TRANSPORT POOLING AS A MITIGATING STRATEGY FOR CARBON DIOXIDE (CO_2) EMISSION

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ABSTRACT: *This study determined the nature of relationship between the volume of CO_2 liberated per passenger kilometre travelled by Public Service Vehicles (PSVs) that have large carrying capacity and those that have low carrying capacity in Kisumu City using observation with a view of reducing the amount of CO_2 liberated by PSVs (matatus). The study particularly sought to reduce the emission of CO_2 into the atmosphere as a result of burning fossil fuel. The study was conceived as a result of the uncontrolled thriving and congestion of the 14-seater public service vehicles commonly called "Nissan Matatu" in Kenya. Over the years, transport pooling has been seen in the light of economizing fuel usage. Due to the global increase in the number of motor vehicles in urban setting, pooling shifted and was seen as a strategy to reduce congestion. The burning of fossil fuels releases CO_2 which is a greenhouse gas into the atmosphere. This study sought to quantify the extent of fuel consumption in relation to the seating capacity of the PSV by determining on the average the quantities of fuel burnt by different capacities of the PSVs. Pearson Product-Moment correlation coefficient showed a relationship of -.917 between the volumes of CO_2 liberated per passenger kilometre travelled in large carrying capacity and low carrying capacity passenger transportation. This study concluded that the 14-seater PSVs emit twice as much volume of CO_2 as the pooled PSVs and recommended the implementation of policies aimed at reducing the usage of the 14-seater PSVs.*

KEYWORDS: Transport Pooling, Nissan Matatu, Carbon Dioxide, Mitigation, Emission

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INTRODUCTION

i. **Pooling** is a resource management term that refers to the grouping together of resources (assets, equipment, personnel, effort, among others) for the purpose of maximizing advantage and/or minimizing risk to the users (Hornby, 2010).

ii. **Transport pooling** is therefore used here to imply the grouping together of people in larger carrying capacity motor vehicles for the purpose of transportation. Transport pooling was used to imply the use of shuttles, mini buses or buses as public service vehicles (PSV), as opposed to the 14-seater passenger van commonly called commonly called **"Nissan Matatu"**.

iii. **Carbon Dioxide**, **CO_2** is a naturally occurring chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state.

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iv. **Mitigate** is to make something less harmful or less serious (Hornby, 2010). Here mitigation was used to refer to the reduction of emission of CO_2 to the atmosphere by PSVs which use gasoline or diesel.

v. **Emission** is the sending out of gas into the atmosphere (Hornby, 2010). CO_2 emission is therefore the sending out of CO_2 into the atmosphere. Here it was used to refer to the release of CO_2 into the atmosphere by PSVs that use gasoline or diesel.

Global warming has been experienced since 1980 (US National Research Council, 2012). Most scientists are certain that most of global warming is caused by increasing concentrations of greenhouse gases produced by human activities such as deforestation and burning of fossil fuels (IPCC AR4 SYR, 2007). These findings are recognized by the national science academies of all the major industrialized countries (US NRC, 2010). Greenhouse effect is the process by which absorption and emission of infrared radiations by gases in the atmosphere warm the planet's lower atmosphere and surface (Weart, 2008). Naturally occurring amount of greenhouse gases have a mean warming effect of about 33^0C (59F) (IPPC AR4 SYR, 2007). The major greenhouse gases are water vapour 36-70% GHE, CO_2 9-26% GHE, methane 4-9% GHE and ozone 3-7% GHE (Russel, 2007; Schmidt, 2005).

Fossil fuel burning has produced about three-quarters of the increase in CO_2 from human activity over 20 years (IPCC AR4 SYR, 2007). CO_2 emissions are continuing to rise due to the burning of fossil fuels and land-use change (World Bank, 2010; US NRC, 2008). CO_2 readings taken in May 2013 at the World's primary benchmark site in Mauna Loa surpassed 400 parts per million (ppm), the highest in about 4.5 million years (Clark, 2013). Efforts of the early 21st century to reduce emissions may be inadequate to meet the UNFCCC's 2˚C target (IEA, 2011). It is expected that most ecosystems will be affected by higher atmospheric CO_2 levels, combined with higher global temperatures (IPCC AR4 SYR, 2007). Most economic studies suggest losses of World Gross Domestic Product (GDP) for this magnitude of warming (IPCC AR4 SYR, 2007).

It is projected that there will be an increase in the frequency and severity of extreme weather events (IPCC SREX, 2012). An increase in global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, and a probable expansion of subtropical deserts, frequent occurrence of extreme weather events including heat waves, droughts and heavy rainfall events, species extinctions due to shifting temperature regimes and changes in agricultural yields. These changes will vary from region to region and ecosystem services upon which livelihoods depend would not be preserved (Solomon, 2007). Evidence of global warming includes observed increases in global air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (US Global Change Research Program, 2010; IPCC AR4 SYR, 2007). Expansions of Sahara Desert in Africa and Arid and Semi Arid Lands in Kenya have been attributed to global warming. The recent flooding experienced in most parts of Kenya has been attributed to global warming (WMO, 2010).

In 2008, 8.6 gigatonnes of carbon (31.8 gigatonnes of CO_2) were released from fossil fuels worldwide (World Bank, 2008). CO_2 has gradually accumulated in the atmosphere, and as of 2009, its concentration was 39% above pre-industrial levels (World Bank, 2009). This has exceeded the balancing effect of sinks (US GCRP, 2010) and is directly associated to global warming (US NRC, 2010). The continued increase in the number of motor vehicles around the world poses a threat to natural environmental health. There is, therefore, need to reduce the number of road trips by transport pooling. Many people travelling in a specific direction may

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choose to travel in one larger carrying capacity PSVs than using many smaller carrying capacity PSVs.

The characteristics of road transport in Kenya are accidents, pollution, congestion and lack of policy, legal and institutional framework (Mukabanah, 2012). The public road transport is dominated by the 14-seater PSVs. Routes are run by formal termini where majority of passengers board and in some of these places, PSVs wait for full load of passengers prior to departing, and off-peak wait times may be in excess of an hour (Ajay & Fanny, 2008). Some of these matatus are overseen by syndicates, unions or route associations. These groups often function in the absence of a regulatory environment and may collect dues from drivers such as pre-use terminal payments, set routes, manage terminals and fix fares. Terminal management may include ensuring each vehicle leaves with a full load of passengers. The termini syndicate can cost delays for passengers (Ajay & Fanny, 2008).

Proposed responses to global warming include mitigation to reduce emissions (United Nations Framework Convention on Climate Change, 1997). To limit warming to the lower range in the overall IPCC'S "Summary report for policymakers" (IPCC AR4 WG1, 2007) means adopting policies that will limit emissions. This can include the reduction of emissions from public service motor vehicles that use gasoline or diesel by pooling of transport, bicycle riding and pedestrian walking. In Kenya the transport industry is regulated but the present regulation may not be sufficient deterrent to prevent small infractions (Mbugua, 2010). Emission challenges require investment in green economy which shifts investments towards low-carbon, clean, waste minimizing, resource efficient, and ecosystem enhancing activities, as covered in the Millennium Development Goals (MDGs) (UNEP, 2012). Transport system should be green and sustainable to support environmental sustainability through measures such as the protection of the global climate, ecosystems, public health and natural resources (UN HABITAT, 2012) because the current fossil-fuel driven motor transport generates a range of environmental, social and economic costs. There is a growing consensus on the need for urban retrofitting since inventing all the green technologies should not lead to tearing down old structures and starting from scratch.

In Kenya, the mission for the integrated national transport policy document is to develop, operate and maintain an efficient, cost effective, safe, secure and integrated transport system that links the transport policy with other sectoral policies, in order to achieve national and international development objectives in a socially, economically and environmentally sustainable manner (GoK, 2009). The document proposes transport pooling through encouraging a shift to high occupancy vehicles amongst other measures.

Research Problem

The big buses and the 14-seater PSVs both emit a lot of CO_2 to the atmosphere whenever they carry passengers. In view of this, there is need to establish the kind of relationship that exists between the volumes of CO_2 released per passenger kilometre travelled by the 4th generation Toyota Hiace 14-seater glass van on the one hand and the Isuzu NKR 26-seater, NPR 29-seater, NQR 33-seater and FRR 51-seater shuttles on the other hand.

Study Objectives

i. Determine the relationship between the volumes of CO_2 liberated per passenger kilometre travelled in the large and in the low carrying capacity transportation.

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ii. Suggest a strategy for planning of low carbon emitting urban PSV transport.

Research Questions

i. What is the relationship between the seating capacity and the volume of CO_2 liberated per passenger kilometre travelled?

ii. What is the most appropriate strategy for planning low carbon emitting urban PSV transport?

METHODOLOGY

This study used descriptive survey research design. This method was suitable because the researcher wanted to make observation of what was on the field and report exactly what was found. This research sampled PSVs within the Kisumu CBD. Data was collected by questionnaires, interviews and documents analysis. The study specifically sought to determine the average amount of fuel used by PSVs in large carrying capacity and low carrying capacity passenger transportation and the overall CO_2 emission. This was done by calculation. The purpose of this study was to establish the relationship between the seating capacity and the volume of CO_2 liberated per passenger kilometre travelled within Kisumu CBD by various PSVs. This relationship was analysed by Pearson Product Moment correlation coefficient. The results were used to suggest strategies for planning of low carbon emitting urban PSV transport system to make the City greener and eco-friendly.

Calculating Carbon Dioxide Emission Using Mass Balance

Fossil fuels are predominantly composed of various forms of hydrocarbons. Hydrocarbons are molecules composed of hydrogen and carbon, linked together in various forms and with varying numbers of atoms. The most common forms of hydrocarbons found in fuels are "paraffinic" hydrocarbons, which have slightly more than two hydrogen atoms for each carbon atom, according to the general formula C_xH_{2x+2}. Propane, for instance, has the chemical formula C_3H_8, or three atoms of carbon (C) and eight atoms of hydrogen (H). Since carbon has a atomic weight of 12, and hydrogen an atomic weight of one, the molecular weight of propane is (3×12) + (8×1)) = 36 + 8 = 44. Therefore, propane is 36/44 = 81.8 percent carbon by weight. When any hydrocarbon is burned (oxidized), the carbon atoms combine with atmospheric oxygen to form CO_2, while the hydrogen atoms combine with oxygen to form water vapor (H_2O). Burning propane produces the reaction in equation 1 (IUPAC, 1993).

Equation 1: Combustion of Propane

$$C_3H_{8\,(g)} + 5O_{2\,(g)} \rightarrow 3CO_{2\,(g)} + 4H_2O_{(g)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The three carbon atoms in each propane molecule end up in the atmosphere as three molecules of CO_2. To calculate the amount of CO_2 released when a fuel is burned, multiply the weight of the fuel by its carbon content and by the ratio of the molecular weights of CO_2 (12 + (2×16)) and the atomic weight of carbon (12), or (12 + (2×16))/12 = 44 / 12. For example, for each ton of propane burned 3.0 metric tons of CO_2 is emitted to the atmosphere (1 × 0.818 × (44/12) = 3.0). The more complex hydrocarbons that make up liquid fuels and coal are generally about

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85 percent carbon by weight, while natural gas is 75 percent carbon by weight. If the weight and chemical composition of the fuel are known, then CO_2 emissions can be accurately calculated using the mass balance approach. Even if only the weight and hydrocarbon share of the fuel are known, CO_2 emissions can still be calculated with reasonable accuracy (US Energy Department, 2007).

RESULTS AND DISCUSSIONS

A total of 317 PSVs were studied.

Table 1: Seating capacity of the PSV as a percentage

Seating capacity of vehicle				
10-20	21-30	31-40	41-50	51-60
52%	8.2%	12%	18.0%	9.8%

Source: Field Survey, 2014

The respondents were picked from the sampled PSVs and comprised 49.2% drivers, 29.5% conductors and 21.3% owners. These were people in charge of the daily operation of the PSVs.

Table 2 shows the relationship between various seating capacities and the daily cost of diesel used.

Table 2: Seating capacity against daily fuel cost

		Cost of fuel per day in Kshs (row %)				
		4000-5500	5500-7000	7000-8500	8500-10000	10000-12000
Seating capacity of vehicle	10-20	62.5	37.5	0.0	0.0	0.0
	21-30	20.0	40.0	40.0	0.0	0.0
	31-40	0.0	42.9	42.9	14.3	0.0
	41-50	0.0	9.1	36.4	54.5	0.0
	51-60	0.0	0.0	16.7	0.0	83.3

Source: Field Survey, 2014

The 14-seater PSVs were concentrated at Kshs 4,000-5,500 and Kshs 5,500-7,000 brackets while the higher capacities are concentrated at above Kshs 7,000 daily consumption.

Pearson Product Moment Correlation coefficient showed a correlation of .877 between the seating capacity and the cost of fuel used. Since the cost of fuel is directly proportional to the amount of fuel, PSVs with larger seating capacities consume more fuel than PSVs with smaller seating capacities. Pearson Product Moment correlation showed a correlation of .877 between the seating capacity and the amount of fuel used. There is a strong positive relationship between the seating capacity and the amount of fuel used. The cost of fuel also did not vary during the study period.

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Table 3: Seating capacity against cost of diesel in Kshs per km travelled in Kisumu in every seating category

		Cost of diesel per kilometre in Kisumu in Kshs			
		10-<15	15-<20	20-<25	25-<30
Seating capacity of vehicle	10-20	84.4	15.6	0.0	0.0
	21-30	20.0	60.0	20.0	0.0
	31-40	28.6	57.1	14.3	0.0
	41-50	0.0	90.9	9.1	0.0
	51-60	0.0	16.7	66.7	16.7

Source: Field Survey, 2014

84.4% of 10-20 seater PSVs consumed between Kshs 10-<15 of fuel per Km within Kisumu Municipality with 15.6% of them consuming between Kshs 15-<20. However, larger carrying capacity PSVs are concentrated in the ranges of Kshs 15-<20 and Kshs 20-25 consumption per Km. 16.7% 51-60 seaters are found in the class of Kshs 25-<30 consumption per Km.

Pearson Product Moment Correlation Coefficient showed a correlation of .763 between the seating capacity and the cost of fuel consumed per kilometre in Kisumu. This showed that the larger carrying capacity transportation consumes much more fuel than the lower carrying capacity transportation per kilometre within Kisumu. However, there are some mini buses PSVs which consume fuel within the range of the 14-seater PSVs.

Table 4: Ranges of consumption (cost) per passenger Km travelled in Kisumu

		Cost (Kshs) of diesel			
		10-<15	15-<20	20-<25	25-<30
Seating capacity of vehicle	10-20	0.5-1.5	0.8-2.0	0.0	0.0
	21-30	0.3-0.8	0.5-1.0	0.7-1.3	0.0
	31-40	0.3-0.5	0.4-0.7	0.5-0.8	0.0
	41-50	0.0	0.3-0.5	0.4-0.6	0.0
	51-60	0.0	0.3-0.4	0.3-0.5	0.4-0.6

Source: Field Survey, 2014

Table 5: Average consumption (cost) of diesel per passenger Km travelled in Kisumu

		Average cost (Kshs) of diesel			
		10-<15	15-<20	20-<25	25-<30
Seating capacity of vehicle	10-20	1.0	1.4	0.0	0.0
	21-30	0.6	0.8	1.0	0.0
	31-40	0.4	0.6	0.7	0.0
	41-50	0.0	0.4	0.5	0.0
	51-60	0.0	0.4	0.4	0.5

Source: Field Survey, 2014

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Table 6: Percentages of PSVs per average cost of diesel in the consumption ranges

		Percentage of PSVs per average cost (Kshs)			
		10-<15	15-<20	20-<25	25-<30
Seating capacity of vehicle	10-20	44.3%	8.2%	0.0%	0.0
	21-30	1.6%	4.9%	1.6%	0.0
	31-40	3.3%	6.6%	1.6%	0.0
	41-50	0.0%	16.4%	1.6%	0.0
	51-60	0.0%	1.6%	6.6%	1.6%

Source: Field Survey, 2014

Out of the 52.5% of the sample (10-20 seater PSVs), 44.3% belonged to an average consumption of Kshs 1.0 per passenger Km travelled with 8.2% at Kshs 1.4 per passenger Km. Most of the 41-50 seater and 51-60 seater PSVs average at Kshs 0.4 per passenger Km travelled.

Emission of CO_2 as a function of diesel cost.

The study used the cost of fuel to derive the amount of fuel. This was then converted to litres of CO_2 using mass balance.

Diesel carbon content =2,778 grams per US gallon

1US gallon=3.78541178L=3.785L

Price of diesel=Kshs 110/L in Kisumu (in September 2014)

Relative Molecular Mass (RMM) of CO_2 =12+16×2=44 (IUPAC, 1993)

Molar Gas Volume (Ideal gas) at Room Temperature and Pressure, RTP (25˚C, 1 atmosphere) =24.465L (IUPAC, 1993) =24L (to the nearest 1L).

CO_2 emission from a gallon of diesel (at 99% oxidation) =2,778g×0.99× (44/12) =10,084g

1L of diesel therefore produces 10,084/3.785=2,664.2g CO_2 equivalent to (2,664.2/44) ×24L of CO_2=1,453.2L of CO_2 at RTP

If 1L of diesel produces 1,453.2L of CO_2 at RTP when burnt, then considering the September 2014 cost of diesel at Kshs 110/L, it implies that for every Kshs 110 spent on diesel 1,453.2L of CO_2 is emitted. The volume of CO_2 passenger Km = (1,453.2/110) ×cost per passenger Km.

Table 7: Percentage of PSVs in the CO_2 per passenger Km emission ranges

		Percentage of vehicles				
		5L-7L	8L-10L	11L-12L	13L-15L	18L-20L
Seating capacity of vehicle	10-20	0.0	0.0	0.0	87.5	12.5
	21-30	0.0	20.0	60.0	20.0	0.0
	31-40	28.6	71.4	0.0	0.0	0.0
	41-50	100.0	0.0	0.0	0.0	0.0
	51-60	100.0	0.0	0.0	0.0	0.0

Source: Field Survey, 2014

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Table 7 shows that the 10-20 seater PSVs emit CO_2 in the range of between 13L-15L and 18L-20L per passenger Km travelled. This is about twice the volume of CO_2 emitted by the higher seating capacity vehicles which are in the range of 5L-7L and a few in the range of 8L-10L per passenger Km travelled within Kisumu municipality. The 21-30 seater NKR however dominated the emission range of 11L-12L per passenger Km.

Pearson's Product Moment Correlation showed a correlation of -.917 between seating capacity of the PSV and the volume of CO_2 per passenger Km travelled. This is a very strong negative correlation. It implies that the seating capacity is inversely related to the volume of CO_2 emitted per passenger Km travelled. Lower seating capacity PSVs (The 14-seater matatu) therefore emit more CO_2 than the higher seating capacity PSVs (larger carrying capacity PSVs), which emit less CO_2 per passenger Km travelled.

CONCLUSION

Many countries that have tried carpooling have the main objective of reducing congestion and saving fuel (Lyndsey, 2002). This study however, looked at transport pooling in the direction of van pooling where it seeks to reduce congestion and reduce CO_2 emission by the 14-seater passenger vans commonly called "Nissan Matatu" and the taxis. Transport pooling was used to imply the use of shuttles or mini buses as public service vehicles (PSV), as opposed to the 14-seater passenger van and the taxi.

The only meaningful way to study urban transport is to regard it as a complex entity influenced by several factors. Urban transport involves PSV owners, passengers, the government, fuel companies, road contractors and many more whose input cannot be ignored.

Pearson Product Moment Correlation Coefficient showed a correlation of -.917 between pooling and the volume of CO_2 liberated per passenger Km travelled. Transporting one passenger per unit distance in a 14-seater PSV has more adverse environmental effects than when using a 51-seater PSV. The 14-seater PSVs emit twice as much volume of CO_2 as the 51-seater PSVs.

RECOMMENDATIONS

Objective 1 sought to determine the relationship between the volumes of CO_2 liberated per passenger Km travelled in larger carrying capacity transportation and in the lower carrying capacity transportation. Pearson's Correlation Coefficient showed a correlation of -.917 between pooling and the volume of CO_2 emitted per passenger Km travelled. This is a very strong negative correlation. It implies that the seating capacity is inversely related to the volume of CO_2 emitted per passenger kilometre travelled. Lower seating capacity PSVs therefore emit more CO_2 than the larger seating capacity PSVs, which emit less CO_2 per passenger kilometre travelled.

1. Policies aimed at discouraging 14-seater PSV usage must be implemented which may include banning the importation and registration of the 14-seater PSVs.
2. The government must take a leading role in educating the public about green economy investment.

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Objective 2 sought to suggest a strategy for planning of low carbon emitting urban PSV transport. Transport planning has historically followed the rational planning model of defining goals and objectives, identifying problems, generating alternatives, evaluating alternatives, and developing plans (Transport Planning Society, 2006).

1. There is need for an intelligent, coherent and pragmatic integrated approach. This approach should cover all aspects including vehicle technologies, fuels, the fuel infrastructure, improved roads and traffic management and, importantly, PSV owners who ultimately hold the key, through their purchasing decisions and the way they use their vehicles. To be effective, policies must involve all stakeholders, including fuel suppliers, the research and development community, the financial investment community, government at all levels, and especially PSV owners.

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