Impact of Technology Adoption in Forward Logistics: A Quantitative Approach

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Abstract

We are seeing our workplace digitally evolving with more and more processes now being completed using technology; this is all because of Industry 4.0. Industry 4.0 is all about connectivity, and it is an opportunity to revolutionize how the industry responds to societal requirements. The introduction of technology into the industry is evolving towards a sustainable digital supply chain in the face of increasing complexity. The benefits of Industry 4.0 technologies in improving various supply chain performance measures have been well described theoretically and established in the existing literature. However, no integrated model compares available technological options in different supply chain stages and shows the impact in quantitative terms in cost, traceability, flexibility, agility, and other metrics. This study aims to quantify the benefits of implementing these technologies in the supply chain through multi-objective modelling. The objective of the study is to minimize the overall transportation cost function and carbon emissions due to transportation for minimal adverse effects on the environment. We begin by proposing a sustainable logistics model that considers various vehicle types such as autonomous and semi-autonomous vehicles and carbon emissions associated with product transportation. With the robust optimization approach, the methodology seeks to consider technological implementation at every stage of forward supply chain. We deploy our model to a sample toy dataset to analyze the administration of technology. Findings suggest that industry 4.0 technology would be effective for supply chain performance parameters, resulting in sunless carbon discharge with a comparative increase in the operational cost.

Keywords
Sustainable, Industry 4.0, Optimization, Supply Chain, Transportation

1. Introduction
The fourth Industrial Revolution (Industry 4.0) is commonly recognized as the most recent industrial revolution (Figure 1) that has the potential to alter production and enable the development of the future smart factory. Its ability to boost productivity and make better use of organizational resources has piqued the interest of practitioners and academics alike (Adebanjo et al., 2021). Digitization, optimization, and customization of manufacturing, automatic data interchange and communication, enhanced human-machine interaction, automation and adaption, and value-added services and enterprises are the major elements of Industry 4.0 (Efthymiou & Ponis, 2021). In recent literature and industrial papers, Industry 4.0 has been mostly studied from the standpoint of production as an operational vision. Industry 4.0 and its enabling technologies, on the other hand, are thought to have the ability to alter every aspect of factories and organizations, and to significantly improve managerial disciplines such as supply chain and logistics management (Fatorachian & Kazemi, 2021). One of the most important aspects of Industry 4.0 is the role of technology as an accelerator or catalyst for tailored solutions, flexibility, and cost reduction in industrial processes. To connect facilities and assets, a wide range of technologies inherent in Industry 4.0 (figure 2), must be implemented, including artificial intelligence (AI) and cognitive technologies, additive manufacturing, high-performance computing, analytics, robots, advanced materials, autonomous vehicles and augmented reality (Hamzeh et al., n.d.).

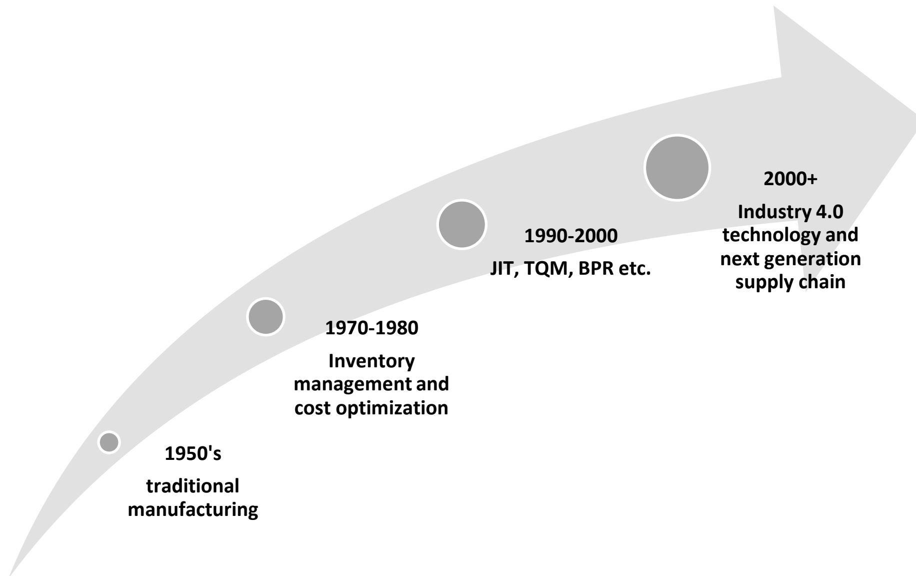

Figure 1: Roadmap of supply chain advancement

By reviewing the literatures related to Industry 4.0, it is clear that there is a strategic plan needed for implementation of these technologies in supply chain to enhance its performance parameters. The importance of autonomous vehicles in supply chain increases with the increase in complexity in product data management. A cyber system to monitor and control the chain and autonomous vehicle which helps in transporting the asset from one stage to another, provide updates and keep track of the assets in turn increasing the traceability. Many literatures available which summaries the importance of Industry 4.0, its applications, technology selection framework and probable benefits. But there is no research available which provides quantitative analysis of these technologies implemented at organization. This paper aims to quantify the relations between various stages of forward supply chain and bridge the gap between conceptual and quantitative analysis for better implementation of technology. We have taken only the transportation part under consideration which includes its cost and carbon emission.

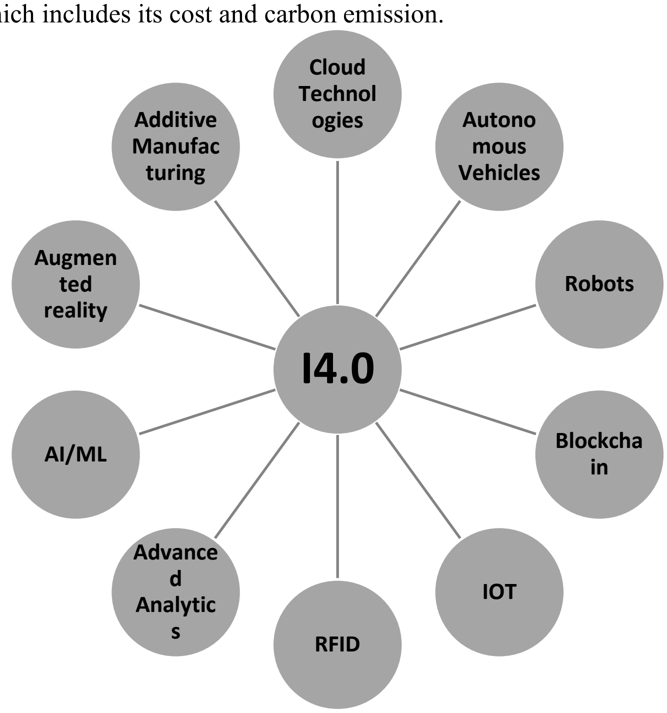

Figure 2: Technology key enablers for I4.0

This paper is organized in a way to meet the desired objective of optimization, an attempt has been made to develop a quantitative model which covers the transportation of product in a forward supply chain with technology implementation. The sections further include objective of the paper, then the detailed literature survey, followed with the methodology part consist of the formulation developed after that toy dataset optimizations results and discussions has been done with some graphical analysis and concluded with limitations and future research directions.

1.1 Objectives

The model represents a linear optimization programming to optimize following objectives

a. Transportation Cost (minimization)
b. Emission due to transportation (minimization)

2. Literature Review

Smart Logistics: Inbound/outbound logistics processes must adapt to this changing situation as the demand for customized commodities grows. It can't be handled using conventional planning and control processes because of its growing complexity. We define Smart Logistics as the integration of logistics activities with the use of cyber systems, robots, and the internet of things. The terms "smart logistics" and "smart factory," "smart product," and "smart services" are interchangeable. With the support of smart products and smart services, we explored the technology-driven strategy for defining smart logistics. Smart Logistics is a core idea section, as well as a vital component of Industry 4.0, where the vertical mix takes place (Verma et al., 2020).

Industry 4.0 research themes: (Nayernia et al., 2021) while addressing to the gap of implementation of Industry 4.0, identified Industry and company, smart manufacturing, data, human resources, and supply chain were among the eleven research streams divided into five levels. After that, the research streams were thoroughly examined and presented. The report covers a number of sub-themes for each stream and highlights key discoveries and areas that may warrant future research. Also, (Adebanjo et al., 2021) narrowed down the variables that enable the adoption of Industry 4.0 technologies in a developing economy country, categorizing them and ranking them according to adoption priorities The research used a mixed-methods approach.

Digital Supply chain: (Woschank et al., 2021) analyze the current literature on digitalization in industrial logistics, with an emphasis on actionable research findings and investigated on four different aspects viz. digitalization in industrial logistics technologies and technological concepts, enablers of digitalization in industrial logistics, hazards of digitalization in industrial logistics, and prospects for digitalization in industrial logistics are all discussed. (Attaran, 2020) emphasizes the importance of Industry 4.0 technologies for supply chains and logistics, examines their trends and challenges in supporting digital supply chain performance, and investigates the implementation and managerial challenges of transforming the digital supply chain into a new integrated paradigm.

Technology selection framework: (Fatorachian & Kazemi, 2021) investigated the impact of Industry 4.0 on SC performance, as well as to conceptualize and develop findings into a systems-theory-based operational framework. According to the study, applying Industry 4.0-enabling technologies to SCM will result in significant performance improvements by enabling a holistic approach to supply chain management as a result of extensive supply chain integration, information sharing, and transparency throughout the supply chain. (Hamzeh et al., n.d.) provides a decision-making framework for selecting manufacturing technology that combines technological, social, and business issues into a single loop. (Farooq & Brien, 2015) developed a framework for technology selection decision making process which aimed to assists the industrial managers in promoting manufacturing and supply chain coordination.

Logistics 4.0: (Tjahjono et al., 2017) studied the collaboration between the supplier, manufacturer, warehouse and market is very important to increase transparency and traceability throughout the life cycle of the product, it is therefore very important to analyses the impact of Industry 4.0 on supply chain as a whole. (Efthymiou & Ponis, 2021) identified emerging aspects and current trends in the field, discussed the main technological developments and evolution of Industry 4.0 and their implications for modern logistics, and finally identified literature gaps and currently under-explored areas with a high potential for impactful future research. The findings of this assessment will ideally serve as a foundation for future research in the logistics 4.0 concept and related areas.

Autonomous vehicles for transportation: (Fernández-Caramés et al., 2019) presented a design and evaluation of autonomous vehicles aiming at automating inventory and keep track of asset through RFID tags. To ensure traceability blockchain is employed to store and verify data. (Frankó et al., 2020) provided the solution as a novel method for asset tracking under industry 4.0 technology, since assets tracking is very important and challenging part of supply chain, he focuses on a method which facilitates the efficient and reliable identification scheme.

3. Methods

The traditional forward supply chain with 3 stages shown in Figure 3 equipped with technology for transporting raw material from supplier to manufacturer then from manufacturer to warehouse and last from warehouse to market. Here in the formulation, we considered the impact of technology implementation on industry budget and rate of carbon emission by technology adaption, a binary variable has taken into account which checks for the whether the technology adapted or not. In our model we divided the industrial product into two parts Normal and Smart product to achieve the goal of whether the smart product is beneficial in terms of cost and gas emission or not. Following section deals with the description of model.

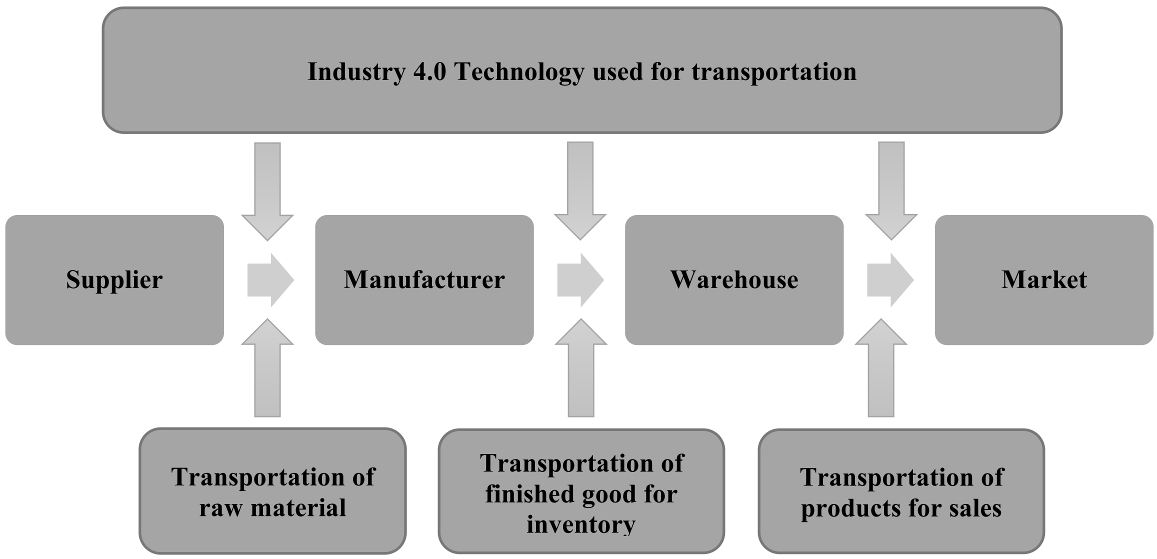

Figure 3: Forward supply chain with technology implementation

3.1 Formulation description and model assumptions

This formulation represents the impact of technology adoption at various stages of forward supply chain. Hence, this model shows a mathematical representation of sustainable supply chain with technological disruption. Following are the assumptions taken while forming the model:

a. Manufacturer and warehouse capacity are independent of product kinds, implying that the goods are believed to be of similar size, occupying similar space/volume and requiring equivalent resources and manufacturing time.
b. The Organization has no restrictions on the amount of money it spends on production, packaging, or shipment via various routes.
c. In the model, any manufacturer and manufacturing activity in the SC network might be considered a supplier with restricted capacity.
d. If the manufacturer is shut down, there will be no operating costs (not producing any product).
e. If the warehouse is closed, there will be no cost (not receiving and distributing any product).
f. There are no time constraints on production and transportation; nevertheless, the time required for different modes of transportation will vary substantially.
g. The market demand is totally deterministic, i.e., it is known ahead of time.
h. The vehicle's capacity and the source are both known.
i. Emission coefficient includes size, distance and mileage of transportation vehicle
j. All kinds of transportation are readily available in all regions, and none are in short supply.
k. The emission per unit index is entirely made up and bears no connection to actual figures.
l. A product type can be delivered between any two nodes using a variety of techniques.

m. In theory, the emission contributions are linearly summed to provide the total emission, although this is not always the case.
n. All technological advancements will have positive impact

To formulate the above-mentioned objectives following parameters have been taken into consideration:

Definitions

$Cost\_TransSP$	Transportation cost to supply raw material for product category *i* from supplier *s* to manufacturer *p* by implementing technology *t*
$Cost\_TransPW$	Transportation cost to supply finished items with product category *i* from manufacturer *p* to warehouse *w* by implementing technology *t*
$Cost\_TransWM$	Transportation cost to supply finished items with product category *i* from warehouse *w* to market *M* by implementing technology *t*
$Em\_TransSP$	Amount of carbon emission due to transportation of raw material for product category *i* to manufacturer *p* procured from supplier *s* by adopting technology *t*
$Em\_TransPW$	Amount of carbon emission due to transportation of finished items with product category *i* to warehouse *w* sourced from manufacturer *p* by adopting technology *t*
$Em\_TransWM$	Amount of carbon emission due to transportation of finished items with product category *i* to market *M* out bounded from warehouse w by adopting technology *t*

Sets and indices

s	be the set of Suppliers ($s \in S$)
p	be the set of Factories ($p \in P$)
w	be the set of Warehouses ($w \in W$)
m	be market ($m \in M$); $M = 1$
t	be the set of technology adopted ($t \in T$)
i	be the set of product variety consists of smart and non-smart product ($i \in I$) I = {smart, non-smart}
TT	be the set of transportation technologies {normal vehicle, semi-autonomous vehicle, autonomous vehicle}

Parameters

S_s^{cap}	Total capacity of supplier $s \in S$ to supply raw material
P_p^{cap}	Total production capacity of manufacturer $p \in P$
W_w^{cap}	Total capacity of warehouse $w \in W$
M_i	Total Market demand for product category *i*

Decision Variables

RS_{spi}	Quantity of raw material for product category *i* supplied from supplier *s* to manufacturer *p*
RQ_{pi}	Quantity of raw material for product category *i* *s*upplied from all supplier *s* received at manufacturer *p*
PQ_{pi}	Quantity manufactured for product category *i* at manufacturer *p*
WQ_{pwi}	Quantity of product category *i* supplied from manufacturer *p* warehouse *w*
MQ_{wi}	Quantity of product category *i* supplied from warehouse *w* to market
TT_Cost_{it}	Cost of transportation depending on technology *t* for product category *i*
$em_{it}^{transSP}$	Emission coefficient (including distance parameter) for transporting raw material for product category *i* from supplier *s* to manufacturer *p* by adopting technology *t*
$em_{it}^{transPW}$	Emission coefficient (including distance parameter) for transporting finished goods for product category *i* from manufacturer *p* to warehouse *w* by adopting technology *t*
$em_{it}^{transWM}$	Emission coefficient (including distance parameter) for transporting finished goods for product category *i* from warehouse *w* to market *M* by adopting technology *t*
TTG_{spt}	Binary variable equals to *1,* if supplier *s* using transportation technology *t* for manufacturer *p; 0* otherwise
TTG_{pwt}	Binary variable equals to *1,* if manufacturer *p* using transportation technology *t* for warehouse *w; 0* otherwise
TTG_{wmt}	Binary variable equals to *1,* if warehouse *w* using transportation technology *t* for market *M; 0* otherwise

Cost Minimization Function
Total cost of transportation represented in eq. 1 at various stages as shown in Figure 3.

$$Z_{min}^{transportation\ Cost} = Cost\_TransSP + Cost\_TransPW + Cost\_TransWM \quad (1)$$

Emission Minimization Function
Total emission represented in eq. 2 consist of emission rates due to transportation (as shown in Figure 3).

$$Z_{min}^{emission} = Em\_TransSP + Em\_TransPW + Em\_TransWM \quad (2)$$

The main constraints for proposed formulation are defined below and subjected to
This inventory balancing constraint eq. 3 shows that each manufacturer receiving certain amount of raw material from all the suppliers should be in consistent with the order placed. Quantity of raw material for product category *i* supplied from supplier *s* to manufacturer *p* should be less than equal to the quantity of raw material for product category *i* supplied from all supplier *s* received at manufacturer *p*.

$$\sum_{s=1}^{S} RS_{spi} \geq RQ_{pi} \ \forall\ i, p \quad (3)$$

This inventory balancing constraint eq. 4 ensure the incoming raw material at manufacturer should be of limited capacity. The quantity of raw material for product category *i* supplied from supplier *s* to manufacturer *p* should be equal to or less than the total capacity of supplier $s \in S$ to supply raw material.

$$\sum_{p=1}^{P} \sum_{i=1}^{I} RS_{spi} \leq S_s^{cap} \ \forall\ s \quad (4)$$

Total cost due to transportation from supplier to manufacturer eq. 5 depends on the technology implementation cost per unit of product and total quantity of raw material.

$$Cost\_TransSP = \sum_{s=1}^{S} \sum_{p=1}^{P} \sum_{i=1}^{I} \sum_{t \in TT} TTG_{spt} * TT\_Cost_{it} * RS_{spi} \quad (5)$$

Toy dataset assumption for normal and smart product transportation through technology implementation with normal, semi-autonomous vehicle and autonomous vehicle are shown in Table 1 and 2.

Table 1: Toy dataset for Transportation cost and emission coefficient of normal products

Transportation Technologies for normal products (i=1)	TT_Cost_{it} Transportation cost	$em_t^{transSP}$ Emission coefficient
Normal vehicle	300	100
Semi-autonomous	500	80
Autonomous	700	50

Table 2: Toy dataset for Transportation cost and emission coefficient of smart products

Transportation Technologies for smart products (i=2)	TT_Cost_{it} Transportation cost	$em_{it}^{transSP}$ Emission coefficient
Normal vehicle	500	80
Semi-autonomous	800	60
Autonomous	1000	20

Total emission due to transportation from supplier to manufacturer eq. 6 depends on whether the technology is used or not, which regulates the emission coefficient (includes distance, size, loading and mileage factors) and quantity of raw material supplied.

$$Em\_TransSP = \sum_{s=1}^{S}\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{t\in TT} em_{it}^{transSP} * TTG_{spt} * RS_{spi} \quad 6$$

Total number of units of product produced at manufacturer *p* of product category *i* should be less than or equal to manufacturer capacity eq. 7

$$\sum_{i=1}^{I} PQ_{pi} \leq P_p^{cap} \; \forall \, p \quad 7$$

Total demand by the manufacturer should be equally fulfilled by supplier in eq. 8

$$PQ_{pi} = RQ_{pi} \; \forall \, i, p \quad 8$$

Total cost due to transportation from manufacturer to warehouse eq. 9 depends on the technology implementation cost per unit of product and total quantity of finished item supplied.

$$Cost\_TransPW = \sum_{w=1}^{W}\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{t\in TT} TTG_{pwt} * TT\_Cost_{it} * WQ_{pwi} \quad 9$$

Total emission due to transportation from manufacturer to warehouse eq. 10 depends on whether the technology is used or not, which regulates the emission coefficient (includes distance, size, loading and mileage factors) and quantity of finished items supplied.

$$Em\_TransPW = \sum_{w=1}^{W}\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{t\in TT} em_{it}^{transPW} * TTG_{pwt} * WQ_{pwi} \quad 10$$

Total number of unit of products supplied from manufacturer to warehouses as per the capacity should be equal to the quantity produced at manufacturer eq. 11.

$$\sum_{w=1}^{W} WQ_{pwi} = PQ_{pi} \; \forall \, i, p \quad 11$$

Total number of unit of products supplied from manufacturer to warehouses should be less than or equal to the effective capacity of the warehouse conditioned at technology adoption eq. 12.

$$\sum_{p=1}^{P}\sum_{i=1}^{I} WQ_{pwi} \leq W_w^{cap} \; \forall \, w \quad 12$$

Total cost due to transportation from warehouse to market eq. 13 depends on the technology implementation cost per unit of product and total quantity of finished item supplied.

$$Cost\_TransWM = \sum_{w=1}^{W}\sum_{i=1}^{I}\sum_{t\in TT} TTG_{wmt} * TT\_Cost_{it} * MQ_{wi} \quad 13$$

Total emission due to transportation from warehouse to market eq. 14 depends on whether the technology is used or not, which regulates the emission coefficient (includes distance, size, loading and mileage factors) and quantity of finished items supplied.

$$Em\_TransWM = \sum_{w=1}^{W}\sum_{i=1}^{I}\sum_{t\in TT} em_{it}^{transWM} * TTG_{wmt} * MQ_{wi} \qquad 14$$

The product shipped from warehouse to market place should be less than or equal to the product supplied from manufacturer to warehouse eq. 15

$$MQ_{wi} \leq \sum_{p=1}^{P} WQ_{pwi} \quad \forall\, w, i \qquad 15$$

Product shipped out from warehouse to market should fulfil the market demand eq. 16

$$\sum_{w=1}^{W} MQ_{wi} = M_i \;\forall\, i \qquad 16$$

4. Results and Discussion

The model develop is executed in Microsoft excel 2019 with the help of solver function for optimizing the linear program. The result obtained are segregated as shown in Figure 4. The model has been solved and the excel sheet for different cases has been attached as appendix for further review.

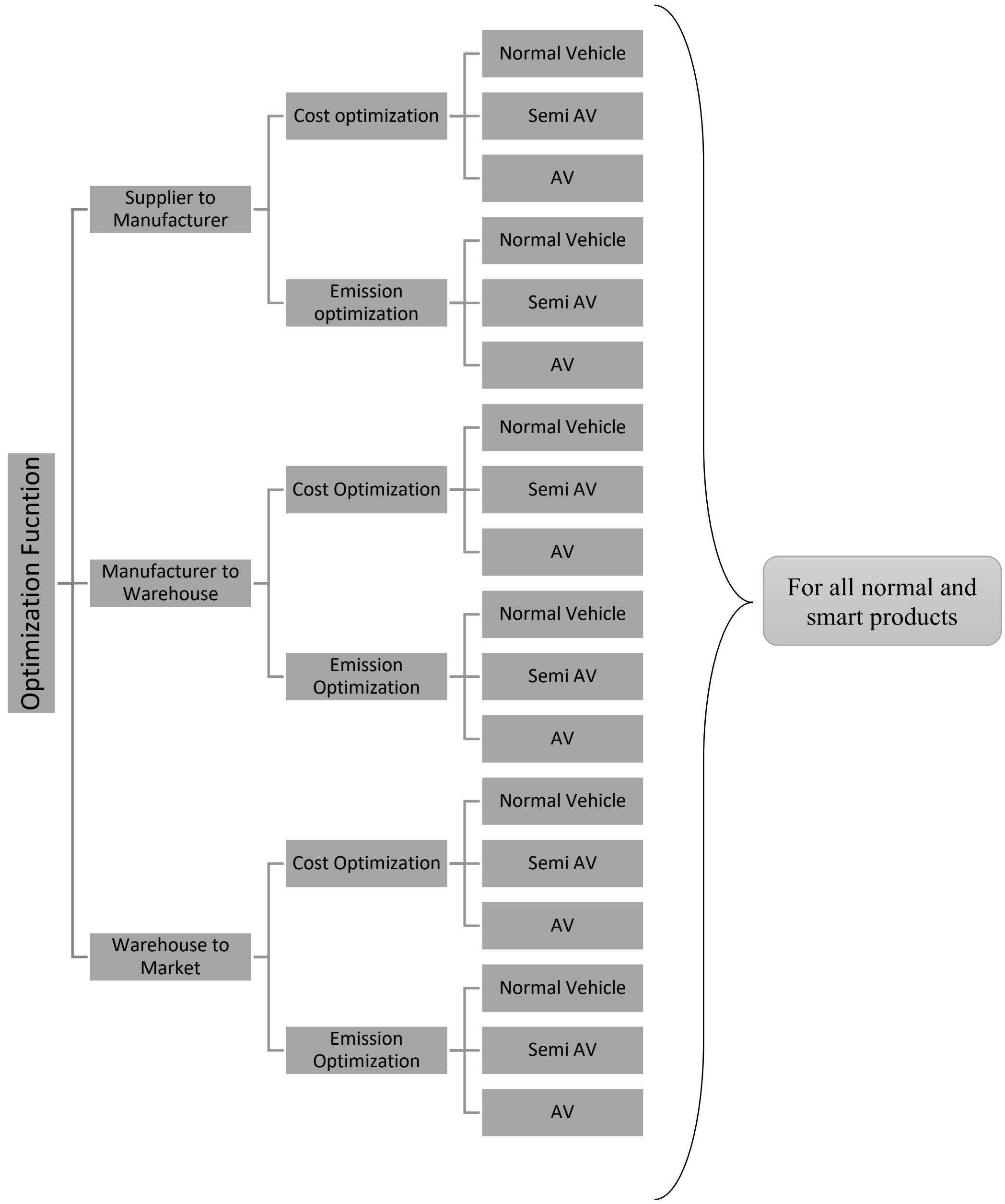

Figure 4: Linear Programming Optimization framework

4.1 Numerical and Graphical Results

The sample dataset is solved by considering random data points (under limits as shown in Table 1 and 2) for transportation cost and emission coefficients and solved for supplier to manufacturer stage. Table 3 describes the outcomes of the optimization process also graph as shown in Figure 5 clearly shows the inverse relation of cost and emission rates. With this we can interpret that the manufacturer will order to the less cost supplier who ships the normal as well as smart product in less cost and if the supplier is using smart and autonomous vehicles the cost might be more but lowers the adverse effect on environment.

Table 3: Solved sample set for Supplier to Manufacturer

		Manufacturer					
		Mini. Trans Cost - Normal Vehicle	**Mini. Trans Cost - SAV**	**Mini. Trans Cost - AV**	**Mini. Emission - Normal Vehicle**	**Mini. Emission - SAV**	**Mini. Emission - AV**
Normal	**Supplier 1**	483470	508179	632571	165414	74184	38301
	Supplier 2	214968	680739	1126170	122907	57663	35244
	Supplier 3	297840	345348	1060500	64080	61320	11615
	Supplier 4	463941	777372	439300	11132	93597	17622
	Sub Total	**1460219**	**2311638**	**3258541**	**363533**	**286764**	**102782**
Smart	**Supplier 1**	201684	329938	482975	48589	37899	13260
	Supplier 2	184877	307563	450453	50292	35919	13320
	Supplier 3	202320	265037	424200	40845	38144	11971
	Supplier 4	198245	308520	364700	52644	37050	17654
	Sub Total	**787126**	**1211058**	**1722328**	**192370**	**149012**	**56205**
	Total	**2247345**	**3522696**	**4980869**	**555903**	**435776**	**158987**

*Note Mini. = Minimizing

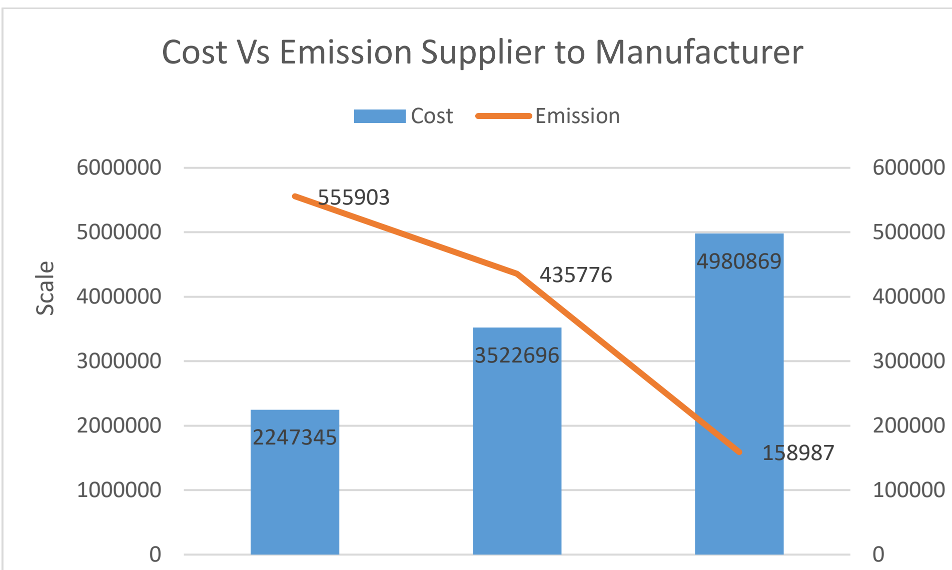

Figure 5: Cost Vs Emission - Supplier to Manufacturer

The sample dataset is again solved for the manufacturer to warehouse stage by using random data points (within limits as given in Tables 1 and 2) for transportation cost and emission coefficients. Table 4 summarizes the results of the optimization procedure, and the graph in Figure 6 clearly demonstrates the inverse relationship between cost and emission rates. With this, we can deduce that the warehouse will place an order with the lowest transportation cost manufacturer, who will ship both standard and smart products at a lower cost; however, if the manufacturer uses smart and autonomous vehicles, the cost will be higher, but the negative impact on the environment will be reduced.

Table 4: Solved sample set for Manufacturer to Warehouse

		Warehouse					
		Mini. Trans Cost - Normal Vehicle	**Mini. Trans Cost - SAV**	**Mini. Trans Cost - AV**	**Mini. Emission - Normal Vehicle**	**Mini. Emission - SAV**	**Mini. Emission - AV**
Normal	**Manufacturer 1**	0	268000	705000	80000	133000	10000
	Manufacturer 2	357000	529000	721000	80000	66000	42000
	Manufacturer 3	319000	781000	725000	0	60000	0
	Manufacturer 4	0	0	793000	0	0	22000
	Manufacturer 5	700000	0	0	170000	0	27000
	Manufacturer 6	0	539000	0	0	0	0
	Sub Total	**1376000**	**2117000**	**2944000**	**330000**	**259000**	**101000**
Smart	**Manufacturer 1**	0	321600	423000	48000	36000	12000
	Manufacturer 2	214200	317400	432600	48000	39600	19200
	Manufacturer 3	191400	309600	435000	0	36000	0
	Manufacturer 4	0	0	0	0	0	0
	Manufacturer 5	420000	0	0	102000	44400	16200
	Manufacturer 6	0	323400	554400	0	0	16800
	Sub Total	**825600**	**1272000**	**1845000**	**198000**	**156000**	**64200**
	Total	**2201600**	**3389000**	**4789000**	**528000**	**415000**	**165200**

*Note Mini. = Minimizing

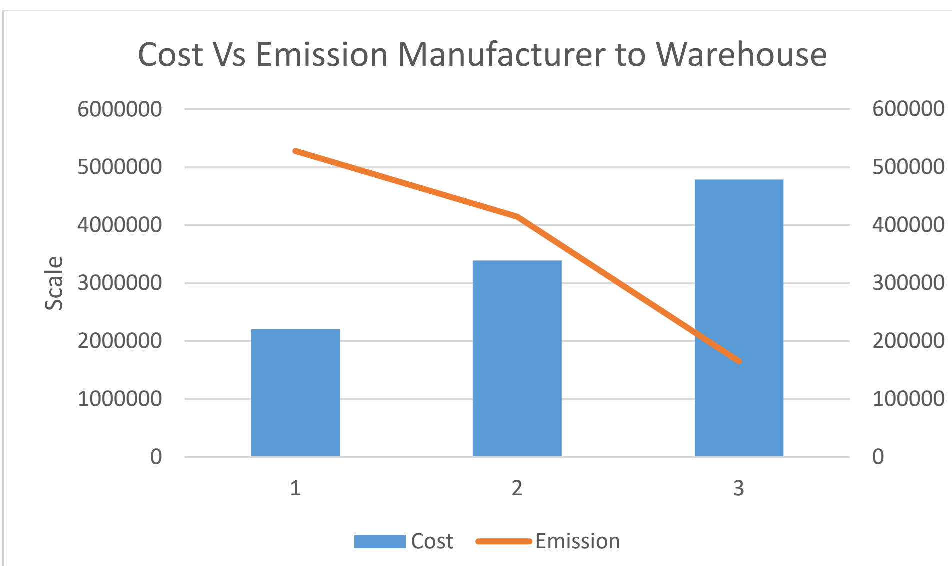

Figure 6: Cost Vs Emission - Manufacturer to Warehouse

For transportation cost and emission coefficients, the sample dataset is solved again for the warehouse to market stage using random data points (within limits as stated in Tables 1 and 2) from the sample dataset. The findings of the optimization technique are summarized in Table 5, and the graph in Figure 7 clearly shows the inverse relationship between cost and emission rates. We can deduce from this that the market will place an order with the lowest transportation cost from warehouse, who will ship both standard and smart products at a lower cost; however, if the warehouse management system uses smart and autonomous vehicles, the cost will be higher, but the environmental impact will be reduced.

Table 5: Solved sample set for Warehouse to Market

		Market					
		Mini. Trans Cost - Normal Vehicle	**Mini. Trans Cost - SAV**	**Mini. Trans Cost - AV**	**Mini. Emission - Normal Vehicle**	**Mini. Emission - SAV**	**Mini. Emission - AV**
Normal	**Warehouse 1**	0	418400	0	0	51200	0
	Warehouse 2	0	0	0	0	0	0
	Warehouse 3	328000	0	0	66400	0	0
	Warehouse 4	0	0	578400	0	0	19200
	Sub Total	**328000**	**418400**	**578400**	**66400**	**51200**	**19200**
Smart	**Warehouse 1**	0	261500	0	0	0	0
	Warehouse 2	0	0	0	0	0	0
	Warehouse 3	205000	0	0	41500	0	0
	Warehouse 4	0	0	361500	0	32000	12000
	Sub Total	**205000**	**261500**	**361500**	**41500**	**32000**	**12000**
	Total	**533000**	**679900**	**939900**	**107900**	**83200**	**31200**

*Note Mini. = Minimizing

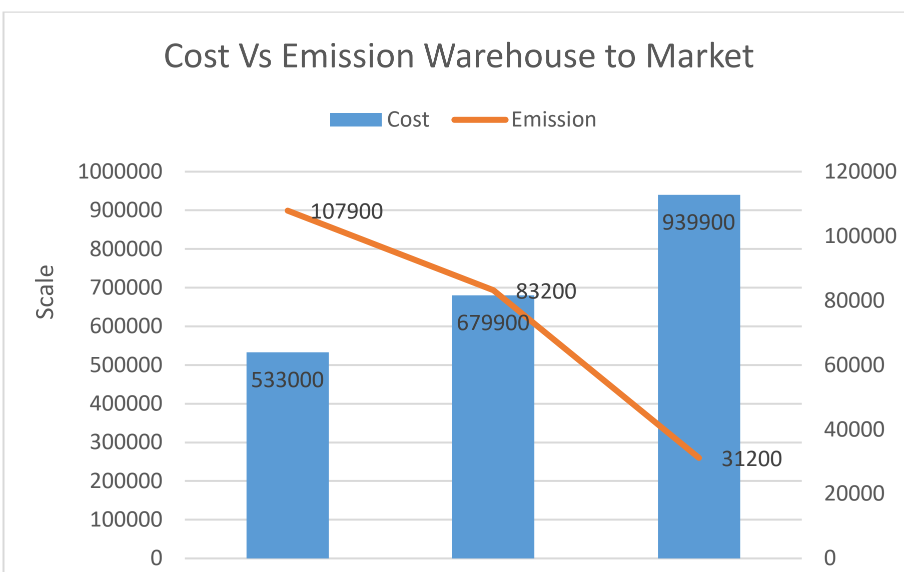

Figure 7: Cost Vs Emission - Warehouse to Market

4.2 Proposed Improvements

The proposed improvements for the above model can done in every aspect of supply chain. As Industry 4.0 gaining its popularity among all the supply chain players, we can apply the technology implementation part at every point to improve the efficiency and effectiveness of supply chain which in turn becomes a sustainable supply chain when if the impact on environment taken into consideration. Even after that the model can be applied over reverse logistics part over which many processes like remanufacturing and recycling utilizes many new technologies. Through the help of example data set and validating the model, model reliability can be established, also more and more research could happen if real time data set can be taken from any industry employing Industry 4.0 technology at its every stage of production.

5. Conclusion

As the model shows with the toy dataset used to validate the linear program formulated, the transportation cost for autonomous vehicles is high as compared to normal vehicles which shows that the operational cost is high for AV which might be the case that it is not being utilized in such a high scale as normal vehicle and also the fixed cost associated with the vehicle is high which make its operations costly. But on the other hand, emissions rates of carbon discharge are low for autonomous vehicles in all the cases, it might be because of the technology used which reduces the fuel consumption optimizes the performance and increases the efficiency of the vehicle. Also, electric vehicle if used as autonomous vehicle will be the best suitable option for transportation having least adverse effect on environment. The main limitation of the model could be the dataset used, which is a toy dataset, since getting exact real-time data for the aspects we consider here, might not be possible because of the lack of total fourth industrial revolution in the industries. Because of it this model is only a representation and validation of the model constructed but will be applicable for all the industries in near future.

References

Adebanjo, D., Laosirihongthong, T., Samaranayake, P., & Teh, P. L. (2021). Key Enablers of Industry 4.0 Development at Firm Level: Findings From an Emerging Economy. *IEEE Transactions on Engineering Management*, 1–17. https://doi.org/10.1109/TEM.2020.3046764

Attaran, M. (2020). Digital technology enablers and their implications for supply chain management. *Supply Chain Forum: An International Journal*, *21*(3), 158–172. https://doi.org/10.1080/16258312.2020.1751568

Efthymiou, O. K., & Ponis, S. T. (2021). Industry 4.0 technologies and their impact in contemporary logistics: A systematic literature review. *Sustainability (Switzerland)*, *13*(21). https://doi.org/10.3390/su132111643

Farooq, S., & Brien, C. O. (2015). *A technology selection framework for integrating manufacturing within a supply chain*. *7543*(December). https://doi.org/10.1080/00207543.2011.588265

Fatorachian, H., & Kazemi, H. (2021). Impact of Industry 4.0 on supply chain performance. *Production Planning and Control*, *32*(1), 63–81. https://doi.org/10.1080/09537287.2020.1712487

Fernández-Caramés, T. M., Blanco-Novoa, O., Froiz-Míguez, I., & Fraga-Lamas, P. (2019). Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability Applications in Big Data-Driven Supply Chain Management. *Sensors (Basel, Switzerland)*, *19*(10). https://doi.org/10.3390/s19102394

Frankó, A., Vida, G., & Varga, P. (2020). Reliable identification schemes for asset and production tracking in industry 4.0. *Sensors (Switzerland)*, *20*(13), 1–24. https://doi.org/10.3390/s20133709

Hamzeh, R., Zhong, R., Xu, X. W., & Zolotova, I. (n.d.). *A technology selection framework for manufacturing companies in the context of Industry 4 . 0*. 267–276.

Nayernia, H., Bahemia, H., & Papagiannidis, S. (2021). A systematic review of the implementation of industry 4.0 from the organisational perspective. *International Journal of Production Research*, 0–32. https://doi.org/10.1080/00207543.2021.2002964

Tjahjono, B., Esplugues, C., Ares, E., & Pelaez, G. (2017). What does Industry 4.0 mean to Supply Chain? *Procedia Manufacturing*, *13*, 1175–1182. https://doi.org/10.1016/j.promfg.2017.09.191

Verma, P., Dixit, V., & Kushwaha, J. (2020). Risk and resilience analysis for industry 4.0 in achieving the goals of smart logistics: An overview. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, *0*(March), 151–157.

Woschank, M., Kaiblinger, A., & Miklautsch, P. (2021). *Digitalization in Industrial Logistics : Contemporary Evidence and Future Directions*.

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