DIJEMSS: Dinasti International Journal of Education Management and Social Science
E-ISSN: 2686-6331
P-ISSN: 2686-6358
https://dinastipub.org/DIJEMSS dinasti.info@gmail.com +62 811 7404 455
DINASTI PUBLISHER

DOI: https://doi.org/10.38035/dijemss.v7i6

Sustainable Logistics: Decarbonizing Inbound Logistics Using Milk Run

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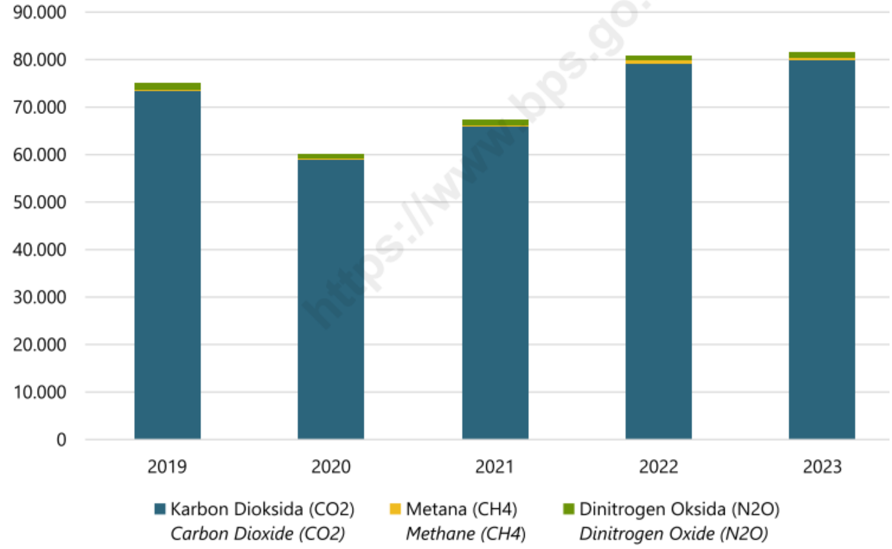
Abstract: The modern transportation and logistics landscape is undergoing a dramatic transformation, driven by the relentless pursuit of efficiency, resilience, and sustainability. A critical aspect of modern green supply chain management is optimizing transportation routes to reduce fuel consumption and minimize carbon footprints. Building on this paradigm, this study examines the impact of the Milk Run Method on distance traveled, fuel consumption, and carbon footprint during delivery, comparing its implementation with the Point-to-Point delivery method. Milk Run method showed a 29% reduction in travel distance and 9% lower fuel usage and CO_2 emissions across six routes. Its effectiveness, however, depended on supplier proximity and cargo volume.

Keywords: Sustainable Logistics, Carbon Emission, Routing Optimization, Milk Run

INTRODUCTION

Global transport was the fourth-largest source of GHG emissions in 2019, following power, industry, and agriculture (IPCC, 2022). Because burning fossil fuels poses significant threats to our environment (Solaymani & Botero, 2025), and within this context, road passenger and freight vehicles dominate global transport-related CO_2 emissions and offer the largest mitigation potentialTaptich et al., 2016). Freight transport, measured in tonne-kilometres (tkm), grew by 68% between 2000 and 2015 and is projected to grow 3.3 times by 2050 (IPCC, 2022). Most countries are examining opportunities for combined mitigation and adaptation efforts, using the need to mitigate climate change through transport-related greenhouse gas emissions reductions (Thornbush et al., 2013; Wang et al., 2020). This urgency is clearly evident in Indonesia during 2019-2023, total emissions in this industry showed an increasing trend, reaching 81,565 $GgCO_2e$ in 2023 as visualized in Image 1 below:

Image 1, Distribution of Greenhouse Gas Emission in Transportation (GgCO_2e) by Type, 2019-2023



Source: Indonesia Energy Flows Accounts and Greenhouse Gas Emission 2019-2023, Vol 5, 2025

If unchecked, this growth will make decarbonization of freight transport very difficult (McKinnon, 2022) as CO_2 emissions contributed the most, accounting for 97.76 percent of total emissions in Transportation in 2023.

In Indonesia, Toyota Motor Manufacturing Indonesia (PT. TMMIN) operates a complex production network that must manage high volumes of parts and vehicles in a congested setting utilizing an integrated supply chain known as the "progress line" essentially a Just In Time (JIT) driven system that synchronizes parts flow so that materials arrive just as they are needed (Purba et al., 2019). To support this system, Toyota implemented the Milk run method in delivery of materials from its suppliers in order to be able to be in production. Milk run method is a delivery system in which vehicles are rotating based on a schedule defined before, stopping at every department to collect products that have been ordered (Setiani et al., 2018). In a milk-run system, routes, time schedules, and the type and number of parts to be transported are assigned to different logistic trains so that they can collect orders from different suppliers (Bocewicz et al., 2021) an effective logistics strategy that optimizes transportation routes and reduces empty vehicle runs.

Published studies predominantly focused on distance and operational cost sectors, leaving the environmental dimension underexplored and not documented. Building upon this paradigm, this study examines the impact of the Milk Run Method on distance traveled, fuel consumption, and carbon footprints by depicting a comparison between the Milk Run and Point to Point method using IPCC-based emission calculation and real-world operational data in Indonesia. By providing a comprehensive analysis of the Milk Run method, this study is one of the first to assess the environmental impact, inform future studies, and contribute to the advancement of resilient and sustainable, low-carbon emission solutions in Green logistics performance Measurement.

Environment Sustainability in Logistic

Logistics is facing new challenges due to rapid climate change, which were not previously present in its regular operations. As global temperatures rise and extreme weather events become more frequent, the logistics sector must adapt to a new reality (SEMRAU, 2025). Approximately 25% of worldwide greenhouse gas (GHG) emissions come from the transportation sector, with road transport being the largest contributor responsible for over half of transportation-related emissions. Increasing private vehicle ownership and growing mobility demands continue to undermine international efforts to reduce transportation-related GHG emissions (R. Zhang & Fujimori, 2020)

Historically, logistical decisions were driven by revenue growth, cost reduction, and customer service objectives. However, as businesses increasingly incorporate sustainability goals into their strategies, reducing the social and environmental impact of operations has gained importance. In logistics, this shift has led warehouse managers to focus on waste and energy reduction, transportation providers to cut vehicle emissions, and product designers to enhance recyclability and reuse all of which require changes in inventory planning (Blanco & Sheffi, 2017)

Governments have also introduced regulations to encourage and facilitate the adoption of green logistics practices (D. Kim et al., 2024). In Indonesia, these efforts are particularly relevant due to the country's high reliance on road-based freight transport, which contributes substantially to national emissions. Improving transportation efficiency and implementing sustainable logistics strategies could play a significant role in reducing environmental impact while maintaining supply chain competitiveness.

Route Optimization, Fuel Consumption and Carbon Footprints

Transportation system considered as a distribution center and a group of vehicles. The distribution center provides transportation arrangement services to the vehicles. That is, the distribution center arranges each vehicle with the transportation task and the corresponding routing. The vehicles start their tasks from the distribution center and return to the distribution center after finishing the task. Suppose that the number of vehicles is large enough to satisfy all the transportation demand. This is reasonable as it is common in practice that the distribution center can adjust his vehicles to satisfy the transportation demand. Each vehicle has a load capacity limit and will incur fuel consumption costs, carbon emission cost and usage costs during its tasks. Thus, the distribution center needs to arrange transportation routing to minimize the transportation cost of the whole system by taking those costs into account (J. Zhang et al., 2015)

Route optimization is a systematic process of determining the most efficient sequence and allocation of delivery or pickup locations for a fleet of vehicles, while simultaneously accommodating operational constraints such as vehicle capacity, delivery time windows, and route length (Zavalishchin & Gabdulhakov, 2022). At the core of this optimization lies the Vehicle Routing Problem (VRP), a fundamental combinatorial optimization challenge that seeks to design the most efficient set of routes for a fleet of vehicles servicing a given set of customers (J. Zhang et al., 2015). Traditionally, VRP models have focused almost exclusively on minimizing economic costs, primarily through distance reduction. However, the modern shift toward environmental sustainability has given rise to the Green Vehicle Routing Problem (Winkelhaus & Grosse, 2020).

Route optimization is generally understood to improve fuel efficiency by influencing several operational aspects. Shorter and more direct routes are associated with lower fuel usage, as vehicles cover less distance (J. K. Kim et al., 2022). The consolidation of shipments also tends to increase load factors and reduce the frequency of empty trips, which can decrease fuel consumed per unit transported. Moreover, smoother operations such as reducing unnecessary stops, limiting idling, and maintaining more consistent driving speeds are often linked with better fuel economy across the logistics process (Feng & Dong, 2023)

Fuel consumption in freight transportation is the quantity of fuel required to operate a vehicle over a given distance or period, often expressed in liters per kilometer or kilometers per liter. It is influenced by factors such as vehicle type, load weight, road conditions, driving behavior, and routing efficiency (Boriboonsomsin et al., 2012). In the context of environment sustainability, fuel consumption serves as both an economic and environmental performance indicator because it directly determines operational costs and is the primary driver of carbon emissions from internal combustion engines.

Carbon footprint is defined as the total amount of GHG emissions caused directly or indirectly by an activity, organization, or product, expressed as carbon dioxide equivalent (CO_2e). For transportation activities, the carbon footprint is predominantly derived from fuel combustion, with diesel-powered heavy goods vehicles (HGVs) contributing significant CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions. Measuring the carbon footprint in logistics typically involves calculating emissions using standardized emission factors and fuel usage data, as outlined in IPCC guidelines (IPCC, 2006)

Milk Run

After the Second World War, the Toyota Motor Company, led by Toyoda, Shigeo Shingo and Taiichi Ohno developed a new manufacturing system; initially known as the Toyota Production System (TPS) and later just-in-time (JIT) or total quality control system or world-class manufacturing system, and finally lean production in 1990 (Sangwa & Sangwan, 2023). From a logistics point of view, this situation has driven the engineers to organize their transports between and within their plants, competing intensively on a small market and had to produce a great variety of car types in very small lots at fixed times along a fixed route (Meyer, 2016).

"Milk Run" as a transportation concept often mentioned in the context of lean manufacturing, came from the definition of milk delivery (Dat Minh et al., 2020). Particularly, the milk deliverer called "Milkman" delivers full milk boxes to a fixed location and takes back the empty boxes during their delivering journey. When the customers use up two milk boxes and leave them in front of their doors, the milkman replaces those empty boxes by other two full ones. After that, the deliverer carries all those empty boxes back to the manufacturer in order to refill them and then starts the next delivering round. This process is repetitive with different locations on the delivering journey of the milkman (Dat Minh et al., 2020).

In a milk run system, routes, time schedules, and the type and number of parts to be transported are assigned to different logistic trains so that they can collect orders from different suppliers are cyclically repeated according to a fixed schedule in a fixed sequence and with fixed arrival times to make frequent supplier-to-plant deliveries, is that they reduce variability by running on fixed schedules (Bocewicz et al., 2021).

Previous studies have highlighted the advantages of Milk-Run logistics in the automotive industry, particularly within Toyota Motor Manufacturing Indonesia (TMMIN). For example, (Setiani et al., 2018) compared Milk-Run and Point-to-Point delivery routes and demonstrated that the Milk-Run system reduced travel distance by 14%, shortened lead time by 13%, and achieved 43% cost savings. However, their analysis was limited to operational performance indicators such as distance, time, and cost. What remains underexplored in the Indonesian context is the environmental dimension of these logistics strategies specifically fuel consumption and associated carbon emissions.

METHOD

Research Design

This research adopts a comparative case study design to evaluate the carbon emissions, particularly CO_2, of two transportation strategies: Milk Run and Point-to-Point (PTP). This comparison is based on the cargo volume requirements that must be transported using different vehicle configurations in the supply chain operations of Toyota Motor Manufacturing Indonesia (TMMIN). Milk Run routes are analyzed using actual operational data from the company, while equivalent Point-to-Point routes are simulated based on the same origin-to-destination network.

The data collected are primary data in April 2025th logistics activities from TMMIN's suppliers to Karawang Engine Plant which containing 6 route clusters (RC13, RC14, RC05, RC06, RC17, and RC18), because it comprehensively represents the full set of consolidated delivery circuits currently active at TMMIN, making it a highly representative model of the company's overall inbound logistics structure. The data includes Supplier to plant delivery volume, distances, fuel economy, vehicle transport capacity and geospatial coordinates.

Simulated point-to-point distances were generated via digital maps or routing software as samples. Missing or ambiguous distance values were verified using Google Maps to ensure consistency. However, it must be acknowledged that relying on consumer-grade digital mapping software for PTP simulations introduces a potential methodological bias, as these platforms may not fully account for specific heavy-duty vehicle constraints, such as road weight limits or industrial routing restrictions. Furthermore, all distances represent fully laden trips for the entire duration of the route unless otherwise specified. This assumption was applied to establish a standardized, conservative baseline for maximum potential fuel consumption and to ensure a fair, consistent comparative framework between the two methods, as dynamic tracking of load weights per individual route segment was not feasible

Toyota Motor Manufacturing Indonesia (TMMIN) selected as the case study for three clear reasons. First, Toyota is the pioneer of lean manufacturing and just-in-time (JIT) logistics, where Milk-Run is a core delivery method, therefore actual Milkrun delivery data are available and up to date. Second, TMMIN manages one of the largest supplier networks in Indonesia, making it a strong example of how inbound logistics affects transport emissions. Third, Toyota provided direct access to operational data, which ensures that the analysis is based on real-world and avoid bias. The raw data given by PT.TMMIN visualized as in Table 1 bellow:

Table 1. Summarized PT. TMMIN Volume and Distance Data

Supplier	RC13 PTP		RC13 MR	
	Volume	Distance	Volume	Distance
Saritakagi	19,81	38,6	350,18	98,2
	0,40	38,6		
	1,43	38,6		
	0,59	38,6		
	0,79	38,6		
	4,99	38,6		
	4,40	38,6		
Ichikoh	30,27	53,6		
	11,32	53,6		
	108,85	53,6		
	58,41	53,6		
	10,15	53,6		
	29,21	53,6		
Fukoku	0,27	54,6		
Menara	10,37	54,2		
Inggress	9,34	48,4		
Mtat	1,38	50,2		
	8,17	50,2		
Sanoh	5,68	47,0		
Furukawa	10,40	47,6		
SGTmpi	12,93	60,0		
	4,77	60,0		
	6,27	60,0		
TOTAL	350,18	1124,0	350,18	98,2
Supplier	**RC14 PTP**		**RC14 MR**	
	Volume	Distance	Volume	Distance
Autocomp	2,08	40,00	109,85	77
	8,07	40,00		
	2,34	40,00		
APM	0,69	36,00		
	0,69	36,00		
Trimitra	0,79	41,40		

SGTadi	32,43	63,60		
Aisin	5,03	50,60		
	18,86	50,60		
	21,05	50,60		
Armst	5,12	45,00		
Aisan	3,79	53,00		
Namicoh	0,76	49,40		
Tboshoku	8,17	64,20		
TOTAL	109,85	660,4	109,85	77,0
Supplier	**RC05 PTP**		**RC05 MR**	
	Volume	Distance	Volume	Distance
DenAsmo	3,09	68		
	28,03	68		
	4,98	68		
	33,49	68		
DenCbt	69,04	68		
DenSls	4,99	68		
Kayaba	38,60	68,20	232,73	68,4
	28,79	68,20		
Nsk	0,56	64,60		
Autoliv	3,79	67,20		
	7,58	67,20		
SGTttec	8,80	63,60		
	1,00	63,60		
TOTAL	232,73	870,6	232,73	68,4
Supplier	**RC06 PTP**		**RC06 MR**	
	Volume	Distance	Volume	Distance
SGTcre	10,16	63,60		
	46,39	63,60		
	0,40	63,60		
SGTrpt	9,74	63,60		
	5,33	63,60	196,42	58,6
	17,05	63,60		
	13,63	63,60		
Sekiso	84,55	53,60		
Setiaguna	9,16	52,00		
TOTAL	196,42	550,8	196,42	58,6
Supplier	**RC17 PTP**		**RC17 MR**	
	Volume	Distance	Volume	Distance
Tboshoku	13,20	15,00		
Aisin	43,69	16,40		
Kyoraku	21,45	8,00		
Nifco	18,89	11,00	117,58	31,1
IdnThai	10,96	10,00		
Toyoda	4,67	13,00		
ATI	4,72	6,00		
TOTAL	117,58	79,4	117,58	31,1
Supplier	**RC17 PTP**		**RC17 MR**	
	Volume	Distance	Volume	Distance
AutoFast	0,27	36,00		
	0,48	36,00		
	1,00	36,00		
	0,37	36,00		
	0,27	36,00		
Koito	9,31	58,40	112,84	79
Sugiura	0,48	35,60		
	0,27	35,60		
	1,08	35,60		
	0,54	35,60		

Chuhatsu	1,43	34,40		
AstraJu	0,37	30,60		
Sanko	95,48	33,00		
Autoplast	1,48	36,00		
TOTAL	112,84	514,8	112,84	79,0

Source: Toyota Motor Manufacturing Indonesia (2025)
Notes: MR is Milkrun, PtP is Point to Point
Volume in Meter Cubic (m^3), Distance in Kilometer (km)

Table 1 presents summarized data from suppliers for Milk-Run (MR) and Point-to-Point (PTP) logistics systems across several route clusters provided by PT. TMMIN. In Point to Point there are volume difference from suppliers based on different designated dock configuration and actual cubications therefore, it's a good practice to minimize cargo consolidation as least as possible. As for the distance defined as a complete logistics tour from the Toyota plant to all assigned suppliers (or to a single supplier in the point to point scenario) and back to the plant (one cycle). Each cycle therefore consists of two trips, one outbound trip from the plant to the supplier(s) and one return trip to the plant.

Table 2. Vehicles Specifications

Vehicles	Max Capacity	Buffer for Loading	Shipping Capacity	Fuel Ratio	Fuel type
Hino 300 136 MDL	36,6 m^3	7,6 m^3	29 m^3	7 km/L	Diesel
Hino 500 FG8JS1A	42,3 m^3	8,7 m^3	33,6 m^3	4,8 km/L	Diesel

Source: Toyota Motor Manufacturing Indonesia (2025)

Table 2 presents Vehicles specifications including the maximum and effective capacities (m^3), fuel economy and fuel type of two truck models used in Toyota Motor Manufacturing Indonesia's inbound logistics. A buffer allowance is applied to account for dead volume caused by pallet space and loading constraints, resulting in the practical transport capacities used in the fuel and emission calculations. These values serve as the basis for calculating total fuel usage and CO_2 emissions under both Milk Run and Point to Point logistics scenarios.

Fuel Consumption

Accurate estimation of fuel consumption is fundamental to calculating CO_2 emissions via the fuel based method. In this approach, emissions are directly proportional to the amount of fuel burned. For each delivery route, the distance (in kilometers) is obtained from Toyota's logistics data and. The fuel required for that distance is then determined by the vehicle's fuel economy, as detailed below:

$$\text{Fuel Consumption (L)} = \text{Distance (km)} \div \text{Fuel Economy (km/L)}$$

Carbon Emission

Carbon dioxide (CO_2) emissions were estimated using the Tier 1 fuel-based approach from the IPCC 2006 Guidelines, cross-validated with the 2019 Refinement. Because CO_2 emissions from transportation are directly proportional to the amount of fuel burned, the calculation relies on volumetric fuel consumption data converted via standard energy densities and emission factors. The equation as applied as bellow:

$$CO_2 = \text{Fuel Consumption (L)} \times \text{Fuel Density (t/L)} \times \text{Net Calorific Value (TJ/t)} \times \text{Emission Factor (kg } CO_2\text{/TJ)} \times \text{Oxidation Factor}$$

Where:
1. Fuel Consumption (L) = Distance (km) ÷ Fuel Economy (km/L)
2. Fuel Density (t/L)
3. Net Calorific Value (NCV)

4. Emission Factor (EF)
5. Oxidation Factor = 1.0 (complete combustion assumed)

Comparative Analysis

Total emissions for the Milk Run system are compared to simulated PTP operations covering the same suppliers. The percentage reduction in CO_2 is computed as :

$$\text{Emission Reduction (\%)} = [\,(CO_2\ PTP - CO_2\ Milk\ Run) \div CO_2\ PTP\,] \times 100$$

RESULTS AND DISCUSSION

The primary finding of this comparative analysis is that route consolidation via the Milk Run method is not universally superior for environmental sustainability. While it successfully reduced CO_2 emissions in four route clusters, it actually resulted in higher emissions in two specific clusters. The calculation of carbon dioxide (CO_2) emissions in this study follows the methodology outlined by the IPCC, which requires several interrelated parameters, as summarized in the equation above. Specifically, CO_2 emissions are derived from fuel consumption volumes (liters), multiplied by fuel density (t/L), Net Calorific Values (TJ/t), emission factors (kg CO_2/TJ), and an oxidation factor. In order to complete the calculation, step by step calculation of each composition needed to avoid bias and bring ease of understanding.

Vehicle Configuration, Delivery Cycle and Total Distance

To estimate fuel consumption and CO_2 emissions, this section identifies the total distance traveled based on each supplier's delivery configuration and volume requirements. Determining the appropriate vehicle type, number of delivery cycles, and resulting total distance is essential to ensure that fuel use and emissions reflect realistic logistics operations under both Milk Run and Point-to-Point systems.

Table 3. Vehicle Configuration, Delivery Cycle, and Total Distance

	RC13 PTP				**RC13 MR**		
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
Saritkg	19,81	H300	1	38,6			
	0,40	H300	1	38,6			
	1,43	H300	1	38,6			
	0,59	H300	1	38,6			
	0,79	H300	1	38,6			
	4,99	H300	1	38,6			
	4,40	H300	1	38,6			
Ichikoh	30,27	HFG	1	53,6			
	11,32	H300	1	53,6			
	108,85	H300	4	214,4			
	58,41	HFG	2	107,2			
	10,15	H300	1	53,6	350,18	11	1080,2
	29,21	HFG	1	53,6			
Fukoku	0,27	H300	1	54,6			
Menara	10,37	H300	1	54,2			
Inggress	9,34	H300	1	48,4			
Mtat	1,38	H300	1	50,2			
	8,17	H300	1	50,2			
Sanoh	5,68	H300	1	47			
Furukawa	10,40	H300	1	47,6			
SGTmpi	12,93	H300	1	60			
	4,77	H300	1	60			
	6,27	H300	1	60			
TOTAL	350,18		27	1338,4	350,18	11	1080,2
	RC14 PTP				**RC14 MR**		

		RC13 PTP				**RC13 MR**	
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
Autocomp	2,08	H300	1	40			
	8,07	H300	1	40			
	2,34	H300	1	40			
APM	0,69	H300	1	36			
	0,69	H300	1	36			
Trimitra	0,79	H300	1	41,4			
SGTadi	32,43	HFG	1	63,6	109,85	4	308
Aisin	5,03	H300	1	50,6			
	18,86	H300	1	50,6			
	21,05	H300	1	50,6			
Armst	5,12	H300	1	45			
Aisan	3,79	H300	1	53			
Namicoh	0,76	H300	1	49,4			
Tboshoku	8,17	H300	1	64,2			
TOTAL	109,85		14	660,4	109,85	4	308

		RC05 PTP				**RC05 MR**	
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
DenAsmo	3,09	H300	1	68			
	28,03	H300	1	68			
	4,98	H300	1	68			
	33,49	HFG	1	68			
DenCbt	69,04	H300	3	204			
DenSls	4,99	H300	1	68			
Kayaba	38,60	H300	2	136,4	232,73	10	684
	28,79	H300	1	68,2			
Nsk	0,56	H300	1	64,6			
Autoliv	3,79	H300	1	67,2			
	7,58	H300	1	67,2			
SGTtec	8,80	H300	1	63,6			
	1,00	H300	1	63,6			
TOTAL	232,73		16	1074,8	232,73	10	684

		RC06 PTP				**RC06 MR**	
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
SGTcre	10,16	H300	1	63,6			
	46,39	H300	2	127,2			
	0,40	H300	1	63,6			
SGTrpt	9,74	H300	1	63,6			
	5,33	H300	1	63,6	196,42	6	351,6
	17,05	H300	1	63,6			
	13,63	H300	1	63,6			
Sekiso	84,55	H300	3	160,8			
Setiaguna	9,16	H300	1	52			
TOTAL	196,42		12	721,6	196,42	6	351,6

		RC17 PTP				**RC17 MR**	
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
Tboshoku	13,20	H300	1	15			
Aisin	43,69	H300	2	32,8			
Kyoraku	21,45	H300	1	8			
Nifco	18,89	H300	1	11	117,58	4	124,4
IdnThai	10,96	H300	1	10			
Toyoda	4,67	H300	1	13			
ATI	4,72	H300	1	6			
TOTAL	117,58		8	95,8	117,58	4	124,4

		RC18 PTP				**RC18 MR**	
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
AutoFast	0,27	H300	1	36	112,84	4	316
	0,48	H300	1	36			

	RC13 PTP				RC13 MR		
SUPPLIERS	VOLUME	VEHICLE	CYCLE	DISTANCE	VOLUME	CYCLE	DISTANCE
	1,00	H300	1	36			
	0,37	H300	1	36			
	0,27	H300	1	36			
Koito	9,31	H300	1	58,4			
Sugiura	0,48	H300	1	35,6			
	0,27	H300	1	35,6			
	1,08	H300	1	35,6			
	0,54	H300	1	35,6			
Chuhatsu	1,43	H300	1	34,4			
AstraJu	0,37	H300	1	30,6			
Sanko	95,48	HFG	3	99			
Autoplast	1,48	H300	1	36			
TOTAL	112,84		16	580,8	112,84	4	316

Notes: Volume in Meter Cubic (m^3) And Distance in Kilometer (km)

Vehicle configuration determined by effective transport capacities specifically, shipments exceeding 29 m^3 were assigned to the Hino 500 FG8JS1A, while volumes below that threshold used the Hino 300 136 MDL. The delivery cycle is calculated by dividing the volume by vehicle capacity. Distance was obtained by multiplying the number of cycles by one cycle distance. This configuration ensures vehicle type and delivery frequency accurately reflect real operational practices and provide a fair comparison between the Milk Run and Point to Point systems. Furthermore, analyzing load utilization is critical to understanding these operational choices. The efficiency of any routing strategy heavily depends on maximizing the cargo space within the assigned vehicle. If a truck operates significantly below its effective transport capacity, it burns fuel transporting empty space, known as "dead volume." In this context, the environmental success or failure of the Milk Run method relies entirely on whether the consolidated supplier volumes effectively maximize the load utilization of the chosen truck model without forcing the use of a significantly less fuel-efficient vehicle.

Fuel Consumption and Carbon Emission

Table 4. Default Net Calorific Values (NCVs)

Fuel Type	NCV Mass	NCV Volume		Emission Factor(kg/TJ)
	NVC (GJ/t)	Fuel Density t/L	NCV TJ/L	
Diesel	43	0,000835	0,000036	74100

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Net Calorific Values (NCVs) expressed in gigajoules per ton (GJ/t) for various fuel types, sourced from the IPCC Guidelines for National Greenhouse Gas Inventories. NCVs represent the energy content of fuels, which is required to accurately convert volumetric fuel consumption. Table 4 illustrates this process by taking the mass based **NCV of 43 GJ/t** and converting it into a volumetric energy density through the application of a standard diesel fuel density. This conversion is essential for maintaining consistency when fuel consumption data is recorded in liters rather than mass. These volumetric energy units are then paired with the default CO_2 emission factors, which are primarily determined by the intrinsic carbon content of the fuel rather than the combustion process itself. Since combustion in transport engines is generally optimized to maximize oxidation, the CO_2 yield is largely stable and insensitive to variations in combustion efficiency. The Fuel Consumption and Carbon Emission calculation results are described as Table 5 below;

Table 5. Fuel Consumption and Carbon Emission Comparison Result

	RC13 PTP				**RC13 MR**		
SUPPLIERS	DISTANCE	FUEL ECO	FUEL	CO_2	DISTANCE	FUEL	CO_2
Saritkg	38,6	7	5,51	14,71	1080,2	225,04	600,32
	38,6	7	5,51	14,71			
	38,6	7	5,51	14,71			
	38,6	7	5,51	14,71			
	38,6	7	5,51	14,71			
	38,6	7	5,51	14,71			
	38,6	7	5,51	14,71			
Ichikoh	53,6	4,8	11,17	29,79			
	53,6	7	7,66	20,43			
	214,4	4,8	44,67	119,15			
	107,2	4,8	22,33	59,58			
	53,6	7	7,66	20,43			
	53,6	4,8	11,17	29,79			
Fukoku	54,6	7	7,80	20,81			
Menara	54,2	7	7,74	20,65			
Inggress	48,4	7	6,91	18,44			
Mtat	50,2	7	7,17	19,13			
	50,2	7	7,17	19,13			
Sanoh	47	7	6,71	17,91			
Furukawa	47,6	7	6,80	18,14			
SGTmpi	60	7	8,57	22,87			
	60	7	8,57	22,87			
	60	7	8,57	22,87			
TOTAL	1338,40		219,28	584,94	1080,2	225,04	600,32
	RC14 PTP				**RC14 MR**		
SUPPLIERS	DISTANCE	FUEL ECO	FUEL	CO_2	DISTANCE	FUEL	CO_2
Autocomp	40	7	5,71	15,24	308	64,17	171,17
	40	7	5,71	15,24			
	40	7	5,71	15,24			
APM	36	7	5,14	13,72			
	36	7	5,14	13,72			
Trimitra	41,4	7	5,91	15,78			
SGTadi	63,6	4,8	13,25	35,35			
Aisin	50,6	7	7,23	19,28			
	50,6	7	7,23	19,28			
	50,6	7	7,23	19,28			
Armst	45	7	6,43	17,15			
Aisan	53	7	7,57	20,20			
Namicoh	49,4	7	7,06	18,83			
Tboshoku	64,2	7	9,17	24,47			
TOTAL	660,40		98,51	262,78	308	64,17	171,17
	RC05 PTP				**RC05 MR**		
SUPPLIERS	DISTANCE	FUEL ECO	FUEL	CO_2	DISTANCE	FUEL	CO_2
DenAsmo	68	7	9,71	25,91	684	142,50	380,13
	68	7	9,71	25,91			
	68	7	9,71	25,91			
	68	4,8	14,17	37,79			
DenCbt	204	4,8	42,50	113,37			
DenSls	68	7	9,71	25,91			
Kayaba	136,4	4,8	28,42	75,80			
	68,2	7	9,74	25,99			
Nsk	64,6	7	9,23	24,62			
Autoliv	67,2	7	9,60	25,61			
	67,2	7	9,60	25,61			
SGTttec	63,6	7	9,09	24,24			
	63,6	7	9,09	24,24			
TOTAL	1074,80		180,28	480,92	684	142,50	380,13

	RC06 PTP				RC06 MR		
SUPPLIERS	DISTANCE	FUEL ECO	FUEL	CO_2	DISTANCE	FUEL	CO_2
SGTcre	63,6	7	9,09	24,24			
	127,2	4,8	26,50	70,69			
	63,6	7	9,09	24,24			
SGTrpt	63,6	7	9,09	24,24			
	63,6	7	9,09	24,24	351,6	73,25	195,40
	63,6	7	9,09	24,24			
	63,6	7	9,09	24,24			
Sekiso	160,8	4,8	33,50	89,36			
Setiaguna	52	7	7,43	19,82			
TOTAL	721,60		121,94	325,29	351,6	73,25	195,40
	RC17 PTP				RC17 MR		
SUPPLIERS	DISTANCE	FUEL ECO	FUEL	CO_2	DISTANCE	FUEL	CO_2
Tboshoku	15	7	2,14	5,72			
Aisin	32,8	4,8	6,83	18,23			
Kyoraku	8	7	1,14	3,05			
Nifco	11	7	1,57	4,19	124,4	25,92	69,14
IdnThai	10	7	1,43	3,81			
Toyoda	13	7	1,86	4,95			
ATI	6	7	0,86	2,29			
TOTAL	95,80		15,83	42,24	124,4	25,92	69,14
	RC18 PTP				RC18 MR		
SUPPLIERS	DISTANCE	FUEL ECO	FUEL	CO_2	DISTANCE	FUEL	CO_2
AutoFast	36	7	5,14	13,72			
	36	7	5,14	13,72			
	36	7	5,14	13,72			
	36	7	5,14	13,72			
	36	7	5,14	13,72			
Koito	58,4	7	8,34	22,26			
Sugiura	35,6	7	5,09	13,57	316	65,83	175,62
	35,6	7	5,09	13,57			
	35,6	7	5,09	13,57			
	35,6	7	5,09	13,57			
Chuhatsu	34,4	7	4,91	13,11			
AstraJu	30,6	7	4,37	11,66			
Sanko	99	4,8	20,63	55,02			
Autoplast	36	7	5,14	13,72			
TOTAL	580,8		89,45	238,63	316	65,83	175,62

Notes: Distance in Kilometer (km), Fuel in Litre (L), Carbon Emission (CO_2) in kilograms Carbon Dioxide ($kgCO_2$)

Comparative Analysis

Table 6. *Comparative Analysis Result*

Route	Indicator	Point to Point	Milk Run	Difference
RC13	Distance	1338,40	1080,20	19%
	Fuel	219,28	225,04	-3%
	CO_2	584,94	600,32	-3%
RC14	Distance	660,40	308,00	53%
	Fuel	98,51	64,17	35%
	CO_2	262,78	171,17	35%
RC05	Distance	1074,80	684,00	36%
	Fuel	180,28	142,50	21%
	CO_2	480,92	380,13	21%
RC06	Distance	721,60	351,60	51%
	Fuel	121,94	73,25	40%
	CO_2	325,29	195,40	40%
RC17	Distance	95,80	124,40	-30%
	Fuel	15,83	25,92	-64%
	CO_2	42,24	69,14	-64%
RC18	Distance	580,80	316,00	46%

Route	Indicator	Point to Point	Milk Run	Difference
	Fuel	89,45	65,83	26%
	CO_2	238,63	175,62	26%

Notes: Distance in Kilometer (km), Fuel in Litre (L), Carbon Emission (CO_2) in kilograms Carbon Dioxide ($kgCO_2$)

The comparative analysis reveals the Milk Run system relative to Point-to-Point (PTP) delivery is not uniformly superior but varies depending on route configuration and operational context. The analysis found that only 66, 7 % Milk Run approach (or 4 out of 6 route clusters) succeed to reduce carbon emission compared to Point to Point routes. While the rest of 33, 3% failed to reduce carbon emission.

The Milk Run method cut travel distance by 19% to 53% on most routes, confirming its strength in route consolidation and travel optimization. RC14, RC05, RC06, and RC18 achieved 21% to 40% lower fuel use and emissions, validating the Milk Run's sustainability potential under balanced loading and optimal scheduling. However, this distance advantage does not always translate into proportional fuel or CO_2 reductions. For example, RC13 resulted in higher fuel consumption and CO_2 emissions (-3%) despite shorter routes. This indicates inefficiencies caused by vehicle variability; the massive consolidated volume in Milk Run forced the use of larger trucks, whereas the Point-to-Point simulation allowed the use of the Hino 300, which is the most fuel-efficient.

Furthermore, RC17 also stands out as an anomaly, where PTP proved more fuel-efficient (-64%) due to low-volume deliveries and close point-to-point distances from the suppliers to the TMMIN Engine Plant. These findings align directly with the theoretical principles of the Vehicle Routing Problem (VRP) and load consolidation. Consolidation theory dictates that grouping shipments improves efficiency only when spatial density and vehicle capacity constraints are optimized. As demonstrated by the empirical data, the Milk Run method is highly effective for high-volume, clustered suppliers, where consolidation maximizes load utilization. However, it is distinctly ineffective for low-volume, short-distance suppliers, where direct routing is mathematically superior.

CONCLUSION

This study demonstrates that while route consolidation via the Milk Run method is a powerful tool for optimizing inbound logistics, it is not a universally superior solution for reducing carbon emissions. The empirical comparison reveals that the environmental efficacy of the Milk Run method is highly dependent on spatial density, supplier proximity, and vehicle load utilization. When applied to high-volume, geographically clustered suppliers, the Milk Run successfully minimizes total travel distance and significantly reduces CO_2 emissions. However, for low-volume suppliers located in proximity to the manufacturing plant, forcing consolidation can inadvertently increase total travel distance and require larger, less fuel-efficient vehicles, making direct Point-to-Point delivery the more sustainable option.

This research advances the theoretical framework of the Vehicle Routing Problem (VRP) in green logistics by challenging the assumption that minimizing travel distance inherently reduces environmental impact. Empirical evidence from route anomalies (e.g., RC13 and RC17) demonstrates that distance reduction does not guarantee emission reduction. Consequently, this study establishes that future consolidation models must explicitly incorporate vehicle variability, payload utilization, and spatial density as primary variables. Methodologically, integrating standardized IPCC calculations with real-world operational data delivers a validated, data-driven framework for accurately assessing the environmental efficacy of supply chain strategies in emerging economies.

For logistics managers at TMMIN and similar manufacturing firms, these results strongly suggest that a "one-size-fits-all" approach to inbound logistics is environmentally and operationally suboptimal. Before implementing a Milk Run strategy, managers must conduct a granular audit of supplier proximity and cargo volumes. The Milk Run method should be selectively deployed only for geographically clustered suppliers that can generate high load utilization on fuel-efficient vehicles. For suppliers located within a close geographic radius to the plant, or those with highly variable, low-volume shipments, maintaining a Point-to-Point delivery system is the more sustainable and efficient decision.

While the findings highlight the potential environmental advantages of adopting the Milk-Run, however Toyota Motor Manufacturing Indonesia (TMMIN) cannot immediately or uniformly implement this strategy. Operational factors, requirements and targets contribute in determining the most feasible configuration. Therefore, any transition toward broader Milk-Run adoption must consider practical constraints to maintain production continuity and operational efficiency.

In terms of practicality and operation performance, there is potential cost savings from lower fuel usage by reducing overall travel distance and improving volumetric efficiency. For a high-volume manufacturer, even modest percentage improvements in fuel efficiency can yield meaningful financial savings over time.

For policy makers, this research revealed the importance of developing standardized measurement and reporting frameworks for freight emissions. It also urged establishing regulation to minimize carbon emission, one of which is by implementing milk run in contributions to national climate targets and design incentive schemes based on verified performance.

Regarding limitations, this research conducted in Indonesia particularly in PT.TMMIN only, therefore, future research should analyse across multiple regions, firms and sectors to enhance generalizability. Additionally this study does not segment the variety of other Green House Gases to discuss more detailed impact. However, future research could consider their inclusion for a more holistic emissions profile.

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