Sustainable Manufacturing as an Approach for Achieving Operational Performance Excellence
(Case study)

التصنيع المستدام كمدخل لتحقيق التميز في الأداء التشغيلي
(دراسة حالة)

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المستخلص:

يُعد التصنيع المستدام Sustainable Manufacturing أحد الاتجاهات الفعّالة التي تحظى باهتمام متزايد في المجتمع البحثي، وقد تجاوز هذا الاهتمام حدود الأوساط الأكاديمية ليحظى بأهمية بالغة في المنظمات الصناعية. وتكمن أهمية التصنيع المستدام في كونه سياسة وإطارًا شاملاً يتبنى مفهوم "عدم الهدر"، ويهدف إلى تقليل الآثار السلبية على البيئة، وتحسين كفاءة استخدام الموارد المتاحة، وتقليل توليد النفايات، مع الحفاظ على جودة المنتجات والعمليات وتحسينها. ويعد الأداء التشغيلي هو محور عملية التحسين ويعكس قدرة المنظمة على تحقيق مستويات عالية من الكفاءة والفاعلية في أنشطتها التشغيلية. ومن هنا تنبع أهمية التصنيع المستدام كمدخل لتحقيق التميز في الأداء التشغيلي.

وقد عالج البحث مشكلة انخفاض التميز في الأداء التشغيلي بسبب الهدر المتعدد الناتج عن العديد من الأنشطة غير الضرورية في عملية الإنتاج. وتُعدُّ هذه الدراسة دراسة حالة قائمة على المنهج الوصفي التحليلي لإحدى شركات الأدوية العاملة في مصر، لدراسة أثر تطبيق التصنيع المستدام على تحقيق التميز في الأداء التشغيلي. واقتصرت عينة البحث على خط إنتاج المستحضر (x) نظراً لكونه يحتوي على خطوات إنتاجية مشتركة مع غالبية خطوط إنتاج المستحضرات السائلة الأخرى، بالإضافة إلى تزايد عدد الأنشطة غير الضرورية فيه مقارنة بغيره من المنتجات. وقد تم إجراء مسح

شامل لجميع العاملين على هذا الخط الإنتاجي. واتبع البحث أسلوب الحصر الشامل لجميع العاملين على هذا الخط بالشركة محل البحث.

وانتهي البحث إلى العديد من النتائج التي من أهمها أن الأنشطة غير الضرورية تؤثر سلباً وبشكل كبير على الأداء التشغيلي، مما يُبرز أهمية التعرف على هذه الأنشطة وإزالتها من العمليات التصنيعية. وعلى الرغم من ذلك، فإن آراء العاملين أظهرت إدراكًا منخفضًا لوجود مثل هذه الأنشطة في بيئة عملهم الحالية. كما أكدت النتائج أن تطبيق التصنيع المستدام والتخلص من الأنشطة غير الضرورية، يمثلان عوامل نجاح حاسمة لتحقيق التميز في الأداء التشغيلي. إذ يُعد التصنيع المستدام محفزًا أساسياً لتحسين الأداء، في حين تشكل الأنشطة غير الضرورية عوائق مؤثرة أمام الوصول إلى نتائج تشغيلية مثلى. وأوصي البحث بضرورة الاهتمام ببناء خارطة طريق ووضع أطر عمل واضحة المعالم لتطبيق التصنيع المستدام، واعتماد مفهوم القيمة المضافة كأساس للإنتاج، ونشر ثقافة تنظيمية قائمة على استبعاد الفاقد، حيث تتزايد أهمية التصنيع المستدام كنهج استراتيجي لتحقيق الكفاءة التشغيلية ومن ثم التميز في الأداء التشغيلي.

الكلمات المفتاحية: التصنيع المستدام، التميز في الأداء التشغيلي

Abstract:

Sustainable Manufacturing (SM) is an increasingly adopted approach, especially in the industrial sector, that promotes non-wastefulness by reducing negative impacts, enhancing energy and resource efficiency, and minimizing waste. In this study, a proposed theoretical framework for the logical relationship between the research variables is represented. The research study is a Case Study based on the descriptive analytical method for one of the pharmaceutical companies operating in Egypt to examine the impact of implementing Sustainable Manufacturing on Operational Performance Excellence (OPE). The sample of analysis is a Purposive Sample of the production line of product (X) suspension, where a comprehensive survey was conducted across all employees working on the production line of product (X), as its manufacturing includes the common steps shared by majority of liquid preparation line products, and the increase in the number of unnecessary activities on this production line compared to other pharmaceutical products. A dual-software approach, combining the strengths of Smart PLS V.3 for Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis with IBM SPSS V.29 for descriptive and inferential statistics is used to test all the hypothesized relationships under investigation. The results and empirical evidence shows the significant negative effects of unnecessary activities on operational performance underscore the importance of identifying and eliminating wasteful processes and activities within manufacturing operations, although respondents generally perceive minimal presence of unnecessary activities and wastes in their production processes. The findings also identify that SM implementation and unnecessary activities elimination represent critical success factors for OPE. As SM implementation serves as a critical driver of OPE, unnecessary activities represent significant impediments to performance outcomes.

Keywords: Sustainable Manufacturing, Operational Performance Excellence.

Introduction:

Industry has progressed through key revolutions: starting with steam-powered machinery, advancing to electricity-based mass production, followed by automation with advanced electronics and IT, and now the fourth industrial revolution, where smart machines and digital technologies combine to enhance productivity and promote industrial sustainability (Hamed et al., 2021:1). Thus, the sustainability theme has attracted increasing attention from academia and researchers, as the fast changing and dynamic global business environment requires organizations to be more flexible to quickly adapt and respond to market changes. So, during such difficult times, organizations are faced with hard choices to survive and requirements for sustainability are getting more urgent and addressing sustainability is critical to the long-term existence and thriving of organizations (Viet *et al.,* 2011:63).

Therefore, the SM concept is gaining increasing attention in organizations especially in the industrial sector (Antonio *et al.,* 2020:1). As Sartal *et al*. (2020:1) mention that SM is the creation of manufactured products that minimize negative impacts while conserving energy and natural resources. SM also enhances employee, community and product safety. In this context, Singh and Kaur (2022:3) state that SM is the creation of manufactured items using techniques that conserve energy and natural resources which are safe for employees, communities, and consumers, and are economically rational. Also, reducing negative impacts, enhancing energy and resource efficiency, minimizing waste, safeguarding worker health, and maintaining quality, while achieving life-cycle cost benefits and performance excellence.

Hence, organizations can use SM as a powerful approach to achieve OPE. Accordingly, Rupesh *et al*. (2024:1) state that organizations must continually elevate their operational performance and outcomes to ensure viability, as organizations now prioritize the enduring sustainability of their industrial entities within the fiercely competitive landscape. Arguably, SM has a positive impact on manufacturing organizations in their quest to improve their performance.

Given the difference in work in the pharmaceutical industry compared to other industrial sectors, as pharmaceutical manufacturing is a continuous manufacturing process, also called process manufacturing, as the process consists of different manufacturing steps that cannot be separated. Hence, the importance of applying SM by eliminating loss as a new philosophy to simplify the internal flow of the production process, and as one of the most important ways to achieve OPE, by eliminating loss in its various forms at each stage of production. Accordingly, the researcher has chosen the Pharmaceutical Industries Sector to be the domain of study, where the importance of SM rises as an approach to achieve OPE.

The study, therefore, is divided into 5 sections as follows: The first section focuses on reviewing the literature on SM and OPE. The second section introduces the methodology and the scales and measurement tools to study the two concepts in the Pharmaceutical Industries Sector. The third section presents the model framework. The fourth section includes the applied part of the study that tests the model using a dual-software approach, combining the strengths of Smart PLS V.3 for Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis with IBM SPSS V.29 for descriptive and inferential statistics. In the last section multiple results and recommendations are presented.

First: The Literature Review:

The first section sheds light on Sustainable Manufacturing and Operational Performance Excellence.

1. Sustainable Manufacturing:

Within the broad field of sustainability, the concept of SM is gaining increasing attention in the research community and has moved beyond it to gain wide acceptance in business and especially in industry (Sartal *et al.,*2020:1). In this context, Abdullahi and Abdullah (2015:490) maintain that policy in this regard should include the concept of 'non-wastefulness' and represent consumption of goods and services. Consequently, Büyüközkan and Karabulut (2018:253) emphasize that sustainability begins to extend towards a more holistic, integrated, and methodological understanding to achieve excellence in all aspects, especially in manufacturing. As they mention that most manufacturing practices are not sustainable due to the excessive consumption needs of nonrenewable natural resources and they emphasize that the solution to this is sustainable growth, without destructive consumption.

The first studies in SM were carried out under the environmental approach, some of the main topics of this approach are source reduction, design for manufacturing. SM was thus becoming popular among manufacturers as a tool for improving their manufacturing performance and will show better performance excellence (Magd and Karyamsetty, 2020:2781). In this regard, Jayal *et al.* (2011:145) clarify that although there is no universally accepted definition for the term SM, numerous efforts have been made in the recent past, with much more concurrent efforts well underway. Accordingly, Singh and Kaur (2022:3) and Jayal *et al.* (2011:145) state that the U.S. Department of Commerce defined SM as the creation of manufactured products through economically-sound processes that minimize negative environmental impacts, conserve energy and resources, are safe for employees, communities, and consumers. While Haetinger *et al*. (2019:2) mention that SM means manufacture of products with processes and systems with higher quality and durability, lower environmental impacts and higher profitability. In this sense, Tonelli *et al.* (2013:143) add that SM refers to the end state of a transformation process where industry is part of, and actively contributing to a socially, environmentally, and economically sustainable planet leveraging on its technological nature.

According to Singh and Kaur (2022:3), many manufacturing organizations now view sustainability as a key strategic and operational goal, aiming to enhance efficiency by reducing costs and waste, drive growth and competitiveness, ensure long-term viability, comply with regulations, and protect brand reputation while building public trust. Furthermore, Umeh *et al.* (2022:83) and Bandehnezhad *et al*. (2012:146) mention that SM focus mainly on waste elimination which has considerable potential for operational performance of adopters, and this also comprehends the need to progress in process planning to reduce materials and energy consumption, emissions, waste, overstocks, generating less toxic waste in manufacturing process and so on.

Accordingly, Haetinger *et al.* (2019:3) suggested a set of practices necessary for the manufacturing to comply to be sustainable, including reducing natural material and energy use, conserving resources, preventing waste through reuse and recycling, safely disposing of non-recyclables, adopting clean technologies, minimizing transport needs, designing products for easy repair, adaptability, and durability, supporting social issues, and ensuring economic feasibility. Subsequently, Jawahir and Bradley (2016:104) point out the need to consider SM as a holistic approach, addressing the initial 'Rs' approach supported by three principles, reduce, reuse and recycle, must be extended to a broad vision of SM -as illustrated in Figure(1)- considering three new activities that complemented the 6R strategy: reduce, reuse, recovery, redesign, remanufacture and recycle.

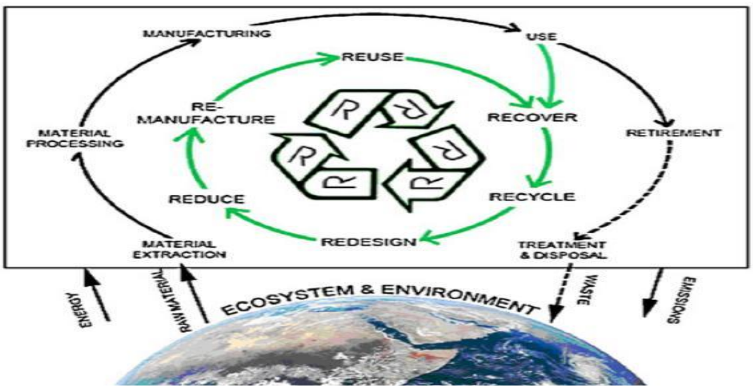


Figure (1): SM as a holistic approach addressing the initial 'Rs'

Source: Jawahir, IS and Bradley, R. (2016). "Technological elements of circular economy and the principles of 6R-based closed-loop material flow in sustainable manufacturing", CIRP Journal of Manufacturing Science and Technology, Vol. 40, p.105.

Additionally, Sony (2019:5) and Dahlgaard *et al.* (2013:522) argue that by addressing the 4P's of SM as shown below in Figure (2), organizations can create a more SM model that balances operational performance with environmental and social responsibility. They state that the P's are excellent people who establish excellent partnerships with suppliers, customers and society in order to achieve excellent processes which are key business and management processes to produce excellent products, which are able to delight the customers. In this context, Dubey (2015:235) illustrates that the 4P's of SM are important for reducing negative impacts, securing better working conditions, and achieving sustainable growth to achieve operational excellence.

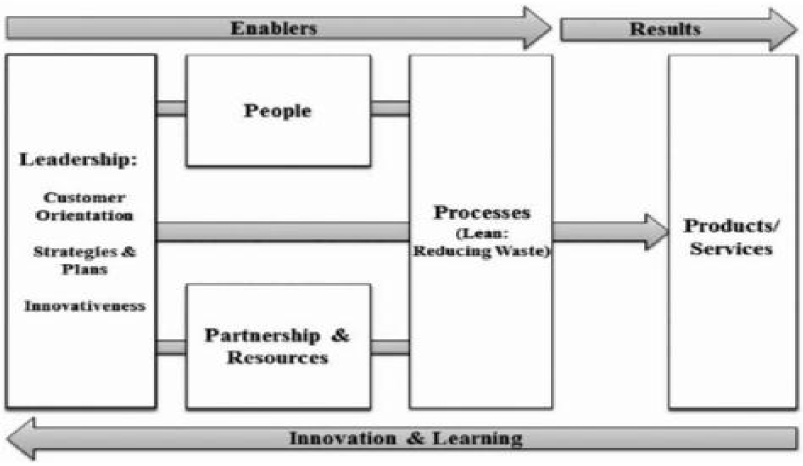


Figure (2): The 4P's of sustainable manufacturing

Source: Sony, Michael. (2019). "Implementing sustainable operational excellence in organizations: an integrative viewpoint ", Production & Manufacturing Research - An Open Access Journal, ISSN: (Print) 2169-3277, p.7.

Potentially, therefore, Previous studies have examined SM from varied perspectives, including environmental impact reduction, resource efficiency, social responsibility, and operational improvement. While these works provide valuable insights and frameworks, such as the 6R and 4P models, they often treat these dimensions in isolation. There is limited integration of these aspects into a single, comprehensive model. This fragmentation leaves a gap in directly linking SM practices to achieving OPE. The present study addresses this gap by examining SM as a unified strategy for achieving OPE.

2. Operational Performance Excellence:

Now in the era of globalization, the dynamic environment demands the organizations to be more efficient in performing their operations to sustain their place as well compete in the market with strong edge (Faizan and Haq, 2022:16). According to Hwang *et al.* (2014:50), organizations strive to make outstanding performance to compete in the global markets. As Elyazid (2016:1) mentions that manufacturing has dramatically changed during the last twenty years, and these changes require sustainable improvements in time to market, efficiencies, high quality, cycle time, reduce costs, response to consumer needs, and focus on continual improvement. Accordingly, Magd and Karyamsetty (2020:2781) state that for these reasons, the concept of operational performance in general has received a considerable amount of attention in academic literature and gained a tremendous amount of attention from managers to better understand and identify organization processes, activities and tasks.

In this context, Princewill and Umoh (2022:301) clarify that operational performance is the backbone of organizational performance and is the strategic variable that promotes competitive advantage. Additionally, Sharma and Modgil (2020:332) state that operational performance is the foundation of quality practices and the super ordinate performance of organizations. Furthermore, Santos *et al.* (2019:2) mention that in the manufacturing sector, operational performance is a means to enhance production, refers to the ability of an organization to reduce costs, order-time, lead-time, improve the effectiveness of using raw material and distribution capacity, a vital determinant of competitive advantage that leads to improved revenue and returns for organizations. Finally, Princewill and Umoh (2022:301) illustrate that Operational performance is conceptually defined and explained as competitive priorities (quality, flexibility, cost and time) of operations strategy. On the other hand, Saoudi and Dehane (2020:705) defined performance excellence as an approach that ensures the improvement of overall organizational effectiveness and capabilities as well as creating sustainable value for customers and stakeholders. While Allen *et al*. (2019:2) define it as the ability to be excellent and maintain a high and recognized competitive position in the market in which the organization operates. Thus, OPE can be defined as the ability of an organization to minimize waste, reduce costs, improve product or service quality, and optimize resource use to achieve and sustain high levels of efficiency, quality, and productivity in its processes, to deliver value to customers and stakeholders.

Accordingly, Faizan and Haq (2022:16) strongly suggest four operational performance indicators (cost, speed, quality & flexibility) which are more crucial to ensure that the operational performance is done properly, enabling the organization to develop comprehensive knowledge about the customer's need, market trends, and demand so that excellence can be accomplished. Furthermore, Elyazid (2016:3) states that operational Performance indicators are tools to help managers understand, manage, and improve what the organizations do. On the other hand, Sylva (2020:300) argues that these performance indicators are more crucial to measure the manufacturing organizations' operational performance and to sustain long term competitive position in the market.

Consequently, Magd and Karyamsetty (2020:2781) emphasize that organizations should experience sustainable growth in operational performance, as adopting those practices will show better OPE from those that do not.

Therefore, Previous studies emphasize operational performance as a key source of competitive advantage, focusing on indicators such as cost, speed, quality, and flexibility. While these works link OP to efficiency, waste reduction, and customer value, they often address it as a standalone goal. Limited research examines how integrating sustainable manufacturing practices can directly drive OPE, highlighting a gap this study aims to address.

Second: General Framework of the Study:

The second section deals with the methodology of the study and the scales and measurement tools as follows:

1. Methodology of the Study:

Research Problem:

Pharmaceutical manufacturing is a continuous manufacturing process, in which its manufacturing area is subject to very strict cleaning procedures to maintain a standard low bacterial count, as the process consists of different manufacturing steps that cannot be separated. Along the way of manufacturing, environmental conditions like pressure, temperature, flow…etc., must be controlled to achieve compliance. The pharmaceutical company under study[1] produces several pharmaceutical dosage forms that are used for human treatment purposes. It was shown through conducting several personal interviews in the company under study that in late 2020, there were multiple forms and types of wastes along the production line of product (X) which were listed as follows (Industrial Affairs Report, 2021):

- Time Waste identified in dispensing department due to the manual process of weighing. The product recipe was not added to the System, Applications and Products (SAP) system during the launch of product (X). All documentation is done manually, and double check is done at the dispensing department from the responsible pharmacist. An extra double check is done by the production pharmacist at the delivery of material.
- Homogenizer used of limited capacity which results in ergonomic constraints due to long duration of mixing time and extra operator for the holding of the homogenizer.
- Time and Motion Waste as connections used to perform micronization operation were limited resulting in increased change over time between each micronization operation.
- Product loss, time loss and risk on pump because the end point of vacuum operation to eliminate bubbles in the solution is not easily detected.
-Over processing as one nozzle of the four filling nozzles was observed for continuous leakage. This leakage leaves the next

[1] The name of the company under study was not mentioned out of respect for the desire of its officials.

bottles in the flow with sticky drops of product on the bottle necks. This defect was temporarily either by disabling the defected nozzle or by adding extra operators on the line to sweep the sticky bottles. In both situations process was facing 25% of defected bottles that requires over processing or defected product if not detected by the operator. Machine speed was also reduced to enable operators to detect the sticky bottles.

- Time and motion waste in finding and collecting the glassware necessary to do one analytical test.
- Time waste, transportation waste, motion waste was all identified in the Quality Control analysis operation. Although the operation was not included in the timeline of the process because it is classified as a necessary non adding value operation, it was identified as bottle neck area as its cycle time is 5 days.

It is clear as mentioned above that there are multiple forms and types of losses, whether in cost, time, movement, or wastes and production bottlenecks occurred which sometimes caused rework and extended the production cycle time along the production line of product X. Accordingly, the research problem is represented as:

" Decrease in operational performance excellence due to multiple wastes resulting from the increasing number of unnecessary activities in the production process."

Research Hypothesis:

The study examines the following set of hypotheses:

H1: There is a statistically significant relationship between unnecessary activities in the production process and achieving operational performance excellence.

The following sub-hypotheses branched out from this hypothesis:

- **H1a**: There is a statistically significant relationship between unnecessary activities in the production process and operational performance cost.
- **H1b**: There is a statistically significant relationship between unnecessary activities in the production process and operational performance quality.
- **H1c**: There is a statistically significant relationship between unnecessary activities in the production process and operational performance flexibility.

- **H1d**: There is a statistically significant relationship between unnecessary activities in the production process and operational performance speed.

H2: There is a statistically significant relationship between implementing sustainable manufacturing and operational performance excellence.

The following sub-hypotheses branched out from this hypothesis:

- **H2a**: There is a statistically significant relationship between implementing sustainable manufacturing and operational performance cost.
- **H2b**: There is a statistically significant relationship between implementing sustainable manufacturing and operational performance quality**.**
- **H2c**: There is a statistically significant relationship between implementing sustainable manufacturing and operational performance flexibility.
- **H2d**: There is a statistically significant relationship between implementing sustainable manufacturing and operational performance speed.

Research Objectives:

This study aims, in addition to testing its hypotheses, to meet the following underlying objectives:

1. Provide a scientific and academic conceptual framework about sustainable manufacturing.
2. Study the 4P's of sustainable manufacturing which are important for achieving sustainable growth to achieve operational excellence.
3. Examine the extent to which sustainable manufacturing practices are implemented within the pharmaceutical company under study.
4. Identify the forms and types of waste and unnecessary activities along the production line of product X under study.
5. Present operational performance indicators that are more crucial to measure the manufacturing organizations' operational performance.
6. Study the effect of sustainable manufacturing approach on achieving operational performance excellence.

Research Methodology:

The research study is a Case Study based on the descriptive analytical method for one of the pharmaceutical companies operating in Egypt. This company was chosen as one of the world's leading companies in the pharmaceutical industry worldwide because it implemented an SM approach. The company is one of the companies that supports research and development to meet future medical needs and is one of the first foreign companies operating in Egypt in the pharmaceutical industry.

The Hypotheses are tested by taking a Purposive Sample of the production line of product (X), where the research population consisted of (7) types of liquid medicines. The study focuses is on one product family, the liquid dosage form preparation line, as there are two types of oral liquid dosage forms are prepared on the liquid's preparation line located at the production floor in Industrial Affairs building of the company: solutions and suspensions, and the product family matrix done for liquid dosage forms showed that product (X) suspension was the product of choice because its manufacturing includes the common steps shared by majority of liquid preparation line products, and the increase in the number of unnecessary activities on this production line, which resulted in a longer production cycle time for manufacturing this product compared to other pharmaceutical products(Industrial Affairs Report, 2021).

To collect data effectively, a comprehensive survey was conducted across all employees working on the production line of product (X), where (109) questionnaires were developed and distributed, but the number of valid and complete questionnaires that were returned was (102) at a rate of 93.5%, with (34) questionnaires for supervisory positions at a rate of 33.3% of the total number of questionnaires, and (68) questionnaires for executive positions at a rate of 66.7% of the total number of questionnaires as indicated in Table (1). This distribution is particularly valuable for the study as it captures perspectives from both strategic decision-makers in executive roles and operational managers in supervisory positions, providing a comprehensive view of SM implementation across different organizational levels.

Table (1): Demographic Characteristics

Variable	Categories	N	%
Job position	supervisory positions	34	33.3%
	Executive positions	68	66.7%
Department	Preparation	37	36.3%
	Filling	25	24.5%
	Packaging	23	22.5%
	Quality department	17	16.7%

Source: From the results of running data on a SPSS V.29 program.

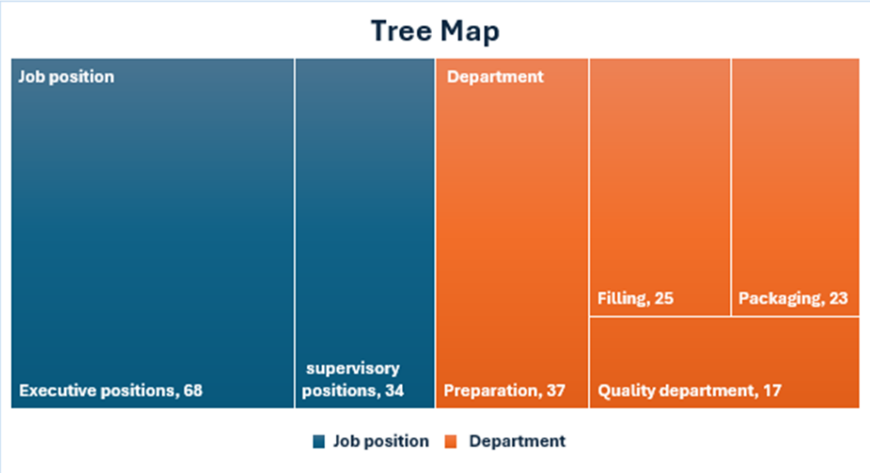


Figure (3): Tree map for the Demographic Characteristics

Source: From the results of running data on Excel 2016.

As illustrated in Figure (3), the distribution rates of questionnaires at the level of each department in the production line of product (X) under study demonstrates broad representation across key manufacturing functions, with the Preparation department showing the highest participation at 36.3% (n=37), followed by the Filling department at 24.5% (n=25), Packaging at 22.5% (n=23), and Quality department at 16.7% (n=17). This cross-functional representation is crucial for understanding SM practices from multiple operational perspectives, as each department plays a distinct role in the manufacturing value chain and may experience different impacts from SM initiatives.

The predominance of executive-level respondents enhances the study's validity, as these individuals typically possess comprehensive knowledge of operational processes, and performance outcomes. Furthermore, the inclusion of supervisory personnel provides valuable operational insights from those directly involved in day-to-day manufacturing activities and process management. The departmental diversity strengthens the generalizability of findings across different manufacturing functions. The higher representation from the Preparation department may reflect the critical role this function plays in SM, as preparation processes often involve significant opportunities for waste reduction and resource optimization. The balanced representation across Filling, Packaging, and Quality departments ensures that perspectives from various stages of the manufacturing process are captured, providing a holistic view of SM impact on operational performance.

And a Personal interviews with the project leader of the SM system, the production planner, the production pharmacist and area supervisor, the maintenance engineer, and the quality controller, in order to learn their opinions regarding the impact of implementing SM approach on the various forms and types of losses resulting from the number of unnecessary activities in the production process on the product (X) production line under study which in turn affects OPE. The personal interview method provided the opportunity to remove any ambiguity about the meanings and concepts applied on the production line under study.

To ensure the accuracy of the content of the questionnaire, it was reviewed by several professors before it was distributed. The questionnaires were distributed over the mail and through field visits over a period of three months to investigate the effect of SM on OPE.

2. Scales and Measurement Tools:

a. Sustainable Manufacturing

Following an extensive review of relevant literature, The SM assessment tool is built based on Sony (2019:5), Moldavska and Welo (2017), Dubey (2015:235), Dahlgaard *et al.* (2013:522), Garetti *et al.* (2012), and Jayal *et al.* (2011) questionnaires, that are in turn based on SM concept that notably gained prominence in the late 20th and early 21st centuries as it have emerged as a response to environmental concerns and the need for resource efficiency in industrial processes. The SM questionnaire contains a scoring set of 24 questions based on a five-point Likert scale ranging from strongly “agree” (5) to “strongly disagree” (1), related to the unnecessary activities in the production process and the 4Ps of SM, namely: (1) Product, (2) Process, (3) People and (4) Practices, that represent the key pillars that organizations should focus on to promote sustainability within their manufacturing processes.

b. Operational Performance Excellence

The OPE assessment tool is built based on the assessment tools set by Porter (1998), Nigel *et al.* (2004), Hwang *et al.* (2014), Elyazid (2016:3), Faizan and Haq (2022:16), and Princewill and Umoh (2022), which are in turn based on the four operational performance indicators that are more crucial and essential components that enable the organizations to maintain its high performance and sustain long term position in the cutthroat competition. The OPE questionnaire contains a scoring set of 14 questions based on a five-point Likert scale ranging from strongly “agree” (5) to “strongly disagree” (1), related to these operational performance indicators namely: (1) Cost, (2) Speed, (3) Quality and (4) Flexibility.

Third: The Conceptual Framework:

Based on the previous literature review, this study argues the effect of SM on OPE through a proposed theoretical framework for the logical relationship between the research variables illustrated in Figure (3) as follows.

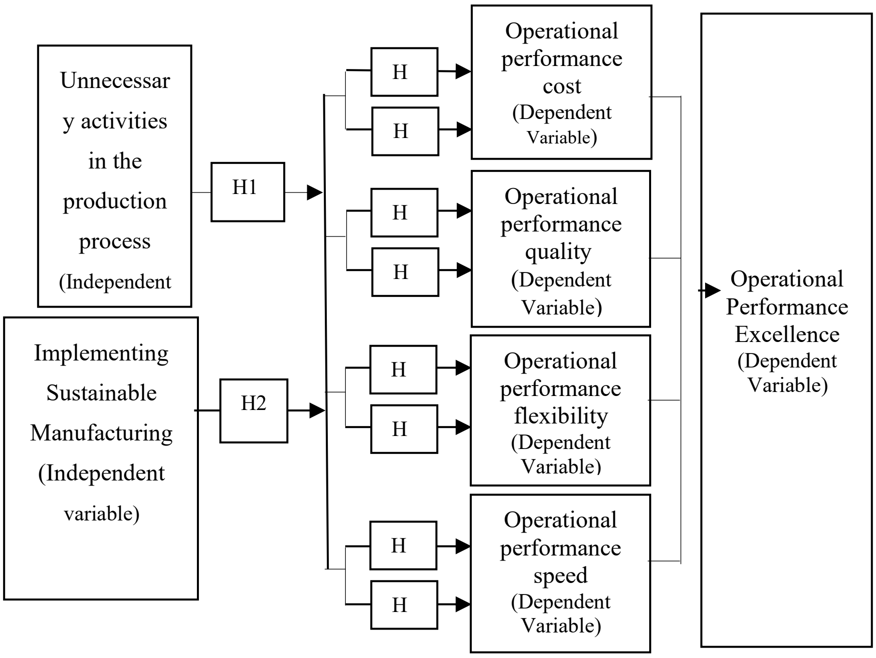


Figure (4): Theoretical Framework for the Relationship between Research Variables

1. Sustainable Manufacturing:

The above model illustrates the implementation of SM. This implementation through the 4Ps of SM namely: (a) People, (b) Process, (c) Product and (d) Practices, that provides a comprehensive framework for achieving SM and consider as the key pillars that organizations should focus on to promote sustainability within their manufacturing processes.

a- People

The employees are the human embodiments of the organization; they are central to SM due to their familiarity with product and process, they are people who actively seek to proactively engage with their stakeholders, establish excellent partnerships with suppliers, customers and society to make industries more sustainable (Sony, 2019:5; Haetinger *et al.*, 2019:11). Umeh *et al.* (2022:88) mention that a crucial aspect for measuring the people influence of a manufacturing process is the well-being and development of employees, health, safety, and environment of the industrial employees. Furthermore, Alves *et al*. (2023:8) state that upskilling and promoting safe practices are key for sustainability-focused workplaces. Subsequently, Huang and Badurdeen (2018:463) argue that those in charge should do all possible to create a safe, happy, and healthy workplace for their employees.

Additionally, Gholami *et al*. (2021:13) state that fostering a sustainable culture requires providing employees with advanced training and education to develop SM skills, improve material use, identify and reduce waste, and support the 6Rs through proper waste disposal, treatment, and suggested improvements. This is what Brauner and Ziefle (2022:1) confirmed, as they point out that in parallel with sustainability, the employees need to be prepared and trained, so that they can take an active role in SM. Also, Broo *et al*. (2021:4) state that to achieve social, environmental, and economic sustainability and resilience in industries, education will have to be reviewed and redesigned to train future employees with technological, data, and knowledge fluency to make manufacturing more sustainable, resilient.

Furthermore, Alves *et al*. (2023:13) illustrate that empowering and engaging employees in sustainability initiatives fosters a culture of sustainability, drives innovative solutions to enhance operational performance, and ensures sustainable growth by prioritizing job satisfaction, safety, and skills adaptability.

b- Process

The manufacturing process is considered the basic unit to analyze, as it is a driver for costs' reduction at the operational level (Umeh *et al*.,2022:84). As mentioned by Chourasiya *et al*. (2024:1), sustainable process is a regenerative and restorative process that reduces energy consumption and optimizes resource utilization throughout its lifecycle. Furthermore, Singh and Kaur (2022:27) and Umeh *et al*. (2022:86) state that a sustainable process enhances efficiency by reducing work-in-progress (WIP), minimizing product waste and material use, utilizing sustainable materials, lowering energy consumption (preferably using renewable sources), and reducing packaging needs through recyclable materials.

Additionally, Sony (2019:11) mentions that sustainable processes are the processes that seek to minimize waste and determine how and where value is added, are environmentally compliable, highly energy efficient, waste reduction, reduce pollution and emission reductions, else, in the long run, it will not be sustainable. In this context, Simon *et al*. (2017:405) clarify that sustainable processes geared towards improvement of the production flow by reducing waste and aimed to eliminate activities and procedures that do not add value to the final product. Moreover, Abdullahi and Abdullah (2015:490) point out that sustainable processes aimed to reduce negative environmental impact, offer improved energy and resource efficiency, minimum quantity of waste generate, provide operational safety and offer improved personal health.

Consequently, Chourasiya *et al*. (2024:7) and Camilleri *et al*. (2023: 2) argue that sustainable processes should consider the following three pillars: economic, environmental, and social sustainability, as these pillars used to assess the sustainability performance of process industries. As Lee *et al*. (2021: 68417) and Feil *et al*. (2019:2) state that environmental sustainability includes using natural resources within replenishment limits, reducing waste and implies the ability to sustain and maintain Eco-Process that is based on eco-efficiency and eco-effectiveness approach that are related to minimize waste, energy consumption, and emissions, reuse and recycling of wastes, types and quantities of environmental resources and reduce costs by eliminating non-value-added environmental issues in the process. While Simon *et al.* (2017:406) and Short *et al.*(2013:2) illustrate that social sustainability decreases impact of manufacturing processes on employees and is related to work safety, ergonomic aspects and level of noise. They state that it is concerned with a broad range of issues including job creation, stakeholder participation and responsibility, labor standards, human rights, health. Furthermore, Lucato *et al.*(2018: 5) and Purvis *et al.*(2019:688) state that economical sustainability refers to better utilization of resources and reflects measures of profitability, growth, and return on investment.

c- Product

A sustainable product is defined as a product that has little impact on the environment, and at the same time, has been designed with consideration of the economic and societal aspects to ensure future benefits (Hassan *et al*., 2017:43). While Pathak and Singh (2017: 3) state that sustainable products are eco-designed with environmental, social, and economic considerations to protect public health, welfare, and the environment throughout their life cycle, thereby meeting the needs of future generations. As mentioned by Camilleri *et al*. (2023:2), an ecofriendly product could be called "green" as its production process is ecofriendly and less damaging to the environment, and they state that the term green product is a synonym for sustainable product, and they illustrate that the features that increase product sustainability are the use of sustainable materials and sustainable production processes. Furthermore, Abdullahi and Abdullah (2015:493) point out a framework for a comprehensive total life-cycle evaluation matrix for product that shows the following six product sustainability elements a. Environmental Impact b. Societal Impact (Safety, Health, Ethics, etc.) c. Functionality d. Resource Utilization and Economy e. Manufacturability f. Product's Recyclability/Remanufacturability.

According to Hassan *et al.* (2017:38), sustainability for a product in general definition is the ability of the product to be sustained over its life cycle. In this context, Chourasiya *et al*. (2024:2) clarify that today businesses are increasingly seeking to minimize waste and maximize resource efficiency by designing products for longevity, repairability, and recyclability. Additionally, Sartal *et al*. (2020:4) argue that sustainable products design, considering the economic, environmental and social performance of associated supply chains. Moreover, Pathak and Singh (2017: 2) illustrate that sustainable product design can be the core in all the traditional design methodologies in which the desired outcome is a sustainable product. Furthermore, Gholami *et al*. (2021:2) and Alves *et al*. (2023:6) point out the need to consider a holistic approach in sustainable product, as they claim that the initial 'R's' approach supported by three principles, reduce, reuse and recycle must be extended to a broad vision of sustainable product, considering three new activities that complemented the 6R's strategy: reduce, reuse, recovery, redesign, remanufacture and recycle. The 6R's strategy allows transforming from an open loop, single life-cycle paradigm to a theoretically closed-loop, multiple life-cycle paradigm. Subsequently, Sartal *et al*. (2020:5) mention that the closed-loop production systems seek efficiency in the flows of materials, components, and energy throughout the successive life cycles of the product during multiple phases of use by encouraging reuse or, if not possible, remanufacturing.

Accordingly, Jawahir and Bradley (2016:105) demonstrate that in the 6R's methodology, reduce mainly focuses on the first three stages of the product life cycle and refers to the reduced use of resources in pre-manufacturing, reduced use of energy and materials during manufacturing and the reduction of waste during the use stage. On the other hand, Feil *et al*. (2019:3) illustrate that the reuse refers to the reuse of the product or its components, after its first life cycle, for subsequent life cycles to reduce the usage of new raw materials to produce such products and components. Furthermore, Alves *et al*. (2023:6) clarify that recycling involves the process of converting material that would otherwise be considered waste into new materials or products. Also, Mata-Lima *et al*. (2017:93) state that the process of collecting products at the end of the use stage, disassembling, sorting and cleaning for utilization in subsequent life cycles of the product is referred to as recovery. Over and above that, Umeh *et al*. (2022:88) explain that the act of redesigning products to simplify future post-use processes, to make the product more sustainable is referred to as redesign. Finally, Chourasiya *et al*. (2024:2) demonstrate that remanufacture involves the re-processing of already used products for restoration to their original state or a like-new form through the reuse of as many parts as possible without loss of functionality.

d- Practices

Sustainable practices enable sustainable value creation for industrial organizations (Abdullahi and Abdullah, 2015:490). As mentioned by Qureshi *et al*. (2015:48), sustainable practices are a toolbox full of methods that can be used to eliminate waste from manufacturing processes. While Sony (2019:11) states that sustainable practices are a set of skills and leverages that allow an organization to structure its manufacturing processes to achieve sustainable performance. Furthermore, Magd and Henry (2020: 2781) argue that manufacturing organizations have taken a hypothetical shift towards sustainable practices in business production to overcome prevailing challenges. Additionally, Pathak and Singh (2017:1) clarify that sustainable practices are a term used to describe manufacturing practices that do not harm the environment during any part of the manufacturing process. In this context, Lee *et al*. (2021: 68419) developed a decision-making framework for costing and environmental management aspects to enhance sustainable practices.

According to Lucato *et al*. (2018:2), As a starting point, the organization should define its sustainability policy and establish the objectives. Also, Chourasiya *et al.* (2024:10) state that manufacturers and decision makers, who need to remain successful in their fields, should practice and establish a sustainability culture in industries as these are key requirements of today and future. Sony (2019:19) supports this view, pointing out that the effort to change the culture should not be in isolation but should be studied as a combination of both organizational strategy and environment. Moreover, Gholami *et al*.(2021:9) and Mata-Lima *et al.*(2017:91) illustrate that several manufacturing organizations elaborate a plan of action for the implementation of sustainability practices and have been working to achieve sustainability by updating their vision, mission, and strategic plans to account for the principles of sustainable development in their organizations' everyday operations. In addition, Sharma *et al*. (2016:12) stress that strong business ethics and public image are important and critical enablers for SM practices.

Consequently, Brauner *et al*. (2022:8) state that sustainable practices promote organizational learning and increase awareness and sustainable understanding. Over and above that, Feil *et al*. (2019:4) explain that sustainable practices provide a tool to measure the organization's achievements of sustainability goals and provide a tool that encourages stakeholder involvement in decision making. In this sense, Sharma *et al*. (2016:8) argue the importance of top management commitment in the successful implementation of SM practices, as they illustrate that top management commitment plays a significant role in translating external pressures into desired managerial actions. Furthermore, Pandey *et al*. (2023:618) and

Sharma (2021:62) demonstrate that clean technology plays a significant role in successful implementation of SM practices, so the technological advancements and process planning reduce energy and resource intake, toxic wastes, and occupational hazards. On the other hand, Sartal *et al*. (2020:7) point out that SM practices includes the planning activities, responsibilities, procedures, processes, resources and making appropriate strategic and operational decisions for developing, achieving, reviewing and maintaining the environmental policy. As mentioned by Umeh *et al*. (2022:83), SM practices seek to reduce environmental impacts, improve energy and resource efficiency, minimal waste generation, and operational personnel health while maintaining or improving product and process quality with overall life-cycle cost benefits. Finally, Vishwakarma *et al*. (2024:379) state that SM practices are eco-efficient and eco-effective focused on systematically eliminating waste streams from entering the environment, considering the product's entire life cycle and practices that restore renewable resources.

2. Operational Performance Excellence

The above model illustrates 4 dimensions to measure OPE, namely: (a) Cost, (b) Quality, (c) Flexibility, and (d) Speed. These dimensions are critical metrics used to evaluate manufacturing operations. So, performing promptly (speed), doing it effectively and cheaply (cost), doing it with more elastic approach (flexibility), and doing it with high standards (quality) play a unique role in ensuring the overall efficiency and success of an organization OPE.

a-Cost:

Cost is one of the most important factors every organization considers by evaluating its day-to-today operations (Faizan and Haq ,2022:16). As mentioned by Princewill and Umoh (2022:306), Cost is a common and important measure in evaluating operational performance as it is the combination of resources, time, energy, and other variables that is undertaken by the organization to produce goods or services. Furthermore, Sylva (2020: 302) states that cost is the total amount or required payment incurred by the organization to carry out every specific activity or operation to manufacture a product or create utility. In this context, Saleh (2015: 45) strongly emphasizes that organizations that are environmentally respectful, expand their manufacturing sustainability efforts to reduce the overall costs through reducing the wasteful use of resources, minimizing waste, maximizing resource utilization, and eliminating non-value-added activities.

Moreover, Mostafa (2023: 95) states that every organization is looking and focusing on being cost effective. In this context, Saoudi and Dehane (2020:716) support this view, emphasizing more on generating sustainable value, and considers sustainability as a major aspect that modern organizations should consider along with delivering value, change and enhancing performance. Subsequently, Hwang *et al*. (2014: 50) mention that in manufacturing organizations, cost is a critical measure of efficiency, and it reflects the overall manufacturing operations currently operating inside the organization. Thus, Princewill and Umoh (2022:305) confirm that to enhance OPE, enhance production to the barest minimal cost by assigning a SM environment that attains the peak of production by doing things differently, promptly, and at lower cost.

b-Quality:

Quality is a strategic tool that ensures the achievement of operational efficiency, also it is working or producing without errors or defects in the production, as well maintaining the operations easy (Faizan and Haq ,2022:16). In this context, Santos *et al*. (2019:12) support this view, pointing out that organizations are expected to expand their manufacturing sustainability efforts to do things right from the first time and every time to reduce product defects and maintain product quality, reduce costs, and increase dependability. Furthermore, Princewill and Umoh (2022:306) stress that quality is a major facet of operational performance entails doing the right things according to specification and they clarify that high quality reduces costs as well as increase reliability.

Moreover, Sylva (2020: 302) argued that quality is the challenge of OPE. Additionally, Elyazid (2016:2) strongly emphasis that quality and elimination of waste are the two foundation principles that govern a state of manufacturing excellence. This means that the less mistake while producing goods and services will make it more cost effective as the resources, time, and money will not be wasted. Substantially, Saoudi and Dehane (2020:704) confirm that quality philosophy ensures achieving OPE, in which managers strive to create a SM environment that ensures their survival and prosperity.

c- Flexibility:

Now, in the era of globalization, the dynamic environment requires organizations to operate more efficiently to maintain their position and compete effectively, with flexibility serving as a crucial tool, as flexibility is the ability in an organization's operations to be as elastic as the need of an hour (Faizan and Haq ,2022:13). According to Mostafa (2023: 95), Flexibility is the ability to being able to change in either, what, how and when so that it reflects the ability of the organization's operations to introduce new or modified products or services. Moreover, Princewill and Umoh (2022:306) state that operational performance should reflect the flexibility in the operations strategy, and clarify that better operational performance cannot ignore flexibility, as it is such an important strategic variable that satisfy more customers, increase revenue and profit. Furthermore, Elyazid (2016:5) states that flexibility is critical, as it refers to the ability to make fast changes because of the demand of the new management concepts of e-commerce, speed-to-market, and flexible manufacturing.

Additionally, Mostafa (2023: 95) mentions that flexibility inside the organization is important as it is the key for the organization's survival because it speeds up responses to change, saves time and maintains dependability. In this context, Saoudi and Dehane (2020:714) support this view, emphasizing more on ensuring flexibility in adapting to changes. In this sense, Santos *et al.* (2019:1) state that achieving the necessary flexibility is essential to enable organizations to progressively improve. Subsequently, Hwang *et al.* (2014: 52) mention that flexibility is one of the performance attributes and most of the performance metrics take charge of activities such as production flexibility. Thus, Flexibility is regarded as widening the range of the operations and makes it more elastic, so flexibility in the operations can bring adaption and lead the organization towards OPE.

d- Speed:

Speed is a vital objective to ensure that the operations are effective as well efficient for the organization (Mostafa, 2023: 95). According to Faizan and Haq (2022:14), Speed is performing promptly that ensures that the operational performance is done properly. As mentioned by Puriwat and Tripopsakul (2014:45), Speed refers to execute the operational performance promptly to support the organization's operational excellence. Moreover, Sylva (2020: 302) argued that speed, responsiveness (on-time delivery) are the challenges of operational performance in the work environment. Furthermore, Elyazid (2016:2) states that speed is a crucial element in all phases of the value chain, as organizations can reduce time by redesigning products and processes, reworking a product and unnecessary movements of materials and subassemblies, by eliminating waste, and by eliminating non-value-added activities.

Accordingly, Princewill and Umoh (2022:306) argue that speed usually defines the operating performance of any process as it includes order-to-delivery times, lead times, and cycle times for specific processes, so it refers to how quickly an organization can complete processes, as it encompasses the time it takes to complete a cycle of activities such as start to end of production. In this context, Longmuir *et al.* (2020: 18) point out that organizations should focus on delivering sustainable value to do things right from the first time and every time, reduce order-time, lead-time, improve the effectiveness of using raw material and distribution capacity. In addition, Saoudi and Dehane (2020:717) strongly emphasize that boosting the speed that delivers the required strategic and operational results quickly is vital for achieving OPE. Consequently, with more speed there is more dependability, and the value it generates is that it drives the OPE of the organization.

Thus, OPE dimensions collectively serve as essential tools that are used as a yardstick to support an organization's OPE.

Fourth: Statistical Results and Analysis:

The extent to which the concepts of study were correctly defined in the measures was a major consideration. According to Veal (2011), the questionnaire is pilot tested on a small sample of participants to check whether the questions are clear and easy to answer, and whether accurate data will be gathered from the field data collection. The questionnaire is accompanied by an introduction about the purpose of the questionnaire and some of the main definitions, while assuring confidentially of any information given.

Measurement Model Assessment

Reliability assessment is performed to examine the internal consistency of the measurement scales, determining whether the indicators within each construct demonstrate adequate coherence and stability. This evaluation encompasses multiple reliability measures, including individual item loadings, composite reliability, and Cronbach's alpha coefficients. Convergent validity, on the other hand, assesses the extent to which indicators of the same construct share a high proportion of variance in common, demonstrating that they effectively measure the intended theoretical concept. The assessment of convergent validity involves examining factor loadings, Average Variance Extracted (AVE), and the statistical significance of item-to-construct relationships.

The measurement model assessment as illustrated in Figure (5) follows established thresholds and criteria recommended by leading scholars in PLS-SEM methodology. Individual item loadings should exceed the minimum threshold of 0.708, indicating that each indicator shares more variance with its construct than with the error term.

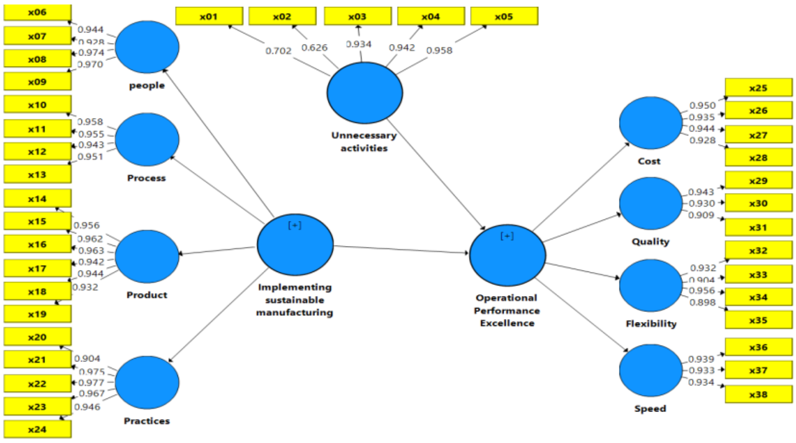


Figure (5): Measurement Model

Source: From the results of running data on Smart PLS V.3.

As shown in Table (2), statistical significance of loadings is evaluated through t-values and p-values derived from bootstrapping procedures, while confidence intervals provide additional insights into the precision and stability of the loading estimates. The examination of factor loadings reveals strong psychometric properties across all constructs in the study. The results demonstrate that all individual item loadings substantially exceed the recommended threshold of 0.708, with loading values ranging from 0.626 to 0.977, indicating robust relationships between indicators and their respective latent constructs. The statistical significance of these loadings is confirmed by consistently high t-values and p-values of zero across all items, demonstrating that the relationships between indicators and constructs are statistically significant at conventional levels.

Table (2): Item Loadings

Item <- Construct	Loading	t-value	P-value	95% CI for Loading	
				LL	UL
x01 <- Unnecessary activities	0.702	11.485	0	0.55	0.799
x02 <- Unnecessary activities	0.626	8.288	0	0.456	0.746
x03 <- Unnecessary activities	0.934	85.29	0	0.911	0.954
x04 <- Unnecessary activities	0.942	96.712	0	0.921	0.96
x05 <- Unnecessary activities	0.958	143.201	0	0.945	0.971
x06 <- people	0.944	71.983	0	0.914	0.964
x07 <- people	0.928	64.233	0	0.894	0.95
x08 <- people	0.974	170.13	0	0.961	0.983
x09 <- people	0.97	161.742	0	0.957	0.98
x10 <- Process	0.958	124.581	0	0.94	0.97
x11 <- Process	0.955	110.487	0	0.934	0.969
x12 <- Process	0.943	85.706	0	0.919	0.961
x13 <- Process	0.951	102.823	0	0.929	0.966
x14 <- Product	0.956	96.483	0	0.933	0.972
x15 <- Product	0.962	106.144	0	0.942	0.976
x16 <- Product	0.963	81.13	0	0.935	0.98
x17 <- Product	0.942	64.319	0	0.908	0.965
x18 <- Product	0.944	79.162	0	0.916	0.965
x19 <- Product	0.932	58.18	0	0.893	0.956
x20 <- Practices	0.904	46.923	0	0.861	0.938
x21 <- Practices	0.975	162.179	0	0.962	0.985
x22 <- Practices	0.977	248.632	0	0.968	0.984
x23 <- Practices	0.967	134.805	0	0.951	0.98
x24 <- Practices	0.946	80.334	0	0.918	0.965
x25 <- Cost	0.95	94.583	0	0.928	0.968
x26 <- Cost	0.935	55.18	0	0.896	0.961
x27 <- Cost	0.944	73.821	0	0.914	0.964
x28 <- Cost	0.928	75.039	0	0.899	0.949

x29 <- Quality	0.943	92.9	0	0.919	0.959
x30 <- Quality	0.93	72.433	0	0.901	0.95
x31 <- Quality	0.909	65.419	0	0.879	0.932
x32 <- Flexibility	0.932	81.967	0	0.907	0.951
x33 <- Flexibility	0.904	48.301	0	0.86	0.931
x34 <- Flexibility	0.956	106.861	0	0.936	0.97
x35 <- Flexibility	0.898	53.649	0	0.86	0.925
x36 <- Speed	0.939	84.595	0	0.913	0.957
x37 <- Speed	0.933	90.484	0	0.912	0.952
x38 <- Speed	0.934	96.738	0	0.913	0.951

Source: From the results of running data on Smart PLS V.3.

As indicated in Table (1), the Unnecessary Activities construct exhibits strong factor loadings, with values ranging from 0.626 (x02) to 0.958 (x05). Also, the dimensions of SM demonstrate outstanding measurement properties, exhibiting strong factor loadings with values ranging from 0.904 to 0.977. The dependent variable constructs as well exhibit strong measurement properties, as all dependent variable constructs maintain statistical significance with high t-values and narrow confidence intervals, confirming their measurement reliability and convergent validity. The comprehensive assessment of factor loadings confirms that the measurement model meets established criteria for reliability and convergent validity, providing a solid foundation for subsequent structural model evaluation and hypothesis testing. The consistently high factor loadings, significant t-values, and appropriate confidence intervals across all constructs demonstrate that the measurement instruments effectively capture their intended theoretical concepts.

The evaluation of internal consistency reliability represents a fundamental component of measurement model assessment, internal consistency reliability is assessed through multiple complementary measures, including Cronbach's alpha, composite reliability (rho_A), composite reliability (rho_c), and Average Variance Extracted (AVE), each providing unique insights into the psychometric properties of the measurement scales. These reliability indicators collectively determine whether the constructs exhibit sufficient internal consistency to support meaningful interpretation of structural relationships and hypothesis testing outcomes. Cronbach's alpha and composite reliability values should exceed 0.70 as suggested by Hair *et al.* (2017) for acceptable reliability.

As shown in Table (2), the internal consistency reliability results demonstrate exceptional psychometric properties across all constructs in the measurement model. The Cronbach's alpha coefficients range from 0.894 to 0.988, substantially exceeding the recommended threshold of 0.70 and achieving levels that indicate excellent internal consistency reliability. These values suggest that the indicators within each construct demonstrate strong intercorrelations and consistently measure their intended theoretical concepts, providing confidence in the measurement quality and interpretability of subsequent analyses. The composite reliability values, which provide a more robust estimate of internal consistency by accounting for the actual factor loadings rather than assuming equal weights, range from 0.923 to 0.989. These values surpass both the minimum threshold of 0.70 and the preferred threshold of 0.80, indicating excellent reliability across all constructs. The composite reliability estimates consistently exceed their corresponding Cronbach's alpha values, which are expected given that composite reliability accounts for the varying factor loadings of individual indicators, as recommended by Hair *et al.* (2019).

Table (3): Reliability and Convergent validity

Dimensions	Cronbach's Alpha	Rho_A	Composite Reliability	Average Variance Extracted
people	0.967	0.968	0.976	0.911
Process	0.965	0.965	0.975	0.906
Product	0.978	0.978	0.982	0.902
Practices	0.975	0.977	0.981	0.911
Cost	0.955	0.956	0.968	0.882
Quality	0.919	0.919	0.949	0.86
Flexibility	0.941	0.942	0.958	0.851
Speed	0.929	0.929	0.955	0.875
Unnecessary activities	0.894	0.938	0.923	0.712

Implementing SM	0.988	0.988	0.989	0.823
OPE	0.984	0.984	0.986	0.831

Source: From the results of running data on Smart PLS V.3.

As indicated in Table (3), the Average Variance Extracted values demonstrate strong convergent validity, with most constructs achieving AVE values well above the minimum threshold of 0.50. The higher-order constructs of Implementing SM and OPE achieve AVE values of 0.823 and 0.831 respectively, indicating strong convergent validity at the aggregate construct level.

The consistency between Cronbach's alpha and composite reliability values across all constructs provides additional evidence of measurement stability and reliability. The higher-order construct of Implementing SM achieves outstanding reliability metrics with Cronbach's alpha and composite reliability values of 0.988 and 0.989 respectively. These comprehensive reliability results provide strong empirical support for the measurement model's psychometric quality and establish a solid foundation for structural model assessment and hypothesis testing. The exceptional reliability and convergent validity demonstrated across all constructs enhance confidence in the validity of subsequent analytical procedures and the interpretability of research findings, aligning with best practices in PLS-SEM methodology as outlined by Henseler *et al.* (2015).

Testing the Research Hypotheses

Data have been analyzed by combining the strengths of Smart PLS V.3 for Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis with IBM SPSS V.29 for descriptive and inferential statistics, and that to examine the effect of the independent variable (SM) on OPE and the effect of Unnecessary Activities on OPE. A PLS-SEM analysis was used to test the proposed model. SEM has numerous advantages in data analysis as it allows the evaluation of the complex and multidimensional relationship among variables; in addition, it has the ability to represent unobserved concepts in these relationships and account for measurement error in the estimation process (Levy *et al.*, 2017). The descriptive statistics reveal distinct patterns in respondent perceptions across different dimensions of the study variables. The results demonstrate a clear dichotomy between responses to items measuring unnecessary activities and those assessing SM implementation and OPE.

- **Study the variable " Unnecessary Activities "**

Table (4): Descriptive Measures of Unnecessary Activities

SN	Item	Mean	SD
x01	The presence of several unnecessary activities in the production process leads to multiple forms and types of waste along the production line	1.80	0.661
x02	The presence of several unnecessary activities in the production process leads to production bottlenecks.	1.85	0.681
x03	Implementing sustainable manufacturing eliminates all unnecessary activities that do not add value to the production process.	1.99	0.906
x04	Implementing sustainable manufacturing leads to reducing waste in all its forms during the operating process.	1.95	0.927
x05	Sustainable manufacturing allows the removal of bottlenecks in production lines when performing processes and activities.	1.90	0.960
Unnecessary activities		1.900	0.706

Source: From the results of running data on a SPSS V.29 program.

As shown in Table (4), Items x01 through x05, which measure unnecessary activities in production processes, exhibit notably low mean values ranging from 1.80 to 1.99, indicating strong disagreement with statements describing negative aspects of current operations. These low means suggest that respondents generally perceive minimal presence of unnecessary activities and waste in their production processes. The standard deviations for unnecessary activities items range from 0.661 to 0.960, indicating relatively low variability in responses and suggesting general consensus among participants regarding the limited presence of unnecessary activities. This pattern aligns with the theoretical expectation that well-managed manufacturing organizations would demonstrate minimal unnecessary activities.

Table (5): Results of Skewness and Kurtosis values for Unnecessary Activities

Variable	Mean	SD	Skewness	Kurtosis
Unnecessary activities	1.900	0.706	0.839	-0.045

Source: From the results of running data on a SPSS V.29 program.

As indicated in Table (5), The Unnecessary Activities construct shows the lowest mean at 1.900 with a standard deviation of 0.706, indicating strong consensus among respondents regarding the minimal presence of wasteful activities in their operations. The Unnecessary Activities construct exhibits positive skewness at 0.839, indicating right-skewed distribution with most responses concentrated at lower scale values, also Kurtosis value is -0.045 reflecting disagreement with statements about unnecessary activities.

- **Study the variable " Implementing sustainable manufacturing "**

Table (6): Descriptive Measures of Sustainable Manufacturing implementation and its dimensions

SN	Item	Mean	SD
x06	Necessary training courses are received that promote a culture of sustainability.	3.84	1.241
x07	Work is performed in a safe and healthy workplace.	3.82	1.181
x08	You feel satisfied about being empowered to make decisions concerning your work.	3.46	1.310
x09	You feel satisfied about being involved in sustainability initiatives.	3.58	1.396
People		3.676	1.225
x10	The manufacturing process is done using sustainable, recyclable materials.	4.01	1.165
x11	The manufacturing process minimizes product waste and determines how and where value is added.	3.84	1.264
x12	The manufacturing process improves and simplifies the production flow and eliminates activities that do not add value to the final product.	3.87	1.248
x13	The manufacturing process optimizes the utilization of the available resource.	4.04	1.185
Process		3.941	1.157
x14	The product and its components are reused to reduce the use of new components and raw materials in its production.	3.89	1.098
x15	The product is recycled.	3.84	1.060
x16	The product has been redesigned to be more sustainable	3.90	1.086
x17	The product is disassembled, sorted and cleaned at the end of the usage phase to be utilized and used in the subsequent product life cycle.	3.79	1.066

x18	The product is remanufactured by reusing as many of its parts as possible to restore its original condition.	3.68	0.956
x19	The manufacturing of the product is based on reducing waste and optimizing the use of available resources.	3.75	1.012
Product		3.809	0.994
x20	The culture of sustainability is promoted in the company's organizational and environmental strategy.	3.97	0.980
x21	Sustainability practices are considered in daily operations.	3.90	1.148
x22	Business ethics are based on practicing sustainable manufacturing while performing work.	3.83	1.394
x23	Production procedures are followed to reduce resource consumption and reduce waste and occupational risks resulting from the manufacturing process.	3.92	1.183
x24	The working environment – according to sustainable manufacturing – is compatible with the physical operating needs.	3.65	1.340
Practices		3.855	1.156
Implementing SM		3.820	1.082

Source: From the results of running data on a SPSS V.29 program.

As shown in Table (6), items measuring SM implementation across the People, Process, Product, and Practices dimensions demonstrate substantially higher mean values, typically ranging from 3.46 to 4.21. The People dimension shows mean values between 3.46 and 4.01, with item x06 (training courses promoting sustainability culture) achieving the highest mean at 3.84. The relatively high standard deviations in this dimension, ranging from 1.181 to 1.396, suggest moderate variability in respondent perceptions regarding people-related SM practices. The Process dimension exhibits mean values from 3.84 to 4.04, with item x13 (optimizing resource utilization) achieving the highest mean at 4.04. The standard deviations range from 1.185 to 1.264, indicating moderate consensus among respondents. These results suggest that process-related SM practices are well-established within the organization. The Product dimension demonstrates mean values between 3.68 and 3.90, with generally consistent standard deviations ranging from 0.956 to 1.098. The relatively lower means compared to other dimensions may indicate that product-related sustainability initiatives require further development, particularly in areas such as remanufacturing and end-of-life product management. The

Practices dimension shows strong performance with mean values ranging from 3.65 to 3.97, and standard deviations between 0.980 and 1.394. Item x20 (promoting sustainability culture in organizational strategy) achieves the highest mean at 3.97, indicating strong organizational commitment to sustainability practices.

Table (7): Results of Skewness and Kurtosis values for Sustainable Manufacturing implementation and its dimensions

Dimensions	Mean	SD	Skewness	Kurtosis
people	3.676	1.225	-1.222	-0.053
Process	3.941	1.157	-1.251	0.072
Product	3.809	0.994	-1.226	0.593
Practices	3.855	1.156	-1.092	-0.164
SM implementation	3.820	1.082	-1.323	0.029

Source: From the results of running data on a SPSS V.29 program

As shown in Table (7), the mean values demonstrate a clear pattern consistent with the theoretical framework, where SM dimensions exhibit substantially higher means compared to unnecessary activities. The People dimension shows a mean of 3.676, Process achieves 3.941, Product reaches 3.809, and Practices attains 3.855, indicating generally positive perceptions of SM implementation across all dimensions. The standard deviation values provide insights into response variability, with most constructs exhibiting moderate dispersion ranging from 0.994 to 1.225. The skewness statistics reveal predominantly negative values across SM ranging from -1.092 to -1.323, indicating left-skewed distributions where most responses cluster toward higher scale values. This pattern suggests general agreement among respondents regarding positive aspects of SM. Kurtosis values remain within acceptable ranges for most constructs, generally between -0.164 and 0.593, indicating distributions that approximate normal distribution characteristics.

- **Study the variable " Operational Performance Excellence "**

Table (8): Descriptive Measures of Operational Performance Excellence and its dimensions

SN	Item	Mean	SD
x25	A sustainable manufacturing environment is promoted where production occurs through reducing the wasteful use of resources, minimizing waste, maximizing resource utilization, and eliminating non-value-added activities.	4.10	1.165
x26	Manufacturing sustainability efforts occur to reduce the overall costs.	3.97	1.206
x27	The presence of several unnecessary activities in the production process increases the cost of operational performance.	4.03	1.121
x28	Sustainable manufacturing is the best model in production systems because it reduces the cost of operational performance.	4.17	1.054
Cost		4.066	1.068
x29	A small improvement is made on a regular basis to eliminate waste in all its forms.	3.95	1.102
x30	Things are done right from the first time and every time.	4.02	1.143
x31	Sustainable manufacturing is the best model in production systems because it achieves the quality of operational performance.	4.21	1.066
Quality		4.059	1.024
x32	Production processes are highly in response to change.	3.71	1.131
x33	Production processes are gradually improved to ensure flexibility in adapting to changes.	3.84	1.041
x34	The presence of several unnecessary activities in the production process makes it difficult for operational performance to respond to change.	4.06	1.142
x35	Sustainable manufacturing is the best model for production systems because it enables operational performance to respond quickly to change.	4.16	0.982
Flexibility		3.941	0.992
x36	The production cycle is characterized by the speed of completion of operations at all stages of the value chain.	3.74	0.994
x37	The presence of several unnecessary activities in the production process causes the production cycle to slow down in completing operations.	4.21	1.056
x38	Sustainable manufacturing is the best model in production systems because it achieves speed in operational performance.	4.08	1.240
Speed		4.007	1.027
OPE		4.018	1.005

Source: From the results of running data on a SPSS V.29 program

As indicated in Table (8), the OPE dimensions demonstrate consistently high mean values, suggesting positive perceptions of organizational performance outcomes. The Cost dimension exhibits means from 3.97 to 4.17, the Quality dimension shows means between 3.95 and 4.21, and the Flexibility dimension demonstrates means from 3.71 to 4.16, while the Speed dimension exhibits means between 3.74 and 4.21. These results support the theoretical framework proposed by the study. The standard deviations across operational performance items generally range from 0.982 to 1.240, indicating moderate variability in responses. This variability suggests that while there is general agreement regarding positive performance outcomes, some respondents may have differing experiences or perceptions regarding the extent of performance improvements achieved through SM implementation.

Table (9): Results of Skewness and Kurtosis values for Operational Performance Excellence and its dimensions

Dimensions	Mean	SD	Skewness	Kurtosis
Cost	4.066	1.068	-1.178	-0.001
Quality	4.059	1.024	-1.146	-0.225
Flexibility	3.941	0.992	-1.213	-0.118
Speed	4.007	1.027	-1.292	0.421
OPE	4.018	1.005	-1.280	0.010

Source: From the results of running data on a SPSS V.29 program

As shown in Table (7), the OPE constructs demonstrate the highest mean values, with Cost achieving 4.066, Quality reaching 4.059, Flexibility at 3.941, and Speed at 4.007. These elevated means suggest strong perceived benefits on operational outcomes. The aggregated constructs of OPE show means of 4.018, reinforcing the positive perceptions across the theoretical model. The skewness statistics reveal predominantly negative values across operational performance constructs, ranging from -1.146 to -1.213, indicating left-skewed distributions where most responses cluster toward higher scale values. This pattern suggests general agreement among respondents regarding positive aspects of performance outcomes. Kurtosis values remain within acceptable ranges for most constructs, generally between -0.225 and 0.421, indicating distributions that approximate normal distribution characteristics.

- **By measuring the correlation between the study variables, the results are as follows:**

Table (10): Correlation Matrix between the Hypotheses' Variables

Variables	people	Process	Product	Practices	Cost	Quality	Flexibility	Speed	Unnecessary activities	Implementing SM
people	--									
Process	.905***	--								
Product	.872***	.863***	--							
Practices	.917***	.902***	.827***	--						
Cost	.902***	.905***	.844***	.909***	--					
Quality	.914***	.900***	.837***	.905***	.934***	--				
Flexibility	.924***	.912***	.844***	.935***	.953***	.949***	--			
Speed	.909***	.889***	.831***	.899***	.933***	.929***	.953***	--		
Unnecessary activities	-.789***	-.751***	-.720***	-.791***	-.834***	-.799***	-.815***	-.756***	--	
Implementing SM	.970***	.962***	.928***	.957***	.933***	.933***	.948***	.926***	-.800***	--
OPE	.933***	.922***	.858***	.933***	.977***	.974***	.985***	.975***	-.819***	.956***

Source: From the results of running data on a SPSS V.29 program

As shown in Table (10), the correlation analysis reveals exceptionally strong and theoretically consistent relationships throughout the measurement model. The inter-correlations among SM dimensions demonstrate robust positive associations, with correlation coefficients ranging from 0.827 to 0.917. The correlations between SM dimensions and operational performance constructs provide compelling evidence for the theoretical relationships proposed in the study. All SM dimensions exhibit strong positive correlations with operational performance outcomes, with coefficients typically exceeding 0.830.

The correlation analysis reveals consistently strong negative relationships between Unnecessary Activities and all other constructs, with coefficients ranging from -0.720 to -0.834. These negative correlations support the theoretical proposition that unnecessary activities impede both SM implementation and OPE. The strongest negative correlation exists between Unnecessary Activities and Cost performance at -0.834, indicating that the presence of unnecessary activities substantially undermines cost-related performance outcomes. The aggregated constructs of Implementing SM and OPE demonstrate exceptionally strong positive correlation at 0.956, providing robust preliminary evidence for the central hypothesis of the study. This strong relationship suggests that comprehensive SM implementation is closely associated with enhanced operational performance across multiple dimensions. All correlation coefficients achieve statistical significance at the 0.001 level, providing strong evidence for the reliability of these relationships. The consistency of correlation patterns across multiple constructs and dimensions strengthens confidence in the theoretical model and supports progression to structural equation modeling analysis for hypothesis testing.

- **Path Coefficients of the study variables**

Path coefficients represent the standardized regression weights that quantify the strength and direction of causal relationships between latent constructs in structural equation modeling. These coefficients provide empirical evidence for testing theoretical hypotheses by measuring the direct effects of independent variables on dependent variables while controlling for other relationships within the model. In PLS-SEM analysis, path coefficients are interpreted similarly to standardized beta coefficients in multiple regressions, with values ranging from -1 to +1, where larger absolute values indicate stronger relationships.

The significance testing of path coefficients employs bootstrapping procedures to generate confidence intervals and calculate t-values for hypothesis evaluation. This non-parametric approach addresses the non-normal distribution of path coefficients and provides robust statistical inference for hypothesis testing. The evaluation criteria include examining the magnitude of path coefficients, their statistical significance levels, and the confidence intervals to determine whether hypothesized relationships receive empirical support. Path coefficients exceeding 0.20 are considered meaningful, while values above 0.50 represent strong relationships, and coefficients surpassing 0.80 indicate very strong effects.

The structural model analysis - as shown in Figure (6) - reveals compelling empirical evidence supporting the theoretical framework, with both primary hypotheses receiving strong statistical validation.

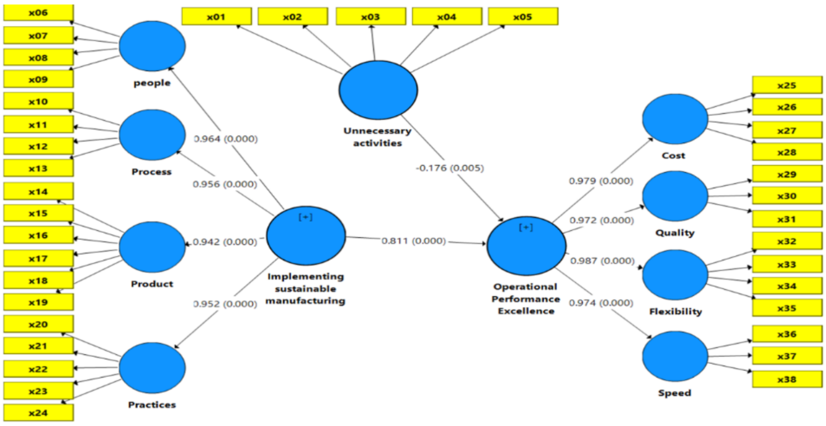


Figure (6): Structural Model

Source: From the results of running data on Smart PLS V.3.

The results of the evaluation of each individual path of Hypothesis H1 are summarized in Table (11) as follows:

Table (11): Results of Path Analysis for Hypothesis H1

H	Path	B	t-value	P-value	95% BCCI	
					LB	UB
H1	**Unnecessary activities -> OPE**	**-0.176**	**2.801**	**0.005**	**-0.289**	**-0.039**
H1a	Unnecessary activities -> Cost	-0.257	3.906	0	-0.395	-0.136
H1b	Unnecessary activities -> Quality	-0.162	2.282	0.023	-0.284	-0.004
H1c	Unnecessary activities -> Flexibility	-0.172	2.384	0.017	-0.298	0.001
H1d	Unnecessary activities -> Speed	-0.048	0.625	0.532	-0.19	0.114

Source: From the results of running data on Smart PLS V.3.

As indicated in Table (11), Hypothesis H1 examining the relationship between unnecessary activities and OPE, receives significant empirical support with a path coefficient of -0.176 and a t-value of 2.801 at p = 0.005. This negative relationship confirms the theoretical proposition that unnecessary activities in production processes adversely affect operational performance outcomes. The 95% confidence interval spanning from -0.289 to -0.039 excludes zero, reinforcing the statistical significance of this relationship. The disaggregated analysis reveals that unnecessary activities demonstrate the strongest negative impact on cost performance with a path coefficient of -0.257 (t = 3.906, p < 0.001), followed by flexibility at -0.172 (t = 2.384, p = 0.017) and quality at -0.162 (t = 2.282, p = 0.023). The relationship between unnecessary activities and speed performance shows a non-significant path coefficient of -0.048 (t = 0.625, p = 0.532), indicating that unnecessary activities may not directly impair speed-related performance outcomes.

All results support the hypothesis (H1) that: "There is a statistically significant relationship between unnecessary activities in the production process and achieving operational performance excellence ".

The results of the evaluation of each individual path of Hypothesis H2 are summarized in Table (12) as follows:

Table (12): Results of Path Analysis for Hypothesis H2

H	Path	B	t-value	P-value	95% BCCI	
					LB	UB
H2	**Implementing SM -> OPE**	**0.811**	**15.008**	**0**	**0.709**	**0.926**
H2a	Implementing SM -> Cost	0.724	11.53	0	0.584	0.834
H2b	Implementing SM -> Quality	0.799	13.371	0	0.688	0.921
H2c	Implementing SM -> Flexibility	0.807	13.678	0	0.694	0.935
H2d	Implementing SM -> Speed	0.886	13.98	0	0.764	1.012

Source: From the results of running data on Smart PLS V.3.

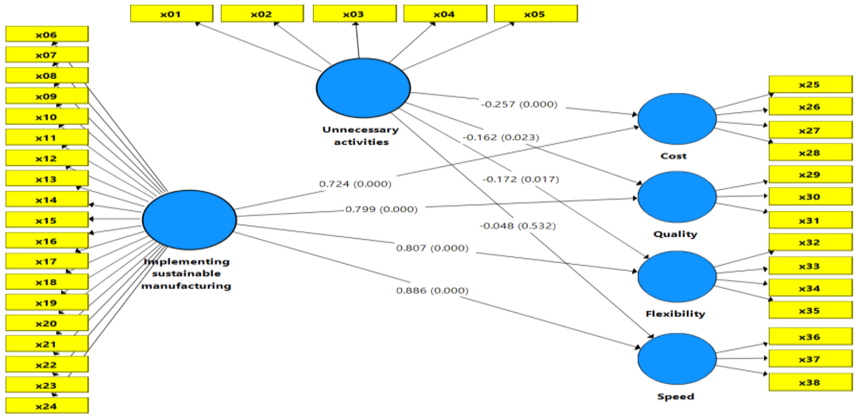
As shown in Table (12), Hypothesis H2, proposing a positive relationship between implementing SM and OPE, receives exceptionally strong empirical validation. The aggregate path coefficient of 0.811 with a t-value of 15.008 and p-value approaching zero demonstrates a very strong positive relationship that substantially exceeds conventional significance thresholds. The 95% confidence interval ranging from 0.709 to 0.926

confirms the robustness of this relationship and provides evidence for the practical significance of SM implementation in driving operational excellence.

The dimensional analysis of SM effects reveals consistent positive impacts across all operational performance dimensions. The strongest relationship emerges between SM implementation and speed performance, achieving a path coefficient of 0.886 ($t = 13.98$, $p < 0.001$). This finding demonstrates that sustainable practices enhance process efficiency and operational velocity. The relationship with flexibility demonstrates a path coefficient of 0.807 ($t = 13.678$, $p < 0.001$), indicating that SM practices significantly enhance organizational responsiveness and adaptability to changing operational requirements. The quality performance dimension exhibits a strong positive relationship with SM implementation, showing a path coefficient of 0.799 ($t = 13.371$, $p < 0.001$). This result supports theoretical propositions that SM practices contribute to quality improvements through waste reduction, process optimization, and enhanced resource utilization. The cost performance dimension demonstrates a path coefficient of 0.724 ($t = 11.53$, $p < 0.001$), representing the relatively weakest but still substantial positive relationship within the operational performance construct.

All results support the hypothesis (H2) that: "There is a statistically significant relationship between implementing sustainable manufacturing and operational performance excellence".

The results of the structural path for the Sub-Hypotheses Testing are summarized in Figure (7): as follows:



<u>Figure (7)</u>: Sub-Hypotheses Testing

<u>Source</u>: From the results of running data on Smart PLS V.3.

As shown in Figure (7), the structural path diagram effectively illustrates the theoretical model relationships, displaying the direct relationships between constructs and operational performance dimensions. The path coefficients displayed demonstrate consistency in relationship patterns and statistical significance levels, reinforcing confidence in the analytical results. The confidence intervals for all significant relationships exclude zero, providing additional evidence for the reliability of the empirical findings. The magnitude of the t-values, consistently exceeding conventional thresholds for significance testing, demonstrates the robustness of the relationships even when accounting for potential sampling variability through bootstrapping procedures.

These results provide comprehensive empirical validation for the theoretical framework, **supporting the sub-hypotheses branched out from hypothesis (H1) and hypothesis (H2)** and demonstrating that SM implementation serves as a critical driver of OPE while unnecessary activities represent significant impediments to performance outcomes.

To confirm the results, of PLS-SEM analysis, we evaluated the explanatory power and predictive relevance of the theoretical model, and got the following results:

Table (13): Structural Model path Assessment

Path	Effect Size	VIF
Unnecessary activities -> OPE	0.134	2.811
Unnecessary activities -> Cost	0.212	2.819
Unnecessary activities -> Quality	0.074	2.819
Unnecessary activities -> Flexibility	0.109	2.819
Unnecessary activities -> Speed	0.006	2.819
Implementing SM -> OPE	2.85	2.811
Implementing SM -> Cost	1.687	2.819
Implementing SM -> Quality	1.792	2.819
Implementing SM -> Flexibility	2.397	2.819
Implementing SM -> Speed	1.923	2.819

Source: From the results of running data on Smart PLS V.3.

As shown in Table (13), the structural model demonstrates exceptional explanatory power and predictive relevance across all measurement criteria. The effect size analysis reveals substantial practical significance for the relationship between implementing SM and OPE, achieving an effect size of 2.85. This value substantially exceeds Cohen's (1988) threshold of 0.35 for large effect sizes, indicating that SM implementation produces practically meaningful improvements in operational performance. The effect sizes for unnecessary activities relationships reveal more modest but meaningful impacts on operational performance outcomes. The aggregate effect of unnecessary activities on OPE achieves an effect size of 0.134, representing a small to medium effect according to Cohen's guidelines.

The variance inflation factor analysis confirms the absence of problematic multicollinearity within the structural model. All VIF values remain consistently at 2.811 and 2.819, well below the conservative threshold of 5.0 recommended by Hair *et al.* (2019) and substantially lower than the more liberal threshold of 10.0 suggested by some scholars. These VIF values indicate that the predictor constructs maintain sufficient independence to provide reliable path coefficient estimates without concerns regarding multicollinearity bias.

Table (14): Structural Model Construct Assessment

Construct	R-Square	Q-Square
OPE	0.918	0.754
Cost	0.89	0.771
Flexibility	0.904	0.76
Quality	0.874	0.741
Speed	0.855	0.738

Source: From the results of running data on Smart PLS V.3.

As shown in Table (14), the coefficient of determination values demonstrates exceptional explanatory power for all endogenous constructs within the model. OPE achieves an R-squared value of 0.918, indicating that the predictor variables explain approximately 92% of the variance in operational performance outcomes. Operational performance dimensions values indicate that between 85% and 90% of the variance in each operational performance dimension can be explained by the predictor constructs, demonstrating robust explanatory capability across all performance outcomes. Such high explanatory power provides strong evidence for the theoretical model's validity and suggests that SM implementation and unnecessary activities represent critical determinants of OPE.

The Q-squared values provide evidence for the model's predictive relevance, with all constructs achieving Q-squared values well above the threshold of zero required for predictive relevance. OPE demonstrates a Q-squared value of 0.754, indicating substantial predictive capability. The performance dimensions show Q-squared values ranging from 0.738 to 0.771, confirming that the model possesses meaningful predictive power for forecasting operational performance outcomes based on SM implementation and unnecessary activities levels.

These comprehensive structural model assessment results provide compelling evidence for the theoretical model's quality, explanatory power, and practical utility. The combination of large effect sizes, acceptable multicollinearity levels, exceptional explanatory power, and strong predictive relevance establishes the structural model as a robust framework for understanding the relationships between SM practices and OPE. **Accordingly, all results support hypotheses H1, H2 and their sub-hypotheses.**

Fifth: Results and Recommendations:

This last section introduces multiple results and recommendations, presents the major managerial implications and the limitations of the study, and suggests further studies.

1-Results:

The hypotheses test confirms the proposed model as follows:

a. The significant negative effects of unnecessary activities on operational performance underscore the importance of identifying and eliminating wasteful processes and activities within manufacturing operations, although respondents generally perceive minimal presence of unnecessary activities and wastes in their production processes.

b. The disaggregated analysis revealed that unnecessary activities demonstrated particularly strong negative effects on cost performance, followed by flexibility and quality dimensions. These results concern the detrimental effects of unnecessary activities on operational efficiency and operational performance outcomes.

c. The dimensional analysis showed that SM implementation produced the strongest positive effects on speed performance, followed by flexibility, quality, and cost dimensions, this aggregated constructs of implementing SM and OPE demonstrate exceptionally strong positive correlation at 0.956, providing robust preliminary evidence for the central hypothesis of the study.

d. The strong empirical relationships demonstrated across cost, quality, flexibility, and speed dimensions confirm the robustness of this relationship and provide evidence for the practical significance of SM implementation in driving operational excellence and generating broad-based performance improvements.

e. SM implementation and unnecessary activities elimination represent critical success factors for OPE. As SM implementation serves as a critical driver of OPE, unnecessary activities represent significant impediments to performance outcomes.

Accordingly, this study presented a valid and reliable structural model that considers the continuous nature of the pharmaceutical industry.

2- Recommendations:

After reviewing the results of the study, there are some key recommendations that could strengthen SM to improve OPE as follows:

a. Dissemination of the SM concept to identify and eliminate unnecessary activities, with a focus on improving cost efficiency and flexibility.
b. Develop well-defined roadmaps and frameworks for successful SM implementation in the pharmaceutical industry, positioning SM as a strategic approach to achieve OPE.
c. Apply SM across all production lines in the pharmaceutical company under study to eliminate waste, prevent bottlenecks and rework, and enhance OPE.
d. Disseminating an organizational culture based on eliminating waste across all production lines in the pharmaceutical company under study, adopting the concept of added value as the basis for production, shifting from a reactive approach to an action-driven approach to ensure continuous improvement in the production process.
e. Build a SM environment that balances the 4Ps of SM to integrate operational performance with environmental and social responsibility.
f. Regularly monitor KPIs for cost, quality, flexibility, and speed to ensure ongoing optimization.
g. Prioritize the full integration of Sustainable Manufacturing (SM) practices while systematically identifying and eliminating unnecessary activities, ensuring both initiatives are embedded as core elements of operational strategies to maximize OPE and minimize performance barriers.

3- Managerial Implications:

The results of this study bring deep insights for strategic decision-makers in executive roles and assist operational managers in supervisory positions; in particular those within Pharmaceutical Industries Sector, to establish, nourish, and promote SM implementation to achieve OPE. Regarding managerial implications, the results emerging from the present study help managers to understand and recognize the importance of the 4P's of SM that are significantly enhance the four operational performance indicators (cost, speed, quality & flexibility) which are more important for ensuring optimal operational performance to achieve operational excellence.

4-Limitations:

Although there are prominent contributions from this study; there are, however, some limitations including :(1) there are two types of oral liquid dosage forms are prepared on the liquid's preparation line located at the production floor of the company: solutions and suspensions; the present study is limited to the liquid dosage form preparation line of product (X) suspension because the increase in the number of unnecessary activities on this production line, which resulted in a longer production cycle time for manufacturing this product compared to other pharmaceutical products. (2)The data collected has certain limitations due to the number of samplings, time and the fact that the desire to keep the questionnaires simple and brief may limit the nature of the research questions. (3) The study focuses on the Pharmaceutical Industry to limit the impact of external factors based on the differences between industry sectors. Therefore, the conclusions drawn from this study should not be generalized to industry sectors in general. (4) The study investigates the relationship between only the core "4Ps" of SM - Product, Process, People, and Practices - and OPE. However, it does not consider other potentially influential Ps such as Profit, Planning, and Public Awareness, which could offer a more holistic understanding of sustainability's impact on OPE. (5) All employees working on the production line of product (X) were very busy, which affected their ability to complete the questionnaire in a timely fashion.

5-Further Studies:

The limitations emerging from the study shed the light on the need for further studies that should (1) Include various industrial sectors such as automotive, electronics, and textiles to actually be able to see how SM holds with them and to determine how sustainable practices uniquely affect OPE in different industrial contexts and to draw a better conclusion, (2) Study the implementation mechanisms and organizational conditions that facilitate successful SM adoption and influence the effectiveness of SM practices across different industrial settings and organizational contexts, (3) Use another statistical method to test the 4Ps of SM and see which of them will be more important to OPE, (4) Explore the positive effects of more Ps of SM on OPE as Profit, Planning, and Public Awareness to provide a more comprehensive analysis.

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