framework, Barnett (2003) states that M&S is a powerful tool for managing change. In fact, it makes the link between the final performance of the product under development and the root causes of it. Consequently, it provides invaluable decision tools for designers and executives in an era where information is more precious than ever before. In other words, M&S can be considered as a tool that brings pedagogy and clarity on the reasons why a particular change should be implemented and why a given decision should be made and executed. M&S play a major role at reducing the risk when conducting change. In addition, the author outlines an important opportunity for M&S which is its compatibility with already established process optimization methodologies in the industry like Six Sigma and lean manufacturing. Indeed, using M&S as a tool for augmenting and empowering such well-established industrial

methodologies can be a golden opportunity for M&S as an entrance door for numerous industrial applications.

Smith (2006) emphasizes on the idea that M&S is a disruptive technology that the modern industrials should take into account in the root of their strategies. In fact, the author defines a disruptive technology as a value proposition that is impossible to ignore. It's a strong game changer that stakeholders adopt which results in creating a new balance in the industry. More concretely, M&S adopters have a clear strategic advantage from the points of view of time to market and efficiency. This image of being a game changer seen by industrial key players is an opportunity that M&S marketers should leverage in order to spread the M&S usage especially among skeptical stakeholders.

b. M&S historical presence in the market

Barnett (2003) reminds that M&S technologies exist since decades in the market even if it provides powerful opportunities since only the past few years. This is an opportunity in itself since during the past time there were many success stories about the usage of M&S in the industry. These examples are increasing the acceptance of the industrial community regarding M&S solutions. These examples should be leveraged by M&S marketers since they represent a convincing tool for potential prospects.

This historic presence increases the visibility of M&S technologies in the market. In addition, it's a major reason why M&S technologies are gaining maturity from an industrial usage point of view. In this framework, the author outlines the important progress of M&S tools from a user interface point of view. This progress is made possible thanks to the different feedbacks that M&S editors received from the users during the past few decades. This usage maturity, that is due to the historical presence in the market, is key for a better deployment in the industry.

c. Fundamental Research Revolution

De Baas (2014) focuses on the particular example of M&S application in the framework of material modeling. The author outlines the high added value of such approaches

allowing an unprecedented connection between all the scales that a material can exhibit starting from electronic scale until the continuum scale passing by the atomic and meso-scales. Consequently, M&S has the capability to reach scales and provide data and information about entities that are not reachable experimentally. This technological leap is only possible with such innovative tools. The author provides valuable capabilities of material modeling and simulation but takes clearly the subjective position of a material modeling enthusiast. In fact, upon various discussions with M&S experts, it appears that the multi-scale material modeling is certainly a promising M&S future application but it's still a fertile area for research that is not yet considered as a mature standard by the industry.

According to Dobrzanski (2006), The particular material modeling example is key since all the technologies enabled for human being is rooted from material advances. In fact, major Human Eras refer to materials like Stone, Bronze and Iron ages. This reality continues to be true nowadays. In fact, the modern high performance technologies such as smart phones, solar panels and high performance computers are enabled thanks to outstanding material properties such as semiconductors and smart materials. Consequently, having the M&S tools capable of making the link between the chemical formula of a given material and its final multi-physical performance is a dream coming true for material scientists.

According to Liu et al (2017), new materials were discovered whether accidentally or after decades and considerable efforts of research and development investments by governments and major fortunes. Today, thanks to the new M&S tools, the next game changer from a materials point of view may be discovered on purpose for tailored applications thanks to virtual computations using M&S technologies.

d. Digital Revolution

Relying on M&S solutions as a key strategic tool for corporate innovation is made true today thanks to a modern technological opportunities such as high performance computing and cloud computing. According to Borovskiy (2009), cloud computing brings 2 major opportunities to M&S deployment: The first is giving the opportunity to Small and Medium Enterprises (SMEs) and single freelancers to have access to high

computing power at a fraction of the historical price. In addition, cloud computing provides new opportunities regarding the pricing of M&S licenses.

In fact, according to several interviewed M&S experts, a software license price ranges in the order of several tens of thousands of dollars for a single license for a lease per year contract. Knowing that the high performance computations need several licenses to be run, it becomes obvious that these tools are not adequate for small businesses. On the other hand, cloud computing comes with a powerful business model which is Software as a Service (SaaS). This consists in leasing the needed software for exactly the time that it's needed for. Consequently, there is no need to spend budget for leasing M&S tools per year and using them only during a small fraction of the time. This makes such tools more affordable for small businesses and opens again an interesting opportunity for a more effective M&S deployment in the industry.

Lundstrom (2009) reminds the close correlation between M&S and computer hardware advances. On the other hand, the latter can be modeled by using the Moore's Law as stated by Holt (2015). This law predicts that the number of transistors is doubling each 2 years. Consequently, it can be expected that M&S capabilities will also be affected by this trend and will show a considerable progress of the M&S capabilities in the next years and even more in the next decades.

In the same framework, Holt (2015) reports 3 main Key Performance Indexes (KPIs) related to the considerable increase in the transistor manufacturing power during the first decade of the 21st century. As reported by Figure 11, the author reports that: First, the transistor size is attaining fraction of the value that it had in the beginning of the years 2000. On the other hand, even if the price of the transistor per square millimeter is increasing due to the implementation of high performance technologies for producing it, the transistor is becoming increasingly affordable in the market. In fact, Figure 11 reports that the price of the transistor is divided by 10 during the considered period. This trend has a first order impact on the global advancements in terms of computing power. The latter itself has a direct impact on the M&S deployment in the industry since it's heavily correlated to the achievable computing power as stated in the beginning of this section.

The analysis conducted by Holt (2015) provides valuable insight among the trends regarding the modern computational power. On the other hand, it omits completely the side effects of such trends such as the ecological effects of such production technologies.

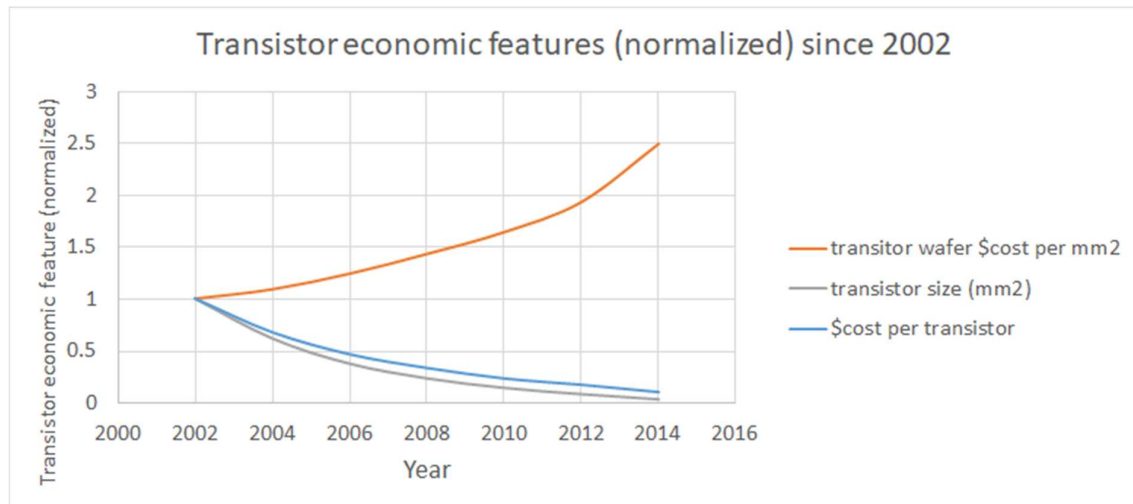


Figure 11: Transistor Economic KPIs (Holt 2015)

e. Increasing Global Ethical Awareness

Britt et al (2004) focus on the key industry of Pharmaceutical. The application of M&S in this industry is also called bioinformatics. This industry has the particular need for developing new drugs by using the most effective tools. In fact, M&S provide drug designers with the opportunity of making the link between different elements of a highly complex ecosystem such as the human genomic information and its interaction with potential new matter and chemicals. On the other hand, Pharmaceutical industry is facing increasing pressure from governments and organizations to adopt safer and more ethical approach. In fact, drug design is a process that involves dangerous chemical products and may result in unsafe chemical reactions. In addition, since several centuries, biological research in general is facing the inevitable ethical debate of sacrificing guinea pigs during the research process. These 2 major hurdles for pharmaceutical industry represent rich opportunities for M&S deployment. In fact, M&S make it possible to perform virtually billions of drug designs without risking any form of life. This is in addition to the savings that M&S tools enable thanks to the

drastic reduction of real drug experimentation. The author outlines the importance of M&S in this industry as a decision making tool.

Additional major opportunity is outlined by the National Training and Simulation Association (2011) which is the increasing awareness of major economic countries such as the USA regarding the importance of M&S and the major role that it could play in the security of the nation. In fact, the authors estimate the US department of defense yearly investment in M&S in the range of \$4B to \$7.5B. In addition, the report states that the US government recognizes officially in July 2017 that M&S as a “National Critical Technology”. One of the major applications outlined by the authors is the significant benefits that can be leveraged from M&S in the field of training soldiers in virtual environments. This makes it possible to save lives and budget as well as providing realistic training conditions that would be very expensive or even impossible to reproduce in real life outside of the real battlefield. Consequently, M&S marketers should leverage this momentum of increasing interest regarding M&S technologies that major governmental and industrial players are exhibiting as a key opportunity for a better industrial deployment.

III. Research Methodology

1. Adopted Research Methodology at a Glance

In the purpose of answering to the stated research questions, the general research methodology is the following: The first step is to build the main marketing analysis tools aiming at structuring the conducted research strategy. This is followed by a detailed literature review of the main hurdles and leverages of the M&S technologies in the studied industry. The literature review provides an exhaustive insight about M&S industry. In order to verify and validate the major outcomes of the literature review, a primary quantitative research survey is conducted. The other added value for the conducted survey is to complement the literature review. In fact, the latter provides mainly qualitative information regarding M&S industry, while the conducted survey provides quantitative evidence about the main findings of the conducted research. The next step consists in summarizing, analysing and discussing the main findings of the conducted survey with respect to the major findings of the literature review. A general conclusion and the remained open questions close the current report.

2. Research Methodology for Primary Data

According to Saunders (2015), a research activity can be divided into 6 layers through an approach called the “Onion Research”. The first layer consists in defining the philosophical stances of the conducted investigation. In the current study, a pragmatic approach consisting in asking qualified interviewees about several specific details regarding M&S marketing aspects. In fact, the major objective is to collect quantitative data from a qualified panel in order to complement the secondary data provided by the literature review. The second layer of the “Onion Research” defines whether the adopted approach is deductive or inductive. In the current study, the former is selected. In fact, the collected data aims at verifying and validating the theory that is built through the literature review which corresponds to a deductive approach. The third layer defines the strategy of the research. In the current case the Survey approach is favored as stated previously. Regarding the fourth layer, a mono-method consisting of a questionnaire is chosen. The former 2 types of layers are chosen since they represent a good trade-off between added value to the study and budget at disposal. The latter should be understood from both time and financial points of view. At the fifth layer, a cross-sectional design is elected. In fact, the survey has a short term delay and aims at

identifying the interviewees feedback at a given point of time. Finally, the sixth layer of the “Onion Research” defines the data collection and analysis procedure. In the current case, the conducted survey is performed by using modern digital marketing tools such as online forms and social media marketing. This choice is made because it’s consistent with the nature of the survey panel. This panel should be qualified, diversified and motivated to participate to the survey. Once the survey is accomplished and the data gathered, the results are post processed, mined and visualized by using data science techniques.

Regarding the survey panel, the latter is designed such that it corresponds to the typical prospect that an M&S marketer can deal with. The typical survey panel is made of manufacturing and industrial engineers and technicians as well as executives and managers from the industry. Their age range from 24 to 50 years old. Several thousands of individuals, of the order of 23000, were addressed through social networks by using a targeted audience strategy. The survey form was accessed by 250 attendees, and the final retained fulfilled surveys corresponds to 63 answered forms. This number is considered as acceptable for the current study since it’s an interesting trade-off between the statistical representativeness of the results and the cost of the survey.

The conducted research aims at verifying the major outcomes of the literature review. In this framework, the survey is designed such that it contains 10 questions. Let’s notice that the indexes of the questions are designated in the titles of the reported figures.

3. Limitations and Difficulties of the Adopted Research Methodology

a. Limitations

Limitations regarding the collected data should be outlined. The limitations are segmented based on data type whether primary or secondary data.

Generally, the provided results are available up to the time period where it was collected. In fact, M&S technologies, like the most of digital technologies, are changing at a fast pace. Consequently, this kind of business research should be updated regularly in order to maintain the validity of the provided findings.

Regarding primary quantitative data, the provided survey is filled by 63 interviewees which is not an exhaustive number even if it can be considered as statistically representative.

Regarding primary qualitative data, the results of the face to face interviews are embedded directly in the analysis and discussions of the findings. In fact, the primary qualitative data is not provided in a separate section like it's the case with the primary quantitative data. This is due to the fact that the adopted research methodology does not rely heavily on primary qualitative data. Indeed, qualitative data is exhaustively covered by the literature review. Consequently, primary data focusses mainly on quantitative information in order to build a balanced study.

b. Difficulties

During the process of data collection, several difficulties are encountered. The difficulties are segmented based on their data type whether primary or secondary data.

Regarding difficulties in collecting secondary data, data scarcity related to M&S industry should be outlined. In fact, this is especially true regarding the economic data such as market size and market share. This is consistent with the market size of M&S. Indeed, small markets like M&S industry generally correspond to rare free data availability in the classical data resources such as public databases and technical journals. In addition, it's difficult to find on the literature a neutral article regarding M&S industry. In fact, writers are generally whether M&S enthusiast or M&S reluctant. Consequently, a deep critical work that compares the different data resources is vital to extract the maximum objective value from it.

Regarding difficulties encountered during the collection of primary data, it can be outlined the difficulty at finding a qualified and motivated audience for filling the requested survey. This makes this activity a continuous creativity challenge.

IV. Primary Research Survey

The current section aims at designing, building and then analyzing quantitative primary data. This data is based on a survey performed for the current study. The survey is designed based on the major outcomes of the former literature review.

The first 3 questions of the survey are focusing on the interviewees' profile and their relationship with the M&S technologies. This is important since it has a first order impact on the results interpretation.

Figure 12 to Figure 14 report the major features of the considered panel for the survey. As reported by Figure 12, 60% of the asked panel do not use M&S technologies in his daily work. These interviewees correspond to typical potential prospects for M&S marketers.

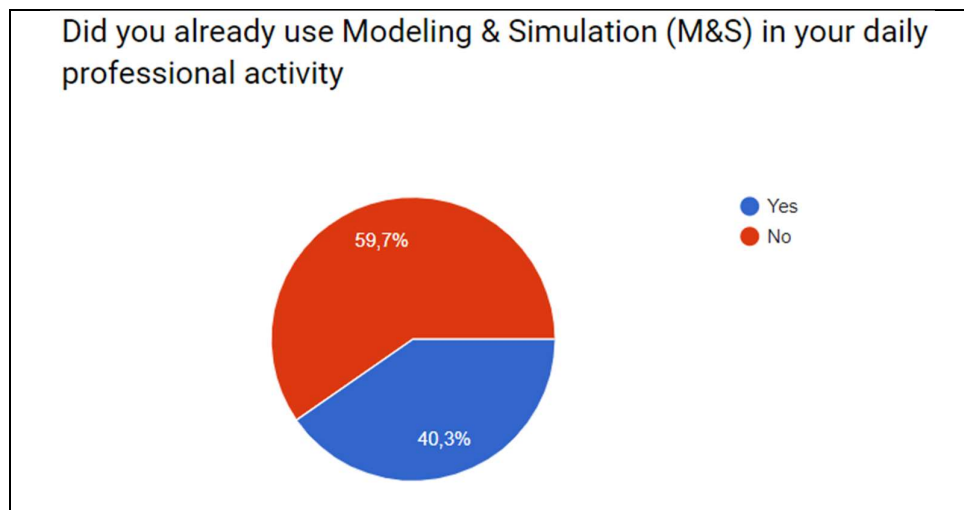


Figure 12: Survey Results Question1: Use of M&S in Daily Job

Figure 13 shows also that M&S is taught for only 38% of the asked interviewees. This is relatively low by comparison to the nature of the considered panel. Consequently, M&S is still not taught enough in the university even for manufacturing and industrial engineers. This is a main reason why there is a lack of M&S qualified resources as outlined by Barnett (2003) and De Baas (2014). In fact, the authors outline how industrials struggle at finding qualified M&S experts and call for a better networking among the M&S community in this framework.

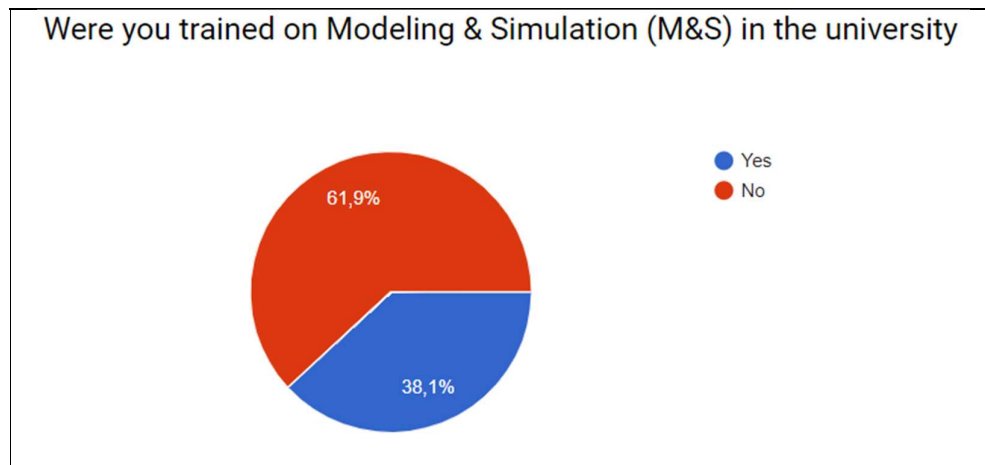


Figure 13: Survey Results Question2: M&S Training in the University

Figure 14 reports that 75% of the interviewees were never trained on M&S technologies in their professional environment. This is also consistent with the literature review stating that M&S is not yet a standard in the industry. This is due to the image that M&S has in the industry of being of very complex technology to master. Consequently, industrials are not eager to invest into building knowledge in their internal teams in this particular field. This finding of being a complex technology is outlined in the literature by different authors such as Khan (2013), Morse et al (2004) and Nelson (2013).

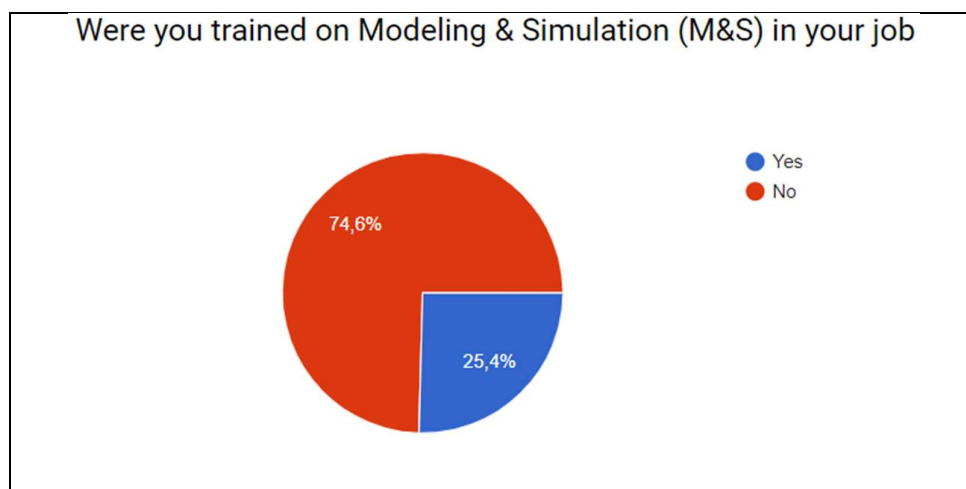


Figure 14: Survey Results Question3: M&S Training in the Current Job

Questions 4 to 6 report how the M&S industry is seen by the interviewees.

Question 4 reports the opinion of the interviewees regarding the current market size of M&S in the industry. This is an important information since the major pillar of the

conducted study is based on the fact that the M&S industry is worth better than its current market value. Regarding the assessment of the market value of the M&S in the market, the audience feedback is consistent with the main purpose of the conducting study.

In fact, Figure 15 reports that 48% of the interviewees think that M&S market size can be much better regarding the value that M&S brings to its customers. This is consistent with the results reported by Figure 3 that shows that M&S represents only 15% of the whole Product Lifetime Management (PLM) industry.

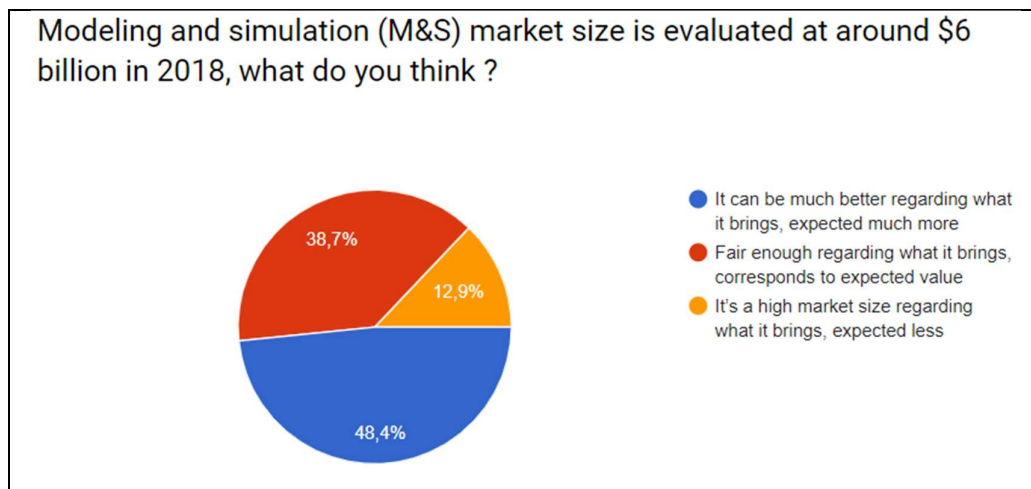


Figure 15: Survey Results Question4: M&S Market Size Feedback

Question 5 investigates on the level of importance that M&S technologies are occupying today in this industry. This aims at verifying the current marketing brand image that M&S have in the market.

In this framework, Figure 16 reports that 70% of the interviewees think that M&S technology is a great strategic advantage for its users. This trend is confirmed by authors from the literature like Smith (2006) who describes M&S technologies as a disruptive technology that has the potential to revolutionize the industry as a main game changer.

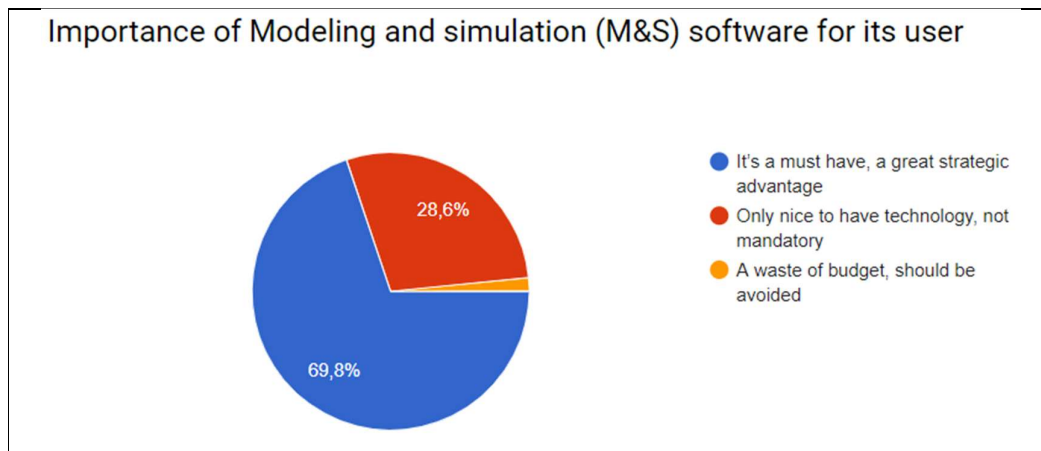


Figure 16: Survey Results Question5: M&S Importance

Question 6 exhibits the 3 most important added values that M&S bring to its users based on the literature review. This questions is important from a marketing perspective since it provides M&S marketers with the most important expectation that potential prospects are waiting for.

In this framework, Figure 17 shows that among 3 options to choose in the survey, 48% of the interviewees state that the most important value brought by M&S in the market is to save budget through virtual testing. This trend is confirmed by authors from the literature such as Gupta (2010) and Barnett (2003) who outline the importance of M&S technologies in reducing time to market among the product life cycle.

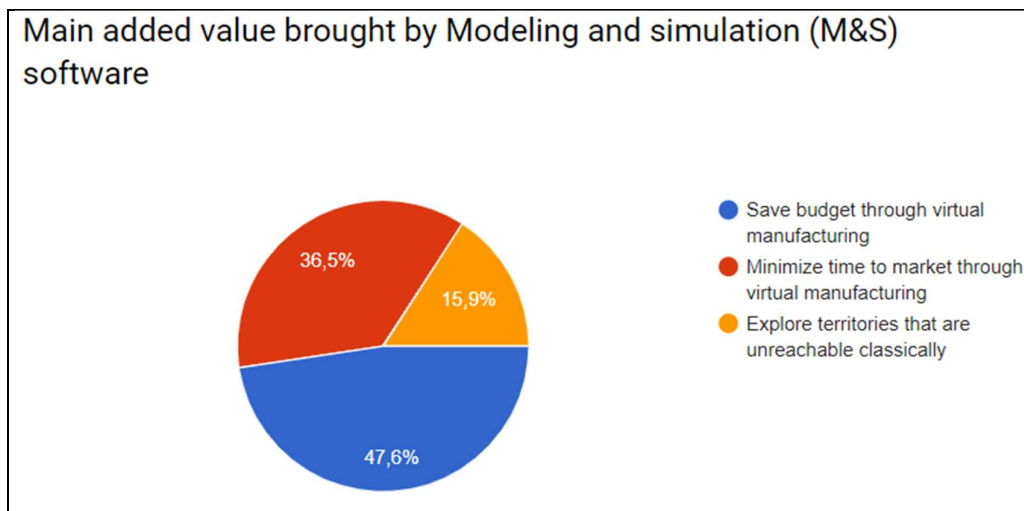


Figure 17: Survey Results Question6: M&S Main Added Value

Questions 7 to 10 report the different components of the SWOT analysis of the M&S industry. The goal of this section of questions is to quantify the consistency of each of the SWOT constitutive bullet points. This information is of high importance for M&S marketers. In fact, this kind of data can orient the marketing strategy to be adopted by identifying the priorities as seen by the market.

Figure 18 reports that the interviewees state that the most important strength of M&S is the unique value that it brings to the market consisting of replacing the real manufacturing by a virtual one. In fact, among 3 options provided by the survey, 42% of the interviewees chose this strength. This trend is also confirmed by several authors like Barnett (2003), Smith (2006) and Gupta (2010). The mentioned authors outline the power of having the capability of replacing real testing by virtual one during the design and the marketing of products of all kinds.

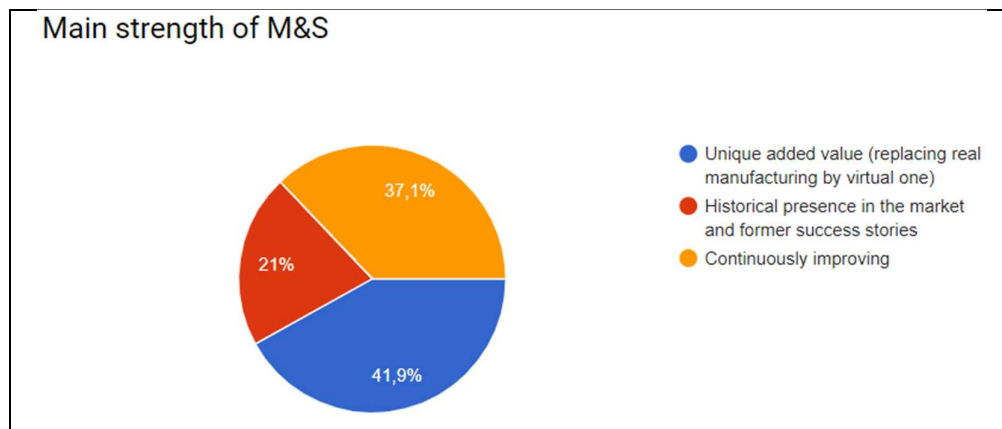


Figure 18: Survey Results Question7: M&S Strength

Figure 19 shows that the main weakness is that M&S is still a very complex technology to master and that it necessitates highly qualified resources to extract the maximum of value from it. In fact, among 6 provided options in the survey, 40% of the interviewees see clearly that complexity of M&S technologies is the main weakness that is slowing down its industrial deployment. This particular weakness is highlighted by several authors from the literature like Fowler and Rose (2004), Morse et al (2004), Khan (2013) and Nelson (2013).

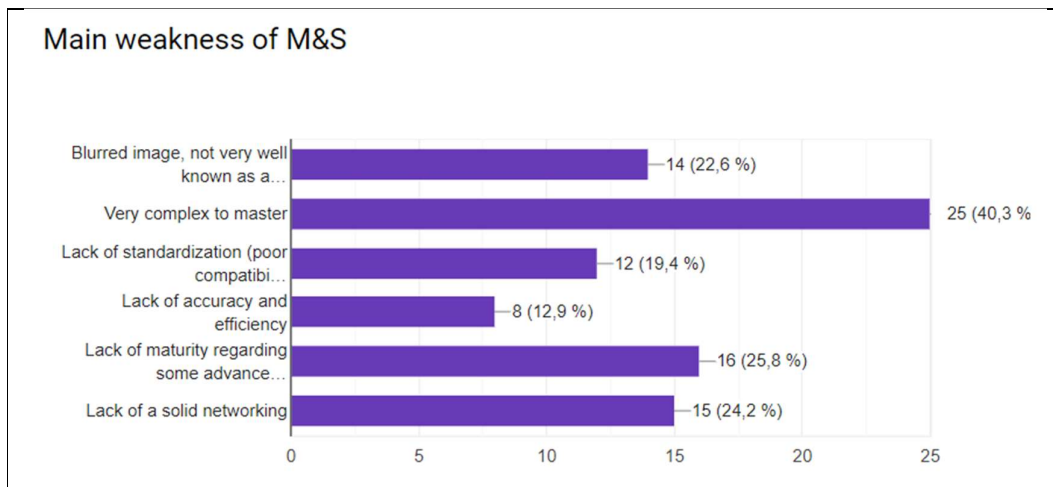


Figure 19: Survey Results Question8: M&S Weakness

In Figure 20, the interviewees see clearly that world digitalization momentum is the most important external factor to a better deployment of the M&S technologies in the market. In fact, among 3 options provided by the survey, 45% of the interviewees see the world digitalization momentum as the main opportunity to M&S deployment in the industry. This is confirmed by several authors from the literature like Borovski (2009), Lundstrom (2009) and Holt (2015) who emphasize on the importance of the current digital revolution as an opportunity for M&S technologies.

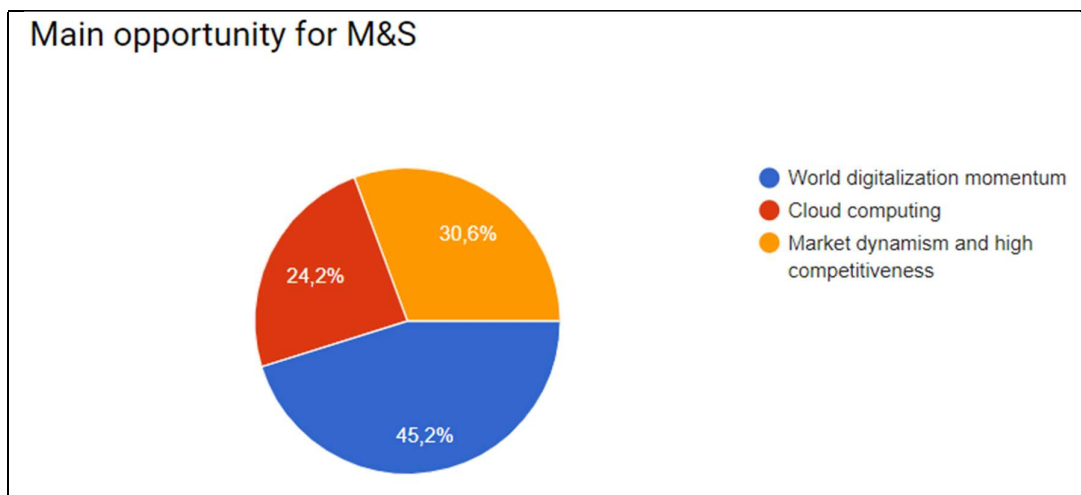


Figure 20: Survey Results Question9: M&S Opportunity

Figure 21 shows that the highest threat to M&S in the industry is that it's not always well accepted by some senior executives. These results are valuable information to M&S marketers since it provides them with the right weapons for building their communication strategies for the market. In fact, Figure 21 reports that 47% of the

interviewees think that the main threat to M&S technologies is that several senior executives are reluctant to M&S deployment in their companies. This trend is confirmed by several authors from the literature like SIAM (2012), Barnett (2003) and Page (2017) who emphasize on the importance of convincing efficiently senior executives for adopting M&S technologies as a new standard in their core culture which is one of the biggest challenges that are facing M&S industrial deployment.

This trend is also confirmed by the conducted face to face interviews. In fact several senior M&S experts are interviewed in this framework. The interviewees come mainly from the field of M&S application in the framework of engineering companies in the automotive, aerospace and energy fields. The main feedback of the interviewees is that senior executives see the replacement of physical validation by using virtual simulation tools as an obsolete activity for their corporations. This is particularly true with big companies that have already well established procedures in their manufacturing process since decades and that don't see any interest in changing their ways of working. They estimate that their processes are already well established and optimized since few years or even decades ago.

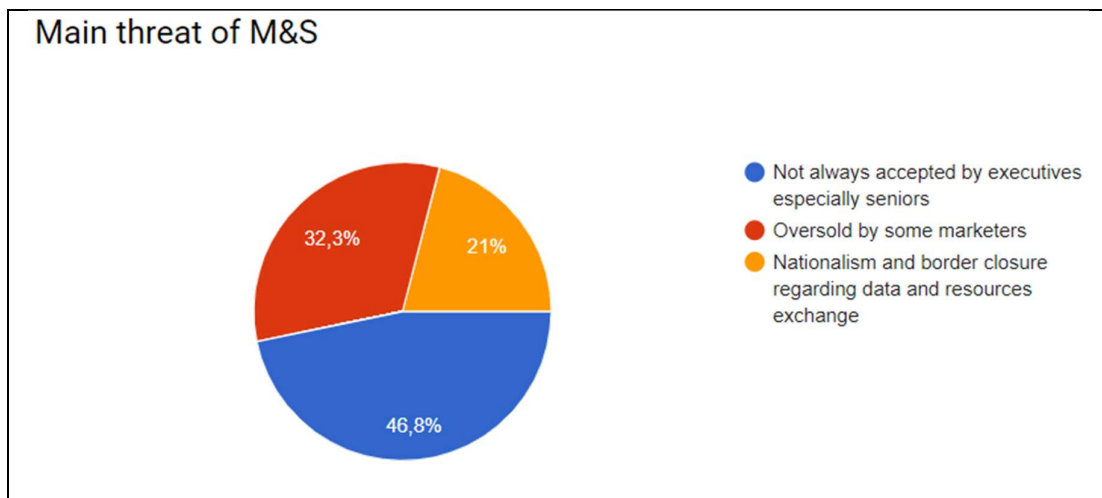


Figure 21: Survey Results Question10: M&S Threat

V. Summary of the Main Findings and Discussion

The current chapter aims at summarizing the main findings based both on the literature review and the collected primary data. The first part of the current chapter provides the summary of the major findings in the form of recommendations to M&S marketers for building an optimal marketing strategy. The second part of the chapter is a discussion about the major takeaways of the conducted study. The second part compares also the findings coming from the literature review to those coming from the primary data sources and outlines the agreements and disagreements between them.

1. Marketing Recommendations Based On The Main Findings

The current section provides the main recommendations for building an effective marketing campaign about M&S technologies. The provided recommendations are grouped into 2 main segmentations based on the previous market segmentation provided in the above “Market Segmentation“ section. These segments are considered from an end-user point of view and from a geographical point of view.

a. From an End-Users Perspective:

The end users segmentation analysis consists of studying the adequate marketing strategies depending on the status of M&S deployment in the respectively considered application field. The main considered application fields are: Healthcare, manufacturing industry, defense and energy.

Regarding healthcare, The main hurdles can be summarized by the need for more mature methods and the need for a more user friendly M&S tools as reported by Taylor et al (2013) as well as by Naseer et al (2008). The high complexity of M&S technologies is also outlined by the conducted survey as reported by Figure 19 where 40% of the interviewees outline that M&S complexity is its main weakness. The opportunities in the considered segment consist of the need for a powerful and accurate decision tool as well as the need for a virtual tool that minimizes real life tests for ethical and safety reasons as reported by the National Training and Simulation Association (2011) and by Britt et al (2004). This trend is also outlined by the primary data in Figure 20 where 45% of the interviewees see the world digitalization momentum

as the main opportunity to M&S deployment in the industry. In this framework, the major recommendations for M&S marketers are to outline the ethical aspects of M&S technologies in this field since it can have a deep impact on both the sides of pharmaceutical industrials as well as on their customers at the same time.

Regarding manufacturing industry, the main hurdles are the senior executive reluctance regarding the M&S technologies and the poor communication that exists between M&S editors and M&S users as reported by SIAM (2012), Barnett (2003), Page (2017), Hofmann (2011) and Yilmaz (2012). These challenges are also confirmed by primary data in Figure 19 where 40% of the interviewees see clearly that complexity of M&S technologies are the main weakness that is slowing down its industrial deployment. It's also confirmed by the results provide by Figure 21 reporting that 47% of the interviewees think that the main threat to M&S technologies is that several senior executives are reluctant to M&S deployment in their corporations. On the other hand, the main opportunities are the good momentum that M&S is gaining among several major economic countries and big companies in the last few years as reported by Barnett (2003) and the National Training and Simulation Association (2011). In this framework, the main recommendations for M&S marketers is to prepare convincing and powerful integration of successful case studies and success stories that are meaningful for senior managers. On the other hand, M&S marketers should play the role of translators between the 2 main communities of M&S which are editors and users as stated by De Baas (2014). In addition, a major opportunity in this field is cloud computing and the digital revolution as reported by Borovski (2009), Lundstrom (2009) and Holt (2015). This is also confirmed by the primary data reported by Figure 20 showing that 45% of the interviewees see the world digitalization momentum as the main opportunity to M&S.

Regarding defense, the most important hurdles are the fact that M&S meaning and purpose are still lacking visibility among a non-negligible amount of potential prospects as reported by Holt (2015) and Yilmaz (2012). On the other hand, the major opportunity in this field is the strong momentum that M&S is gaining among the major world national armies as reported by the National Training and Simulation Association (2011). In this framework, the major recommendation for M&S marketers is to emphasize on

testimonials coming from major influencers belonging to the same community that are already using M&S technologies and satisfied by it.

Regarding energy field, the major opportunity that marketers can leverage in this framework is the important improvements that material M&S tools are witnessing during the last few years as reported by De Baas (2014). In fact, material and matter knowledge and their mastery is in the core business of energy industry. Indeed, examples of this industry are oil and gas and renewable energies such as solar and wind energies to name a few. It's trivial that advances among these fields are tightly related to material field as reported by Dobrzanski (2006) and Liu et al (2017). In this framework, marketers should communicate massively and effectively regarding these new capabilities since they are very recent and, so far, they are under communicated to potential prospects.

b. From a Geographical Perspective:

Geographic segmentation aims at studying the proper marketing strategy that should be implemented depending on the considered area. Even if this is a classical market research segmentation, it's particularly relevant in the case of M&S industry. In fact, cultural awareness and history regarding the usage of M&S technology depends heavily on this segmentation. The considered geographical segments are: USA, Europe, China and the rest of the world.

Regarding USA, this area is a highly fertile field for R&D in general and M&S in particular as reported by Figure 1. In fact, the latter reports that 30% of the global R&D investments worldwide are performed by North America. In this framework, M&S marketers should adopt an aggressive strategy in deploying further M&S technologies in this area. Indeed, since the major prospects are already educated regarding M&S technologies in this area, M&S marketers can directly invest their energy in engaging bigger deals and sales pipelines. On the other hand, the momentum of having a positive mindset regarding M&S in this area should be kept and even improved by providing the local M&S stakeholders with regular updates and trainings regarding the last and best discoveries on M&S. Here comes again the vital role that M&S marketers can play as

translators between innovative M&S editors and motivated customers as emphasized by De Baas (2014).

Regarding Europe, the situation is more ambiguous. In fact, from a historical point of view, Europe is also one of the major original lands for R&D and M&S worldwide as reported by Figure 1. The latter reports that 20% of the global R&D investments worldwide are performed by Europe. On the other hand, Europe is still have a considerable margin for a better M&S deployment. This is mainly due to an inefficient communication between the different M&S stakeholders in Europe. In this framework, a relevant strategy that can be conducted by M&S marketers in Europe is to fill this lack of standardization and communication between the M&S stakeholders by playing the role of an intellectual and technical animator. This is exactly the key role of translator that M&S marketers should play massively as stated by De Baas (2014).

Regarding China, the situation is a mix between the former two. In fact, Chinese government is betting heavily on R&D during the past decade as reported by Figure 1. The latter reports that 40% of the global R&D investments worldwide are performed by Asia. On the other hand, M&S technology is far of being a standard tool in the Chinese industry. This junction is clearly a golden opportunity for M&S deployment in this area. In this framework, M&S marketers should set up a subtle sales funnel strategy. This can be performed through 4 main steps: The first step is to create attention through case studies and success stories based on former experiences. Then, a particular attention should be given to training the interested prospects in a deeper manner. Third step is to go further with the motivated stakeholders for concrete projects in the form of consultancy where the prospects are fully supported and educated during their activities. Finally, the ultimate step is to train the final motivated prospects in a massive manner by performing a deep knowledge transfer, hence transforming them into ambassadors and translators of M&S in China. Consequently, the M&S marketing effort in China is expecting the longest term strategy among the studied areas. On the other hand, let's remind that it's also the market with the biggest M&S deployment potential and reward.

Regarding the rest of the world, a special focus is provided on the developing countries such as India, Brazil, South Africa and Pakistan. In this purpose, several M&S experts from these regions are interviewed. The interviewees report that M&S is still used in a

very limited way in this area. This limited usage is generally due the high cost of M&S technologies and its need for tremendous computational power. On the other hand, and surprisingly, M&S technology is very well known and already taught in the universities and research laboratories of these areas. This is why the rest of the world is a very good provider of M&S experts that generally migrate to developed countries where they have the opportunity to build careers and bring value in their respective expertise.

In this framework M&S marketers have 2 major action items. The first one is to leverage the opportunity of cloud computing in order to improve the M&S deployment in this area. In fact, as stated previously, cloud computing made it possible the democratization of M&S. The second recommendation for M&S marketers is to leverage the richness of M&S human resources in this area by making the link between them and the other international areas where there is a need for them. This constitutes again the key role of translators that M&S marketers should play in this area.

2. Discussion

The current section summarizes and evaluates at which level the major findings of the conducted study fit with the major outcomes of the literature review. In this framework, let's remind that the adopted research approach is built on 4 main steps: The first is to define the M&S industry as well as its main features and framework. This first stage ends up by identifying the main pain points to be addressed by the study. The second step is to perform a deep literature review on the selected topic. The next step consists in collecting primary quantitative data through a survey. The survey is designed based on marketing analysis tools as well as on the main outcomes of the literature review. In fact, the main objective behind the collection of the primary data is to verify, validate and discuss the major findings of the literature review. This discussion constitutes the final part of the conducted research project and the purpose of the current section.

Several definition of M&S are considered based on different articles beginning by Pritsker (1979) and ending by more recent definitions like the ones provided by Law (2007), Hayes (2008), Glotzer et al (2009), Mittal (2017) or Macal (2013). Some definition extracted from reviews like SIAM (2012) are also considered. Even if the different authors did not provide a unique definition, the current study adopted one that aims at being holistic and embedding the majority of the literature findings. The final

adopted definition of M&S states that: Modeling and Simulation (M&S) can be defined as the realm of replacing a real experimentation by a virtual one through the implementation of applied mathematics models into advanced software solutions. This definition is based on the major added value brought by M&S technologies according to the performed survey as reported by Figure 17. The latter shows that among 3 options to choose in the survey, 48% of the interviewees state that the most important value brought by M&S in the market is to save budget through virtual testing. After defining the considered market, the conducted study reports the market size of M&S industry based on the data provided by Industrial Research Institute (2016) and Mordorintelligence (2018). These data sources evaluate the M&S market size at \$6B in 2017. This raises the main pain point of the study which is: Why M&S market size is relatively low by comparison to its added value ? This pain point is confirmed by the questioned audience during the conducted survey as reported by Figure 15 showing that 48% of the interviewees think that M&S market size can be much better regarding the value that M&S brings to its customers. This statement is also confirmed by the results of the survey reported by Figure 16 reporting that 70% of the interviewees think that M&S technology is a great strategic advantage for its users.

The literature review can be seen as a detailed SWOT analysis of the M&S market size. The SWOT analysis is provided by Figure 6. In fact, the literature review investigates on the state of the art feedback regarding the different constitutive bullet points of the provided SWOT analysis. The conducted survey quantifies the SWOT analysis by reporting the feedback of the interviewees regarding its different components.

Regarding M&S strength, the literature review as well as the conducted survey in Figure 18 identify the main one as the ability of replace real manufacturing by virtual one. In fact 42% of the interviewees selected this strength among 3 proposed options. This strength gives the opportunity to the user to shorten the time to market and have a serious strategic advantage regarding the competition as reported by several authors like Barnett (2003), Smith (2006) and Gupta (2010).

Regarding M&S weaknesses, De Baas (2014) outlines the importance of creating a “Leadership Council” for M&S. In fact, the lack of effective networking and communication between the different M&S stakeholders is highlighted as a major

weakness by the author. This weakness was not particularly outlined by the conducted study. In addition, M&S high complexity is a recurrent weakness that is outlined in the literature as it's the case by Fowler and Rose (2004), Morse et al (2004), Khan (2013) and Nelson (2013). This status is also consistent with the conducted investigation as reported by Figure 19 where, among 6 provided options in the survey, 40% of the interviewees see clearly that complexity of M&S technologies is the main weakness that is slowing down its industrial deployment.

Regarding the opportunities of the M&S industry, the literature consensus is that digital revolution is definitely a golden opportunity for M&S. In fact, this statement is made by several authors like Borovski (2009), Lundstrom (2009) and Holt (2015). This is also consistent with the results reported by the survey in Figure 20 where 45% of the interviewees see the world digitalization momentum as the main opportunity to M&S deployment in the industry.

Regarding the M&S major threat, Chick (2013) and Page (2017) emphasize on the reluctance of several senior executives to M&S technologies. This is confirmed by the conducted survey as reported by Figure 21. In the survey, the majority of the interviewees report that 47% of the interviewees think that the main threat to M&S technologies is that several senior executives are reluctant to M&S deployment in their companies.

VI. Conclusions and Open Questions

This report provides a study of the M&S industry in general and the potential marketing strategies for a better industrial deployment in particular. In this framework, a literature review is performed in order to answer to 2 main questions: First, what are the major hurdles that the M&S industry is facing. Second, what are the major opportunities that the M&S industry can leverage? The literature study is used in order to design and conduct a survey aiming at verifying, validating and quantifying the major findings of the conducted literature review. In addition, this research is leveraged in order to bring answers to the major aim of this report. In fact, different marketing strategies are addressed depending on 2 major segmentations based on end-users and geographical considerations.

Based on the performed study, the major hurdles that are facing the M&S deployment are: First is the reluctance of senior management regarding M&S technologies as reported by Chick (2013) and Page (2017). This trend is confirmed by the conducted survey in Figure 21 reporting that 47% of the interviewees think that the main threat to M&S technologies is that several senior executives are reluctant to M&S deployment in their companies. The second outlined main challenge is the lack of visibility and comprehension regarding M&S in many cultures and big companies as reported by Hofmann (2011) and Yilmaz (2012). The third major challenge is the relatively high complexity and lack of user friendliness that such tools are presenting as reported by Fowler and Rose (2004), Morse et al (2004), Khan (2013), Nelson (2013) and confirmed by the conducted survey in Figure 19 reporting that 40% of the interviewees see clearly that complexity of M&S technologies is the main weakness that is slowing down its industrial deployment.

On the other hand, the major M&S marketing actions that should be taken are: M&S marketers should play massively their role of educators and translators in the market for deploying such tools as reported by De Baas (2014). In addition, M&S marketers should imperatively adopt ethical marketing principles by being transparent and avoid overselling the capabilities of M&S technologies as reported by Law (2007), L'Ecuyer (2013), Wilson (2006) Mesirov (2010), Fomel and Claerbout (2009) Karr et al (2012) and Morse and Schloman (2011). In fact, the idea behind building an effective M&S

marketing strategy is to build value on the long term. As always in marketing activities, this is only possible through building a trust relationship especially with new prospects.

An important question to be addressed at this point is how to standardize the M&S practices from an international perspective ? This is particularly important because it addresses a main challenge of M&S which is the lack of consistency and standardization among its different stakeholders. In this framework, what would be the valuable common interest that would motivate the international stakeholders for undertaking such efforts ?

As stated previously, this study focuses mainly on the marketing aspects of setting up strategies for a better M&S industrial deployment. What about the other business aspects? What can be the effective way of improving M&S deployment from a financial, a strategic or a human resources point of views ?

Another important aspect that is out of scope in this study is the M&S implementation inside new prospects. In fact, this is generally related to a deep change management and leadership aspects. In this framework, what would be the best rules of good practice for conducting such a change management? These recommendations will probably be dependent on the considered audience from a cultural and geographical points of view. How should it be adapted accordingly?

An additional question to be addressed is what kind of innovative solutions can be implemented for a better deployment of M&S in the industry? In fact, so far, only traditional ways of resolving a business challenge are exposed. An example of an innovative solution could be the usage of M&S technologies as embedded technologies and sensors without the need of external experts. This avoids the need for an additional skills to be able to leverage the M&S capabilities in the industry. What can be considered as additional innovative solutions for a better M&S deployment in the industry ?

VII. References

- Barnett, M. W. (2003) Modeling and Simulation in Business Process Management. *Gensym Corporation*. pp.1-10.
- Borovskiy V. and Zeier A., (2009) Enabling enterprise composite applications on top of ERP systems. *Services Computing Conference, APSCC 2009 IEEE Asia-Pacific*. pp.492-497.
- Box, G. E. P. (1976) Science and Statistics. *Journal of the American Statistical Association*. **71**, pp.791-799.
- Britt, H., Chen, C.C., Mahalec, V. and McBrien, A. (2004) Modeling and Simulation in 2004: An Industrial Perspective . *Aspen Technology, Inc*.
- Chance, F., Robinson, J. and Fowler, J. (1996). Supporting manufacturing with simulation: Model design, development, and deployment. *In Proceedings of the 1996 Winter Simulation Conference, San Diego, CA*. pp.1-8.
- De Baas, A.F. (2014) Materials Modelling: Where do we want to go? *European Commission European Union*. pp.1-24.
- Dobrzanski, L. (2006) Significance of materials science for the future development of societies. *Journal of Materials Processing Technology*. **175**, pp.133-148.
- Fomel, S., and Claerbout, J. (2009) Guest Editors Introduction: Reproducible Research. *Computing in Science and Engineering*. **11**, pp.5-7.
- Fowler, J.W. and Rose, O. (2004) Grand Challenges in Modeling and Simulation of Complex Manufacturing Systems. *Simulation*. **80** (9), pp.469-476.
- Glutzer, C.S., Sangtae, K., Cummings, P., Deshmukh, A., Head, M., Karniadakis, G., Petzold, L., Sagui, C., Shinozuka, M. (2009). WTEC Panel Report on International

Assessment Of Research And Development In Simulation-Based Engineering And Science. *World Technology Evaluation Center, Inc., Baltimore, MD, USA*.

Gupta, A., Singh, K. and Verma, R. (2010) A critical study and comparison of manufacturing simulation softwares using analytic hierarchy process. *Journal of Engineering Science and Technology*. **5** (1), pp.108-129.

Hayes, B. (2008) Accidental algorithms. *American Scientist*. pp.1-6.

Hofmann, M., Palii, J. and Mihelcic, G. (2011) Epistemic and normative aspects of ontologies in modelling and simulation. *Journal of Simulation* **5**, pp.135-146.

Holt, B. (2015) Advancing Moore's Law, Presentation to Intel Investor Meeting, Santa Clara

Industrial Research Institute European Commission (2016) The 2016 EU Industrial R&D Investment Scoreboard [online] Available from <http://iri.jrc.ec.europa.eu/scoreboard16.html>. [Accessed 20/10/18]

Kadanov, L.P. (2004) Excellence in computer simulation. *Computing in Science & Engineering*. **6** (2), pp.57-67.

Karr J.R., Sanghvi, J.C., Macklin, D.N., Gutschow, M.V., Jacobs, J.M., Bolival, B., Assad-Garcia, N., Glass, J.I., Covert, M.W. (2012) A Whole-Cell Computational Model Predicts Phenotype from Genotype. *Cell*. **150**, pp.389-401.

Law, A. M. (2007) Simulation Modeling and Analysis. *New York McGraw-Hill* (4)

Lehtinen, A. and Kuorikoski, J. (2007) Computing the Perfect Model: Why Economists Shun Simulation? *Philosophy of Science*. **74** (3), pp.304-329.

Liu, Y., Zhao, T., Ju, W. and Shi, S. (2017). Materials discovery and design using machine learning. *Journal of Materiomics*. **3**, pp.[not found]

Lloyd, J., Stavness, I., Fels, S. (2011) ArtiSynth: A fast interactive biomechanical modeling toolkit combining multibody and finite element simulation. *Soft Tissue Biomechanical Modeling for Computer Assisted Surgery*, Springer, New York.

Lockney, D. (2018) *NASA Software Catalog 2017-2018*. pp.3-3.

Lohr, S. (2011), Unboxed: When there is no such thing as too much information. *The New York Times*, April 24, 2011

Lundstrom, M. (2009) Challenges and Opportunities, Frontiers for Modeling and Simulation. *Network for Computational Nanotechnology*, Purdue University, West Lafayette, Indiana USA

Market research future (2019) Product Life Cycle Management Research Report - Global Forecast till 2023 [Online] Accessible from <https://www.marketresearchfuture.com/reports/product-life-cycle-management-market-2195> [Accessed 20/01/19]

Mesirov, J. (2010) Accessible Reproducible Research. *Science*. **327**, pp415-416.

Mittal, S., Durak, Oren, U. and Page, E.H. (2017) Modeling and Simulation (M&S) Technology Landscape. *Guide to Simulation Based Disciplines*. pp.25-35.

Morse, K.L. and Schloman, J. (2011) Toward Data Interoperability for HSCB Models. *In Proceedings of the 2011 Spring Simulation Interoperability Workshop, Boston, MA, April 4 – 8, 2011*.

Morse, K.L., Petty, M., Reynolds, P., Waite, W. and Zimmerman, P. (2004) Findings and Recommendations from the 2003 Composable Mission Space Environments Workshop. *In Proceedings of the 2004 Spring Simulation Interoperability Workshop, Arlington VA, April 18-23, 2004*.

Mourtzis, D., Doukas, M. and Bernidaki, D. (2014) Simulation in Manufacturing: Review and Challenges. *Procedia CIRP*. **25**, pp.213-229.

Naseer A., Eldabi T. and Jahangrian M. (2008) Cross-sector analysis of simulation methods: A survey of defense and healthcare. *Transforming Government*. **3** pp181-189.

National Training and Simulation Association (2011) A Primer on Modeling and Simulation. pp.1-32.

Saunders, M., Lewis, P. and Thornbill, A. (2015). *Research Methods for Business Students*. Seventh Edition, Pearson Education Ltd

Simulation Software Market (2018) Mordorintelligence [online]. Accessible from <https://www.mordorintelligence.com/industry-reports/simulation-software-market> [Accessed 02/11/18]

Smith, R. (2006) Technology Disruption in the Simulation Industry. *Journal of Defense Modeling and Simulation*. pp.[not found]

Society for Industrial and Applied mathematics SIAM (2012) *Mathematics in Industry* [online]. Available from <http://www.siam.org/reports/mii/2012/report.pdf>. pp.1-48. [Accessed 15/10/18]

Sokolov, A.P., Schlosser, C.A., Dutkiewicz, S., Paltsev, S., Kicklighter, D.W., Jacoby, H.D., Prinn, R.G., Forest, C.E., Reilly, J.M., Wang, C., Felzer, B., Sarofim, M.C., Scott, J., Stone, P.H., Melillo, J.M. and Cohen, J. (2005) The MIT Integrated Global System Model (IGSM) Version 2: Model Description and Baseline Evaluation. *MIT Joint Program on the Science and policy of Global Change, Report Series*. (124), pp.1-46.

Taylor, S.J.E. , Brailsford, S., Chick, S.E., L'Ecuyer, P., Macal, C.M. and Nelson, B.L. (2013) Modeling and Simulation Grand Challenges: An OR/MS Perspective. *Proceedings of the 2013 Winter Simulation Conference*

UNESCO – Institute of Statistics (2019) Gapminder [online] Available from <https://www.gapminder.org/data/> [Accessed 20/01/19]

Valvida, W. D. and Clark, B.Y. (2015) The politics of Federal R&D: A Puntuated Equilibrium Analysis. Washington, DC: Brooklings Institute.

Yilmaz L. (2012) Reproducibility in M&S Research: Issues, Strategies, and Implications for Model Development Environments. *Journal of Experimental and Theoretical Artificial Intelligence*, **24** (4), pp457-474.

Zander, J., Schieferdecker, I. and Mosterman, P.J. (2011) Model-Based Testing for Embedded Systems. *CRC Press*. Taylor & Francis.