



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

**Dynamic Modeling of Transformation Capabilities towards
Circular Economy for Automotive Manufacturing Company of
Ethiopia (AMCE)**

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Declaration

I hereby declare that the work which is being presented in this thesis entitled **Dynamic Modeling of Transformation Capabilities towards Circular Economy for Automotive Manufacturing Company of Ethiopia (AMCE)** is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.

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Abstract

Manufacturing industries face enormous hindering factors during the production process. One of the reasons is the scarcity of raw materials. Automotive Manufacturing Company of Ethiopia (AMCE) is one of the industries who faced the raw material scarcity. This scenario forced the industry to operate only for about 10.7% of its annual production capacity. Using these scarce raw materials wisely is crucial. Hence, this research aimed to visualize the capability of the industry to use this scarce raw material circularly through reducing, reusing, and recycling (3R) mechanisms.

During data collection and analysis, both qualitative and quantitative data collection and analysis tools have been used. The data has been analyzed through system dynamics modeling of reducing, reusing, and recycling of raw material. The capability variables identified were technology, leadership, strategy, finance, human aspect, collaboration, culture and mindset. The strategic scenario has been developed through the change in the raw material input and automated work stations. As a result, the amount of waste accumulation decreases while reusing and recycling of scrap increases. As the automated work stations increase, the scraps recycling increase significantly.

The company has the capability to transform to a circular economy system through reducing the defect, reusing and recycling of metallic scraps in order to enhance the raw material availability. Automated work station development will decrease the amount of waste accumulation by an average of 58%. Therefore, it is safe to conclude that circular economy can be applied for wise raw material utilization in the case company.

Keywords: Resource Utilization, Circular Economy Implementation, Transformation Dynamic Capability, Sustainability.

Table of Contents

Title	Page
Declaration.....	ii
Abstract.....	iii
List of Figures.....	vii
List of Tables.....	viii
Acronym.....	ix
Acknowledgment.....	x
CHAPTER ONE.....	- 1 -
1. Introduction.....	- 1 -
1.1. Introduction and Background.....	- 1 -
1.2. Problem Statement.....	- 2 -
1.3. Research Questions.....	- 3 -
1.4. Objectives of the Research.....	- 3 -
1.4.1. General Objective.....	- 3 -
1.4.2. Specific Objective.....	- 3 -
1.5. Scope.....	- 3 -
1.6. Limitations.....	- 4 -
1.7. Significance.....	- 4 -
1.8. Organization of the Paper.....	- 4 -
CHAPTER TWO.....	- 6 -
2. Literature Review.....	- 6 -
2.1. Introduction.....	- 6 -
2.2. Definition.....	- 6 -
2.3. Concept of Circular Economy.....	- 7 -
2.3.1. Circular Economy Strategies.....	- 8 -
2.3.2. Circular Economy in Automotive Manufacturing Industries.....	- 9 -
2.3.3. Circular Economy Transformative Capabilities.....	- 10 -
2.3.4. Dynamic Modeling and system complexity in Circular Economy.....	- 10 -
2.4. Previous Research of Circular Economy Transformative Capabilities.....	- 11 -

2.4.1.	Literature gaps and findings.....	- 12 -
2.5.	Summary and Methodological review of literatures	- 15 -
CHAPTER THREE		- 16 -
3.	Methodology	- 16 -
3.1.	Introduction.....	- 16 -
3.2.	Background of Automotive Manufacturing Company of Ethiopia (AMCE)	- 16 -
3.3.	Research Design.....	- 17 -
3.4.	Data Collection Methods	- 18 -
3.5.	Sampling and Targeted Participants	- 20 -
3.6.	Data Analysis Methods	- 20 -
The complexity of the System		- 23 -
3.7.	Summarized Research Framework	- 25 -
CHAPTER FOUR.....		- 27 -
4.	Data Presentation and Simulation Model Development	- 27 -
4.1.	Introduction.....	- 27 -
4.2.	Data Collection Results.....	- 27 -
4.2.1.	Empirical Data	- 28 -
4.2.2.	Company Reuse, Reduce and Recycle Existing Status.....	- 29 -
4.2.3.	CE Transformative Capability Assessment	- 30 -
4.3.	System Dynamics Model Development.....	- 31 -
4.3.1.	Problem Clarification.....	- 31 -
4.3.2.	Formulation of Dynamic Behaviors and Model Boundary	- 31 -
4.3.3.	Simulation Model Formulation.....	- 34 -
4.3.4.	Casual Loop Diagrams and Cause & Effect Diagram Description	- 34 -
4.3.5.	Stocks and Flows	- 35 -
4.3.6.	Mathematical Formulation.....	- 35 -
4.3.7.	Model Verification and Validation	- 41 -
4.3.8.	Simulation Run, Result and Discussion.....	- 41 -
This scenario explores a rapid transition towards a circular economy for AMCE.		- 47 -
CHAPTER FIVE		- 53 -
5.	Conclusions and Recommendations	- 53 -
5.1.	Conclusion	- 53 -

5.2. Recommendations.....- 55 -

5.3. Future Study Area.....- 55 -

REFERENCES- 56 -

Annexes- 60 -

Annex 1: Observation Checklist and Interview Questions- 60 -

Annex 2: Secondary data collection checklist points.....- 60 -

Annex 4: Model cause and effect diagram description.....- 60 -

List of Figures

Figure 2-1: Literature selection summary	- 15 -
Figure 3-1: Actual Annual production	- 17 -
Figure 3-2: A summarized research framework.....	- 26 -
Figure 4-1: Annual scrape waste generation.....	- 29 -
Figure 4-2: RM inventory Causal Loop Diagram	- 34 -
Figure 4-3: CE transformative capability model for AMCE	- 40 -
Figure 4-4: RM Inventory Graph due to increasing the value of RM input.....	- 43 -
Figure 4-5: product inventory graph due to increasing the value of RM input.....	- 43 -
Figure 4-6: Reusing graph due to increasing the value of RM input	- 44 -
Figure 4-7: Recycling graph due to increasing the value of RM input	- 44 -
Figure 4-8: waste accumulation due to increasing the number of automated work stations.....	- 45 -
Figure 4-9: Reusing graph due to increasing the number of automated work stations	- 46 -
Figure 4-10: recycling graph due to increasing the number of automated work stations	- 46 -
Figure 4-11: Human Aspect capability behavior	- 48 -
Figure 4-12: collaboration capability behavior	- 48 -
Figure 4-13: culture and mindset capability behavior.....	- 49 -
Figure 4-14: waste accumulation behavior	- 49 -
Figure 4-15: Reusing rate behavior.....	- 50 -
Figure 4-16: technology capability behavior	- 51 -

List of Tables

Table 2-1: Literature Gaps	- 13 -
Table 3-1: Summary of data collection.....	- 19 -
Table 3-2: 3R Existing practice	- 21 -
Table 3-3: types of tests applied for model validation.....	- 24 -
Table 4-1: Raw material for a unit truck cargo manufacturing.....	- 28 -
Table 4-2: consumable chemicals required for a unit truck product manufacturing	- 28 -
Table 4-3: Key variables description	- 32 -
Table 4-4: Mathematical Formulation	- 38 -
Table 4-5: RM input increasing Scenario Description.....	- 41 -
Table 4-6: Automated work station increasing scenario description	- 42 -
Table 4-7: Strategy capability increasing scenario description.....	- 47 -
Table 4-8: Waste accumulation decreasing scenario	- 52 -
Table 0-1: Secondary Data Checklist points.....	Error! Bookmark not defined.
Table 0-2: Cause and effect diagram	- 60 -

Acronym

3R	Reduce, Reuse, Recycle
AMCE	Automotive Manufacturing Company Of Ethiopia
CDE	Circular Dynamic Capability
CE	Circular Economy
CKD	Completely Knocked-Down Components
DC	Dynamic Capability
FDI	Foreign Direct Investment
MIDI	Manufacturing Industry Development Institute
MoI	FDRE Ministry of Industry
MTEIRDC	Manufacturing Technology And Engineering Industries Research and Development Center

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CHAPTER ONE

1. Introduction

1.1. Introduction and Background

Since the 1960s, the concept of circular economy has been adopted in various countries and industries. This is because a circular economy can generate a robust model that allows manufacturing firms, as is the case of companies in the automotive industry, to meet the requirements of sustainable development (Maldonado-guzm & Garza-Reyes, 2021).

As a response to increasing pressure on natural resources, pollution, and waste generation, circular economy (CE) has been disseminated to propose a shift in existing industrial and consumption foundations. Although primarily concerned with economic prosperity and environmental aims, CE can contribute to achieving several sustainable development targets. At the industrial level, the adoption of CE as a business strategy entails a new business logic away from the 'take- make-use-dispose' (Pieroni et al., 2020) (Pieroni et al., 2021). The principles of the CE emphasize closed-loop material flows, by considering product reuse, remanufacturing, reprocessing, and recycling (Chizaryfard, 2020).

The concept of optimal resource utilization and sustainability forced automotive industries to tend their attention to using resources wisely. As an industrial engineering program, the use of automotive manufacturing resources (raw materials, additives, and utilities), products, and by-products need to be processed in a sustainable and optimal possible way. The end-of-life disposal mechanism needs to get an appropriate treatment mechanism.

From the automotive industry's perspective, the quality and cost of the products are decisive. The industry is facing issues regarding raw material scarcity, fuel economy, gas emissions, safety, and affordability. Moreover, the competitive pressures on the cost, quality, performance, and manufacturability of vehicles today are bigger than ever (Nina, 2019). Basically, due to the unavailability of fundamental iron ore extraction in

the local market, the Ethiopian automotive industries are severely affected by the availability of raw materials. This scenario forced them to use the international market as a solution to get the necessary components through foreign currency (which is one of the other insufficient national resources).

The issue of automotive industries resource utilization, sustainability, green manufacturing strategies, and the company's willingness are the main causes to take the Automotive Manufacturing Company of Ethiopia (AMCE) as a case company. Furthermore, the company will allow seeing both the assembly and manufacturing aspects of the automotive industry. Therefore, to use these resources sufficiently and effectively, a transformative strategy is needed that tends to the manufacturing system from a linear to circular perspective.

1.2. Problem Statement

The manufacturing industry faces a growing challenge in transitioning towards a circular economy strategy. The traditional linear method of “take, make, dispose” is no longer sustainable with concerns about resource depletion, waste generation, and environmental impacts(Kaswan & Rathi, 2020) (Ershadi et al., 2021).

Although the Automotive Manufacturing Company of Ethiopia (AMCE) was expected to manufacture 85% of its designed production capacity, it is indicated that the actual production performance of the company from 2016 to 2020 was 12%, 11%, 13%,8%, and 10% of its capacity respectively(MTEIRDC, 2021). There is a scarcity in raw material resource to achieve the planned capacity. Hence as a means of sustainability, circular economy with reducing, reusing, and recycling (3R) offers a promising solution.

However, while the benefits of circular economy are clear, the major hurdle lies in developing the capabilities necessary to effectively implement circular economy 3R principles in the company. Existing researches often focuses on static capabilities, overlooking the dynamic nature of circular economy in the automotive industry.

Therefore, this research aims to address the critical needs to understand the capabilities required for AMCE to successfully transform towards a circular economy by developing a dynamic model.

1.3. Research Questions

The research questions for this study are:

- A. What is the status of AMCE from the perspective of the circular economy system?
- B. What capabilities does the factory have to transform from its current state to a circular economy system?
- C. How do potential strategic scenarios enable the company to transform towards a circular economy system?

1.4. Objectives of the Research

1.4.1. General Objective

The main objective of this research is to investigate and model the transforming capabilities of the Automotive Manufacturing Company of Ethiopia (AMCE) towards a circular economy to visualize the resilience of the company to use raw material within circular loops of material flow.

1.4.2. Specific Objective

The specific objectives of the research are:

- To assess the existing practices of resource utilization of the company.
- To identify key strategic transforming capabilities and tools required for a circular economy within the industry.
- To formulate a simulation model, test and experiment with potential scenarios for a circular economy transformation.

1.5. Scope

This research focused on raw material circular utilization through reducing, reusing, and recycling for the Automotive Manufacturing Company of Ethiopia. The simulation model contains a five year time boundary. The variables included are Strategy, technology (Automated work station), finance, leadership, collaboration, human aspect, culture and mindset.

1.6. Limitations

One of the limitations of the research is that the automotive manufacturing sector of Ethiopia didn't have a detailed literature in its dynamic behavior. Even though it didn't affect the data collection procedure, the temporary production interruption has forced the researcher to change the schedule for data collection.

1.7. Significance

Regarding the significance of this research, it can be viewed in two aspects. Theoretically, the research will provide insight into resource utilization while using in a circular loop. It will show the possible process optimization indicators that contribute to waste minimization and wise use of resources. Practically, it will provide a positive impact on the Automotive Manufacturing Company of Ethiopia (AMCE) for effective resource utilization, and waste minimization as well as for the automotive manufacturing sub-sector as a whole. It will clearly show the existing practice of the industry. The incorporation of dynamic transformation capabilities with a circular economy strategy will enable the industry to minimize wastage, enhance efficient resource utilization, process safety enhancement, and compliance with regulatory bodies, cost minimization, and profit maximization. This enables the industry to be in a sustainable business operation and competent. As its profit maximizes, the industry will have a great contribution to the national revenue and provide routine input for the transportation sector.

1.8. Organization of the Paper

This research has five chapters. The first chapter describes the introductory section of the research with its background, problem statement, research questions, and scope of the study, significance and limitations. The related literature has been reviewed in the second chapter. The third chapter emphasized the methodological approach of the research such that the data collection, data analysis, and simulation model development methods have been discussed. The fourth chapter presents the collected data and its analysis in a suitable manner to model development. The overall data analysis and system dynamics

model development had been discussed in this chapter. The fifth chapter covers the conclusion and recommendation parts of this research.

CHAPTER TWO

2. Literature Review

2.1. Introduction

In this section, different articles, reviews, manuscripts, books and reports reviewed to get the relevant data on the basic knowledge. It mainly focused on the concept of circular economy, circular economy dynamic capabilities and system complexity, transformative capabilities, and previous researches on automotive industry circular economy transformation. Consequently, the literature gaps, and areas that need further researching have been identified.

2.2. Definition

The concept of sustainability and sustainable use has recently become a major focus area of business trends in manufacturing industries. In most manufacturing industries, the input-output parameters indicate the amount of raw materials used to provide the desired products in the production process. Successful optimization of maximum input utilization capacity increases the productivity and profitability of manufacturing industries. At the same time, the amount of waste generated in pre-production, production, and post-production processes is also observed to create environmental and economic problems related to resource utilization and compliance. Considering this and similar events, One of the strategies that emerged in the early 2000s was the concept of the circular economy, which is the principle of using the resources of manufacturing industries in circular loops(Zengwei Yuan, Jun Bi & S, 2006).

This study shows that the circular economy system is an ideal way to develop industrial systems that support resilience by delinking economic growth from material consumption. Yet, many studies are exploring the impact of circular economy business practices on resilience, and few studies detailing how firms, industries, and socio-ecological systems can adapt and change in the face of shocks and disruptions(Kennedy & Linnenluecke, 2022). Circular economy and circular business models are open to various criticisms beyond declaring principles regarding the necessity and possibility of a

transition to circularity and what they need and offer and therefore offer to a transition to circularity. It shows that it is necessary to work for such a transition to bring more concrete fruit(Corvellec et al., 2022).

2.3. Concept of Circular Economy

The concept of using resources in a circulating loop becomes crucial in China in the early 2000s(Doberstein, 2010)(Zengwei Yuan, Jun Bi & S, 2006). Later on, the concept of the Circular Economy (CE) based on the regenerative cycle, which facilitates the reuse of used products, parts, and materials efficiently, thereby increasing profitability and reducing environmental distraction becomes crucial among industrialists and professionals(S. Khan & Haleem, 2021). It became to be the prominence as an alternative to the classic approach of “make-use-dispose”(Vikas et al., 2019). The socio-political, economic, legal, and environmental perspectives of circular economics implementation had been investigated(Vikas et al., 2019). Macro-level circular economy evaluation indicator for China's economy was developed with a group of resource output rate, resource consumption rate, integrated resource utilization rate, waste disposal, and pollutant emission(Geng et al., 2012).

Economic challenges, such as supply risk, problematic ownership structures, deregulated markets, and flawed incentive structures lead to increasingly frequent financial and economic instabilities for individual companies and entire economies. Concerning this issue, the paradigm of sustainability and the circular economy was explored(Geissdoerfer et al., 2016). Another study shows a systematic and detailed review of Finland's industrial economy in terms of industrial business lines. There is a need to work together on waste issues to provide a sustainable solution to the problems of product specification, waste and operational confusion, wide opening of the product market by actors, the complexity of international waste transportation, the limitation of efficient waste use, and so on. Organization and business lines and issues related to ownership of waste should be evaluated(Oy, 2019). Generally circular economy is a fundamentally new model of industrial organization that is needed to de-link rising prosperity from resource consumption growth – one that goes beyond incremental efficiency gains to deliver transformative change. It is an approach that would transform the function of resources in

the economy. Waste from factories would become a valuable input to another process – and products could be repaired, reused, or upgraded instead of thrown away(Preston, 2012).

2.3.1. Circular Economy Strategies

A circular economy allows for the creation of a closed-loop ecosystem for efficient consumption and use of resources. This refers to moving material flows from a straight-line production approach (resource-product-waste) to a closed-loop approach (resource-product-waste-new) (Esposito, 2016). The circular economy is well received by organizations in the public, private, and civic sectors as it brings economic benefits and reduces pressure on the environment(Velenturf & Purnell, 2021). The new restructuring model creates a sustainable and waste-free ecosystem due to its ability to reduce, reuse and recycle(Esposito, 2016).

The 3R principles of CE are to reduce, reuse and recycle materials. Unlike the current linear system, these principles account for a circular system where all materials are recycled, all energy is derived from renewables, activities support and rebuild the ecosystem, and resources are used to generate value and support human health and a healthy society. The concept of CE, with its principles of reducing, reusing, and recycling energy, materials, and waste is seen as offering a viable alternative development strategy to ease tensions between national economic development and environmental concerns. It also helps address resource scarcity and pollution problems, and enables producers to improve their competitiveness by removing green barriers in their international trade relations(Heshmati, 2015) and (Maldonado-guzm & Garza-reyes, 2021).

Reducing the use of raw materials needs to have a better production process that will decrease the over consumption of raw material while keeping the desired product being produced. The strategy, technology, and value capture of companies play a vital role in reducing the waste generation(Maldonado-guzm & Garza-reyes, 2021).

Directly or indirectly, the reusing of materials is affected by strategy, stakeholder collaboration, and culture and mindset(Nowakowski, 2016). On the other hand, recycling of waste materials for the production of new product, there exist some factors that affect

the capability of the company to recycle the waste material. These dynamic capability variables are leadership, finance, technology, and strategy(Esposito, 2016).

2.3.2. Circular Economy in Automotive Manufacturing Industries

The automotive industry is at the beginning of its deepest transformation since its rise. Electrification, digitalization, and de-carbonization require massive investments and attention. The approach to creating value in circularity is fundamentally different from the current model. It requires a life cycle optimization approach considering the cost and revenue benefits of circularity, which are distributed potentially across many stakeholders(Ben Dror et al., 2022). When it comes to the automotive industry, the quality and cost of the products are decisive. The industry is facing issues regarding fuel economy, gas emissions, safety, and affordability. Moreover, the competitive pressures on the cost, quality, performance, and manufacturability of vehicles today are bigger than ever(Nina, 2019).

A circular economy is also directly related to genuine systematic innovation, which can be interpreted as green innovation or more commonly eco-innovation, through the transition that manufacturing companies have to achieve clean production. This is characterized not only by the improvement of the use of its resources but also by the redesign of its production systems. This leads, on the one hand, to the migration of companies to a technological eco-innovation, That is, to a sensitive environmental innovation that improves their sustainability level and generates significant positive effects on ecology.

On the other hand, the circular economy requires the redesign of social regimes in terms of the generation of official and tacit rules, as well as a change in collective and individual behavior, which favor the adoption and development of new business models. In this sense, the relationship between eco-innovation and the circular economy can be considered as a new combination of harder (generation of products with greater investment and development processes, with cost reduction and technical solutions in the generation of cleaner products and processes)(Maldonado-guzm & Garza-reyes, 2021).

2.3.3. Circular Economy Transformative Capabilities

Circular Economy (CE) has been identified as a better alternative economic model for a sustainable development system than the direct production process (Ranta et al., 2018). Although most companies perceive that they might not be able to implement a circular economy (CE), some scholars perceive that companies may do so by developing dynamic capabilities. It shows that DCs and organizational activities significantly facilitate CE implementation, which consequently improves the overall performance of companies. Furthermore, a circular dynamic environment (CDE) may stimulate companies toward CE implementation (O. U. R. Khan et al., 2020). For a successful CE implementation, improving institutional support and allowing it to fulfill its potential as a sustainable growth model, diversified institutional support for reducing the products produced and materials used as well as increasing reuse are needed. Furthermore, the circular economy needs an enabling factor that has to be fulfilled with the methods of analyzing the transformative capabilities of the circular economy at a firm level using leadership capability, financial capability, strategy, technological capability, human aspect, collaboration, and culture & mindset capability assessment system (Ranta et al., 2018), (Chari et al., 2022). The flows of resources define the state of the system at different stages of the transformation process, concerning both temporal and spatial dimensions (Chizaryfard et al., 2021).

2.3.4. Dynamic Modeling and system complexity in Circular Economy

System Dynamics (SD) is a simulation modeling approach that represents the structure of complex systems through the material and information feedback loops formed around stocks, flows, and auxiliary variables (Guzzo et al., 2022). In manufacturing industries, the scope of the model, and inventories are modeled as multiple stocks based on the overall supply chain including raw materials, suppliers' inventories, manufacturers' inventories, retailer inventories, products in use, and recycled material inventories (Kibira, 2009.). The automotive industry is one of the biggest manufacturing sectors and represents an increasingly important strategic and catalytic role in overall economic engagement. It impacts directly or indirectly on many important aspects, such as contribution to gross domestic product (GDP), employment, skills development,

economic linkages, technology and innovation, and making significant contributions through taxes, and substantial foreign direct investment. Modeling the dynamic nature of the manufacturing system is one of the complex system solutions(Mona, 2020).

There are two main ways that companies encounter complex problems: first, they create a sense of complexity by trying to connect very large and disparate entities in a meaningful way resulting in a feeling of complexity. The second is, that the dynamic change of such a system and its development cannot be predicted due to its size and diversity concerning product complexity in companies, while it is legitimate to assume that this is true even more so when talking about production systems in a circular economy(Veite & Steinhilper, 2016). Dynamic complexity, in contrast, can arise even in simple systems with low combinatorial complexity. Dynamicity, tightly couplings, governed by feedback, nonlinearity, history-dependency, self-organizing, adaptations, counterintuitive, policy resistance, and trade-offs are the characteristic features of dynamic complex systems(Sterman, 2000).

2.4. Previous Research of Circular Economy Transformative Capabilities

Previous researches indicate that the circular economy principle is a strategy for economic development (Zengwei Yuan, Jun Bi & S, 2006) and (Geng et al., 2009). Another study gives an insight into the circular economy as a means of minimizing environmental burdens(Andersen, 2007). In addition to that, by promoting the adoption of closing-the-loop production patterns within an economic system CE aims to increase the efficiency of resource use, with a special focus on urban and industrial waste, to achieve a better balance and harmony between the economy, environment, and society(Ghisellini et al., 2015), (Dwivedi et al., 2019), (Merli et al., 2018), and (Govindan & Hasanagic, 2018). In recent years researchers targeting a circular economy through resource conservation and recycling as means of CE strategy, the CE principles exclude not fully recyclable materials(Morseletto, 2020).

Some researchers also took attempts to respond to challenges of resource scarcity, environmental impact, or economic benefits or combinations of these have been made(Lieder & Rashid, 2015). Those efforts indicate circular economy as a solution to

severe problems of resource inefficiency and lack of resource productivity(Mathews et al., 2018). The ever-increasing consumer demand burdening the environment and society also forces industrialists to tend to a circular economy(Patwa et al., 2021). It is also indicated that the integration of a circular economy with core business models enhances the efficiency of the operational firms(Hanuláková et al., 2021).

2.4.1. Literature gaps and findings

Recent studies show that a circular economy with the strategy of reducing, reusing, and recycling have a positive impact in response for minimize waste through cycles of reduction, reuse, and recycling with limited leakage and minor environmental impact(Parida et al., 2019), (Kurniawan et al., 2022), and (Bressanelli et al., 2022).

But the researches are focusing mainly on the smooth circularity of resources within the loop. Some researches indicate the dynamic nature of the circular economy's transformative capabilities taking reducing, reusing, and predominantly recycling strategies independently(Guevara-Rivera et al., 2021), (Sassanelli et al., 2020), and (Guzzo et al., 2022). Taking the above considerations, investigating the dynamic system transformative capabilities of circular economy at a firm level can be mainly analyzed through the 3R strategy for the circular economy wing as it is stated by Maldonado-guzm & Garza-reyes, (2021) and through the leadership, strategy, human aspect, finance, culture and mindset, technology, and stakeholder collaboration capability.

In general the key gaps and findings are:

- ☞ Most researches focus on general frameworks for dynamic capabilities in circular economy transition.
- ☞ Limited in integrating the role of technological advancement with the organizational agility.
- ☞ Most researches focus on a single point in time. They lack the evolution of organizational dynamism in terms of circular economy.

This research focused on the reducing, reusing, and recycling CE strategies simultaneously with their five year dynamic behavior.

The following tabulated description of literature gaps indicate the major gaps the researcher identified that implies most of the previous researches focus mainly on recycling approach alone.

Table 2-1: Literature Gaps

Author/S	Topic	Objective	Methodology /tool	Result/Solved Problems	Gaps
(Kusi-sarpong & Agyemang, 2019)	Drivers and Barriers to circular economy implementation An explorative study in Pakistan's automobile industry	to identify the drivers and barriers to implementing a CE	qualitative and quantitative methods using a survey instrument and interviews	profitability/market share/benefit, cost reduction and business principle/concern for environment/appreciation	☞ Doesn't consider the dynamic behavior of implementation drivers and barriers
(Lieder & Rashid, 2015)	Towards circular economy implementation: a comprehensive review in the context of manufacturing industry	to provide a comprehensive review of research resources scarcity, waste generation, and economic advantages	Systematic literature review	CE framework and a practical implementation strategy developed	☞ Ignores the dynamic behavior of transforming capabilities ☞ Focus on the framework and implementation strategy dev't alone.
(Golroudbary & Zahraee, 2015)	System dynamics model for optimizing the recycling and collection of waste material in a closed-loop supply chain	To meet the immediate environmental challenges and sustainable development	System Dynamics (SD) simulation/ Vensim PLE software	Improved customer satisfaction and Green Image Factor (GIF)	☞ Takes only recycling as a pillar in SD modeling of CE.
(Sassanelli et al., 2020)	Circular Economy-oriented Simulation: A Literature Review Grounded on	To assess Simulation behavior (as part of industry 4.0)through a	Sort-Label-Integrate-Prioritize as a systematic literature	Assured the role of simulation (as part of Industry 4.0 technologies) in supporting the	☞ Doesn't model and experiment with the system ☞ Focus mainly

Author/S	Topic	Objective	Methodology /tool	Result/Solved Problems	Gaps
	Empirical Cases	literature review	review	adoption of CE.	on disassembling electrical and electronics industries as a review.
(Guevara-Rivera et al., 2021)	Dynamic simulation methodology for implementing circular economy: A new case study Journal	to design a methodology for building a simulation model to implement CE strategies for a confectionery factory	Hybrid Services Simulation Mode (HSSM) of service-dominant logic, ecosystem services, system dynamics, and agent-based modeling	highest profit improvement	☞ Takes only recycling as a pillar in SD modeling of CE.
(Guzzo et al., 2022)	A system dynamics-based framework for examining Circular Economy transitions	To find SD modeling practices to support decision-making in CE transitions	System Dynamics (SD) simulation/ Vensim PLE software	☞ adopting the sharing platform allows for lower amounts of total acquired products ☞ higher values for total useful products over time	Discuss recycling as the main circular economy strategy neglecting Reduce and Reuse
(Chari et al., 2022)	Dynamic capabilities for circular manufacturing	to identify how dynamic capabilities theory can	qualitative research process through	Explored the convergence of dynamic capabilities,	Focuses only on the qualitative aspect of the dynamic natures.

Author/S	Topic	Objective	Methodology /tool	Result/Solved Problems	Gaps
	supply chains— Exploring the role of Industry 4.0 and resilience	enable circular economy implementation	literature review and framework	circular economy, and resilience and Industry 4.0 concepts for manufacturing supply chains.	

2.5. Summary and Methodological review of literatures

Preliminarily 193 publications of articles, conference papers, technical manuals, reports, books, and other essential scientific papers in different journals and databases using the indicated keywords had been collected. After refining based on their objectives and the intention of this research, only 51 of them were taken as key reference materials. It has been found that the previous researches focus mainly on the independent CE implementation approaches and hence, this research focused on using the three of reducing, reusing, and recycling CE strategies simultaneously.

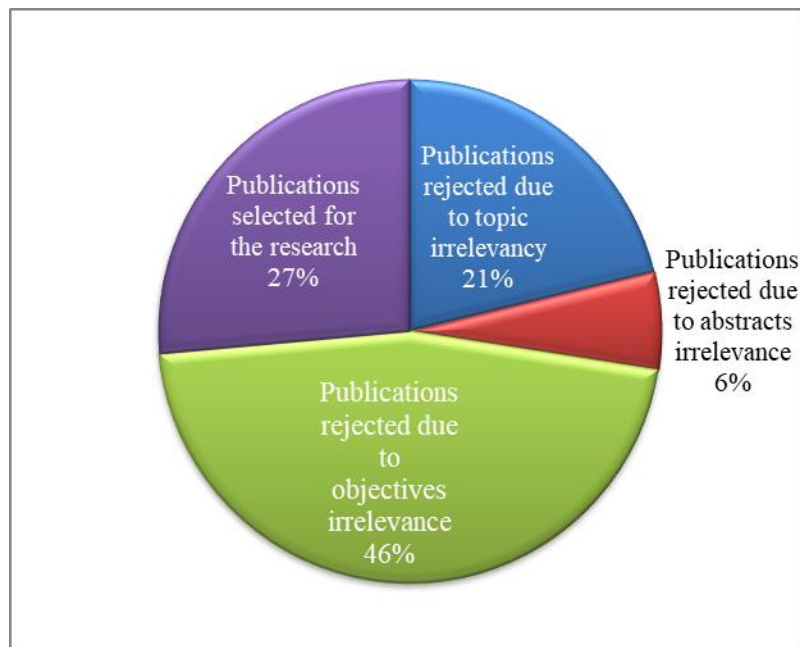


Figure 2-1: Literature selection summary

CHAPTER THREE

3. Methodology

3.1. Introduction

This section intended to explain the data collection and analysis methods that have been used in this research. It explains what has been done and how the researcher did it to get the intended research objectives and answer the corresponding research questions rose earlier in the introduction section. The qualitative and quantitative data had been used by taking due consideration for the reliability of the data to get precise results.

3.2. Background of Automotive Manufacturing Company of Ethiopia (AMCE)

Automotive Manufacturing Company of Ethiopia (AMCE) is a Joint Venture between IVECO S.P, A. (70%) and the Ethiopian Government founded in 1970 (30%). Back in 1930, FIAT introduced in Ethiopia the first truck model in history, with the 621 model and then 634 models, which gained visibility in the country. This success led FIAT to open an assembly plant in Addis Ababa with the authorization and collaboration of the Ethiopian government from this time. The erection of premises started in 1972 in Addis Ababa on an area of 50,000 m² of which 8,000 m² was covered. Since 1975, AMCE has expanded from 50,000 m² to 175,000 m² and its manpower increased considerably. AMCE is not only an assembly plant. Already some parts are being manufactured in-plant as well as in other ancillary industries in the country. The company has a scope of:

- Assembling of Trucks imported as CKD from Europe.
- Selling IVECO vehicles completely built up.
- PDI (Pre-Delivery Inspection), and
- Servicing IVECO products for mechanical and bodywork

Currently, the company has a production capacity of 700 vehicles manufacturing. There are ninety-eight (98) employees within the company out of this sixty-eight are employed by an external agency and the remaining are internal staff of AMCE. The company has

five core functional working departments namely: manufacturing department, sales & marketing department, customer & technical service department, parts department, purchasing & logistics department.

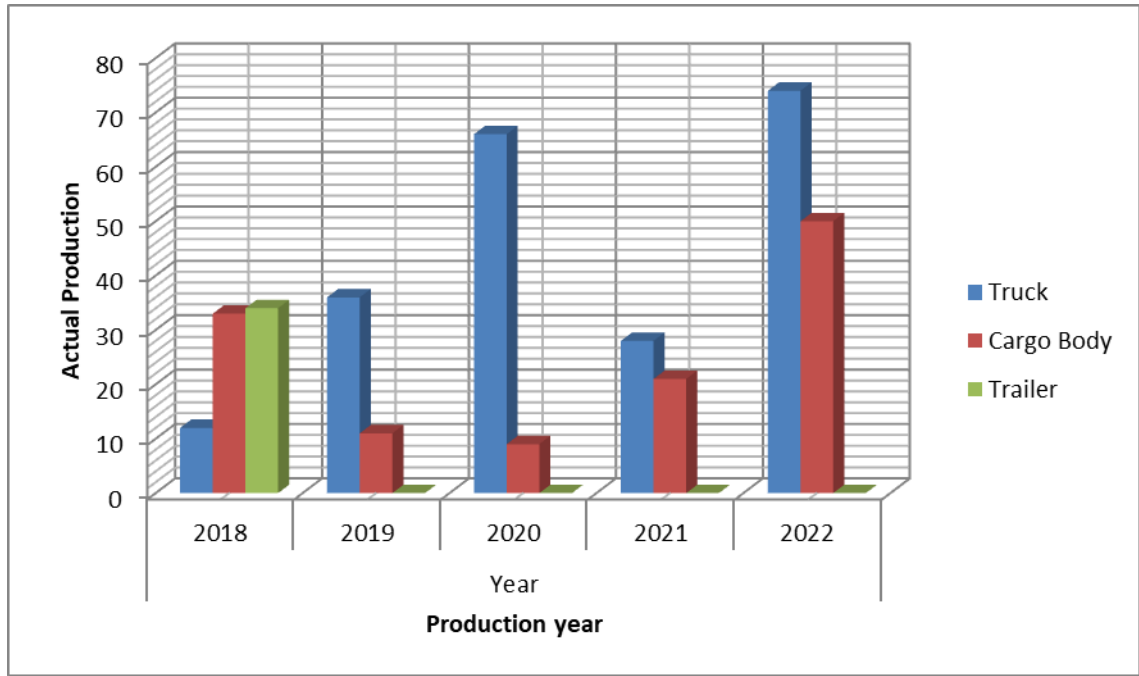


Figure 3-1: Actual Annual production

3.3. Research Design

The research is designed by taking the research framework, data collection, reliability, and analysis into consideration. It is based on descriptive and experimental research types as it is aimed to give scientific investigation and examine results under a simulation model and various scenarios. The schematic framework design is shown in Figure 3-2, at the end of this sub-section.

Method of Literature Review

A related literature review had been assessed to find out the theoretical concepts of the research thematic area. Different scientific databases and journal sites have been used to find out the articles. Web of Science, Emerald, Z library, Scopus, Science Direct, pdf derive.com, SciELO.org, Directory of open access journals, and Google Scholar have been used to find out necessary data about the circular economy and its transformation capability within a dynamic situation. Consequently, the research gap was identified.

The researcher used articles and other reference materials published in three timeframes. The first six reference materials published from 2000 to 2010 had been collected. Another twenty-three sets of articles published from 2011 to 2020 highly relevant articles been collected. Finally, recent articles published later in 2021 up now been collected. They had been used based on the evolution of basic science from time to time to keep the coherence of the research thematic area over time.

3.4. Data Collection Methods

Both quantitative and qualitative data collection have been used in this research in both primary and secondary data collections. The data collection methods, tools, source of data, and objectives/purpose/ of observation, interview, and literature review are summarized in Table 3-1 as shown below.

A. Primary Data collection

Observation: Raw material types, product types, assignment of industry experts, production process flow, production technologies, and the general working environments of the industry were observed to assess the overall insight. While taking an observation, audio-video instruments were used.

Interview: An interview has been conducted in two parts. The first part of the interview was for the first objective of this research. It focused on the assessment of the company's circular economy status through 3R analysis. The second part was for the second objective of this research to assess the dynamic capability of circular economy transformation.

B. Secondary Data Collection

Annual reports, billings, website information, and recordings were collected from the case company, Manufacturing Industries Development Institute, and Manufacturing Technology & Engineering Industries Research and Development Center.

Table 3-1: Summary of data collection

No	Type of Data Collection	Source of Data	Purpose	Data Collection Tools
1	Observation	<ul style="list-style-type: none"> ☞ Production department (site) ☞ Raw material and product inventory sites ☞ Each functional working department ☞ Production flow labeling, directions, working procedures, and precautions. 	<ul style="list-style-type: none"> ☞ raw material types ☞ product types, ☞ production process flow, ☞ production technologies(methods) ☞ working environment highlight 	<ul style="list-style-type: none"> ☞ Audio-Visual instruments ☞ Notebook
2	Interview	<ul style="list-style-type: none"> ☞ Factory Manager ☞ Department Managers/Supervisors 	<ul style="list-style-type: none"> ☞ Amount of raw material, product, waste ☞ Quantity of reduced, reused, and recycled resource flow. ☞ Transformation capability of the company 	<ul style="list-style-type: none"> ☞ Interview checklist questions ☞ Audio-Visual instruments ☞ Notebook
3	Literature Review	<ul style="list-style-type: none"> ☞ Scientific literature ☞ Factory archive and documentation office ☞ Stakeholder organizations 	<ul style="list-style-type: none"> ☞ To get the existing research and debates on the circular economy, sustainability, and dynamic capability towards CE in the automotive manufacturing industry. ☞ To identify the gap in previous research on circular economy transformation capability and dynamic simulation. ☞ To get valuable secondary 	<ul style="list-style-type: none"> ☞ Scientific journal and database sites

No	Type of Data Collection	Source of Data	Purpose	Data Collection Tools
			data	
4	Modeling Data	<ul style="list-style-type: none"> ☞ Primary data ☞ Secondary data ☞ Literature review 	<ul style="list-style-type: none"> ☞ To quantify variables ☞ To see variable deviations 	

3.5. Sampling and Targeted Participants

As it was stated in other sections, this research intended on the circular economy analysis and its transformative capability dynamic modeling for circular resource utilization. Hence, the research identified key sample target segmentation within the research case company. A non-probabilistic purposive sampling has been used by the researcher to use the advantage of their expertise so that it is useful for the research and enables the researcher to gain detailed knowledge about specific concepts of circular resource utilization. Based on this, out of the entire working employees within the company, the factory manager, department manager, and supervisor have been selected for interviews. For observation, even though the overall working environment of the company has been observed, a special focus was on the raw material inventory sites, production main workshop, maintenance, and product accumulation sites.

3.6. Data Analysis Methods

A. Circular Economy Existing status

The company's existing raw material utilization trend has been analyzed exhaustively. The assembly, maintenance, and parts manufacturing units of the company materials were assessed through input-output coefficient analysis using the amount of raw material used per unit product.

The circular economy has a strategy of managing resources through reducing, reusing, and recycling (3R)(Maldonado-guzm & Garza-reyes, 2021). The existing practice of the company's resource utilization was assessed through the:

- Assessing each available production process.
- Quantifying the amount of RM utilized, produced, and wasted within the production process.
- Assessing the available circular economy strategies implementation status.

Table 3-2: 3R Existing practice

CE Principle	Objectives	Tasks	Expected Result
Reduce	To investigate the amount of resources reduced/saved	Identify resource consumption-reducing methods and materials	Resource consumption reduction mechanisms identified
	To investigate the amount of waste minimized	Identify pollution reduction production methods and materials	Pollution reduction mechanisms identified
Reuse	To investigate the quantity of resources reused	Identify reusable products	Reusable products identified
	To investigate the quantity of waste minimized	Identify reusable wastes/by-products	Reusable wastes identified
Recycle	To investigate the quantity of resources recycled	Identify materials that would otherwise be thrown away as trash and turn them into new products.	Recyclable wastes identified
	To investigate the quantity of waste minimized		

B. CE Transforming Capabilities

To implement a successful circular economy strategy, an enabling factor needs to be fulfilled. Circular economy mainly focuses on the circular utilization of resources before they are disposed of. The principle recommends disposing of waste materials after the maximum possible circular utilization. To analyze the transforming capability it is necessary to see the variables that will affect the circularity of the raw material utilization. The capability assessment variables were identified through an interview and literature review and questionnaire. The variables identified were leadership, finance, strategy, technology (work station automation), human aspect, collaboration, culture and mindset as it is stated on sub-section 2.3.3 and refer annex 1 of this document for the scale data collection format of the seven capability assessment variables. The variables interact and vary with respect to time. The change in the behaviors of the variables within the system was analyzed through system dynamic modeling to visualize the dynamic resilience of the company for circular raw material utilization.

C. System Dynamic Modeling

In its broadest definition system dynamics is a method that enables to describe, model, simulate and analyze complex systems in a dynamic nature/behaviors. The model considers the processes, information, organizational boundaries, and strategies of the system. The behavior of the system is determined by the variables within the system. Basically the dynamic simulation enables the modelers to describe and calibrate the system dynamically (Pruyt, 2013).

In this particular firm-level case, the organizational system consists of the whole of closely interacting elements and their interactions within the company. Automotive Manufacturing Company of Ethiopia (AMCE) has three distinct but interrelated sections: the assembling section, maintenance & parts manufacturing, and after-sales section.

The complexity of the System

In this world one of the aspects of natural behaviors is that the dynamic change of the characteristics of the variable over a certain period of time. This change can be dynamic with a specified system components (Sterman, 2000). This implies that system dynamics concept can handle both the closed loop system (generates a behavior of endogenous variables behavioral change) and by external/exogenous events or driving forces of the dynamic system (Pruyt, 2013).

In AMCE, the causal and effect relationship within the organizational system as well as out of the system is vast. The availability of raw material, employee competence, and international logistics issues, stakeholder collaboration & compliance, and internal organizational capability has a complex nature to relationships.

The general system dynamics model development steps that have been used in this research are described as follows (Sterman, 2000) and (Pruyt, 2013):

- ☞ Problem articulation
- ☞ Formulation of dynamic behaviors
- ☞ A simulation model formulation, and
- ☞ Validation

The components and sub-systems of the dynamic system of the company were identified. Feedback, Stock accumulation, and Flows have been defined. The dynamic and complex nature of problems encountered in the industry initiates systematic solving of those issues.

The Stocks of the system analyzed were raw material inventory, product inventory, and waste. The flows were raw material flow rate, production flow rate, reusing flow rate, and recycling flow rate. The model has a time boundary of data simulated for five years (60 months). The validations and verification of the model has been done.

Table 3-3: types of tests applied for model validation

No	Test	Purpose of the test	Techniques applied for testing
1	Parameter assessment	to be certain about the consistency of the parameter values	Literature review
2	Extreme Condition test	To check the simulation values of variables resulted in an acceptable behavior of the system.	Use of extreme values of exogenous variables and sensitivity simulation
3	Model boundary	To check and detect errors occurring at the boundary values of important concepts addressing the problem and scenarios of the model	Consultation with AMCE inspection of the SD model
4	Structural Assessment	To check whether the model structure is consistent with relevant descriptive knowledge of the system being modeled	Literature review
5	Dimensional consistency	To check whether each equation in the model dimensionally corresponds to the real system	Unit consistency test
6	Scenario setting & sensitivity analysis	To ensure that the model provides reasonable or justifiable results for the system	Based on scenario options
7	Based on simulated and historical data	To compare simulated and historical data	Comparing historical and simulated data

3.7. Summarized Research Framework

The general flowchart of the research starting from the preliminary ideal inception (preliminary assessment) to the final ending point has been developed as follows. It has three distinct and simultaneously interrelated activity patterns. The first part is the literature review part intended to assess the body of knowledge of the research topic area through identified keywords. The second part is the data collection section which has an observation and interview checklist questions. The third part is the data analysis section in which the identified gap and the collected data were analyzed through CE analysis and CE transformative capability analysis mechanism. Finally, the simulation model was developed and through a series of consecutive experimenting and testing activities, a finalized result has been developed.

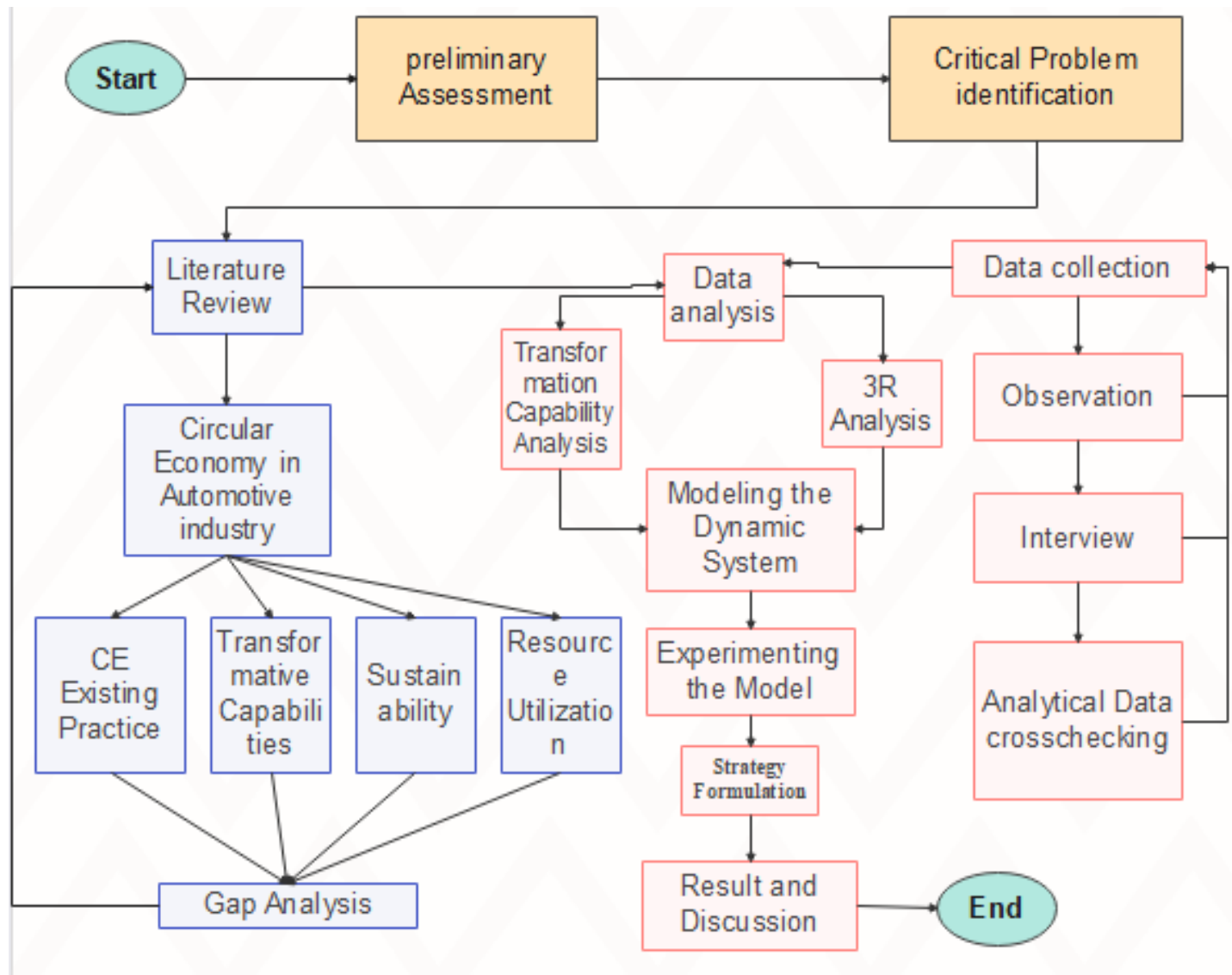


Figure 3-2: A summarized research framework

CHAPTER FOUR

4. Data Presentation and Simulation Model Development

4.1. Introduction

This chapter presents the outputs of data collection activities and the dynamic behavior of variables through system dynamic modeling. The observation, interview, and secondary data results are well summarized and presented based on the methodology specified in chapter three of this research.

4.2. Data Collection Results

The observation was conducted to get valuable data about the overview of the production site, raw material, and product inventory sites, each functional working department's operational status, production flow labeling, directions, working procedures, and precautions throughout the working stations of the company compound. After preliminarily observing the company in late February 2023 during proposal preparation, the researcher conducted the formal observation on March 30, 2023, with the guidance of the Production Engineer of the factory. The following table shows the summarized observation results.

Considering the last five years from 2018 to 2022, the company has a total actual production capacity of 374 vehicles. This figure implies that the company has used approximately 10.7 % of its designed production capacity of 700 trucks per annum. This was due to the lack of sufficient raw materials and foreign currency issues to import CKD components.

Currently, during the observation, it has been seen that there is no sufficient raw material accumulation in their inventory sites. Within the company, there are visible and neat production flow labeling, directions, working procedures, and precautions that support the cleaner production procedure at each work station. The interview was conducted considering the reducing, reusing, and recycling status of the company and the resilience

of the organization to transform from linear raw material utilization to a circular loop of resource utilization.

4.2.1. Empirical Data

1. Raw Material and Accessories Requirement

The summarized data collected from secondary data collection methods are explained as follows.

Table 4-1: Raw material for a unit truck cargo manufacturing

Raw Material Description	Amount Per Unit Product			Amount of Scrap waste generated (Kg)
	Dimension (mm)	Pcs.	Kg	
Black Sheet Metal	2350x1000x3	8	301	15.05
Black Sheet Metal	2350x1000x2	4	163	8.15
Black Sheet Metal	3000x1000x3	3	216	10.8
Black Sheet Metal	3000x1000x2	2	96	4.8
Black Sheet Metal	2500x1000x4	6.5	520	26
Black Sheet Metal	3000x1000x4	2.1	202	10.1
Black Checkered Sheet metal	3000x1260x3	5	528	26.4
RHS	80x40x25	9	248	12.4
Flat Strip sheet metal	45x45x8	2	35	1.75
Total			2309	115.45 Kg

(Source: MTEIRDC and Company archives)

2. Consumable Chemicals and Utilities

The types of chemicals used for a unit product manufacturing are described as follows.

The major utilities used are electricity, fuel, and water.

Table 4-2: consumable chemicals required for a unit truck product manufacturing

No	Name
1	Carbon Dioxide Gas
2	Oxygen
3	Acetylene

No	Name
4	AC Gas
5	Break Oil
6	Engine Oil
7	Steering Oil
8	Coolant (Para-flu)
9	Paint
10	Anti-Rust
11	paint thinner - Diluent

4.2.2. Company Reuse, Reduce and Recycle Existing Status

The case company's circular economy status was assessed through reducing, reusing, and recycling principles which those principles have been proposed on Table 3-2 in the methodology section of this research.

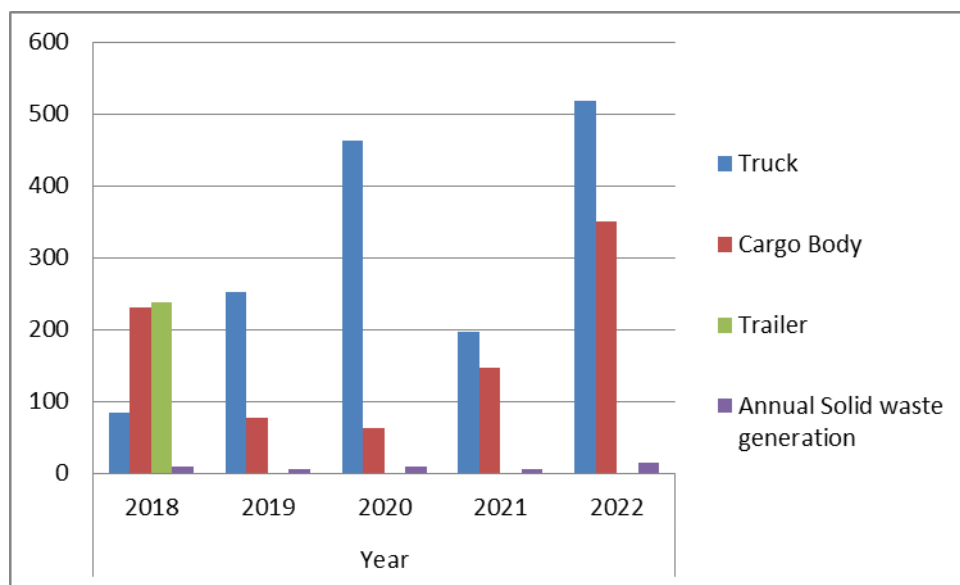


Figure 4-1: Annual scrape waste generation

In both resource utilization and environmental aspect, reducing the use of resources without affecting the result of the final desired product is one of the mechanisms of circular economy implementation. From the above five year data, it has been seen that an average of 5% scrap waste have been generated per annum. It needs a financial investment to manage the waste appropriately.

4.2.3. CE Transformative Capability Assessment

A transformative capability that has a strategic focus and strategic capabilities to give an organization its unique operational positioning as well as how it needs to change to retain a competitive position over time. It shows the resilience of a company to change in a dynamic situation. Hence, the implementation of a circular economy with the pillars of reducing, reusing, and recycling needs an appropriate organizational transformative capability and resilience over some time. As it is indicated in the literature review section on sub-section 2.3.3 of this research, the reducing, reusing and recycling capability variables are strategy, technology, finance, culture and mindset, collaboration, leadership, and human aspect.

The existing capability of the company shows that:

- Leadership Capability: The Company is moderately supportive of CE, but lacks a clear vision and roadmap.
- Financial Capability: it has a limited budget allocated for CE initiatives. Risk assessment for CE projects is rudimentary.
- Strategy: Existing strategy does not explicitly address CE principles.
- Technological Capability: Current technology is geared towards linear production. Investment in CE-enabling technologies is minimal.
- Human Aspect: Limited awareness among employees about CE principles. Training programs related to CE are scarce.
- Collaboration: Weak collaboration with suppliers and partners on CE initiatives. Knowledge sharing is limited.
- Culture & Mindset Capability: The company culture prioritizes short-term profits over long-term sustainability.

Bearing the reducing, reusing & recycling, and the transformation capabilities on hand, the empirical data were obtained from the interview and secondary data collection as it is

stated in sub-section 4.2 and sub-section 4.2.1 of this research used as an input for the dynamic simulation of the variables interaction. For instance: as it is stated on sub-section 3.2, the company production capacity is 700 vehicles per annum and the amount of raw material required to manufacture a single vehicle is 2309 kg. The company can manufacture about 58 vehicles per month a total of 133,922 kg raw materials. This data has been used as a baseline monthly raw material input in the simulation. Therefore, to visualize the behavior of those variables, it is necessary to see the dynamic nature of the variables.

4.3. System Dynamics Model Development

4.3.1. Problem Clarification

The automotive manufacturing industry is tied with problems of raw material scarcity, waste generation, and environmental compliance issues. This problem affects the performance of the industry as it is indicated that its actual annual production capacity is too low. At the same time, the organizational system is affected by various factors that arise inside as well as outside the system. Those endogenous and exogenous variables have made the problem more complex to solve. This scenario has to be solved dynamically by analyzing the behavior of the variables within the system.

4.3.2. Formulation of Dynamic Behaviors and Model Boundary

Model Boundary

Elements that influence other parts of the system components and influenced by elements of the internal system modeled as endogenous variables of the system whereas all those elements that have an impact on the system but they are not influenced by the internal system becomes exogenous variables (Pruyt, 2013). Based on this principle, AMCE as an organization has been taken as a system. The endogenous and exogenous key variables of the system have been articulated. The model takes a five-year time boundary (60 months) to show how far in the future the behavior of the variables will vary.

Key Variables

System dynamics provides the means for modeling complex systems such as those required to analyze many economic and marketing phenomena. When tackling highly complex problems, modelers can soundly increase their understanding of these systems by automatically identifying the key variables that arise from the model structure (Barranquero et al., 2015). In this research, the endogenous and exogenous variables used for the dynamic simulation had been identified.

Table 4-3: Key variables description

Variables	Description
Start Time	The starting time of the simulation which is taken as zero
End Time	The final simulation time taken as five years (60 months)
TIME STEP	The time interval of the simulation(The frequently of calculations are performed within the model to update the values of variables)
Repeat time	The raw material flow frequency (every 12 months). It is the factory raw material reorder time.
RM Inventory	The accumulation of raw materials
Product inventory	The accumulation of products
Waste	The accumulation of total waste of the production system
Periodical RM flow rate	The amount of raw material flow in each repeat time
Production flow rate	The production flow per month
Recycling flow rate	The amount of recycling wastes flow rate per month
Reusing flow rate	The amount of reusing wastes flow rate per

Variables	Description
	month
Monthly input	The amount of raw materials input
Reducing Consumption	The raw material consumption reduction index
Leadership	Represents the commitment, communication, and effectiveness of leadership in driving circular economy practices.
Finance	Reflects the adequacy of financial resources, risk assessment practices, and financial planning for circular economy projects.
Technology	Represents the advancement of technologies used, adoption rate of new technologies, and effectiveness in achieving circular economy goals.
Strategy	Captures the clarity, review frequency, and alignment of the circular economy strategy with the overall business strategy.
Human Aspect	Encompasses employee awareness, training frequency, and motivation to participate in circular economy initiatives.
collaboration	Represents the frequency of collaboration with external partners, effectiveness of these collaborations, and support from suppliers/partners.
Culture and Mindset	Captures the strength of the sustainability culture, integration of circular economy principles into operations, and employee receptiveness to change.
Production Capacity	The monthly production capacity of the factory

Variables	Description
Unit Production time	The amount of time required to produce a single product.
Inventorying time	The time required to setup raw annual raw materials within the inventory site.

4.3.3. Simulation Model Formulation

Understanding the actual system behavior and determining the basic requirements of the model is necessary for developing the right simulation model for complex systems (Sterman, 2000). In this research, the model has been formulated by creating a flow chart of how the organizational system operates, facilitating the understanding of what variables are involved, and how these variables interact within the system.

4.3.4. Casual Loop Diagrams and Cause & Effect Diagram Description

The conceptual and communication inter relationship of the dynamic model simulation characterized by the causal loop diagrams of the simulation model. Within the spaghetti model, the arrow going from one state apex of the line to the other side implies that a certain state of variation being created due to the cause of another variable (Inc., 2005). The system cause and effect are described at the annex section on Table 0-1 cause and effect diagram.

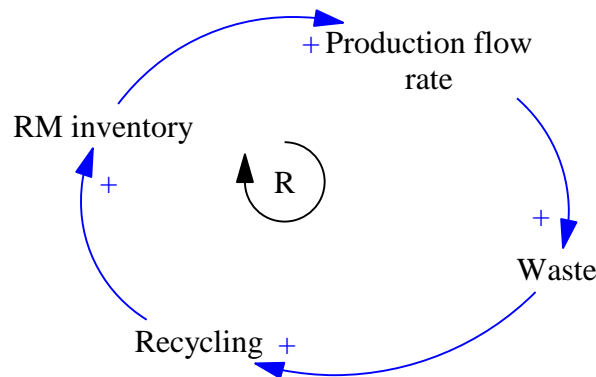


Figure 4-2: RM inventory Causal Loop Diagram

4.3.5. Stocks and Flows

As the stock generates the behavior of the system and flows cause the stock to change, this model has the following stocks and flows.

Stocks

- Initial Raw Material (IRM) Inventory
- Raw Material (RM) Inventory
- Product Inventory
- Waste

Flows

- Initial Raw material (IRM) flow rate
- Raw Material (RM) flow rate
- Periodical Raw Material flow rate
- Production flow rate
- Reusing
- Recycling

4.3.6. Mathematical Formulation

Considering the behavior of the model structure and variables interaction, the mathematical equations of the model has been described as follows. The raw material accumulation of the model is the result of the periodical (annual) flow of raw material and the initial raw material accumulation. For the periodical flow with 12 months repeat-time of the five year simulation time boundary, the starting time taken as zero and the simulation end time is 60 months (five years). The time step of the simulation was taken as 0.03125. In order to increase the accuracy of the simulation, the time step of the simulation is taken as 0.03125 which is much smaller than 1/3. The reorder time of raw materials in the factory is 12 months of the five year with a baseline annual flow rate of 173,175 kg.

- The mathematical equation for periodical raw material flow was formulated based on the PULSE TRAIN function of the Vensim PRO software. It is because of that the PULSE TRAIN function can create a train of pulses starting at zero months and then going up to pulsing in each twelve months for five years. This enables the simulation to show the flow of material in each repeat-time term.

$$\text{Periodical RM flow rate} = \text{PULSE TRAIN}(\{\text{start}\},\{\text{duration}\},\{\text{repeattime}\},\{\text{end}\}) \text{,Equation 4-1}$$

Where

Start = Start Time

Duration = Time Step

Repeat time = the frequency of order, and

End = End time of the simulation

The mathematical equation used in the model is:

$$\begin{aligned} \text{Periodical RM flow rate} \\ &= \text{Monthly RM input} \\ &\times \text{PULSE TRAIN}(\text{Start Time}, \text{TIME STEP}, \text{repeat time}, \text{End Time}) \end{aligned}$$

Since PULSE TRAIN function taken as constant, the unit of Periodical raw material flow rate takes the unit of monthly RM input:

$$\begin{aligned} &= \text{Dmnl} \times \frac{\text{Kg}}{\text{month}} \\ &= \frac{\text{Kg}}{\text{month}} \end{aligned}$$

- The equation used in raw material inventory is:

$$\text{RM Inventory} = (\text{Periodical RM flow rate} + \text{Recycling rate} - \text{Production flow rate}) \times \text{Inventory time}$$

The unit for this inventory is:

$$\begin{aligned} \text{RM inventory} &= \left(\frac{\text{Kg}}{\text{month}} + \frac{\text{Kg}}{\text{month}} - \frac{\text{Kg}}{\text{month}} \right) \times \text{month} \\ &= \left(\frac{\text{Kg}}{\text{month}} \right) \times \text{month} \\ &= \text{Kg} \end{aligned}$$

- The production flow rate mathematical formulation is:

$$\begin{aligned}
 \text{Production flow rate} &= \frac{\text{RM Inventory} \times \text{Production Capacity}}{\text{Reducing consumption}} \\
 &= \frac{\text{Kg} \times \frac{\text{Kg}}{\text{month}}}{\text{Kg}} \\
 &= \frac{\text{Kg}}{\text{month}}
 \end{aligned}$$

- The mathematical equation for product inventory is
 $\text{product inventory} = \text{Production flow rate} \times \text{Unit Production time}$

$$\begin{aligned}
 &= \frac{\text{Kg}}{\text{month}} \times \text{month} \\
 &= \text{Kg}
 \end{aligned}$$

- The waste accumulation equation:
 $\text{waste} = (\text{Production flow rate} \times 0.05) - (\text{Recycling} + \text{Reusing})$
 $\times \text{unit production time}$

$$\begin{aligned}
 &= \left(\frac{\text{Kg}}{\text{month}} - \frac{\text{Kg}}{\text{month}} + \frac{\text{Kg}}{\text{month}} \right) \times \text{unit production time} \\
 &= \frac{\text{Kg}}{\text{month}} \times \text{month} \\
 &= \text{Kg}
 \end{aligned}$$

Where 0.05 is the average waste generation rate of the company per each year from 2017-2021 (average 5% of the total raw material wasted as a defect and scrap)

- For reusing:
 $\text{Reusing} = \frac{\text{waste} \times \text{culture and mindset} \times \text{collaboration}}{\text{unit production time}}$

$$\begin{aligned}
 &= \frac{\text{Kg} \times \text{Dmnl} \times \text{Dmnl}}{\text{month}} \\
 &= \frac{\text{Kg}}{\text{month}}
 \end{aligned}$$

- For recycling, the mathematical equation is:
 $\text{Recycling} = \frac{\text{waste} \times \text{leadership} \times \text{finance} \times \text{strategy}}{\text{unit production time}}$

$$\begin{aligned}
 &= \frac{\text{Kg} \times \text{Dmnl} \times \text{Dmnl} \times \text{Dmnl}}{\text{Month}} \\
 &= \frac{\text{Kg}}{\text{month}}
 \end{aligned}$$

- An interview was conducted about the qualitative organizational capability indexes to know how the company organizational management will react on the transitions of the industry in to circular economy. Based on this the interview was conducted to rate the company's status on financial capability, leadership, technology, strategy, human aspect, collaboration, culture and mindset using an ordinal scale of measurement. Technology was taken as the number of automated work station development within the industry.

In the ordinal scale of measurement, the percentage commitment rate of the organization from 100% (100% = 1, 0% = 0), the leadership, financial, strategy, human aspect, collaboration, culture and mindset, the reply of the respondents was indicating that the company has a 100% (rated as 1) capability.

Table 4-4: Mathematical Formulation

Variable Name	Equation	Unit
Constant Variables		
Start Time	0	Month
End Time	60	Month
TIME STEP	0.03125	Month
Repeat time	12	Month
RM Inventory	<i>periodical RM flow rate + Recycling – production flow rate</i>	Kg
Product inventory	<i>production flow rate × unit production time</i>	Kg
Waste	<i>Unit production time × (production flow rate – (recycling + Reusing))</i>	Kg
Periodical RM flow rate	<i>Monthly input × PULSE TRAIN(Start time, TIME STEP, repeat time, End time)</i>	Kg/month
Production flow rate	$\frac{RM\ Inventory \times Unit\ Production\ time \times production\ Capacity}{Reducing\ Consumption}$	Kg/month
Recycling flow rate	$\frac{Waste \times 0.8(Leadership \times Finance \times Technology)}{Unit\ Production\ Time}$	Kg/month

Variable Name	Equation	Unit
Reusing flow rate	$\frac{Waste \times 0.001(Culture \text{ and } Mindset \times Collaboration)}{Unit \text{ Production time}}$	Kg/month
Monthly input	173,175	Kg/month
Reducing Consumption	$Monthly \text{ input} \times 0.001 \times Unit \text{ production time}$	Kg
Leadership	$\frac{1}{Strategy}$	Dmnl
Finance	$\left(\frac{1}{Strategy}\right) \times 0.04$	Dmnl
Technology	$(1 \times Strategy) \times 0.02$	Dmnl
Strategy	1	Dmnl
Human Aspect	$1 \times Strategy$	Dmnl
collaboration	$1 \times Human \text{ Aspect}$	Dmnl
Culture and Mindset	$1 \times Human \text{ Aspect}$	Dmnl
Production Capacity	133,922	Kg/month
Unit Production time	0.1	Month
Inventorying time	1	Month

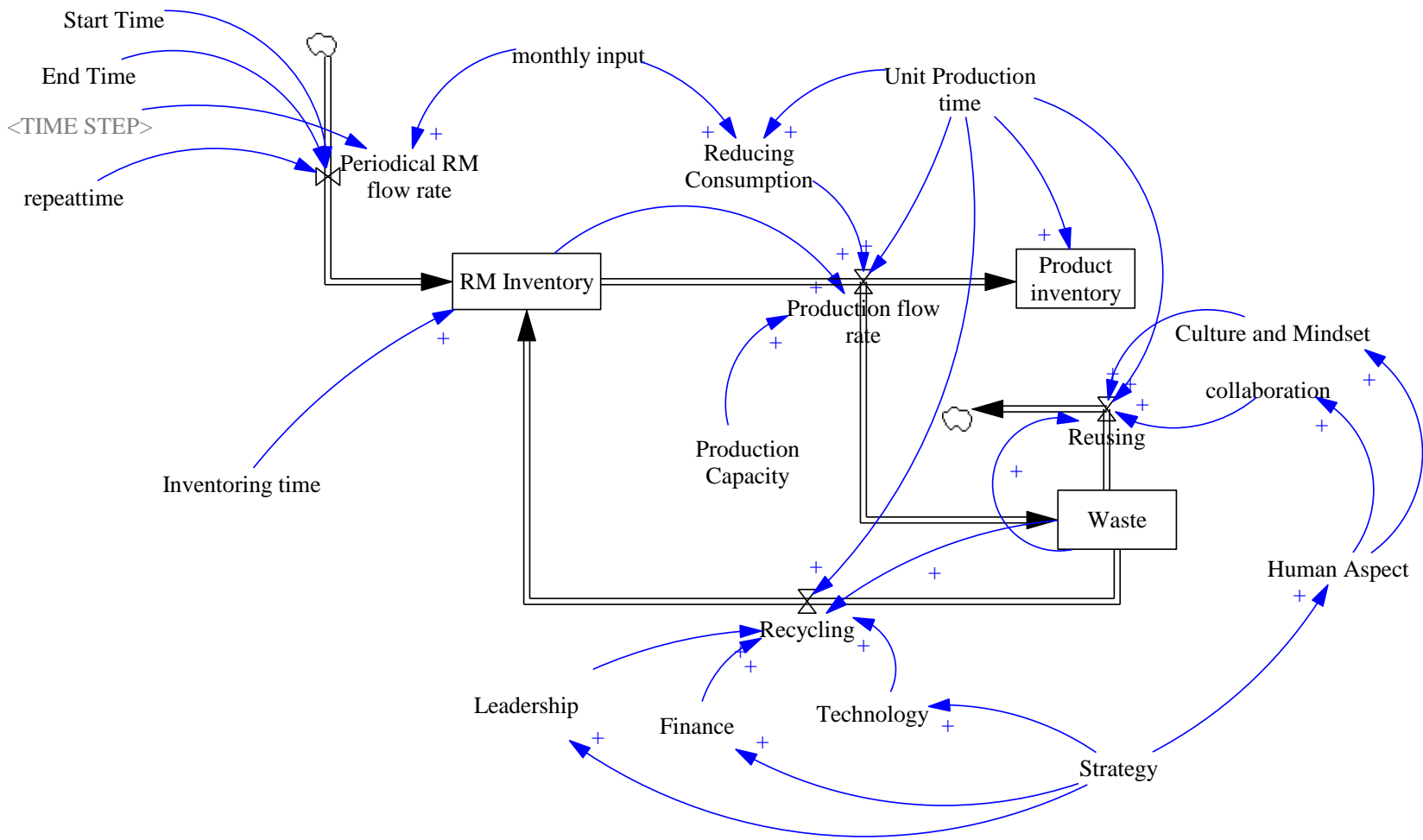


Figure 4-3: CE transformative capability model for AMCE

4.3.7. Model Verification and Validation

The model overall behavior corresponding to the real system behavior is crucial in validating the system modeling behavior. The best approach for model validation is based on simulated and historical data validation technique whereby a relevant data from the real system comparing to the simulated results. It requires a less significant difference between the real and simulated results to consider that the model is valid.

In doing so, the production quantity, reusing waste generation and recyclable waste generation quantity of the real and simulated data has been compared. The five year actual production data (2018 – 2022) and the corresponding simulated data for the future five years have been used for validation. The historical data shows that, the actual production was 374 vehicles in total for the five years. Whereas the simulated data from the model shows that for five years it can be manufactured 381 vehicles.

The consistency of the parameter values and the simulation values of variables resulted in an acceptable behavior of the system. It had been checked and detect errors occurring at the boundary values of important concepts addressing the problem and scenarios of the model. The model dimensional consistency considering the real system configuration has been checked through unit consistency and the model provides reasonable results for the system experimental scenarios.

4.3.8. Simulation Run, Result and Discussion

The dynamic simulation has been indicated through the change in the behavior of the variables within the model with respect to time. It has been seen that the effect of increasing the value of raw material input and increasing the number of automated work stations with in the system through different scenarios.

Table 4-5: RM input increasing Scenario Description

Scenarios	Description
Baseline	Take 173175 Kg/month of raw material as a baseline(Obtained from empirical data)
Scenario 1	Increasing the value of RM input by 10% keeping the other variables constant

Scenarios	Description
Scenario 2	Increasing the value of RM input by 30% keeping the other variables constant
Scenario 3	Increasing the value of RM input by 50% keeping the other variables constant
Scenario 4	Increasing the value of RM input by 75% keeping the other variables constant
Scenario 5	Increasing the value of RM input by 100% keeping the other variables constant

Table 4-6: Automated work station increasing scenario description

Scenarios	Description
Baseline	Take two automated work stations as a baseline(Obtained from secondary data)
Scenario 1	Increasing number of automated work stations to 3 by keeping the other variables constant
Scenario 2	Increasing number of automated work stations to 4 by keeping the other variables constant
Scenario 3	Increasing number of automated work stations to 5 by keeping the other variables constant

A. The effect of increasing the value of RM input

The baseline data simulation shows that, with a period of twelve months, 14,431.25 tons of raw material flow towards the inventory site.

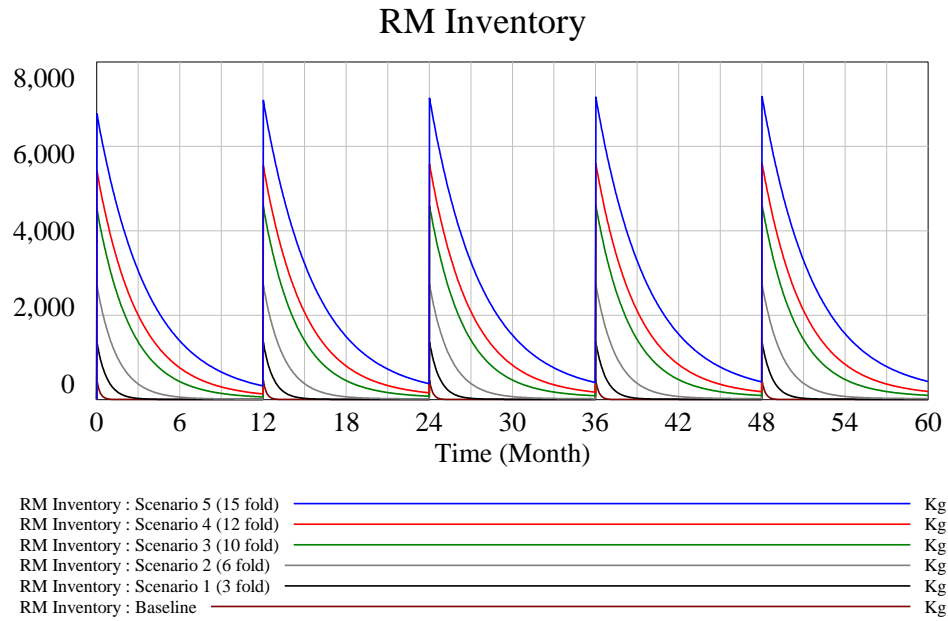


Figure 4-4: RM Inventory Graph due to increasing the value of RM input

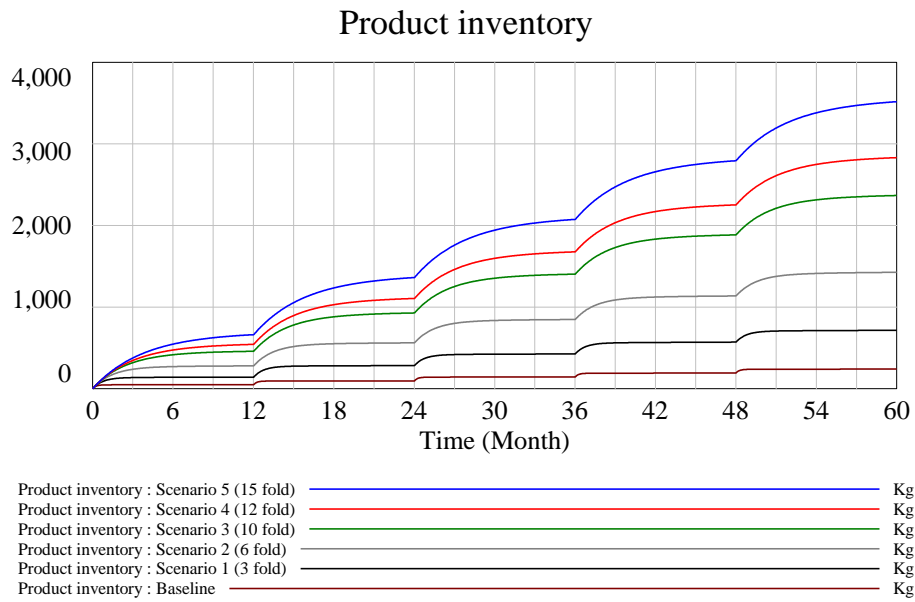


Figure 4-5: product inventory graph due to increasing the value of RM input

Reusing

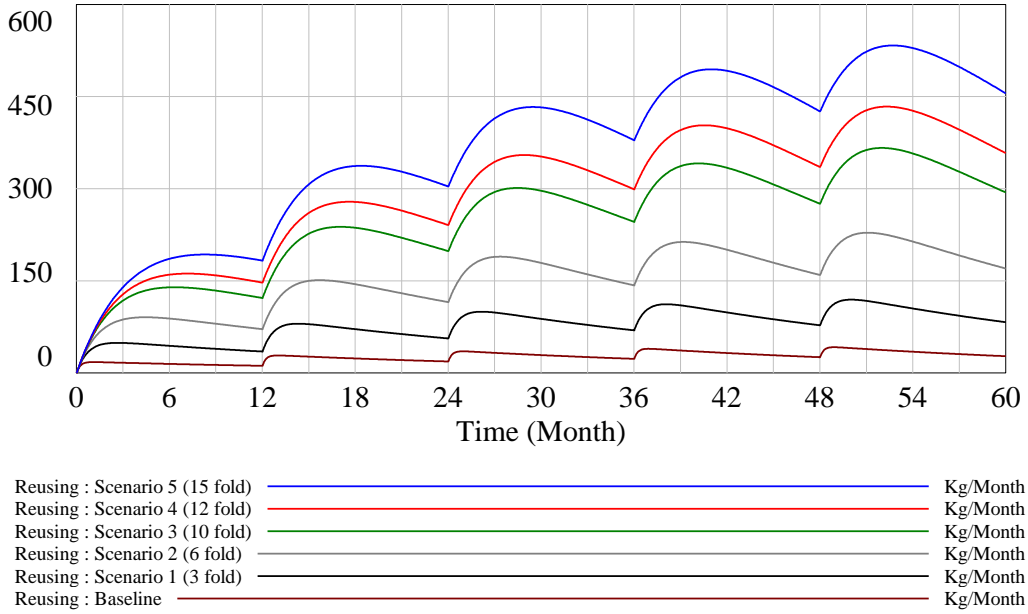


Figure 4-6: Reusing graph due to increasing the value of RM input

Recycling

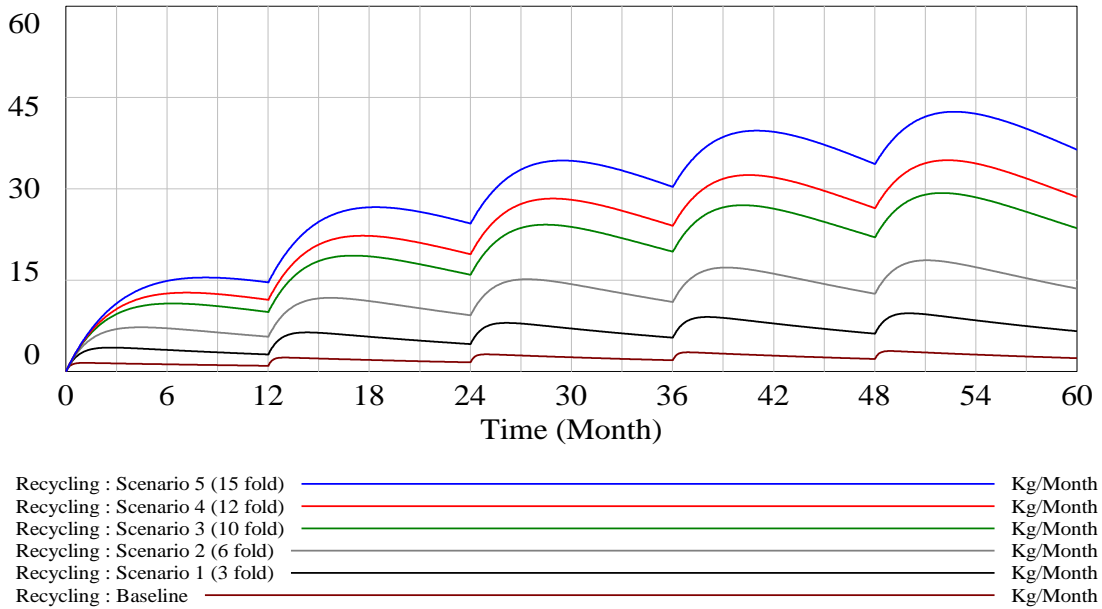


Figure 4-7: Recycling graph due to increasing the value of RM input

B. Increasing the number of automated work stations

As the number of automated work stations increase, there is a significant decrease in waste generation. The leadership commitment, internal and external stakeholder collaboration, financial requirements increase and human aspect indexes increase. Since the amount of wastes accumulated decreases, the amount of recycling and reusing. When the number of automated work stations increase from 2 to 3, 4, 5, 6, and 7, the amount of wastes accumulated at the end of 60 months decrease from 6775 ton to 2679, 1105, 463.84, 195.62, and 87.14 tons. Simultaneously, the increasing in the number of automated work stations decrease the amount of recycling wastes from the base of 21.68 to 0.0796 tons.

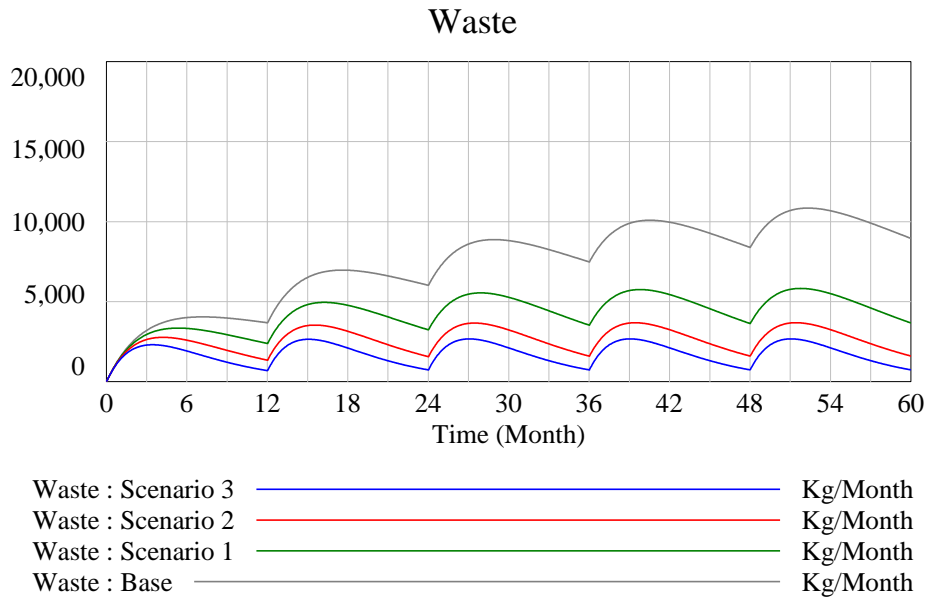


Figure 4-8: waste accumulation due to increasing the number of automated work stations

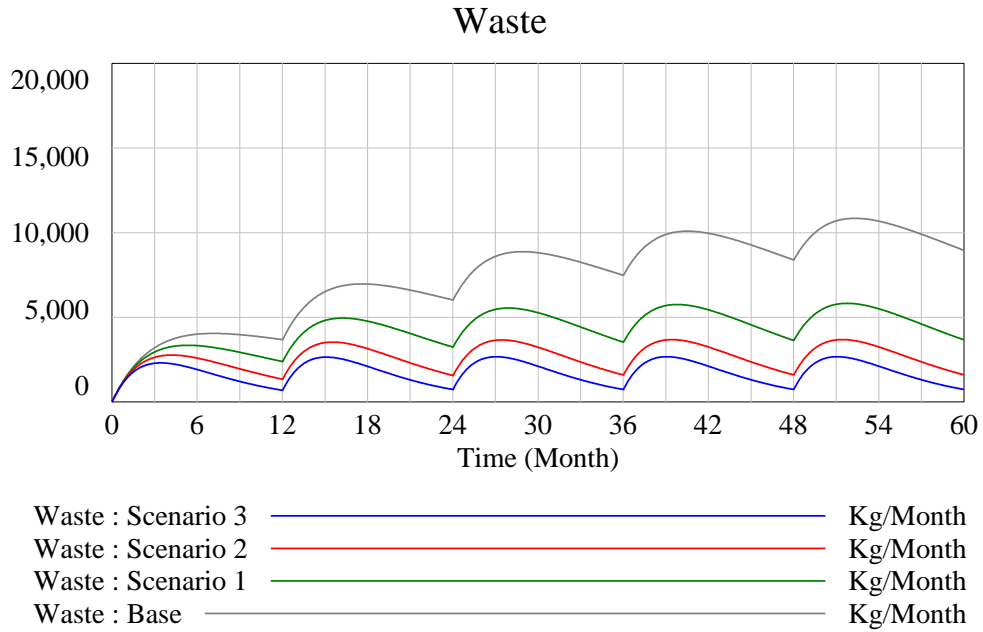


Figure 4-9: Reusing graph due to increasing the number of automated work stations

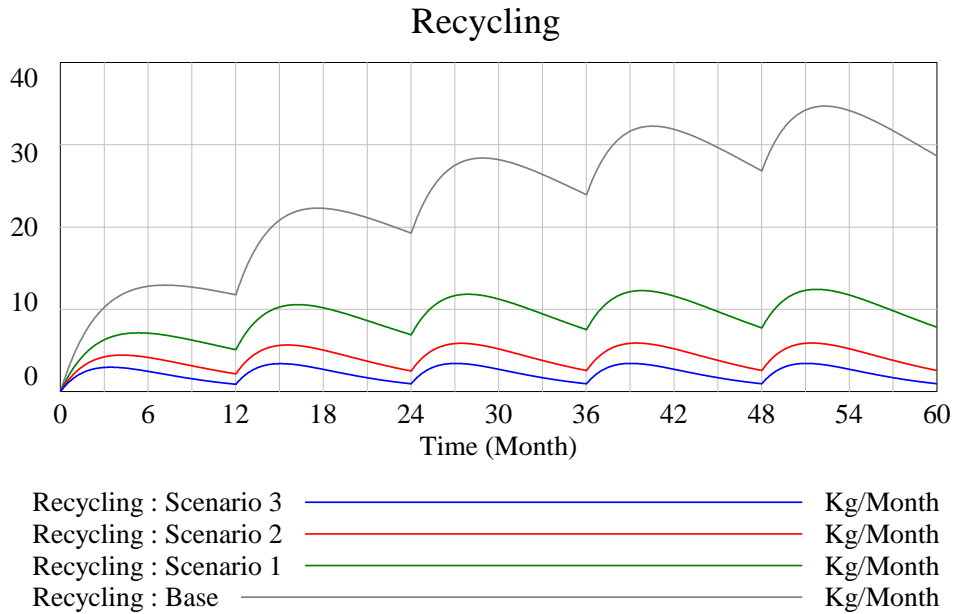


Figure 4-10: recycling graph due to increasing the number of automated work stations

C. Transformation Capabilities Scenario

This scenario explores a rapid transition towards a circular economy for AMCE.

Table 4-7: Strategy capability increasing scenario description

Scenarios	Description
Base	Take low strategy capability with rate of 0.4 (obtained from the likert scale) keeping the other variables constant
Scenario 1	Increasing strategy capability to moderate (0.6) keeping the other variables constant
Scenario 2	Increasing strategy capability to high (0.8) keeping the other variables constant
Scenario 3	Increasing strategy capability to Very high (1) keeping the other variables constant

(i). The behaviour of Human Aspect capability

As the strategy of the company captures the clarity, review frequency, and alignment of the circular economy strategy with the overall business strategy, it encompasses employee awareness, training frequency, and motivation to participate in circular economy initiatives such that the human aspect of the organization can be capable of adopting the circular economy concept. The following Figure 4.11 illustrates this behaviour as the strategic capability increases from low rate to very high capacity.

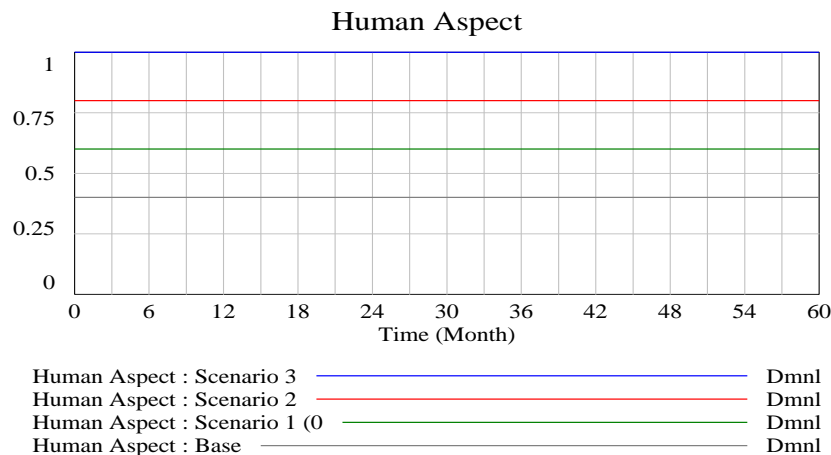


Figure 4-11: Human Aspect capability behavior

(ii). **The behaviour of Collaboration capability**

As it is shown below from figure 4.12, the frequency of collaboration with external partners, effectiveness of these collaborations, and support from suppliers/partners will be in parallel with the circular economy strategy with the overall business strategy alignment increases.

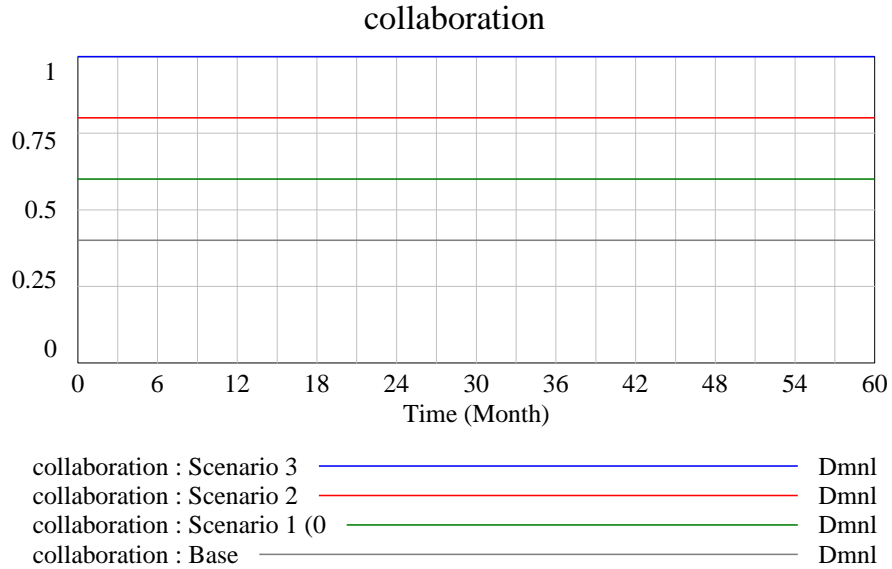


Figure 4-12: collaboration capability behavior

(iii). **The behavior of culture and mindset capability**

The cultural and mindset capability with the strength of the sustainability culture, integration of circular economy principles into operations, and employee receptiveness to change increases as the circular economy strategy with the overall business strategy is aligned. The following figure 4.13 described the graphical illustration of the behavior of culture and mindset capability with respect to strategy development.

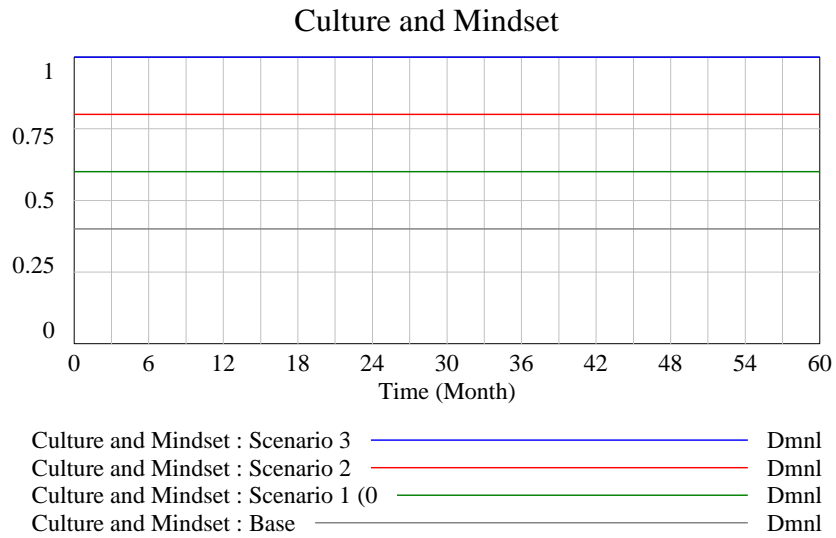


Figure 4-13: culture and mindset capability behavior

(iv). The behavior of waste accumulation

The accumulation of total waste of the production system decreases as the rate of strategic development increases. It is because of that as the rate of reusing in the circular economy strategy increases, the amount of waste stock within the company will reduce significantly. In other words, it implies that there will be a minimum waste inventory within the company since the rate of reusing will be high. The following figure 4.14 shows the behavior of waste accumulation due to strategic development.

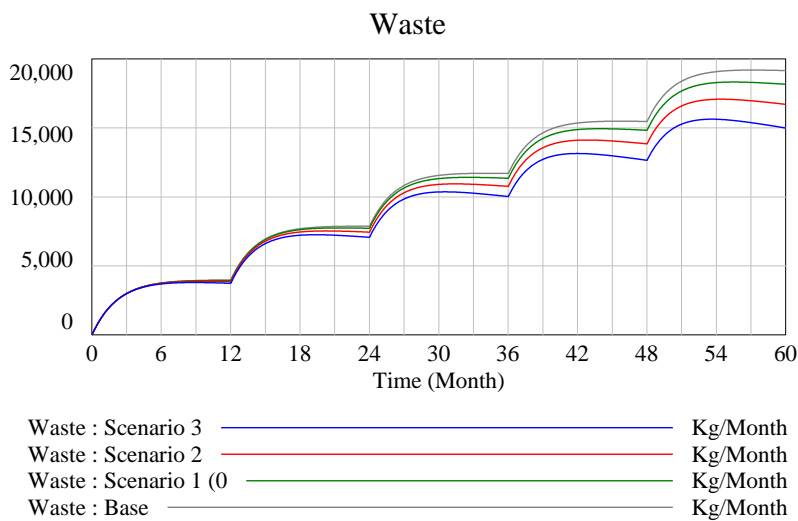


Figure 4-14: waste accumulation behavior

(v). The behavior of reusing rate

The rate of reusing increases as the rate of CE strategy capability increases. It is because of that as the rate of reusing in the circular economy strategy increases, as the rate of waste generation decrease. The following figure 4.15 shows the behavior of reusing rate due to strategic development change.

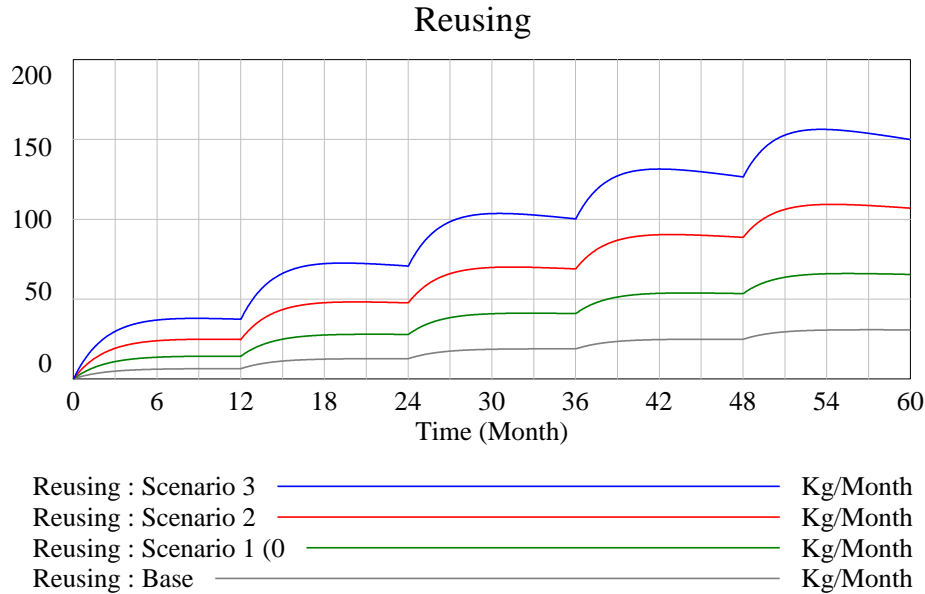


Figure 4-15: Reusing rate behavior

(vi). The behavior of technological capability

The strategy development has a direct contribution to technological capability development and hence, the following figure 4.16 reflects how the technology capability behaves with respect to strategic alignment of CE with the organizational business strategy.

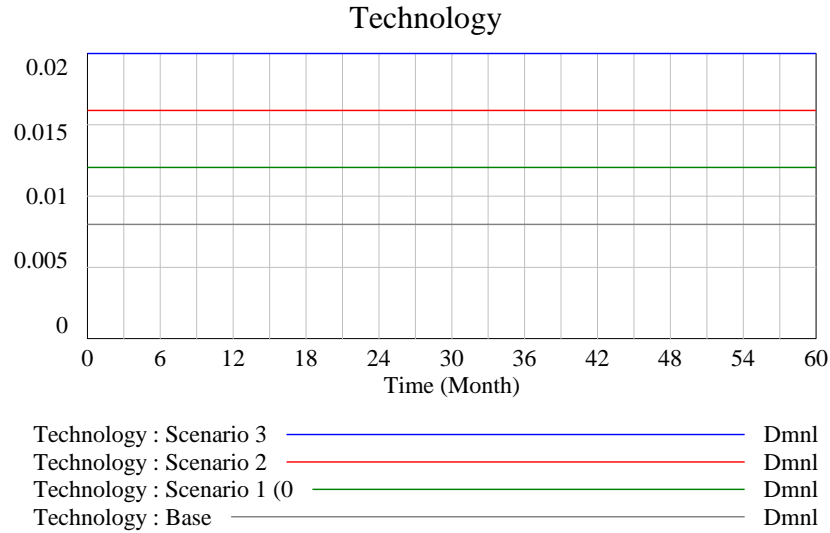


Figure 4-16: technology capability behavior

Generally, the simulation result with the change in raw material input variation and automated work station shows that there is a significant variation in the behavior of other variables. The baseline simulation data indicates that the production process will last only for about a month due to the raw material scarcity. Within the case company, it has been observed that there are scrap metals that can be recycled and reused.

The baseline data simulation shows that, with a period of twelve months, 173.175 ton of raw material flow towards the inventory site and generates 865.88 kg of scrap waste during production. This implies that the amount of raw materials required for five years is 865.875 ton and simultaneously it generates 4.33 ton of scrap waste.

However, while keeping the baseline raw material availability constant and changing the behavior of the technological capability (taken as automated workstation), will decrease the waste accumulation. On the other hand the reusing and recycling will increase.

The following simulation result table shows the decrement of scrap waste accumulation as the number of automated work stations increase.

Table 4-8: Waste accumulation decreasing scenario

Time (Month)	0	↔	59.8	59.90	59.93	59.96	60
Scenario 3	0	↔	747.55	742.80	738.08	733.38	728.71
Scenario 2	0		1,621	1,614	1,607	1,600	1,593
Scenario 1	0		3,696	3,686	3,677	3,668	3,659
Baseline	0		8,987	8,977	8,966	8,956	8,946

(Source: Model Simulation dataset from Time 59.8 – 60 months)

Therefore, the company has the capability to transform to a circular economy system through reducing the defect, reusing and recycling of metallic scraps in order to enhance the raw material availability. Automated work station development will decrease the amount of waste accumulation by an average of 58%.

CHAPTER FIVE

5. Conclusions and Recommendations

5.1. Conclusion

In this dynamic world, considering the challenges facing particularly the Automotive Manufacturing Company of Ethiopia concerning environmental compliance issues and resource scarcity, the circular economy has an important role in using raw materials efficiently and effectively through reducing, reusing, and recycling.

This research investigated the dynamic modeling of circular economy transformation capabilities within the Automotive Manufacturing Company of Ethiopia (AMCE) focusing on Reduce, Reuse, and Recycle (3R) principles. The model has been simulated for 60 months with a starting time of zero, end time of 60 months, and time step of 0.03125 such that the simulation provides an accurate result. The dynamic model has been represented by the variables within the complex system as shown in Figure 4-9. The key transforming capability variables are technological (automated work stations), leadership, finance, collaboration, strategy, human aspect, culture and mind set.

The model highlights the significance of dynamic capabilities for the company to navigate the complexities of circular economy transformation. The 3R principles serve as a strong foundation for building these capabilities with specific focus needed on the raw material circular usage. The integration of technological advancement holds a promise in the company within the overall block chain for material traceability.

The existing scenario of the case company from the perspective of the circular economy system shows that it has reducible, reusable, and recyclable materials. The baseline data simulation shows that, with a period of twelve months, 173.175 ton of raw material flow towards the inventory site and generates 865.88 kg of scrap waste. Based on the current baseline scenario, the amount of raw materials required for five years is 865.875 ton.

The rise in the technological development significantly decreases the waste generation. The leadership commitment, internal and external stakeholder collaboration, financial requirements increase and human aspect indexes increase. Since the amount of wastes accumulated decreases,

the amount of recycling and reusing. When the number of automated work stations increase from 2 to 3, 4, 5, 6, and 7, the amount of wastes accumulated at the end of 60 months decrease from 6775 tons to 2679, 1105, 463.84, 195.62, and 87.14 tons. Simultaneously, the increasing in the number of automated work stations decrease the amount of recycling wastes from the base of 21.68 to 0.0796 tons. The datasets from the model simulation runs show that variables have a positive impact on the circular economy transformation within the company. In general the company is capable to transform towards circular economy in its financial, leadership commitment, organizational strategy, collaboration, human aspect, culture and mind set capability through reducing, reusing, and recycling.

To sum up;

- Leadership drives the vision and strategy for CE, impacting recycling and technology adoption.
- Finance provides necessary funding for recycling initiatives and technological advancements.
- Technology is critical for efficient recycling processes and reducing production waste.
- Strategy guides the overall approach to CE, influencing leadership and human aspect initiatives of the organization.
- Human aspect represents the workforce's skills and engagement, essential for reusing and recycling efforts.
- Collaboration involves partnerships and stakeholder engagement, facilitating waste management and reusing activities.
- Culture and mindset underpins the acceptance and promotion of CE principles, affecting recycling, reusing, and collaboration.

5.2. Recommendations

The researcher recommends the company:

- Establish a dedicated CE task force and setting ambitious circularity goals, secure funding for CE projects through green bonds and partnerships through comprehensively assessing financial risks are to ensure project viability.
- Developing a new corporate strategy, integrating CE principles, invests in new technologies for material reuse and remanufacturing. Research and development focus on eco-design and lightweight materials.
- Providing comprehensive training programs on CE are implemented for all employees, recognition and reward systems incentivize CE-oriented behaviors, establish strategic partnerships with waste management companies and material suppliers to create a closed-loop system and fostering knowledge sharing platforms.
- Embed CE principles in daily operations and decision-making processes.

5.3. Future Study Area

This research finds out the resilience of an organizational-level circular economy transformation capabilities through reducing, reusing, and recycling strategies. The effects of the organizational system variables' behavior on the circular economy strategies have been discussed. In the meantime, the researcher suggests some aspects of this research thematic area to be elaborated in the future.

- ☞ As this research has been done in a firm-level context, it will be more concrete to be done for a large-scale context like sectorial level or national level transformative capability investigation.
- ☞ Even though this research has shown the resilience of the company through system dynamic simulation, in future research, the researcher suggests that it can be done an additional investigation by implementing the circular economy strategies and taking a comparative analysis with the existing scenario with more variables.

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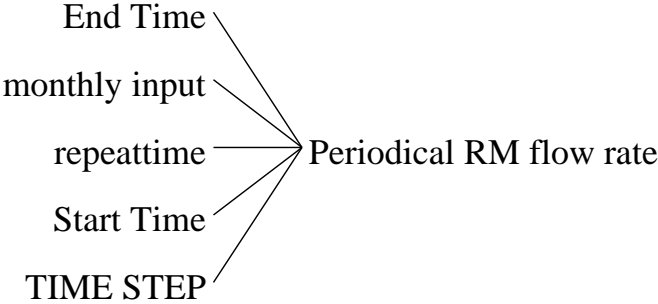
Annexes

Annex 1: Observation Checklist and Interview Questions

Annex 2: Secondary data collection checklist points

Annex 4: Model cause and effect diagram description

Table 0-1: Cause and effect diagram

Stock and Flow Variable	Diagram type	Cause/Effect Diagram
Periodical RM flow rate	Cause	
	Effect	<p>Periodical RM flow rate ——— RM Inventory ——— Production flow rate</p>

Stock and Flow Variable	Diagram type	Cause/Effect Diagram
RM inventory	Cause	<p>The diagram shows 'RM Inventory' as the central effect. It is caused by four main factors: <ul style="list-style-type: none"> Inventory Duration: A direct cause. Periodical RM flow rate: Caused by 'End Time', 'monthly input', 'repeattime', 'Start Time', and 'TIME STEP'. Production flow rate: Caused by '(RM Inventory)', 'Production Capacity', 'Reducing Consumption', and '(Unit Production time)'. Recycling: Caused by 'Waste', 'Finance', 'Leadership', 'Startegy', and 'Unit Production time'. </p>
	Effect	<p>The diagram shows 'RM Inventory' as the cause, which leads to three effects: 'Product inventory', '(RM Inventory)', and 'Waste'.</p>

Stock and Flow Variable	Diagram type	Cause/Effect Diagram
Production flow rate	Cause	<pre> graph LR ID[Inventory Duration] --> RI[RM Inventory] PRF[Periodical RM flow rate (Production flow rate)] --> RI R[Recycling] --> RI MI[monthly input (Unit Production time)] --> RI RI --> PFR[Production flow rate] PC[Production Capacity] --> PFR RC[Reducing Consumption] --> PFR UPT[Unit Production time] --> PFR </pre>
	Effect	<pre> graph LR PFR[Production flow rate] --> PI[Product inventory] PFR --> RIR[RM Inventory (Production flow rate)] PFR --> W[Waste] W --> R[Recycling] W --> Re[Reusing] </pre>
Product Inventory	Cause	<pre> graph LR RI[RM Inventory] --> PFR[Production flow rate] PC[Production Capacity] --> PFR RC[Reducing Consumption (Unit Production time)] --> PFR UPT[Unit Production time] --> PFR PFR --> PI[Product inventory] UPT --> PI </pre>
	Effect	Product inventory

Stock and Flow Variable	Diagram type	Cause/Effect Diagram
Waste	Cause	<p>A fishbone-style cause-and-effect diagram for 'Waste'. The central node is 'Waste'. Three main branches point to it from the left: 'Production flow rate', 'Recycling', and 'Reusing'. 'Production flow rate' is influenced by four causes: 'RM Inventory', 'Production Capacity', 'Reducing Consumption', and 'Unit Production time'. 'Recycling' is influenced by five causes: '(Waste)', 'Finance', 'Leadership', 'Startegy', and '(Unit Production time)'. 'Reusing' is influenced by four causes: '(Waste)', 'collaboration', 'Culture and Mindset', and '(Unit Production time)'.</p>
	Effect	<p>A fishbone-style effect-and-cause diagram for 'Waste'. The central node is 'Waste'. Two main branches point to it from the right: 'Recycling' and 'Reusing'. 'Recycling' is influenced by two causes: 'RM Inventory' and '(Waste)'. 'Reusing' is influenced by one cause: '(Waste)'.</p>

Stock and Flow Variable	Diagram type	Cause/Effect Diagram
Reusing	Cause	<pre> graph LR A[Production flow rate] --> B[Waste] C[Recycling (Reusing)] --> B D["(Human Aspect) collaboration"] --> B E[Human Aspect Culture and Mindset] --> B F[Unit Production time] --> B B --> G[Reusing] </pre>
	Effect	<pre> graph LR A[Reusing] --> B[Waste] B --> C[Recycling] B --> D["(Reusing)"] </pre>
Recycling	Cause	<pre> graph LR A["Production flow rate (Recycling)"] --> B[Waste] C[Reusing] --> B D["(Automated work stations) Finance"] --> B E["Automated work stations Leadership"] --> B F["(Automated work stations) Startegy"] --> B G[Unit Production time] --> B B --> H[Recycling] </pre>
	Effect	<pre> graph LR A[Recycling] --> B[RM Inventory] A --> C[Waste] B --> D[Production flow rate] C --> E["(Recycling)"] C --> F[Reusing] </pre>