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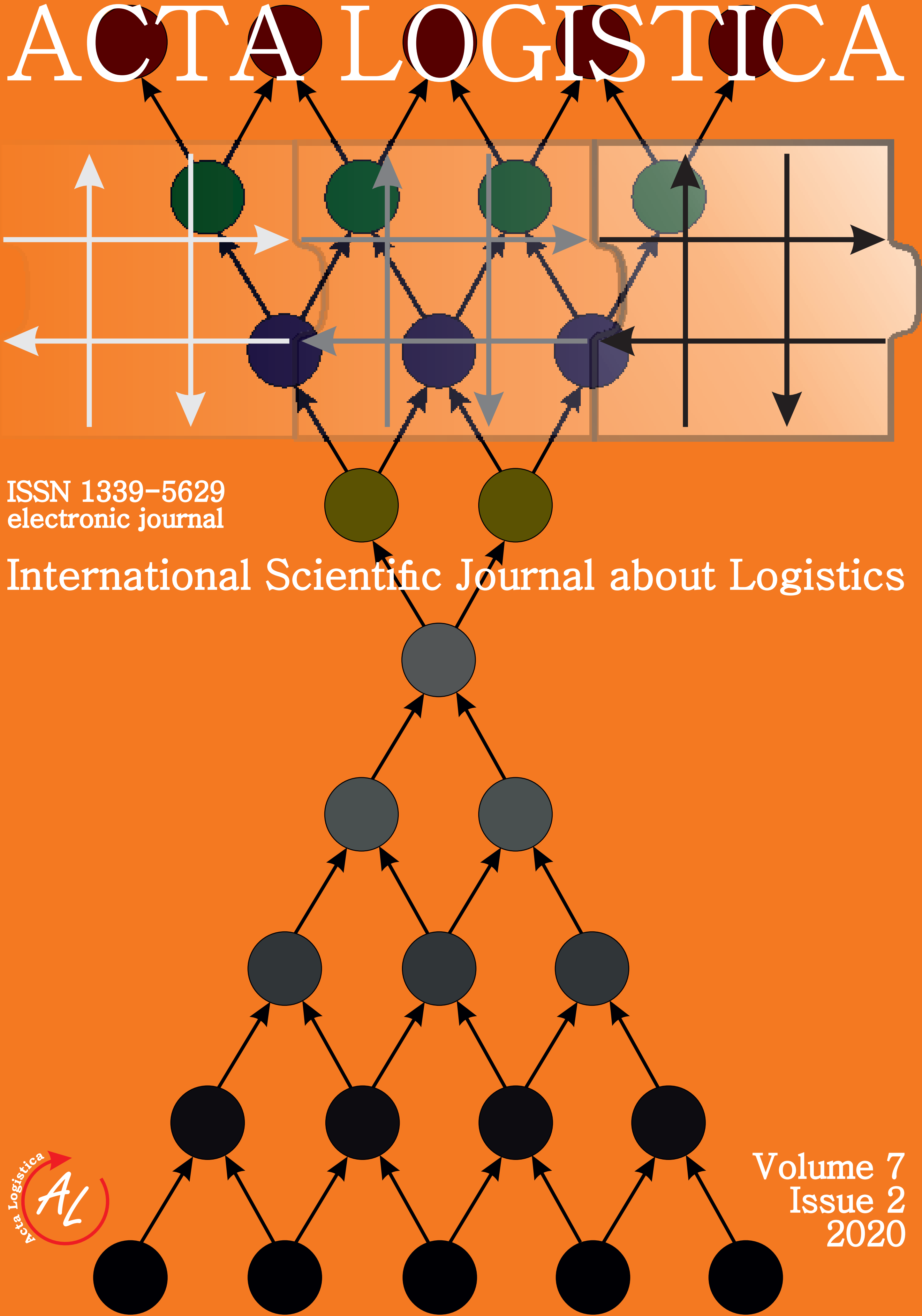

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MEASURING AND DECOMPOSING TOTAL FACTOR PRODUCTIVITY OF VIETNAMESE SEAPORTS

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Abstract: In this paper the total factor productivity of Vietnamese seaports is measured and decomposed into three main components, namely technical, scale and mix efficiency. The analysis results using the data of 40 seaports show that the seaport sector is underperformed, while seaports in the northern region are the most efficient group on any measures of efficiency, southern ports are the least efficient group if scale efficiency is utilised. It has also been found that container ports outperform non-container ports, and those belonging to logistics companies are overall more efficient than their partners operated by the local governments.

1 Introduction

Over the last three decades, the world has seen accelerating economic growth of emerging economies and their significant and active contribution to the global economy through international trade [1-3]. It is well known that more than 90 percent of international trade is carried by ships through ports. Being an emerging economy, Vietnam increasingly depends on maritime transportation and its seaport sector plays a pivotal role in connecting the country's hinterland and sea [4]. However, Vietnamese seaports appear to be less competitive compared with other countries in ASEAN (the Association of Southeast Asian Nations) [5]. In terms of financial cost, port charges in Vietnam are 16% more than those in Shanghai, Ningbo, or Shenzhen (China), and 28% more than those in Hong Kong [6]. These raise concerns about the competitiveness of the seaport sector in particular and the country's trade competitiveness in a broader sense. Accordingly, finding the causes behind the underperformance of Vietnamese seaports will be useful for relevant authorities.

There are numerous studies on seaport efficiency [7-9]. Most studies mainly focus on technical efficiency as a measure of seaport performance. However they do not provide comprehensive information on efficiency [10-12] with De [13] being one of a few exceptions; the only measure is overall technical efficiency without further information on how it is attributed to different types of efficiency. In fact, this issue is related to the total factor productivity (TFP) concept [14]; generally TFP comprises three main sources, namely technical efficiency, scale efficiency, and mix efficiency.

O'Donnell [12] (p. 873) noted on the decomposition of TFP in productivity and efficiency evaluate at both micro (firm and sectoral) and macro (national) levels:

"Several estimates of technical change and efficiency change are available e.g. [15,16] but they are not coherent in the sense that they do not combine to yield recognizable productivity indexes. And while several researchers have decomposed well-known productivity indexes into various components [17], not all of these components have unambiguous interpretations as measures of technical change or efficiency change."

This implies that the incoherent knowledge of TFP components can be misleading to seaport management and policy makers, who face the challenge of finding the best approach to improve productivity.

Against this background, the current study seeks to extend the analysis of Vietnamese seaport efficiency to decompose it into technical efficiency, scale efficiency and mix efficiency, and based on this, proposes recommendations for management and policy makers. To this end, O'Donnell [12] approach is adopted to measure overall productive efficiency (to be further explained below) based on aggregating inputs and outputs. This approach has been chosen as it is less restrictive requiring no assumption on market structure, competition and production, i.e. constant versus variable returns to scale, and single versus multiple input, output cases. (For more detail about the literature on seaport efficiency analysis, see for example [18-20]).

Following the introduction section, Section 2 presents the methodology to estimate and analyse TFP and its components. Section 3 describes the data set and variables.

Section 4 presents the analysis results, and Section 5 provides the concluding remarks.

2 Methodology

2.1 Total factor productivity

The productivity of a one-output, one-input firm can intuitively be defined as the output-input ratio. This concept is generalized by O'Donnell [11] by defining the total factor productivity of a firm to be the ratio of an aggregate output to an aggregate input. Let $\boldsymbol{x}_{it} = (x_{it1}, x_{it2}, \dots, x_{itK})'$and $\boldsymbol{q}_{it} = (q_{it1}, q_{it2}, \dots, q_{itJ})'$ denote the input and output vectors of firm i $(i = 1, 2, \dots, n)$ in period t. Then the TFP of the firm can be defined as:

$$TFP_{it} = \frac{Q_{it}}{X_{it}}, \quad (1)$$

where $Q_{it} = Q(q_{it})$ is a scalar 'aggregate' output, $X_{it} = X(q_{it})$ is a scalar 'aggregate input', and $Q(.)$ and $X(.)$ are "aggregator" functions, which are assumed to be non-negative, non-decreasing and linearly homogenous.

As shown in O'Donnell [11], the aggregator function may take various forms depending on its parameters which can be vectors of input and output prices, vectors of representative prices and quantities, and Shephard [21] output/input distance functions. In this paper, Shephard's output and input distance functions, denoted as D_o and D_I respectively, are used as the output and input aggregator functions:

$$Q(.) = D_o(x_{it}, q) = min\left\{\delta > 0: \left(\boldsymbol{x}_{it}, \frac{q}{\delta}\right) \in P\right\}, \quad (2\text{-a})$$
$$X(.) = D_I(x, q_{it}) = max\left\{\rho > 0: \left(\frac{x}{\rho}, \boldsymbol{q}_{it}\right) \in P\right\}, \quad (2\text{-b})$$

where P is the production possibility set of the t period.

The distance functions can be estimated using the Data Envelopment Analysis (DEA) models developed by O'Donnell [12].

2.2 Measures of efficiency

The so called "total factor productivity efficiency" (TFPE) or overall productive efficiency of firm *i* for period *t* is defined as:

$$TFPE_{it} = \frac{TFP_{it}}{TFP^*} \leq 1, \quad (3)$$

where TFP^* is the maximum TFP that is possible using the technology available in period t.

The output-oriented overall productive efficiency can be decomposed into three main components:

$$TFPE_{it} = OTE_{it} \times OSE_{it} \times RME_{it}, \quad (4)$$

where:

- *output-oriented technical efficiency (OTE)* measures the difference between observed TFP and the maximum TFP that is possible while holding the input-output mix and input level fixed;
- *output-oriented scale efficiency (OSE)* measures the difference between TFP at the technically efficient point and TFP at the technically scale efficient point; and
- *residual mix efficiency (RME)* measures the difference between the maximum TFP subject to the fixed output-input mix and the optimal output-input mix.

Figure 1 illustrates the relationship between measures of efficiency. The curve passing through point D is referred as a mix-restricted frontier – it is the boundary of the set of all technically-feasible aggregate input-output combinations that have the same input-output mix as the firm operating at the point A. The curve passing through point E is an unrestricted production frontier – it is the upper boundary of the production possibility with variable input-output mix. O'Donnell [11] shows how different measures of efficiency of firm *i* for period *t* (point A in Figure 1) can be expressed in terms of slopes of rays in aggregate quantity space. Its TFP is $TFP_{it} = \frac{Q_{it}}{X_{it}} = slope(OA)$; the optimum TFP efficiency is defined as $TFP^* = \frac{Q_t^*}{X_t^*} = slope(OE)$; the TFP efficiency defined by equation (3) is $TFPE_{it} = \frac{slope(OA)}{slope(OE)}$; the output-oriented technical efficiency is $OTE_{it} = \frac{slope(OA)}{slope(OC)} = \frac{\frac{Q_{it}}{X_{it}}}{\frac{\bar{Q}_{it}}{X_{it}}} = \frac{Q_{it}}{\bar{Q}_{it}}$; the output-oriented scale efficiency is $OSE_{it} = \frac{slope(OC)}{slope(OD)} = \frac{\frac{\bar{Q}_{it}}{X_{it}}}{\frac{\tilde{Q}_{it}}{\tilde{X}_{it}}}$; and the residual mix efficiency, $RME_{it} = \frac{slope(OD)}{slope(OE)} = \frac{\frac{\tilde{Q}_{it}}{\tilde{X}_{it}}}{TFP^*}$.

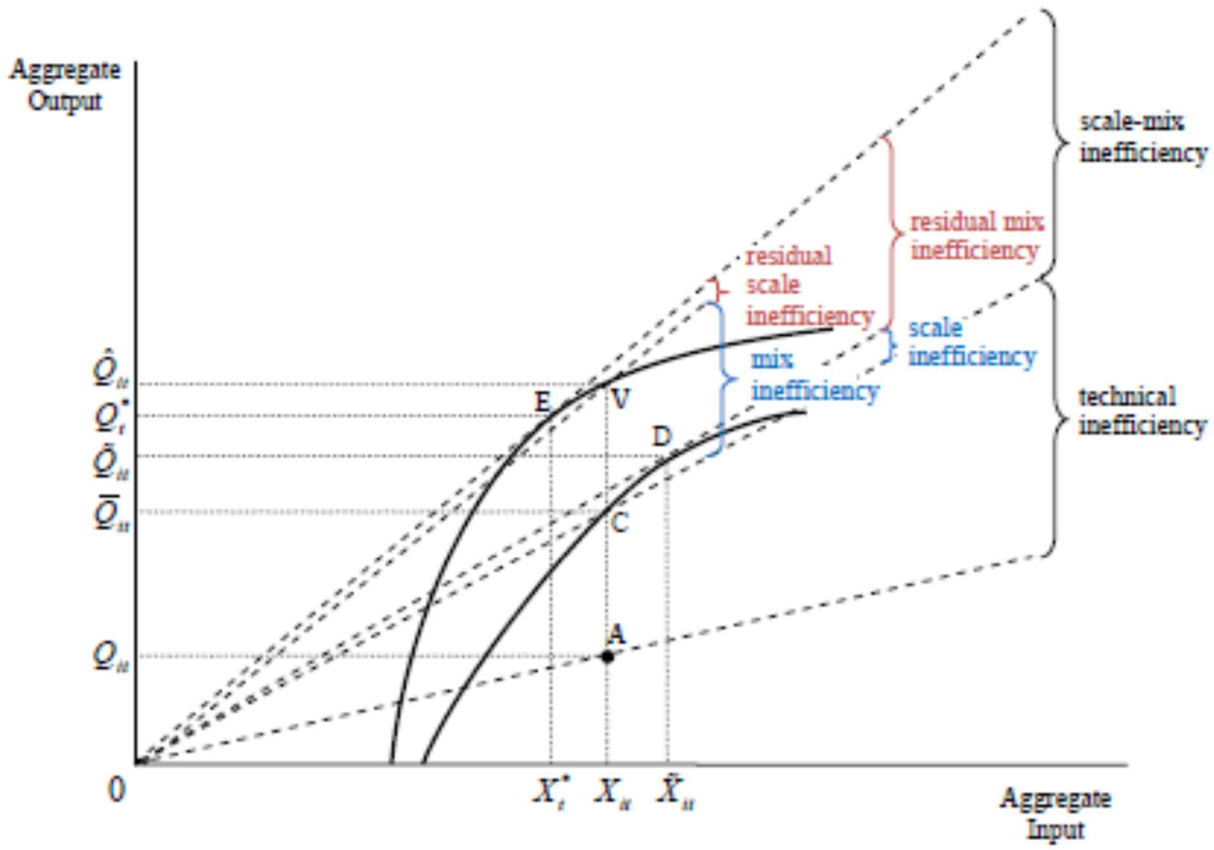

Figure 1 Output-oriented measures of efficiency for a multiple-input multiple-output firm
Source: Adapted from O'Donnell [11]

3 Data

A cross-sectional data set of Vietnamese seaports in 2016 is collected from Vietnam Seaport Association (VPA). The system consists of 44 seaports, located along the 3260 km coastline from the North to the South. Of which, the data of 40 seaports are available in the sample, which can be categorized into three groups locating in the northern, central and southern region. Due to the fact that the economic-social conditions of three regions are different, seaports in particular regions are significantly impacted by these conditions. In terms of ownership, these seaports can be owned either by provincial authorities or logistics companies. The latters are expected to manage seaports better because of their expertise and financial capability.

Estimating the efficiency of seaports requires the information of inputs and outputs. The inputs consist of a number of seaports' resources, which include infrastructure and building proxied by the total length of berths; in terms of land resource the terminal and workshop area are chosen as input variables; and the capital stock of seaports is proxied by the total number of handling equipment. There are a number of output variables that can be utilized including containerized cargo (in TEUs or MT), bulk cargo (MT), general and rolling freight (MT) [6]. In case the sample includes both specific and general seaports the throughput variable is employed [6,22]. In this papers, two output variables are domestic and international throughput.

Table 1 describes input and output variables used to estimate seaport efficiency. In general, there is a difference in terms of the size of employed variables. For example, in terms of infrastructure input, the maximum berth length is 3,567 meter while the shortest is only 110 meter. A significant number of Vietnamese seaports have their berth length under international standard. According to World Bank [23], the required length of seaports should be at least 300 meter for containerships. Other seaports' resources including land and equipment also expose a substantial disparity. The information of outputs reveal a fact that the average export and import cargo volume through a Vietnamese seaport are approximately 3.5 times higher than domestic cargo throughput. This issue highlights the important role of international trade on Vietnam's economy.

Table 2 presents statistical description of input and output variables in different categories. While export-import cargo volume through a Southern seaport stands at 7.15 million MT, only 2.94 million and 0.84 million tons of cargo were transported through a seaport located in the

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Northern or Central area respectively. Southern seaports use more land resource than their rivals in the Northern and Central area. Seaports managed by different entities including local government and logistics companies. Accordingly, seaports belonging to the former have significantly smaller inputs and outputs.

Table 1 Description of input and output variables
Source: [24]

Variables	Unit	Min	Max	Mean	Standard Deviation
Inputs					
Total berth length	Meter	110	3,567	689	791
Terminal area	1000 m2	10,850	5,450,486	317,516	846,378
Warehouse area	1000 m2	850	596,550	35,613	99,604
Total number of handling equipment	Number	5	355	65	75
Outputs					
Domestic cargo throughput	1000 MT	1,050	9,485,755	1,099,541	1,747,869
International cargo throughput	1000 MT	0	60,512,435	3,574,264	9,753,353

Table 2 Distribution of input and output variables by geographical, ownership and service factors
Source: [24]

Variables	No. of sea_ ports	Total berth length (in meter)		Terminal area (in m^2)		Warehouse area (in m^2)		No. of equipment		Domestic throughput (in 1000 MT)		International throughput (in 1000 MT)	
		Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Categories by geographical factor													
Northern seaports	10	949	1,117	136,246	72,160	48,418	76,537	64	78	1,586,339	2,762,067	2,941,034	3,258,182
Central seaports	16	433	306	142,885	208,715	9,517	8,537	49	44	586,463	717,812	841,423	1,690,981
Southern seaports	14	796	809	646,573	1,351,526	56,290	150,849	84	94	1,338,203	1,470,872	7,149,819	15,470,522
Categories by service factor													
Seaports with container services	19	718	739	231,762	193,514	20,392	43,581	75	65	1,194,848	1,075,884	3,626,858	4,311,277
Seaports without container services	21	663	834	395,103	1,148,012	49,384	129,536	56	82	1,013,311	2,180,871	3,526,680	12,820,854
Categories by ownership													
Seaports managed by logistic SOEs	18	981	950	545,136	1,206,503	47,521	134,026	103	95	1,261,787	1,291,098	6,773,999	13,703,706
Seaports managed by local government	22	451	522	131,282	185,480	25,869	55,949	34	25	966,794	2,037,551	956,300	2,020,306

4 Empirical results

Table 3 presents the estimated efficiency measures of individual Vietnamese seaports, including output-oriented overall productive efficiency (TFPE), output-oriented technical efficiency (OTE), output-oriented scale efficiency (OSE), and output-oriented residual mix efficiency (ORME). There are only two efficient seaports if using the overall productive efficiency measure, including Chan May and Tan Cang Sai Gon port. The variation of efficiency level among Vietnamese seaports is significant. While having five seaports with TFPE index higher than 90%, there are 17 seaports under 10%. Output-oriented technical efficiency reveals the capability of seaport operators in terms of exploiting their scarce inputs to generate as much output as possible. Under this criterion five of ten Northern seaports (Quang Ninh, Cam Pha, Transvina, Dinh Vu and Nam Hai Dinh Vu port), four of 16 Central seaports (Quang Binh, Cua Viet, Chan May, and Vung Ro port) and seven of 14 Southern seaports (Binh Duong, Tan Cang Sai Gon, Sai Gon, Tan Thuan Dong, Ben Nghe, TCIT and My Tho port) are the best-practice operators. Obviously, there is a difference when using TFPE and OTE for benchmarking seaport system in the context that most of previous researches on seaport efficiency are preferred in the latter measure.

Output-oriented scale efficiency identifies the gap between temporary and optimal scale of seaports' inputs and is a roof for adjusting the seaport size to raise the benefit of scale effect. For example, the OSE score of Quang Ninh port is 0.8002 and its operator, accordingly, can reduce/increase the size of the port's inputs to obtain a nearly 20% increase of its TFPE. The number of seaports achieving the scale effect is eight. Of which, four ports locate in the northern area, three in the southern area and only one operating in the Central of Vietnam.

Table 3 Efficiency measures of individual Vietnamese seaports
Source: Author's calculations

Seaports	Q	X	TFP	TFP*	TFPE	OTE	OSE	ORME
Quang Ninh	1.0000	1.0000	1.0000	2.4505	0.4081	1.0000	0.8002	0.5100
Cam Pha	1.0000	1.0000	1.0000	1.0539	0.9489	1.0000	1.0000	0.9489
Hai Phong	0.9585	1.3883	0.6904	2.1776	0.3170	0.9585	0.8914	0.3710
Đoan Xa	0.0911	1.2208	0.0747	1.2518	0.0596	0.0911	0.9700	0.6745
Vat Cach	0.7670	1.2876	0.5957	0.8092	0.7362	0.7670	1.0000	0.9598
Cua Cam Hai Phong	0.3047	1.0000	0.3047	2.0826	0.1463	0.3047	0.5595	0.8582
Transvina	1.0000	1.0000	1.0000	11.73	0.0853	1.0000	0.1645	0.5185
Đinh Vu	1.0000	1.0000	1.0000	1.0004	0.9996	1.0000	1.0000	0.9996
Nam Hai Đinh Vu	1.0000	1.0000	1.0000	1.3175	0.7590	1.0000	1.0000	0.7590
Tan Cang 128 – Hai Phong	0.7668	2.2424	0.3420	1.3463	0.2540	0.7668	0.5655	0.5858
Thanh Hoa	0.0675	2.3804	0.0284	0.5872	0.0483	0.0675	0.9222	0.7759
Nghe Tinh	0.5276	5.1247	0.1030	0.7625	0.1350	0.5276	0.3174	0.8062
Vung Ang Viet Lao	0.3542	2.3991	0.1476	3.5460	0.0416	0.3542	0.8433	0.1393
Quang Binh	1.0000	1.0000	1.0000	117.86	0.0085	1.0000	0.0542	0.1568
Cua Viet	1.0000	1.0000	1.0000	52.4547	0.0191	1.0000	0.0408	0.4681
Thuan An	0.1187	1.1988	0.0990	1.9862	0.0498	0.1187	0.6813	0.6158
Chan May	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Đa Nang	0.8772	1.4962	0.5863	2.9832	0.1965	0.8772	0.5781	0.3875
Hai Son	0.0254	1.5608	0.0163	1.1498	0.0142	0.0254	0.8305	0.6732
Ky Ha	0.0676	1.3774	0.0491	3.5983	0.0136	0.0676	0.7316	0.2750
Ky Ha – Quang Nam	0.0440	1.0772	0.0408	6.1617	0.0066	0.0440	0.7190	0.2086
Quy Nhon	0.6547	2.0864	0.3138	2.3584	0.1331	0.6547	0.6634	0.3065
Thi Nai	0.5336	1.3862	0.3850	0.8760	0.4395	0.5336	0.8742	0.9422
Vung Ro	1.0000	1.0000	1.0000	63.8482	0.0157	1.0000	0.0366	0.4290
Nha Trang	0.1653	2.7911	0.0592	0.5434	0.1090	0.1653	0.9770	0.6749
Cam Ranh	0.1585	4.9738	0.0319	0.7732	0.0412	0.1585	0.3195	0.8136
Đong Nai	0.9455	1.5849	0.5966	117.59	0.0051	0.9455	0.6565	0.0082
Binh Duong	1.0000	1.0000	1.0000	3.2816	0.3047	1.0000	1.0000	0.3047
Tan Cang Sai Gon	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sai Gon	1.0000	1.0000	1.0000	10.6078	0.0943	1.0000	0.3367	0.2801
Tan Thuan Đong	1.0000	1.0000	1.0000	5.5094	0.1815	1.0000	0.2755	0.6588
Ben Nghe	1.0000	1.0000	1.0000	7.2012	0.1389	1.0000	0.5099	0.2724
Bong Sen (Lotus)	0.2676	2.3342	0.1147	1.2353	0.0928	0.2676	0.9059	0.3828
Rau qua	0.0892	1.0000	0.0892	2.8689	0.0311	0.0892	0.4033	0.8645
Phu My	0.4751	2.4569	0.1934	0.9603	0.2014	0.4751	0.8455	0.5014
TCIT	1.0000	1.0000	1.0000	1.3283	0.7528	1.0000	1.0000	0.7528
CMIT	0.9776	1.0199	0.9586	1.0684	0.8972	0.9776	0.9956	0.9218
My Tho	1.0000	1.0000	1.0000	3.5642	0.2806	1.0000	0.5177	0.5420
Vinh Long	0.0617	1.5471	0.0399	4.7440	0.0084	0.0617	0.9320	0.1461
Can Tho	0.5047	3.0122	0.1676	0.9064	0.1849	0.5775	0.3201	1.0000
GeoMean	***0.4382***	***1.4136***	***0.3100***	***2.7207***	***0.1139***	***0.4397***	***0.5470***	***0.4738***

Notes: X is aggregate input, Q is aggregate output, TFP is total factor productivity index, TFP* is the maximum TFP, TFPE is TFP efficiency (overall productive efficiency), OTE is output-oriented technical efficiency, OSE is output-oriented scale efficiency, and ORME is output-oriented residual mix efficiency.

Output-oriented residual mix efficiency determines the ability of firms to composite different outputs and inputs for generating the maximum ratio of aggregate output and aggregate input. In this paper, we classify Vietnamese seaports' outputs into domestic and international cargo throughput. ORME in this case measures the seaports' capability to maximize the aggregate cargo throughput from given two mentioned outputs. However, due to the Vietnamese maritime regulations, there are seaports serving only domestic cargoes and a limited number of seaports capable to serve both types of outputs. As a result, they are impossible to achieve maximal mix efficiency. Increasing ORME via better compositing adjustable inputs (warehouse area, cargo handling equipment) can be a feasible solution. Empirical results show that three seaports achieve the maximum level of mix efficiency, including Chan May, Tan Cang Sai Gon and Can Tho port.

In general, the estimated mean of TFPE is extremely low at 0.1139, pointing out that the seaport system is underperformed and inputs are employed substantially inefficient. This underperformance can be due to a number of factors which are found via decomposing the overall productive efficiency. First, a low level of technical efficiency at 0.4397 provides evidence of poor management quality of Vietnamese seaports' operators, while there is a potential to increase the temporary outputs by 56.03%. In fact, the Vietnamese seaports are mostly a cluster of many small terminals operated by different entities and not connected via either contiguous wharf or road links. Subsequently, additional land-side infrastructure is required to connect multiple marine terminals and more dredging and channel maintenance expenses are also required for facilitating vessel navigation to various port locations. Another subsequence is the difficulties in setting up transshipment hubs due to a lack of inter-terminal connections and dispersion of cargo volumes.

Second, scale effect is not well utilized with the low mean value of OSE standing at 0.5470. The fragmentation of Vietnam's current port system makes individual ports unable to leverage economies of scale and duplicates their operating costs due to congestion at certain terminals and under-utilization in other terminals.

Third, mix efficiency, recorded at a value of 0.4738, is the last factor contributing to the overall underperformance of Vietnamese seaport sector. There is a substantial room to increase this criterion through coordinating properly output and input variables.

Figure 2 demonstrates the variation of overall productive efficiency and its components including technical, scale and mix efficiency. Seaports in the sample are organized in their increasing TFPE score order. The figure exposes a significant disparity of performance among Vietnamese seaports.

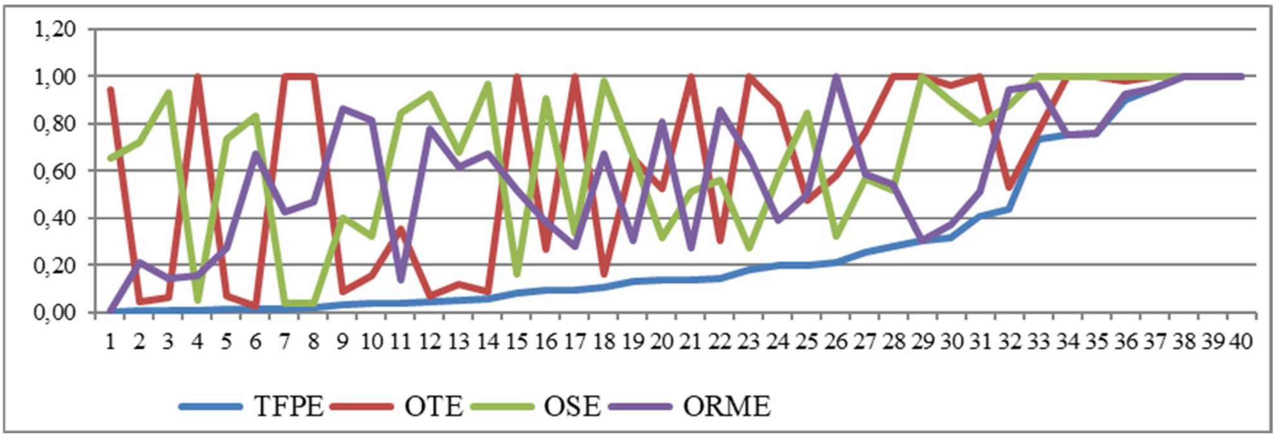

Figure 2 Distribution of individual Vietnamese seaports' efficiency measures

Notes: TFPE is output-oriented overall productive efficiency, OTE is output-oriented technical efficiency, OSE is output-oriented scale efficiency, and ORME is output-oriented residual mix efficiency.

Table 4 illustrates the figures of seaport efficiency in groups categorized by geographical factor, types of services and ownership. It is clear that seaports in different areas of Vietnam reveal a distinction. While those located in the North reach the highest level of overall productive efficiency (0.3245), their partners in the central area are the least efficient (0.0513). Central seaports obtain the lowest technical efficiency at 0.2722, exposing the poor management quality of the operators in one hand. On the other hand, the small volume of cargo transported through these hubs is another cause when the central area contributes only three percents of the total national throughput [23]. Inspire of having better overall performance, southern seaports are less efficient in terms of scale efficiency if compared with the central ones (0.2790 versus 0.4094). This fact can be explained by the oversupply of southern maritime terminals resulted from the concession granting for new terminal building projects [23,25].

Seaports serving container ships are more overall efficient due to their better technical and scale performance. Containerization technology can be seen as the main factor contributing to the outperformance of container terminals if compared with those only server traditional cargoes (bulk and general cargoes). Over the last 10 years, the container cargo has increased at a rapid speed at 20 percent annually, while on average, a 16 percent growth rate is recorded for all types of cargo through Vietnamese seaports [24].

Ownership is also found as a significant factor that differentiates the performance of Vietnamese seaport system. Those under the management of logistics SOEs attain an overall efficiency score at 0.1899, while their rivals owned by local governments have their efficiency value equivalent to less than a half (0.0755). Technical efficiency is the cause of this substantial disparity, exposing the low quality of business administration of local governments. Logistics companies with superior experience in their specified businesses are the better operators.

Table 4 Decomposing Vietnamese seaports' overall productive efficiency
Source: Author's calculations

Efficiency measures	No. of sea_ ports	Overall productive efficiency		Technical efficiency		Scale efficiency		Residual mix efficiency	
		GeoMean	S.D	GeoMean	S.D	GeoMean	S.D	GeoMean	S.D
Categories by geographical factor									
Northern seaports	10	0.3245	0.3405	0.6599	0.3121	0.7172	0.2672	0.6857	0.2086
Central seaports	16	0.0513	0.2458	0.2722	0.3841	0.4094	0.3281	0.4599	0.2738
Southern seaports	14	0.1358	0.3206	0.5691	0.3561	0.2790	0.2790	0.3319	0.3319
Categories by service factor									
Seaports with container services	19	0.1721	0.2981	0.6350	0.3135	0.6593	0.2649	0.4111	0.2904
Seaports without container services	21	0.0790	0.3450	0.3153	0.4060	0.4620	0.3352	0.5422	0.2864
Categories by ownership									
Seaports managed by logistic SOEs	18	0.1899	0.3190	0.6272	0.3057	0.6068	0.2801	0.4989	0.2913
Seaports managed by local government	22	0.0755	0.3210	0.3288	0.4194	0.5024	0.3270	0.4570	0.2821

5 Conclusion

Using the data set of Vietnamese seaports in 2016 and following the method of O'Donnell [11,12], we measure overall productive efficiency of these ports and decompose into a number of efficiency measures, including technical, scale and mix efficiency. In general, the results point out the underperformance of Vietnamese seaport system, using the overall or any component measures of efficiency.

Particularly, ports locating in different regions reveal a disparity of performance. Northern ports are the most efficient ones compared with their partners in the Central and the South. While having better overall productive efficiency, southern ports are the least efficient if using scale efficiency measure. Seaports providing containership services are more efficient due to their better technical and scale efficiency. Ownership is also effective to seaports' production when ports operated under the logistics companies perform better than those under local government.

This study contributes to the literature of port performance via applying a complete measure of efficiency following the work of O'Donnell [11,12] in the context of an emerging economy like Vietnam. This measure is believed to be more comprehensive than the common measure of efficiency, technical efficiency that is mostly used in the literature.

Further studies on Vietnamese seaport performance can be conducted if the time series data is available; accordingly, technical progress of these seaports can be observed. While many Vietnam's seaports are conducting "Green port" strategy, integrating environmental factors such as carbon dioxide emission from ships in Total Factor Productivity models could improve the results and make researches of Vietnamese seaports more comprehensive.

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MOTORCYCLE TAXI IN ADDRESSING THE RURAL TRANSPORT CONUNDRUM

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Abstract: Rural people need transport services to access basic services and livelihoods. This study analyses the extent to which the motorcycle taxi addresses rural transport problems. Such an analysis could inform the future of rural transport interventions. Rongo, a rural sub-county in Kenya, was chosen for the study. The analysis results using data from 289 household heads show that predominant activities in the study area transformed motorcycle taxi activities throughout the day. Motorcycle taxis offered useful rural transport services and complemented many public transport systems in facilitating access to places, markets, facilities, and activities. Respondents associated the physical characteristics of the motorcycle taxi with motivations for its use along with its actual use. Although most of the respondents expressed satisfaction with the motorcycle taxi sector, there was a clear difference between groups. Respondents' satisfaction with motorcycle taxi services was mainly due to the motorcycle taxi physical attributes. The respondents mainly related negative reasons to motorcycle taxi riders' mannerism, unprofessional driving, and poor safety. This paper concludes that the motorcycle taxi facilitates the movement and operations in rural villages. Using motorcycle taxis have shown to have a close link to rural areas and rural life. This study calls on transport practitioners to rethink the concept and image of sustainable rural mobility and identify with rural informal motorcycle taxi transport as well. For equitable, accessible and sustainable rural transport, the transport practitioners need to empower and expand on existing realities in rural areas.

1 Introduction

Rural people need transport services to access basic services and livelihoods. However, poor maintenance and provision of road infrastructure plus poor availability of transport services, unreliability, high fares, and security issues are widespread restrictions on rural travel. There are particular ownership restrictions on motor vehicles and intermediate means of transportation to rural elites. Certain vulnerable groups—the young, the old, infirm, and women—face particular mobility difficulties; with women and girls, this may include cultural constraints on their movement [1].

In many rural and urban parts of sub-Saharan Africa, motorcycle taxis (MTs) have become the most used means of motorised transport [2]. This could have been due to increased transport demand and inadequate conventional rural transport services [3] such as (four-wheel) taxis or buses. In these rural areas, MTs complement existing public transport services by transporting people between villages and the road network where long-distance transport services are available. They play a vital role in linking people to services, farms, and markets. Nowadays, rural people use MTs to make journeys that they previously made on foot.

The MTs operate on a relatively short distance (usually less than 10-20 km) from 'stands' in towns and business centres and stops along the major roads for passenger service providing access to feeder routes [4]. The MTs begin in urban areas [5], where there is a high demand for point-to-point transport services, it stretches out to the peri-urban areas and then to broader villages before entering remote rural areas [6]. Men appear to dominate activities related to MT transport [7].

The fares charged by the MT riders vary depending on distance, time, locations, weather, day, or even location of approaching a MT rider for example on the road or at a stage. However, the user can either bargain or search for another rider at a more reasonable price [8]. The fares go up during rainy [9] and may decrease by approximately 60% if the MT carries two passengers [5]. Although rural MT users often complain that the fares per kilometre for rural MTs are typically more costly and say they prefer to use conventional (four-wheel) taxis or buses, when these are available [10], it is the lack of timeliness (or absence) of such alternatives that provide the 'market' for MTs [5,11].

MTs provides even the most remote rural communities with a means to access essential services and livelihoods. According to [11], MTs offer benefits such as flexible access to the major routes plied by lower-cost public transport services such as conventional (four-wheel) taxis. It also provides door-to-door travel, which is of particular use to older or disabled passengers. They offer timely transport of people and goods, with no waiting time, and take people straight to their required destinations. Rural inhabitants appreciate this [10]. The efficiency advantages that rural people get when they can access MTs by mobile phones are impressive [1,5]. As noted by [12], several riders use mobile phones so that customers can call them.

Even though people use MTs for public transport in both urban and rural areas, their operations in urban areas are reportedly becoming a nuisance due to recklessness, lack of lane discipline, unsafe manoeuvres and high incidence of crashes [13,14]. The same cannot be said of rural areas because of the low volumes of traffic, absence of congestion on the networks, lack of alternative modes of public transport among others. According to [15], the main driving force of MT growth is socio-economic considerations including the low initial purchase costs, low operating cost that are typically linked to the superior fuel economy or reliability of MTs relative to cars, their relatively low maintenance costs, and perhaps the main employment opportunities for unemployed youth in Kenya.

In most countries, the law allows for one driver and one passenger only [11]. However, one can see four to five riders on a single MT, seriously overloading acceptable limits on motorcycles for travellers [16]. The result is that where there are many MTs in use, there are often increasing numbers of disadvantages, to which the authorities have to respond [8]. Government efforts to regulate the MT market in Kenya have had the problem by distorting market structures. This is probably because policies planned to regulate the market have failed to consider the peculiar rural contexts and concerns. The government either lack awareness or may be ignorant of the rural transport situation.

The sheer numbers and scale of uptake in rural Kenya probably show that many people believe the benefits offered by MTs outweigh the risks [7]. Existing studies on MT transport focus on sub-Saharan and Asian cities, but rarely in rural areas. They concentrated on the problems, regulatory approaches, and barriers for change while focusing only on MT riders–demographics, ownership, and associations. Overall, there is a knowledge gap on the extent of MT transport services in rural Kenya. Besides, familiarity with the trip purpose, passenger profile and needs, travel patterns and user preference in rural areas is also lacking. This paper analyses the extent to which the MT addresses rural transport problems, taking Rongo sub-County in Kenya as a typical case.

2 Methodology

This is a cross-sectional descriptive survey that used a mixed-method approach that used different methods, including a survey, observation, and analysis of secondary data, for collection and analysis of qualitative and quantitative data. The study was conducted in Rongo sub-County, in Migori County, Kenya, in the months of November and December 2019. The study purposively selected Rongo sub-County as the study site because the sub-County is a typical case of a peri-urban Kenyan setting. The main respondents comprised all the heads of household in the Sub-County, from whom the study drew a sample size of 395 household heads. The study determined the sample size using Taro Yamane's formula [17]. The formula states (1):

$$n = N/[1+N(e)^2] \quad (1)$$

where n is the required sample size, N is the size of the target population and given as 29,087 household heads [18], and *e* is the error term (.05). Respondents were selected through the two-stage cluster sampling technique, in which the study area was first divided into the seven locations that comprise Rongo sub-County. Two locations were purposively selected - Central Kamagambo which is predominantly urban and West Kamagambo which is predominantly rural. A sampling frame was drawn for each of the selected locations, from which respondents were picked using the systematic random sampling method. The study complemented data from main respondents by information gathered from key informants, who included six village elders, four ward administrators, and two chiefs. It purposively selected all key informants from the study area. Further, the study used convenient sampling to select 16 focus group discussion (FGD) participants based on their accessibility and readiness to take part.

Research assistants administered a semi-structured questionnaire to the main respondents. The questionnaire obtained information about the MT travel patterns, MT trip distance, frequency of MT use, reasons for MT use and respondents' satisfaction with MTs. To complement the questionnaire, the study conducted two FGDs, one in each of the selected locations. Each FGDs had eight participants of the same sex and age group and discussed the MT travel patterns, MT trip distance, frequency of MT use, reasons for MT use and satisfaction with MTs. The principal investigators conducted all the key informant interviews to collect data about travel patterns of MT users; average MT trip distance; frequency of MT use; MT trip purposes; reasons for MT use; riding styles of MT users; and MT users' satisfaction. The study also observed MT trip density at different times of the day and riding styles of MT users at the main termini and along the major roads in the sub-County.

This study sought informed consent from the respondents. It also assured the respondents of their anonymity and confidentiality of all information obtained. Quantitative data collected were analysed descriptively using IBM SPSS V.25 software and findings presented in frequency tables and bar charts. Qualitative data were analysed thematically.

3 Result and discussion

This study achieved a response rate of 73.2%. It distributed 395 questionnaires out of which the respondents duly filled and returned 289. Based on [18], the study deemed the response rate as adequate for the generalisation of the study findings to the target population. The study attributed part of the non-response to the non-availability of respondents who were busy working during the day and were reluctant to take part in the study because it could interfere with their earnings. The respondents composed of 96% and 4%, household heads and spouses respectively, primarily indicating the reliability of the responses as the study assumed them to have accurate facts about the status of household travel activities. Table 1 presents the socio-demographic characteristics of the respondents.

Table 1 Socio-demographic characteristics of household heads

Total N=289			
Socio-demographic Characteristic		**Frequency (n)**	**Percentage (%)**
Gender	Male	230	79.6
	Female	59	20.4
Age group	Below 20 years	12	4.2
	21-30 years	61	21.1
	31-40 years	94	32.5
	41-50 years	59	20.4
	51-70 years	45	15.6
	Above 70 years	18	6.2
Level of Educational Attainment	No formal schooling	5	1.7
	Primary	72	24.9
	Secondary	126	43.6
	Post-secondary	86	29.8
Marital Status	Single	13	4.5
	Married	206	71.3
	Divorced/ Separated	31	10.7
	Widow/ Widower	39	13.5
Main occupation of Household Head	Student	24	8.3
	Petty trading	63	21.8
	Farmer	154	53.3
	Civil servant	17	5.9
	Employed in private sector	31	10.7
Average Family Monthly Income in Kenya Shillings (Kshs).	Less than 10,000	108	37.4
	10,001- 25,000	84	29.1
	25,001-35,000	58	20.1
	Over 35,000	39	13.5

Note: Kshs. 106.50 (Kenya) = $1.00 (Dollar)

As shown in Table 1, over two-thirds (79.6%) of households in the study area male-headed, as is typical of rural areas in Kenya [19]. This finding has a direct bearing on transport choices, considering that more than half of passengers are usually male [12] The finding also indicate the patriarchal nature of the study area, which could have a bearing on transport use patterns. The study also found that slightly more than half (52.9%) of all household heads are aged between 31-50 years, as stated in Table 1. Of greater interest, however, is the revelation that one-tenth of the household heads were below the age of 20 (4.2%) or above the age of 70 years (6.2%), in conformity with the population structure in developing countries.

Data in Table 1 shows that the level of literacy in the study area is relatively high, with approximately two-thirds of the respondents (63.4%) having attained at least secondary school education out of which 29.8% of them have attained post-secondary education. Only about 1.7% of the respondents did not have any formal schooling. This can result from the free primary education programme in Kenya which was reintroduced by the National Rainbow Coalition (NARC) government that was elected into office in December 2002 [20]. The findings of the study are so synonymous to the rural area because secondary education level is the limit of free education opportunity in Kenya where education is still affordable by the average poor. In most cases, those who meet requirements for higher education give up at this stage due to the cost involved. Such people settle for other means of livelihood thus underlining the potential of MT transport in the provision of employment to various categories of people in rural Kenya.

Over two-thirds (71.3%) of the respondents were married, and only 4.5% were single and had never been married, as shown in Table 1. The marital orientation of an individual, to a great deal, is a determinant of engagement in certain occupations, and more often, adult responsibilities can always compel people to travel take up any engagement provided gains are promised. Married people may have to travel on a daily or regular basis for employment. Through MT transport, family ties are established, reaffirmed, and consolidated [21]. According to [22], the average household size in Rongo sub-County was at 4.3 members. In the present study, the average household size is 4.1 which is close to 4.3 hence consistent.

The study also revealed that slightly more than half (53.3%) of the respondents were engaged in peasant farming and approximately fifth (21.8%) were engaged in petty trading, as stated in Table 1. Of important note, only 16% of the respondents were in formal employment. This suggests that the majority of the population in Rongo sub-county are small-scale farmers who need to access markets for sale produce and purchase of inputs. They want transportation services that allow them to travel with baskets or sacks from and to those markets. The results are in line with [23], that the main socio-economic activity of Rongo sub-County is agriculture. Rural Kenya is mostly characterised as an agrarian region as most of its inhabitants remain heavily dependent on agriculture as the key employment source.

The above findings could explain the fact that on average, the majority of the respondents (66.5%) earn less than Kenya Shillings 25,000 per month, as stated in Table 1. This implies that unemployment is high relative to levels of income. According to [15], socio-economic considerations are the primary driving force behind the growth of MTs. Among the study respondents, MTs can be profitable to own and profitable to lease because of low-cost capital and low operating costs that usually have to do with superior fuel efficiency or vehicle performance. Perhaps the most important in Kenya's rural context is the employment opportunities it offers to our unemployed youths.

3.1 Motorcycle Taxis in Addressing Rural Public Transport Problem

This study analyses the extent to which the MT addresses rural transport problems by looking at travel patterns of MT users; average distance covered during the MT trips; frequency of MT use; reasons for MT use; the MT safety concerns, and MT user's satisfaction in the study area. The findings are discussed below.

3.1.1 The Travel Patterns of Motorcycle Taxi Users

The study observed the density of MT trips based on time of the day within Rongo sub-County to identify the users, common trip origin, destination, and time of the day of MT trips. The most exciting aspect was that motorbike taxi trips seem to be scattered from various areas while destination points are more focused on Rongo town. Whereas the town is the focus of most MT trips, time changes based on MT trip origins and destinations in Rongo sub-County could better inform the purpose and pattern of the trip. Therefore, Table 2 shows the percentage of trips that the respondents took at different times depending on their origin and destination points throughout the day.

Table 2 Points of origin (O) and destination (D) of motorcycle taxi trips

Category	Point of Interest	Percentage of points of origin (O) and points of destination (D) based on time of day									
		05:01-10:00		10:01-13:00		13:01-16:00		16:01-20:00		20:01-05:00	
		O	D	O	D	O	D	O	D	O	D
Formal commercial and business areas	Regional centre	7	9	13	15	15	15	17	11	14	9
	Main markets	9	12	14	15	15	15	17	12	12	7
	Public institutions	8	9	12	11	14	14	11	10	8	6
	Places of leisure	4	2	4	2	2	2	5	3	20	18
Hospitals and health facilities		4	4	4	5	4	11	5	9	3	3
Education centres	Universities	3	11	7	11	12	9	8	7	4	4
	Schools	0	16	0	3	2	1	12	0	0	0
Small-scale and informal business areas		9	9	9	10	10	12	11	10	11	12
Agricultural areas		5	5	5	4	4	2	3	2	3	1
Centres of worship		3	3	3	4	2	2	4	3	1	3
Residential places of respondents based on their income levels in Kshs.	Below 10,000	16	6	14	6	7	7	5	14	8	11
	10,001-25,000	14	5	9	4	4	5	4	10	6	10
	25,001-35,000	12	4	4	4	3	4	2	9	4	8
	35,001 and above	6	3	3	2	3	4	1	5	3	7
Total		100	100	100	100	100	100	100	100	100	100

Note: Kshs. 106.50 (Kenya) = $1.00 (Dollar)

Table 2 reveals two contradictory phenomena. First is the revelation that MT trips to commercial areas peak from mid-morning to mid-afternoon. The heavy flow of MT traffic at these hours indicates that Rongo town is essentially a daytime economy. Interestingly, these peak hours also apply to health facilities. Even more interesting, is the revelation that although FGDs pointed to the use MTs to commute to work, Table 2 does not show a marked intensity in traffic during early morning and late evenings, which are the typical times for reporting to, and leaving work. The second phenomenon that can be gleaned from Table 2 is the fact that even though the intensity of MT traffic reduces from late afternoon, it does not die off completely. This shows that while Rongo is mainly a daytime economy, activities continue, albeit at a slower pace, even through the night. During such times, MT is the only mode of transport for people without private cars. Remarkably, from 20:00 to 04:59 between evening and dawn, MT trips in places of leisure escalated. Other purposes reported during this period travelling to places of worship, when it is risky to walk at night. Also, respondents resonated that those who arrive late in the night from cities using public buses usually use MTs to travel to residential areas.

Table 2 also shows that the points of origin and destination in the morning and after working hours, were mostly residential areas, particularly among the respondents with low levels of income. This reflects MTs' dependence among respondents with low levels of income. The activities of MT in medical and educational centres were fairly consistent, with increased demand at a specific time interval. Rongo University, for example, was the most common destination, especially if lectures were before noon. Besides, there were high MT activity after-school hours between 13:01 and 18:00 and between 10:00 and 16:00 which is normally the lecture periods for Rongo University and visiting hours for hospitals. Variation of MT trips destination and origin with time highlights the purposes and drivers of the MT trips. The early period, 05:01 to 10:00, showed a high number of trips, showed many trips, especially from residential areas. This explains that the trips entering these major roads were from distant parts of Rongo Sub-County and even surrounding areas outside the sub-County to go to school or work. This was true in areas of small business centres such as Kanyawanga, Kangeso, and Opapo.

There were many MT trips concentrated within the economically active area of Rongo town between 10:01 and 13:00 working hours. This was heightened between 13:01 and 16:00 especially within the socially and economically active places. Table 2 further shows a clear shift in the activities from the town to smaller centres in the late afternoon, a sign that commuters were returning home. This shows that the day population of Rongo town is higher than its night population and that many people live away from the town. The findings are in line with related studies showing that MT trip purposes vary from one user to the other. For example, [21] argues that the rural population mainly uses the MT service to maintain or create social interactions. According to [5], produce markets, shops, government and private services, clinics or hospitals and high schools are the key destination for rural MT services. Major activities in Rongo sub-County, especially commercial activities, change with the predominant MT trips over various periods. The change of trip patterns corresponds with the rural people's daily life and activities to reach different markets, places, and activities.

3.1.2 Average Motorcycle Taxi Trip Distance

The MT trip distance was established by looking at frequency distribution for all the MT trip's distance in kilometres. The findings are as presented in Figure 1.

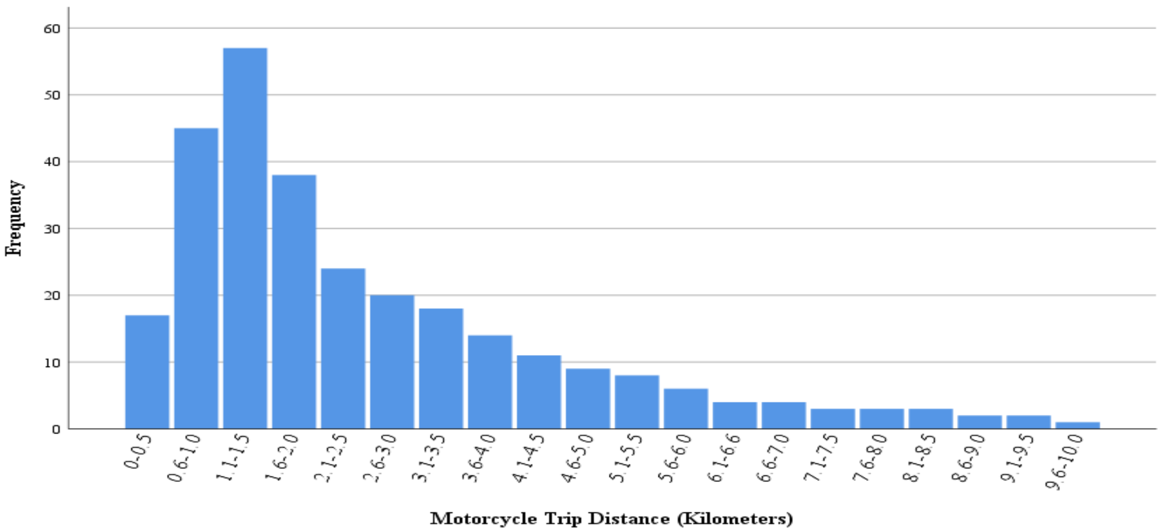

Figure 1 Motorcycle taxi trip distance

Figure 1 illustrates that most of the MT trips were between 600 meters (m) and 2 kilometres (km), while long-distance trips of over 6 km were lesser. The results of the study showed that most MT trips were short, with an average distance of 2.98 km for all trips. Amongst the respondents who knew the time they took on a MT trip indicated that the time taken ranged between 3 minutes and 30 minutes. These findings reveal that people in the study area mostly used MTs for travel between shorter distances. Most respondents expressed a preference for conventional (four-wheel) public buses or taxis for long-distance travel.

The study finding on MT trip distance is consistent with the results of [12], who found that MTs provide a low-capacity, short-distance services to serve low-density demands. They are complementary to conventional (four-wheel) taxis or public busses by transporting people between villages and the roads where longer-distance transport services operate [5,6]. Starkey [6] also argues that MTs operate on fairly short distances (often less than 10-20 km). This study attributed the short distance MT trips to the physical location between locations and the flexibility of MT, which could opt for alternative shorter routes for faster access.

3.1.3 Frequency of Motorcycle Taxi Use

The study asked respondents about how frequently they used MTs. The findings are as stated in Figure 2.

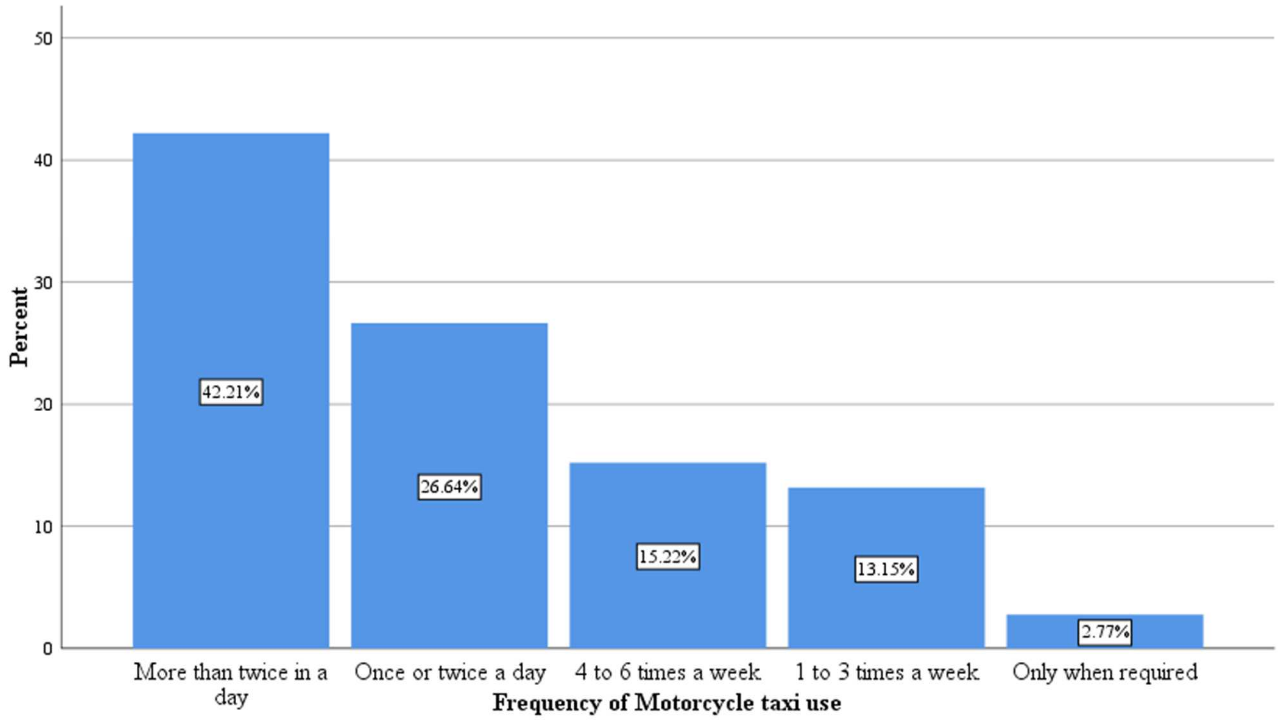

Figure 2 Frequency of motorcycle taxi use

As stated in Figure 2, more than half (68.9%) of respondents used MT transport every day. Out of this (42.2%) are even more frequent users because they use MT transport more than twice in a day. Only about 2.8% of respondents use it only when it is necessary or in an emergency. These study findings imply that most respondents very depend on a MT for mobility within and even outside of Rongo sub-County. A key informant informed the study:

"In Rongo sub-County, so many people rely on motorcycle taxis for transport. Without them, many people won't be able to get around quickly at all." (Ward administrator 2, Rongo sub-County, December 2019).

These study findings are in line with other studies on MTs. For example, [7] shows that MTs thrive in areas where conventional motor transport services are uneconomical or where tough terrain makes operation of other types of vehicle challenging, such as in remote rural Kenya. According to [5], MTs are increasingly acting as feeder services, linking off-road villages to other, more affordable forms of motorised transport services, moving passengers from rural areas where unmade road networks exist, to paved roads.

The study findings can be explained by the restriction on ownership of motorised vehicles and intermediate means of transportation to rural elites. Most rural people require personal transport or some form of public transportation service to carry themselves and their goods on rural roads, which are slippery and rocky at an affordable cost. MTs are adapted to these rural roads, thus becoming the preferred means of public transport by the inhabitants of Rongo sub-County. On many rural roads, they are the only motorised means of transport for most rural people.

3.1.4 Reasons for Motorcycle Taxi Use

The study asked respondents to explain their reasons for their choice for the use of MTs. The study ranked the responses: (1) Convenience (82.4%); (2) Cost-effective (79.2%); (3) Motorcycle taxi riders know specific destinations, are trustworthy, and relational (71.6%); and (4) Saves and keep time (57.1%). In this study, the ease with which rural people can access MTs underlines the convenience of using them. Data from observation and corroborated by qualitative data from FGDs show that finding a MT in the study area is fairly easy. The FGDs further revealed that most of the frequent users have contacts of several riders in their phones, further reinforcing the notion of convenience since the riders are available at the client's convenience. Based on user budget, time, and accessibility, the MT trips can be a direct point to point, or initial or final segments of a longer trip. A FGD participant well summarises MT transport characteristics:

"Boda-boda [motorcycle taxi] can help you reach places if you don't have a car…there are some places the motor vehicles can't reach and obviously one can always lock his/her motor vehicle, take on a boda-boda and complete the journey and come back later, enter the vehicle and continue driving. They can come and pick you. They are also quick...! So, when I need to go home early so, they are convenient and are always available…. one can always use his/her phone to call the riders." (FGD01, Male, Age 36, December 2019).

Data from observation also revealed that MTs are available in abundance at very many points within the study area. Throughout the study area, the study observed MTs parked at shades constructed for that purpose, dotted all over the study area. MT riders could also be seen riding around the study area without passengers, scouting for clients. Qualitative data from FGDs revealed that locals perceive that MT transport is a very convenient and functional mode of transportation that offers advantages in terms of easy manoeuvrability, capacity for poor road travel, and demand responsiveness. The qualitative data revealed that the performance advantages that rural people get when they can access MTs by mobile phones are impressive. To rural people, this additional level of connectivity is a travel revolution. Even though they cannot afford to travel regularly more individuals can now access MTs in an emergency. Rural people consider this to be of crucial importance to their well-being.

Similarly, the ability of MTs to save and keep time featured as one reason for using MTs, at 57.1%. During FGD for females, it was largely agreed that the MT is *"the fastest means of transport"*, and that this was valuable, as many women were now trying to combine trading activity with family life. Another prominent reason for using MTs was their perceived cost-effectiveness. Over four-fifths of the respondents (84.4%) listed cost-effectiveness consideration for using MTs. Although conventional (four-wheel) public buses or taxis maintains the competitive edge of cost, passengers opt MT transport for its timesaving. A FGD participant indicated:

"While going to Rongo town, a conventional matatu [four-wheel taxi] charges me a fare of Kshs.50 compared with a motorcycle taxi, which charges a minimum of Kshs. 100. It is significantly more expensive to travel on a motorcycle taxi but if you think about the time that you save, it gets cheaper. Time is money! It even becomes cheaper if you consider all other factors." (FGD05, Male, Age 41, December 2019).

The study findings also reveal that the price paid for MT trips varies and is negotiable. A key informant reported:

"The price depends on how you are dressed up or how you bargain… The riders charge you accordingly so long as you are dressed presentably. For instance, a four-kilometre could cost between Kshs. 20 and Kshs.30 but a two-kilometre trip could cost Kshs. 40. The riders charge between Kshs. 50 to Kshs.100 for trips ranging between five to seven kilometres are." (Key informant 2, Male, Village elder, Age 62).

The respondents listed another reason for choosing to use MTs as their perception that MT riders know specific destinations, are trustworthy, and relational, at 71.6%. They perceived the MT riders to know every route and every place, including shops and offices. The respondents saw the riders as friendly and trustworthy and reported to not only used MTs for commuting but also for running personal errands. Most customers were referring to specific MT riders as '*my boda-boda [MT] guy'*.

The findings of this study show that MTs fill the gap in the demand and supply of rural public transport; by providing reliable and continuous rural public transportation services to the locals. Rural people perceive the MT as a very convenient and functional mode of transportation that offers advantages in the form of easy manoeuvrability, the ability to travel on poor roads, and demand responsiveness. The findings are consistent with related studies conducted on MTs showing that passengers opt for MTs because they are timely (minimum waiting, point-to-point journeys, sometimes able to travel faster than conventional vehicles) or because there are no appropriate alternatives. As a result, rural people appreciate this and value MTs high as they are fast [24] and readily available. Rural users hire the MTs for their journey by only waiting until one came by. Although, rural users often complain about the high costs of rural MTs, and say they prefer to use conventional (four-wheel) public buses or taxis when these are available [10]. The fares go up during rainy seasons as echoed by [9]. Howe [12] also noted that some riders were already using mobile telephones so that customers could summon them.

In certain parts of Rongo sub-County, some unmaintained roads were not wide enough for conducive car driving. The MTs provide a reliable, rapid, and relatively inexpensive transport service that can traverse dirt roads too rugged and/or narrow for a car while going longer distances and into steeper terrain. They are the only motorised transport services that people can rely on. For example, the villages surrounding the Kangeso Sub-location do not have any other public transportation option aside from the MT transport service. The convenient, easily available, and affordable means of transport is the MT which is more affordable and marches their purchasing power. In this study, MT fares have been varying especially according to the will of the transport drivers who in a situation of monopoly dictated their prices to the population that became a hostage of the situation. The fares vary depending on distance, time, locations, weather; day, or even location of approaching a MT rider for example on the road or at a stage. However, the user could bargain or search for another rider at a more reasonable price.

3.1.5 Safety Concerns

Data from observation revealed several safety concerns. The first was the practice of carrying two or more passengers, which appeared to be the norm, rather than the exception. This was corroborated by qualitative data from FGDs, which showed that in the study area, it is normal for MTs to carry two or more passengers. A FGD participant indicated:

"Sometimes it forces us to share the only available boda-boda [MT]... there are other times when children, people with disabilities and older persons are required to travel with their supporting persons (parents/helpers)." (Respondent 21, Male, Age 71).

Another FGD participant indicated that:

"I feel more secure when we are two or three people on one MT, especially at night. The riders, however, do not reduce the fares paid when they carry more than one passenger. They charge us per person." (Respondent 127, Female, Age 26).

Data from FGDs further revealed that in certain circumstances, rural people even considered it necessary for MTs to carry two or more passengers. One such circumstance arises when only one MT is available and there are two or more passengers. Another circumstance occurs when an adult need to travel with an infirm person such as a child, a sick person, or an elderly person who requires support or prop up on the MT. Some female passengers feel more secure when they outnumber the rider, especially at night. These findings explain why in many African, Asian, and Latin America countries, enforcement officials often hesitate to apply the 'one passenger' limit in rural areas. Contrary to [5] that fares may decrease by approximately 60% if a MT carries two passengers, qualitative data revealed that even though the price is negotiable, the cost rarely reduces significantly when there is more than one passenger.

Another observation regarding safety was that passengers rarely used safety helmets. FGDs revealed that many female pillions refused to use helmets, citing that it could interfere with their hairstyle. This was making them more vulnerable to head injury in the event of an accident. This study however observed that the residents including well-dressed ladies were sitting astride on the MT. This reduced the risk of the passenger being dislodged from the MT. In pillion accidents, passengers suffer a serious injury to their bodies. Key informant interviews also showed that many passengers refused to use reflectors as required by law. They argued that the reflectors were dirty and susceptible to skin disease transmission. This threatened the lives of both the rider and the passengers on board as they were not visible from afar, especially in the obscurity.

The study also found that drunk male pillion passengers posed a lot of challenges to the riders. The study could attribute this to the fact that some drunk pillion passengers even fall asleep while they are on the MT, and as such, they fall off the bike. This forced the riders to look for another rider to sit behind a drunk passenger. During the FGD for the male, it was reported that some intoxicated passengers turned out to be annoying, especially when they said they had paid while they had not. In some situations, they asked riders to fight so they could avoid paying for travel. Besides, the study observed that MT transported regular items such as foodstuffs, boxes, water to more unusual items such as furniture, construction materials (such as cement, roofing sheets, and steel reinforcements rods), farming tools, coffins, and human corpses. Sometimes the goods carried were more massive than the capacity of MTs hence causing accidents.

These findings are in line with related studies on MT safety. For example, [6] notes that in some countries, four or five people can be seen on a single MT, dangerously overloading the recommended limits on motorcycles for passengers. This is despite the law in most countries that only allows for one driver and one passenger [11]. The study findings are consistent with [25] who noted that in the Rural Community of Tombel, South-West Region Cameroon, the MTs transport of goods to and from the markets and farms in quantities heavier than their capacity. People also used these MTs in transporting uncommon items such as coffins and human corpses [25,26].

3.1.6 Motorcycle Taxi Users' Satisfaction

In assessing whether MTs are a problem or as a solution to rural public transport issues in Rongo sub-County, the users' satisfaction and perceptions are valuable especially because they are the main MTs customers. The users' satisfaction and perceptions could identify the MT's characteristics, performance, and potential for addressing rural public transport problems. The study required the respondents to rate their satisfaction with the MT transport service. Table 4 presents the findings.

Table 4: Motorcycle taxi users' satisfaction

Strongly Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	Total	Min.	Max.	Mean	Std. Dev.
24	33	56	143	33	289	1	5	3.44	1.098
8.3%	11.4%	19.4%	49.5%	11.4%	(100%)				

As stated in Table 4, the level of satisfaction with MT is slightly above average, with a mean of 3.44 on a scale of 0-5. Approximately two-thirds of the respondents (60.9%) were satisfied or very satisfied with MT. Only one-fifth of the respondents (19.7%) were strongly or otherwise dissatisfied with MT. This is a very interesting finding when seen together with qualitative data from FGDs. Whereas only one-fifth of the respondents expressed dissatisfaction with MT, qualitative data revealed that an overwhelming majority of the respondents perceive MTs as being recklessly ridden, by riders of questionable character. There was a consensus in all the FGDs, that MTs are an unsafe mode of transport, with a very high likelihood of involvement in accidents. The study attributed the perception that MT is affordable, convenient, and timesaving to the apparent contradiction. Rural people believe that MT riders are very well versed with different alternative routes and know most places, reducing the likelihood of getting lost, or wasting time asking for directions.

There was a variation in the responses by the respondents with standard deviation reaching 1 which is a testimony to the heterogeneity of the responses. This study compared the levels of satisfaction against respondents' gender and level of income to establish any underlying differences or influences. Figure 3 presents a comparison of the levels of satisfaction with gender while Figure 4 compares the satisfaction levels based on different levels of income.

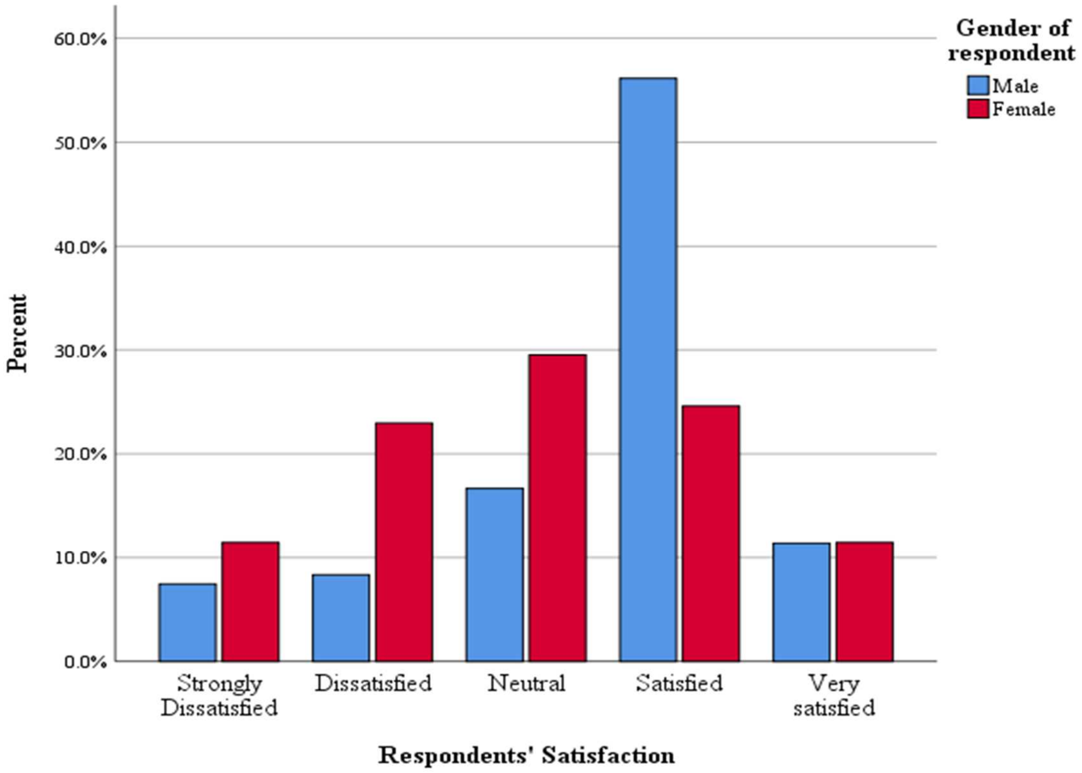

Figure 3 Respondents' level of satisfaction with MT, segregated by gender

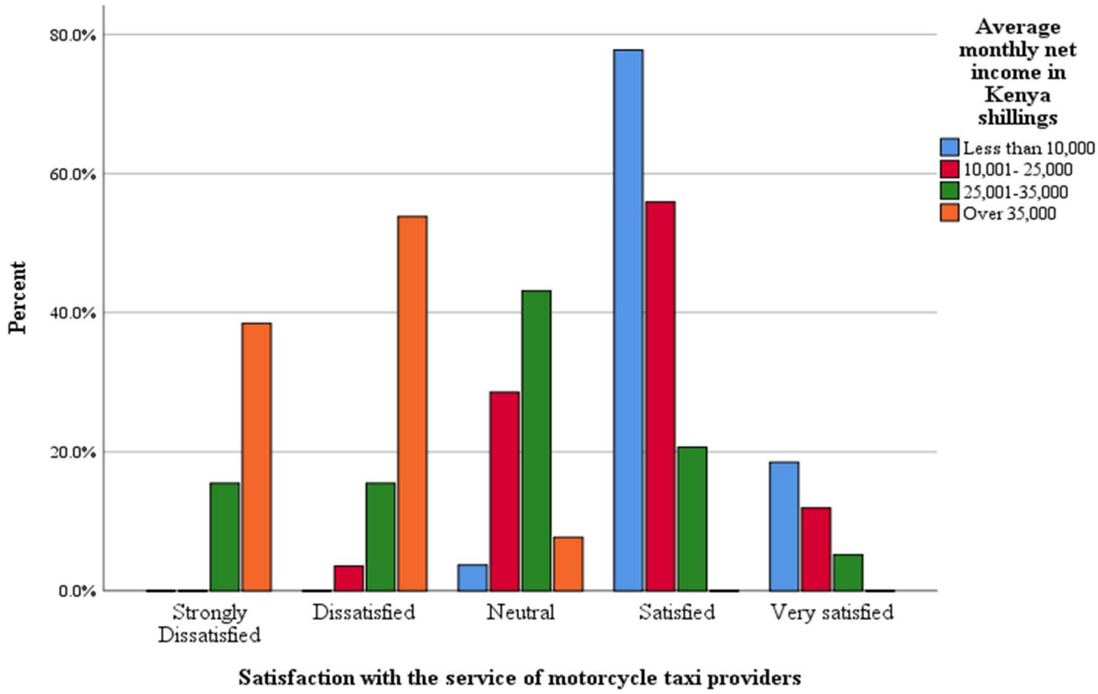

Figure 4 Motorcycle taxi services satisfaction level based on levels of income

Figure 3 reveals that male respondents were somewhat more satisfied with motorcycle taxi services than their female counterparts. Three gender themes emerged from FGDs. First, female respondents were more concerned about safety compared to their male counterparts. Second, female respondents appeared to be more taken aback by MT riders' perceived inappropriate behaviour than their male counterparts. Male respondents did not appear to find issues with the riders' behaviour, with some respondents even finding words of praise for the riders' apparent bravado. Third, male respondents consider MT to be affordable, as opposed to females, who find it expensive. This finding corresponds with the data in Table 5. Besides, Figure 4 shows that respondents with lower levels of income were more satisfied with motorcycle taxi services than respondents with high levels of income.

The findings are consistent with other studies on MT transport. For example, by 2001, on the Jos Plateau in Nigeria, more men than women patronised MTs. Despite safety issues associated with MTs, young women still saw MTs as a lifeline [27]. Zuure and Yiboe (2017) [28] noted that although the MT business posed a lot of risks to the youth riders, most of them were unwilling to stop the business because of the socio-economic benefits they obtained through it.

This study attributed the neutral stance by to the women's concern about MT safety risks while preferring them for their speed and convenience. It attributed the higher satisfaction level among the respondents with low levels of income to the lifestyle changes and improved income derived from MT transport. The lifestyle changes and improved income derived from MT include the low initial purchase cost, the low operating cost which relates to the superior fuel economy or efficiency of MTs in relation to cars, their relatively low maintenance cost and perhaps the most important in Kenya's context, is the employment opportunities it offers to our unemployed youths.

MTs dissatisfied respondents with high levels of income. This was largely attributed to the drivers' behaviour, and safety risks associated with MT transport. Thus, most respondents were satisfied with the MT services, largely because of the physical attributes of the MT, while negative reasons were mainly related to MT riders' mannerism, unprofessional driving, and poor safety.

Two household heads with comparable demographic backgrounds responded contrastingly about the affordability of MT transport. The first said: *"I do not use a motorcycle taxi because it is too expensive that I cannot afford"* (Respondent 127, Male, Age 35). In contrast, another respondent reported: *"Their prices are reasonable because... I mean, from physical observation, the poor man will travel using a MT"* (Respondent 21, Male, Age 35). Table 5 presents the affordability of motorcycle taxis based on gender and average family monthly income.

Table 5 Affordability of motorcycle taxi transport based on respondents' gender and levels of income

		Expensive		Affordable		Total	
Gender	Male	46	(15.9%)	184	(63.7%)	230	(79.6%)
	Female	44	(15.2%)	15	(5.2%)	59	(20.4%)
	Total	90	(31.1%)	199	(68.9%)	289	(100.0%)
Average family monthly income in Kshs.	Below 10,000	9	(3.1%)	99	(34.3%)	108	(37.4%)
	10,001-25,000	55	(19.0%)	29	(10.0%)	84	(29.1%)
	25,001-35,000	4	(1.4%)	54	(18.7%)	58	(20.1%)
	35,001 and above	22	(7.6%)	17	(5.9%)	39	(13.5%)
	Total	90	(31.1%)	199	(68.9%)	289	(100.0%)

Note: Kshs. 106.50 (Kenya) = $1.00 (Dollar)

Rural women have the largest financial restrictions for the use of transportation [28], and one would expect transport affordability to be a gender issue. This is supported by data in Table 5 which reveals that most of the male respondents consider MT to be affordable, compared to the majority of female respondents who regarded MT as expensive. Besides, this study reveals that the affordability of MT services was largely regarded as being very positive among the respondents with low levels of income, while some respondents with high levels of income considered MT as expensive. Majority of respondents with middle levels of income considered them affordable. The respondents' income levels probably did not influence their perceptions of the affordability of motorcycle taxi transport.

According to [12], those engaged in formal or informal sector wage employment seem likely to have enjoyed the enhancement of their income-earning activities through the greater mobility afforded by MT usage. Therefore, this study expected the levels of income to influence the MT users' perception of its affordability. However, the study findings have dispelled one of the commonly held illusions that levels of income influence perceptions on MT affordability. In this study, opinions on affordability hinge closer to the respondent's appreciation on lifestyle changes and the improved income derived from MTs, rather than on the levels of income.

4 Conclusion

The results show the active relationship between Rongo sub-County and MT transport services. The informal MT transport system seems to provide a partial solution to rural access. MTs offer useful transport services to rural communities difficult to reach by conventional (four-wheel) taxis or busses, due to the poor road condition and low demand. MT transport can complement many public transport systems. Removing MT from any part of the sub-county could impede the movement and operation of rural villages as its use is so closely linked to rural life.

This paper calls on transport practitioners to rethink the concept and image of sustainable rural mobility and identify with rural informal motorcycle taxi transport as well. Ultimately, the goal of mobility is to ensure that the informal MT transport system facilitates access to places, markets, facilities, and activities. For equitable, accessible and sustainable rural transport, the transport practitioners need to empower and expand on existing realities in rural areas. They should seek to understand rural transport needs and options from rural people of different ages, gender, occupation, and income.

This study bases itself on perception data; hence bias responses may affect results. Besides, the study does not cover how MTs contributes to social development in rural areas and perceptions of rural people on the social risks and adverse consequences of MTs in rural Kenya. These are scope for the future course of the research.

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ADJUSTING DIRECT DISTANCE TO ROAD FOR V4 COUNTRIES

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Abstract: This article describes the determination of the direct distance correction factor that reflects the actual density of the road network in V4 countries. V4 countries are the Czech Republic (CZ), Slovakia (SK), Poland (PL) and Hungary (HUN). No correction factors reflecting road density among major population places were still available for V4 countries. Three-level administrative classification and data from statistical offices concerning population density on 31 December 2017 was used. In MS-Excel was designed functions for obtaining coordinates of selected places and road distances using queries to Web Map Service Google Maps (WMS). Road distances obtained by queries represent the fastest connection on the road. The great-circle distance and spherical triangle were used to calculate direct distances from coordinates. The places were selected using ABC analysis based on the population sample and it was reduced so that the monthly limit of queries to WMS was not exceeded. The obtained values of correction factors can be used in vehicle routing. For the smallest classification items, in CZ, for 273 places with a population of over 5 000, the average values of the correction factor (k_{avg}) range between 1.277 and 1.326. In SK, for 245 places with a population of over 3 000, k_{avg} ranges between 1.424 and 1.446. In PL, for 376 places with a population of over 20 000, k_{avg} ranges between 1.206 and 1.285. Finally, in HUN, for 287 places with a population of over 5 000, k_{avg} ranges between 1.301 and 1.345.

1 Introduction

The design of an efficient distribution system is an important part of the modern concept of material flow management commonly referred to as supply chain management [1]. Supply chain management (SCM) is defined as a material, information and money flow planning in a network of mutually linked organizations that add value to goods and services intending to satisfy the end consumer´s needs [2]. Seen from the perspective of processes, SCM includes planning, purchase, production, and distribution [3].

The main goal of the distribution is to supply customers with the required goods of the required quality and promptly. Distribution is a link between production and customers [4]. When designing distribution systems, companies typically decide about the number and location of warehouses [5] and the way how goods are transported to customers from warehouses (i.e. vehicle routing) so that distribution costs are as low as possible while maintaining the required service level [6]. The service level is represented particularly with the lead time [7]. The trend in the current market environment is extreme customers' pressure on lead time shortening [8]. It is important to model the whole supply chain to satisfied customers´ requirements [9].

A wide range of model approaches can be used to deal with the issue of vehicle routing. For instance, literature mentions the use of tabu search heuristic [10], simulated annealing algorithm [11] and genetic algorithm [12]. Another very efficient algorithm is the savings heuristic [13] and its modifications for vehicle routing with restrictions such as time windows [14] or vehicle capacity [15, 16]. All these algorithms are very influenced by the fact, that the size of the optimization model which results from its formulation grows extremely rapidly as the number of customers increases [17]. Also, it is necessary to distinguish, if the distance or time should be optimized [16].

What is common for the application of the above-stated models in vehicle routing is the necessity to take into account the distances among warehouses and customers. Warehouses and customers are most often represented with an address that indicates their location. Having an address means that geographic coordinates may be obtained from a geographic information system (GIS), typically using queries to a web map service (WMS). GIS is an organized aggregate of information technology, software and geographic data that allows for efficient obtaining, storing, updating, analyzing, transferring and viewing all kinds of geographic information [18]. WMS works on the client-server principle and it allows for sharing geographic information in the form of grid maps on the Internet [19].

If coordinates indicating the location of warehouses and customers are available, the direct distances among them can be calculated using, for example, the great-circle distance and spherical triangle [20]. However, such distances do not reflect the actual density of transportation routes in the regions where distribution takes place and they lead to distribution costs distortion. Actual distances can be obtained in two following ways:

- WMS direct query at the actual distance between two places linked by some kind of transport route,
- adjustment of direct distance using the correction factor that reflects the actual density of the transport network.

A drawback of the first way is a frequent limitation of WMS to the number of queries that can be made within a certain time interval as well as the fact that when queries exceed a certain number, the service is usually charged for. If distribution routes among *n* places using the savings algorithm is designed that works with a matrix of distances consisting of *n* lines and *n* columns, presuming that a distance between two places is the same as the distance on the way back, in order to fill the matrix of distances it would be necessary to make such an amount of queries to WMS that corresponds with the sum of an arithmetic line where the first term equals 1, the last term equals *n-1* and the difference is 1. If it is taken into consideration the fact that distribution commonly occurs between hundreds of places and vehicle routing is often performed daily, such an amount of queries to WMS presents a big burden. By contrast, when using the other option, it suffices to obtain only *n* geographic coordinates through queries to WMS.

The objective of this paper is to determine the correction factor of direct distance that reflects the actual density of the road transport network in V4 countries. V4 countries are the Czech Republic (CZ), Slovakia (SK), Poland (PL) and Hungary (HUN).

2 Materials and Methods

Administrative classification of V4 countries in 3 levels (see Table 1) together with data from statistical offices of those countries concerning numbers of population in L_3 on 31 December 2017 were used to determine the correction factor of direct distance (*k*), there was used.

Table 1 Administrative classification of V4 countries used for determining k

Level / Country	CZ	SK	PL	HUN
L_1	kraj	kraj	województwo	megye
L_2	okres	okres	powiat	kistérség
L_3	obec	obec	gmina	település

L3 components are first arranged in MS Excel according to the size of population and an ABC analysis is performed for each country following the share of the population living in *L3* components of the total population of each country. Group A includes *L3* components that contribute to the total number of each country´s population with 80%, Group B includes another 15% and Group C the remaining 5%.

After conducting an ABC analysis, *L3* components with the highest number of the population are involved in the calculation of k so that the monthly limit of queries to WMS Google Maps for three unique API keys is not exceeded. WMS Google Maps is employed for obtaining coordinates and route distances. *L3* components included in k calculation are shown in Table 2.

Table 2 L3 components included for determining k and the size of the population living in them

Country	No. of L_3 components	Population in L_3 components
CZ	273	>5 000
SK	245	>3 000
PL	376	>20 000
HUN	287	>5 000

The share of L_3 components included in *k* calculation in CZ is approx. 61%, in SK and PL it is around 62% and in HUN it is approx. 68% of the country´s population. In all monitored countries, the selection only included L_3 components from Group A. These are generally places where supply and demand are concentrated and with community facilities such as shops and restaurants are better developed. That means that such places are interesting from the perspective of distribution.

"Function1" is created in MS Excel (see Appendix 1) that uses Google Maps API Geocoding as a platform to calculate coordinates. The platform was accessed in 1/2019. The argument of the function (i.e. Address) used is the following string:

Table 3 Function1 - argument address

Country	L_1	L_2	L_3	Address
CZ	Středočeský kraj	Kladno	Slaný	L3&", okres "&L2&", "&L1
SK	Košický	Trebišov	Sečovce	L3&", okres "&L2&", "&L1&" kraj"
PL	Kujawsko-pomorskie		Tuchola	L3&", "&L1&" województwo"
HUN	Somogy	Fonyódi	Balatonlelle	L3&", "&L2&", "&L1

For instance, for the L_3 component from Table 3, situated in CZ, Function1 returns string 50.2304622, 14.0869439. After splitting the string into a part indicating latitude and longitude and once they are transformed to a number, L_3 coordinates are plotted on the graph and visual check of their location is performed in the administrative classification of L_1 (see Table 4).

Table 4 Administrative classification of L1 components in V4 countries

No./Country	CZ	SK	PL	HUN
1	Jihočeský	Banskobystrický	Dolnośląskie	Bács-Kiskun
2	Jihomoravský	Bratislavský	Kujawsko-pomorskie	Baranya
3	Karlovarský	Košický	Łódzkie	Békés
4	Královéhradecký	Nitranský	Lubelskie	Borsod-Abaúj-Zemplén
5	Liberecký	Prešovský	Lubuskie	Budapest
6	Moravskoslezský	Trenčínský	Małopolskie	Csongrád
7	Olomoucký	Trnavský	Mazowieckie	Fejér
8	Pardubický	Žilinský	Opolskie	Győr-Moson-Sopron
9	Plzeňský	x	Podkarpackie	Hajdú-Bihar
10	Praha	x	Podlaskie	Heves
11	Středočeský	x	Pomorskie	Jász-Nagykun-Szolnok
12	Ústecký	x	Śląskie	Komárom-Esztergom
13	Vysočina	x	Świętokrzyskie	Nógrád
14	Zlínský	x	Warmińsko-mazurskie	Pest
15	X	x	Wielkopolskie	Somogy
16	X	x	Zachodniopomorskie	Szabolcs-Szatmár-Bereg
17	X	x	X	Tolna
18	X	x	X	Vas
19	X	x	X	Veszprém
20	X	x	X	Zala

Direct distance D_1 between two L_3 components is always determined in MS Excel for two locations with a higher and lower number of the population using the following formula (1):

$$=6378{,}135*ARCCOS(COS(RADIANS(90-(x_2)))*COS(RADIANS(90-(x_1)))+SIN(RADIANS(90-(x_2)))*SIN(RADIANS(90-(x_1)))*COS(RADIANS((y_2-y_1)))), \quad (1)$$

where x_1 and y_1 are latitude and longitude of the location with higher number of population; x_2 and y_2 are latitude and longitude of the location with lower number of population.

In the case of CZ 37 128 direct distances are calculated, for SK it is 29 890, for PL 70 500, and for HUN 41 041.

"Function2" is created in MS Excel (see Appendix 2) that uses Google Maps API Directions as a platform to calculate the route distance D2 between two L3 components. Same as in the case of obtaining L_3 coordinates, the API Directions platform was accessed in 1/2019. The arguments of the function (i.e. Origin and Destination) used are strings in the form coming from Function1. Thanks to that, direct as well as route distances correspond with places of the same coordinates. Achieved D_2 represents the fastest route between two L_3 components on the road. That means that L_3 connection using motorways and main roads is preferred when queries are made to API Directions.

The direct distance correction factor when calculating road distance is defined for two L_3 components in the following way (2):

$$k = D2 / D1 \quad (2)$$

For each country, values of correction factors are arranged in a matrix, grouped according to the minimum number of population living in the L_3 components and averaged.

3 Results and Discussion

Table 5 shows the results of the ABC analysis by the share of the population living in L_3 components of the total population of each country.

Table 5 ABC analysis by the share of population living in L3 components of the total population of each country

		L_3 components in the group			
Group	**Group population/Country´s population**	**CZ**	**SK**	**PL**	**HUN**
A	80%	1 213	805	938	679
B	15%	2 474	1 075	899	1 142
C	5%	2 571	1 009	491	1 324
Total L_3 components in country		6 258	2 889	2 328	3 145

In CZ, 80% of the population lives in 1 213 L_3 components, which is approx. 19% of the total L_3 components in the administrative classification used. In SK, the same goes for 805 L_3 components with approx. 28%, in PL, it is 938 with approx. 40% and in HUN, it is 679 L_3 components with approx. 22% of the total number of L_3 components. In CZ, SK, and HUN the results of the ABC analysis are in line, to a great degree, with the Pareto principle (the 80/20 rule). In PL, the great number of municipalities classified in Group A is due to L_3 administrative classification when certain L_3 components unify populations of administrative centers and their related municipalities in the vicinity into one.

L_3 coordinates from Group A included in *k* calculation are plotted in graphs in Fig. 1 – 4.

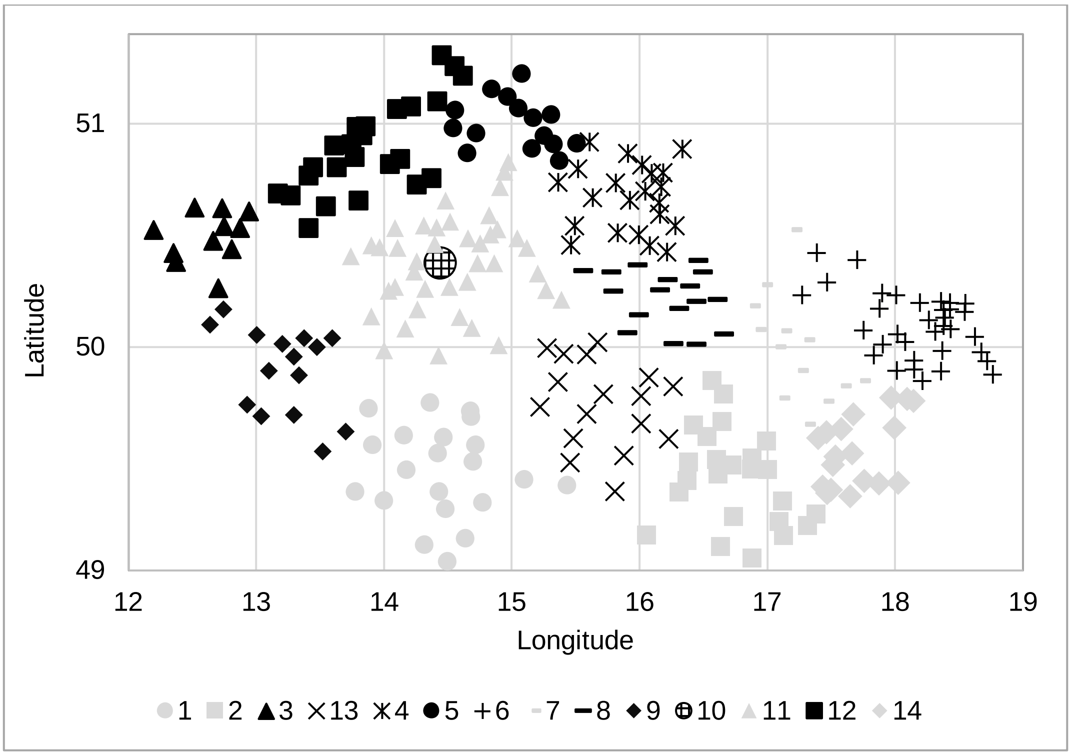

Figure 1 Location of L3 included in k calculation in L1 - CZ

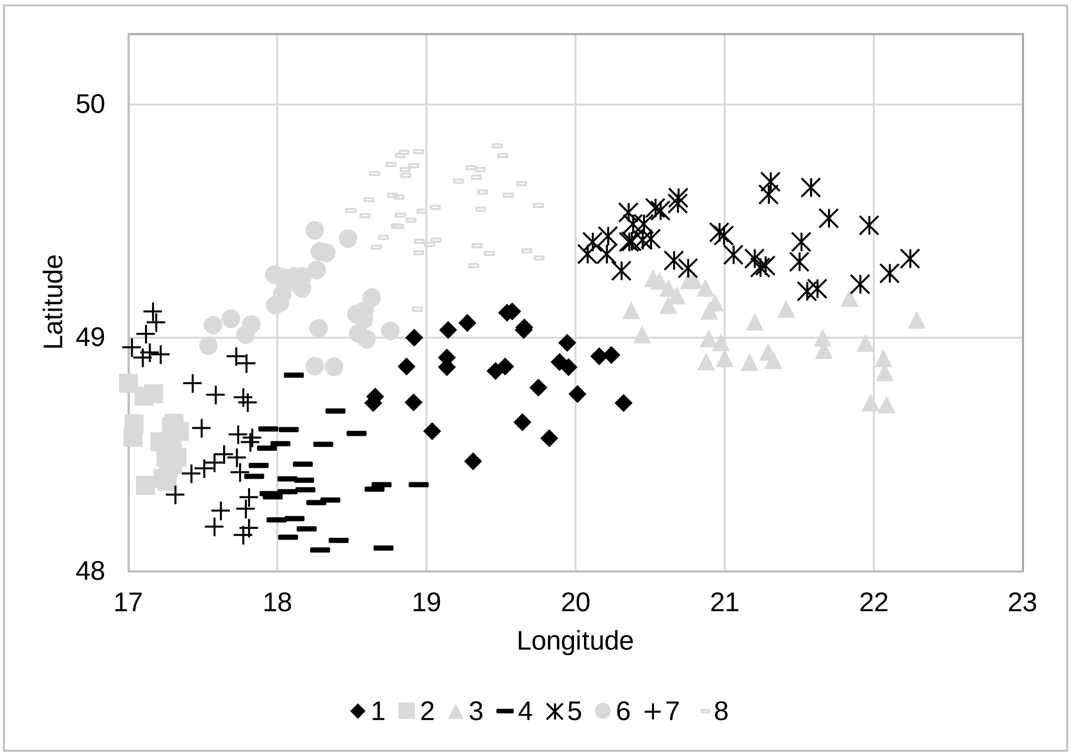

Figure 2 Location of L3 included in k calculation in L1 – SK

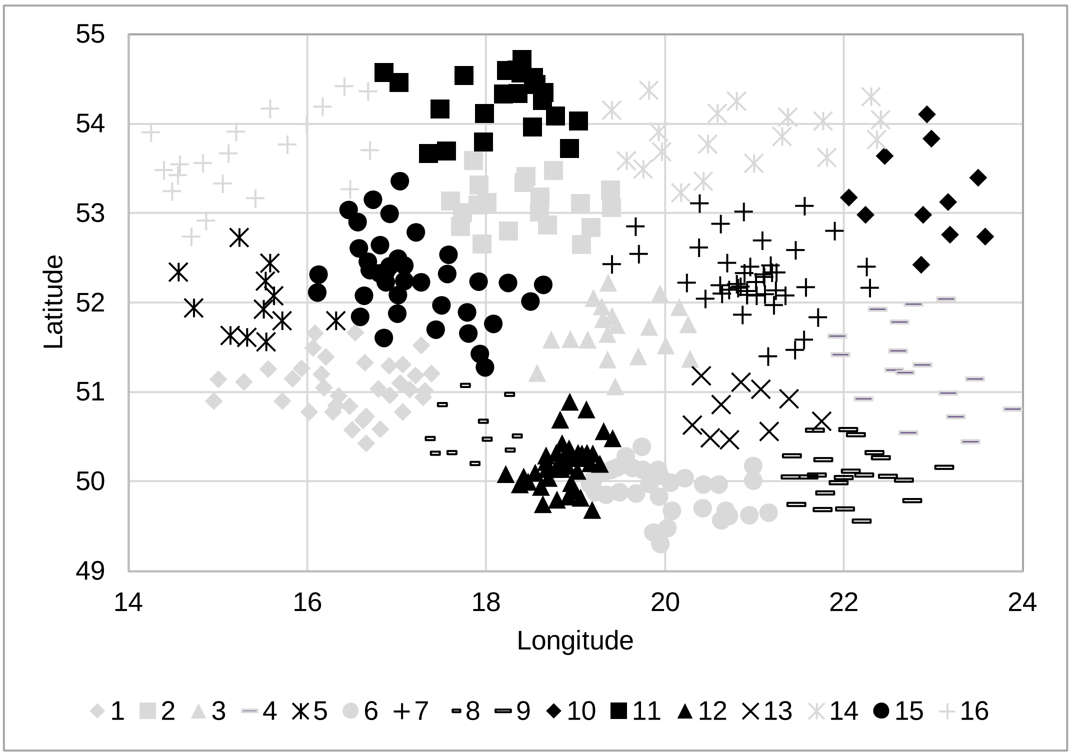

Figure 3 Location of L3 included in k calculation in L1 – PL

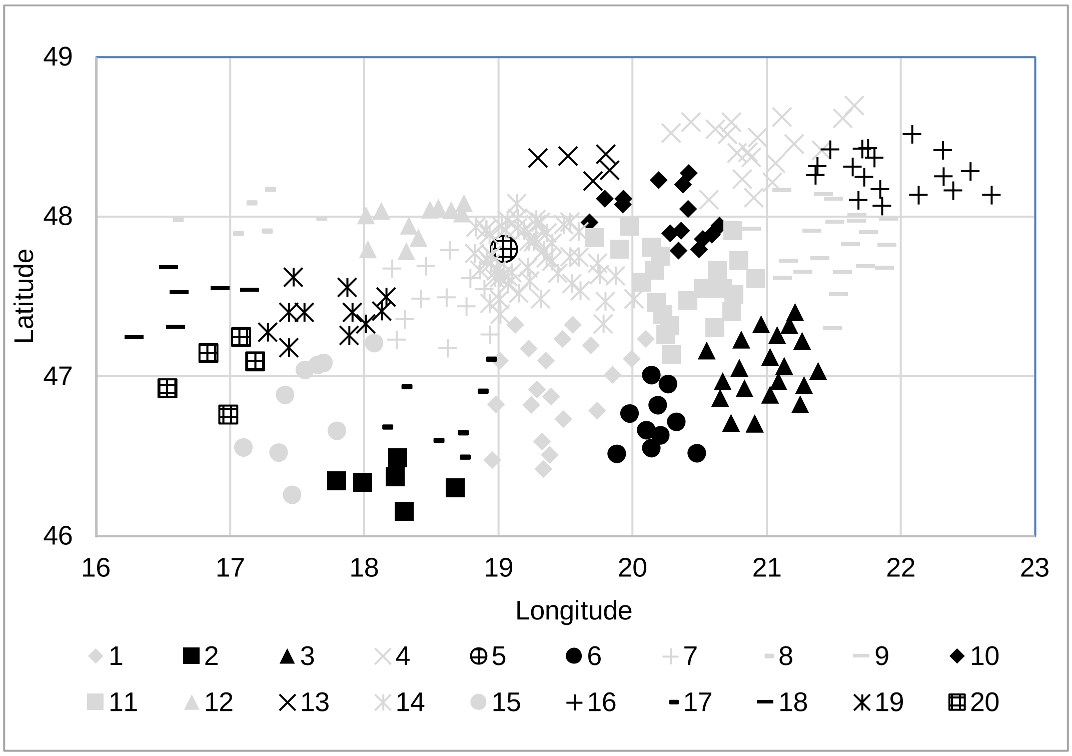

Figure 4 Location of L3 included in k calculation in L1 - HUN

It is important to note that L_3 components included in *k* calculation are only a part of Group A (see Table 2), which is due to the existence of a limited number of queries concerning coordinates and route distances of used WMS. In all the countries placement of L_3 within L_1 forms a compact area, while points mark L_3 locations, from two different L_1 components they only overlap at the frontier of L_1. Locations of L_1 components correspond with the actual locations of such administrative units in the real map and in the general view, they correspond with the actual shape of the countries.

Average values of correction factors for L_3 groups that differ with the minimum number of population living in L_3 components are shown in Table 6.

Table 6 Average k values for L3 groups differing with the minimum population living in L3 components

Country	**CZ**		**SK**		**PL**		**HUN**	
Population in L_3	No. of L_3	k_{avg}	No. of L_3	k_{avg}	No. of L_3	k_{avg}	No. of L_3	k_{avg}
>= 500 000	x	x	x	x	5	1.206	x	x
>= 250 000	x	x	x	x	11	1.231	x	x
>= 100 000	6	1.277	2	1.446	41	1.257	9	1.324
>= 50 000	18	1.322	10	1.428	111	1.275	21	1.301
>= 20 000	62	1.326	38	1.427	376	1.285	61	1.326
> =10 000	131	1.319	72	1.430	x	x	141	1.334
>= 7 000	190	1.323	97	1.425	x	x	202	1.343
>= 5 000	273	1.325	135	1.424	x	x	287	1.345
>= 3 000	x	x	245	1.426	x	x	x	x

In CZ, the average values of the correction factor (k_{avg}) range between 1.277 and 1.326. In SK, the k_{avg} values are between 1.424 and 1.446. In PL, the k_{avg} values are between 1.206 and 1.285, while in HUN the k_{avg} values they are between 1.301 and 1.345.

In CZ, PL, and HUN, the value grows together with the increasing number of L_3 components included in k_{avg} calculation (i.e. with the decreasing minimum number of population living in L_3). In SK, the trend is quite opposite, which is due to the mountainous landscape in the central part with only one backbone road connecting L_3 in the west and in the east that goes around the mountains and concentration of L_3 components with a higher number of population in the western part of the country.

The biggest difference between the route distance between L_3 with a higher and lower population as compared with direct distance (i.e. the difference given by the minimum and maximum k_{avg} value) is in PL (approx. 8%), followed by CZ (approx. 5%), HUN (approx. 4%), the difference in SK is very small (approx. 2%).

4 Conclusions

The objective of this article was to determine the correction factor of direct distance that reflects the actual density of the road network in V4 countries (the Czech Republic, Hungary, Poland, and Slovakia). The obtained values of correction factors correspond with the state of road networks in maps provided by WMS Google Maps in 1/2019. These values can be used for vehicle routing under the following assumptions:

1. Goods are distributed by vehicles in the road network.
2. Customers demanding goods are at locations with a population of more than 3 000 (in SK), 5 000 (in CZ and HUN) and 20 000 (in PL).
3. Locations, where demand is concentrated, are scattered all over the country. Therefore, goods are not distributed, for instance, exclusively (or predominantly) in the capital city or in a relatively small region where actual distances may be distorted by the presence of natural obstacles such as mountains or great rivers.
4. When designing the distribution route, the fastest connection is preferred, which means that motorways and/or main roads without the risk of free passage restriction for vehicles exceeding certain weight are primarily used.

Obtained correction factors can be primarily used on a strategic level to support decisions about distribution system (re)design based on historical demand data. By reducing the time necessary to calculate distances between the places with a demand it is possible to assess many different varieties of a distribution system structure design (i.e. appropriate number and a location of warehouses and a strategy of supplying the customers) in a short time. On the other hand, the usage of correction factors as a part of vehicle routing for operative planning can lead to the estimation of distances that is too optimistic. That is because of not considering real-time traffic data about rush hours or road closures or including the places of demand with a very small population.

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Review process
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Appendix 1

```
Function Function1(Address As String) As String
 Dim Request As New XMLHTTP60
 Dim Results As New DOMDocument60
 Dim StatusNode As IXMLDOMNode
 Dim LatitudeNode As IXMLDOMNode
 Dim LongitudeNode As IXMLDOMNode
  On Error GoTo exit
    Request.Open "GET", "https://maps.googleapis.com/maps/api/geocode/xml?" _
    & "&address=" & Application.EncodeURL(Address) & "&key=A*zaS*DQ**y***lPX3u****y7ogt*J1**u*k9*", False
    Request.send
    Results.LoadXML Request.responseText
    Set LatitudeNode = Results.SelectSingleNode("//result/geometry/location/lat")
    Set LongitudeNode = Results.SelectSingleNode("//result/geometry/location/lng")
    Function1 = LatitudeNode.Text & ", " & LongitudeNode.Text
exit:
 Set StatusNode = Nothing
 Set LatitudeNode = Nothing
 Set LongitudeNode = Nothing
 Set Results = Nothing
 Set Request = Nothing
End Function
```

Appendix 2

```
Function Function2(Origin As String, Destination As String) As Double
 Dim myRequest As XMLHTTP60
```

```
 Dim myDomDoc As DOMDocument60
 Dim distanceNode As IXMLDOMNode
  On Error GoTo exit
   Origin = WorksheetFunction.EncodeURL(Origin)
   Destination = WorksheetFunction.EncodeURL(Destination)
   Set myRequest = New XMLHTTP60
    myRequest.Open "GET", "https://maps.googleapis.com/maps/api/directions/xml?" _
    & "&origin=" & Origin & "&destination=" & Destination & "&sensor=false" &
"&key=A*zaS*DQ**y***lPX3u****y7ogt*J1**u*k9*", False
    myRequest.send
   Set myDomDoc = New DOMDocument60
    myDomDoc.LoadXML myRequest.responseText
   Set distanceNode = myDomDoc.SelectSingleNode("//leg/distance/value")
    If Not distanceNode Is Nothing Then Function2 = distanceNode.Text / 1000
exit:
 Set distanceNode = Nothing
 Set myDomDoc = Nothing
 Set myRequest = Nothing
End Function
```

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TRACEABILITY IN INDUSTRY 4.0: A CASE STUDY IN THE METAL-MECHANICAL SECTOR

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Keywords: smart assets, GPS, technologies, logistics, supply chain
Abstract: With the emergence of production systems characterized by Industry 4.0 technologies, asset traceability problems have become more relevant at different echelons of the supply chain. The management of intelligent assets promoted by Industry 4.0 is considered as a process that, in addition to collecting information, allows tracking and ensuring the security of assets. This article shows various technologies for traceability and asset monitoring, from the perspective of Industry 4.0. Through a case study in the metal mechanical industry, the solutions and benefits offered by the implementation of technologies based on RFID and GPS were analysed. With this proposal, it was possible to respond to the problem of the control and monitoring of welding equipment inside and outside the company. An automatic update of the locations was also achieved, through the use of GPS. The company estimates that with this implementation levels of reliability in the inventory close to 99% can be obtained, which would lead to guarantee the traceability of the assets.

1 Introduction

The incorporation of new information and communication technologies to transform aspects related to the design of production systems, manufacturing, storage, and logistics are some of the current trends in Industry 4.0 and intelligent manufacturing. To achieve an advantage in the market and ensure an adequate level of customer service, companies have used a set of technological tools to optimize different processes such as production, human resources, finance, information management, research and development, sales and logistics, maintenance, environment, security, design, project management, and asset management [1]. In the manufacturing sector, it is where technology-based applications mainly allow companies to stay and position themselves in increasingly competitive markets, providing innovative solutions to the different challenges they face throughout the supply chain.

Obtaining real-time information generated systematically through technologies for traceability has been one of the key factors for the digital transformation of the industry, boosting global competition and innovation of supply chains [2,3]. Due to the emergence of highly automated production processes and cyber-physical production systems in manufacturing operations in Industry 4.0, asset traceability problems have become more relevant at different stages of the supply chain, impacting not only in companies that traditionally perform highly regulated operations such as the pharmaceutical, aerospace and automotive sector.

Asset management has become a critical activity in organizations that share assets between their own companies or facilities, that is, a company that has several facilities within a region can share equipment or tools to perform different production processes in different locations. Mismanagement of assets, such as raw material and/or equipment, can hamper the quality of the product or cause the loss or theft of equipment. However, with the use of new technologies in Industry 4.0, these problems can be solved, to manage assets efficiently and advanced, as well as provide real-time data [4].

Technologies in Industry 4.0 play an important character in handling the flow of products and assets throughout the supply chain. Big data, the Internet of Things, and tag-based technologies for Radio Frequency Identification (RFID) allow us to share information on inventory levels, order policies, and forecasts of future demands, thus effectively communicating requirements throughout the supply chain. These internet-based technologies, connected with physical environments (machinery, equipment, mechanisms, among others), generate the so-called cyber-physical systems (CPS) which are the main foundation of Industry 4.0. Fernandez-Carames et al. [5] also mention that these technologies promote horizontal integration of the supply chain, dynamically determining supply needs efficiently and in real-time, mainly between suppliers and manufacturers. The objective of this article is to show some technologies for asset traceability, from the perspective of Industry 4.0. Through a case study in the metal mechanical industry, the solutions and benefits offered by the implementation of technologies based on RFID and GPS were analysed. The hypothesis for this study was that with the implementation of technologies for traceability it is possible to significantly improve the levels of inventory reliability.

1.1 Asset Administration

Pittman and Atwater [6] through the APICS dictionary defines an asset as: "any resource owned by a company, whether tangible (cash, machinery, equipment, and inventories) or intangible (patents, software or licenses)". The ISO 55000 standard generalizes an asset as "an element, a thing or entity that has potential or real value for an organization". On the other hand, the British Standard Institute defines in BSI PAS 55-1, the term "active" as "machinery, property, buildings, vehicles and other items, and related systems that have a different and quantifiable commercial function or service" [7].

Asset management is described as a set of activities to achieve a specific business or organizational objective, which includes the identification, maintenance, and renewal of assets [8]. The British Standards Institute defines asset management as "the systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets, its performance, risks, and associated expenses throughout its life cycle with to achieve its strategic organizational plan" [7]. Maletič et. al [9] points out that asset management is also essential, especially for companies where their assets are the basis of their success. According to Hastings [10], asset management also involves the use of information technology-based systems to offer efficient visibility and control for the identification of equipment, locations, and monitoring of activities throughout the organization. Inventory management, sourcing and purchasing, cost estimation, maintenance routines, financial reports, and work processes are some of the main applications of information systems for asset management.

Lima and Costa [11] mentions that asset management is based on four fundamentals or principles that translate into continuous actions such as 1) focus on the value that the asset can deliver to the organization (value); 2) transform strategic decisions into technical, economic and financial decisions (alignment); 3) strengthen the implementation, operation and improvement of asset management within the organization (leadership); and 4) be confident that the assets will achieve their essential objective (assurance). In the environment of Industry 4.0, the transformation has been promoted towards the so-called "intelligent asset management", with the purpose of monitoring and tracking physical assets anywhere, by including technologies such as RFID or GPS tags to transform assets physicists in "intelligent assets". Nel and Jooste [12] indicate that intelligent asset management emphasizes the notion of technological processes to improve the collection and processing of information, in support of strategic decision making. The digitalization of the assets allows, in turn, the increase of the value of these for the organization. In the research carried out by Nel and Jooste [12], they point out that intelligent asset management is the integration between physical and virtual media that organizations use innovatively, to improve the management of their assets.

1.2 Traceability in Industry 4.0

The growing demand for highly customized products is a factor present in the fourth industrial revolution, directly impacting the different stages of the supply chain, which implies more flexible production systems and shorter product life cycles. To meet these requirements, CPS is applied to interconnect and self-manage production processes in an "intelligent factory" environment that incorporates external and internal conditions for autonomous adaptation for the benefit of optimizing these processes [13]. In the intelligent factory, the flow of bidirectional information between all components such as machines, products, control programs, and assets is understood through traceability.

Technology and systems for traceability are the main support for monitoring products within Industry 4.0. The concept of traceability according to ISO 8402 and ISO 9000 refers to the ability to track the history, application or location of an entity through registered identifications. Bougdira et al. [14] also mentions that due to the properties and characteristics of Industry 4.0, traceability should be considered as an intelligent process to register, identify and collect data in the different processes throughout the supply chain to recover the information, not only to track but also to ensure the security of the (active) objects within their environment. The information provided by the technology for traceability may include location, speed, acceleration, temperature, humidity, product information (price, dimensional information, physical characteristics, among others), as well as physical and physical condition. characteristics of the means of transport used for logistics [3].

Bar codes and global positioning systems (GPS) are some of the first technologies used for traceability and tracking. According to Halawa et. at [15], other technologies that are commonly used for tracking and location are Ultra Wide Band, radio frequency identification systems, and Wi-Fi vision and technology systems.

With the development of information systems and new concepts on CPS combined with the Internet of Things (IoT) and cloud computing, innovative technologies have been promoted for traceability among which are: wireless networks, identification by radiofrequency and smart tags. In general, these technologies aim to provide real-time information for traceability and product tracking [4].

Table 1 shows some technologies for traceability and applications of these in different sectors such as construction, medical equipment, and the education sector [16-19]. RFID, GPS, IoT, Cloud Computing, and Big Data are common technologies for asset management and identification.

Table 1 Traceability technologies

Source	Technology for traceability	Application / Tracked Object
[16]	RFID	Construction sector
[14]	Cloud computing Big data GPS	Not specified
[4]	Internet of things	Health sector
[17]	RFID Internet of things	Educational sector
[15]	RFID	Not specified
[18]	RFID	Health sector
[19]	GPS sensors	Construction sector

In the review of concepts and trends in Industry 4.0 by the authors Ben-Daya et al. [20], also indicate as technologies related to traceability to RFID, IoT and Big Data tags. The IoT applied to traceability in the supply chain, arose from the evolution of information and communication technologies that have been used for object tracking.

IoT refers to global networks in which several objects are integrated with electronic sensors, actuators, or other digital devices to collect and exchange data [21]. Ben-Daya et al. [20] also mention that IoT is a network of physical objects that are digitally connected to identify, track, and interact within a company and its supply chain, allowing visibility, monitoring, and information exchange. The main characteristics of the IoT that favour traceability in the supply chain are: (1) intelligent manufacturing systems, (2) real-time data acquisition, and (3) real-time visibility of production processes. Lee and Lee [22] identify IoT, wireless sensor networks (WSN), cloud computing, and RFID, as key technologies for IoT.

Besides, RFID tags are also considered as one of the most advanced technologies for supply chain traceability, influencing most of the industry, specifically impacting manufacturing sectors. Unlike barcode scanners, RFID generated data can be read at a distance of up to several meters [18]. RFID technology is widely used in the intelligent identification of assets so that they can connect and interact with each other through specific forms of interconnectivity [21]. RFID identification devices are labels or bar codes that are increasingly associated with systems for asset management. Systems for asset management based on architectures such as IoT are developed to track the products attached with the labels, which contain all the necessary information for traceability [15, 23].

Other technologies used by logistics companies, with information and data flow processes, are Real-Time Location Systems (RTLS). RTLS has properties for object identification, like those offered by RFID systems. Unlike RFID, RTLS enables continuous label localization in a space with an accuracy of up to 15 cm in supervised areas [24].

In this context, RFID technology is a key element for asset management due to its ability to integrate CPS, connecting objects in the physical world with their representations in information systems [12]. For example, among the applications of this technology for traceability, Bisio et al. [16] propose an original architecture designed to manage and track assets within construction sites, where they integrate a classic radio frequency (RFID) tracking solution, Bluetooth low energy tags and smartphones.

Finally, the preponderant technologies for traceability is Big data. Big data is a term that refers to a large amount of data, which exceeds the capacity of conventional software. In the context of Industry 4.0, data collection is the first step towards a comprehensive analysis of smart asset management. For example, in the manufacturing sector, Big data is used to obtain information to understand customer requirements and improve the user experience [25]. In asset management, Big Data in conjunction with IoT offer great opportunities, but also great challenges, for example, in terms of data exchange [8, 26].

2 Methodology

The company in which this case study was conducted is a company in the mechanical metal sector focused on the manufacture of mass cargo transportation for the railway industry, which has manufacturing centres located in Mexico and different countries. At the international level, the railway industry is characterized by technical, organizational, and operational complexity. Technological progress for rolling stock, as well as infrastructure and increased capacity utilization, are some of the challenges facing the railway industry [27].

In Mexico, the supply chain of this company consists of national and international suppliers that deliver different inputs and materials (steels, welding, and special parts) for production. Some of the assemblies that are required within their production process, due to capacity and manufacturing times, are made outside the company.

One of the improvement issues that this manufacturing company has is the proper management of its assets. The reliability and traceability of assets are determining factors for the company's performance indicators. Because this company is under a projected organization, that is, production plans and programs are executed based on projects; Asset reliability levels are a vital element to ensure the proper administration and planning of inventories and assets that are required for the execution of a specific project. Particularly, welding equipment used in most production processes is one of the assets with the highest economic and strategic value for the business. The welding processes that are carried out with these assets represent 90% of the total production operations in the company, being the most relevant processes executed with MIG (Metal Inert Gas) welding.

A welding equipment consists of two basic elements: (1) a source, which has the function of generating energy, and (2) a feeder, which is used to initiate and maintain the arc between the wire and the base metal. The company owns about 1,000 welding equipment, with an average cost per team of USD 6,000, which presents a considerable investment in this type of assets. Welding equipment is distributed in two types of locations depending on the manufacturing processes, (1) internal locations, corresponding to the work positions along the different production lines, and (2) external locations corresponding to warehouses both own and suppliers, where special manufacturing processes are performed.

Due to outsourcing operations and in compliance with the quality requirements in the processes, the company has 31% of its welding equipment outside its facilities, that is, in external locations. Thus, the fact that the assets are in different internal and external locations, has caused problems for the traceability of inventories in this company. As shown in Figure 1, the process in which the welding equipment interacts starts at the request of the manufacturing department, which makes a requisition for the movement of the welding equipment to the previously planned external or internal locations.

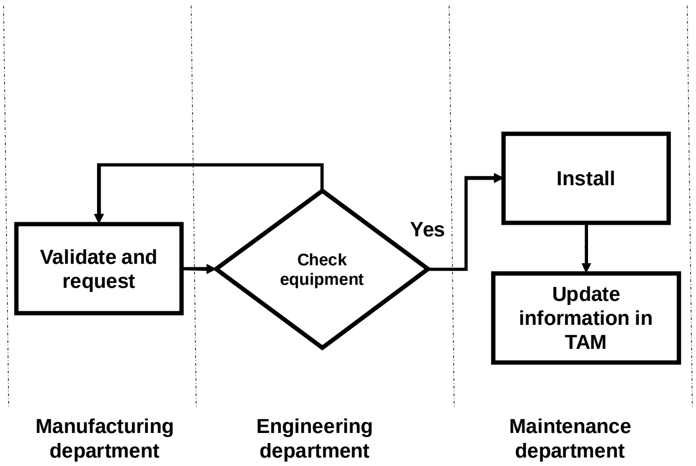

Figure 1 Welding equipment application process

Subsequently, the welding engineering department validates that said equipment has the necessary technical characteristics for the assigned process and simultaneously generates the service request with which the maintenance department performs the corresponding installation. Once the installation of the equipment is completed, the same maintenance area updates the location of said asset through the Tool & Asset Manager (TAM) application. The TAM is an asset management tool, which allows the use of barcode readers and RFID tags, to identify and traceability of company assets [28].

The main function of the TAM in the company is the control of assets, such as tools, hydraulic equipment, communication equipment, power tools, and welding equipment. This application allows to manage and know the traceability, as well as the amount of tools and equipment that the company has, in addition to helping to determine the status of the same (new, in use, with failures, in repair, obsolete, with report of theft, in calibration, among others). The information collected by the TAM serves as a support in the decision-making process for the acquisition of equipment and tools for future projects, optimizing current resources. One of the restrictions of the TAM, is that the information mainly obtained from external locations, involves manually updating the databases by company personnel. In addition to the above, the continuous change of location of the assets and the lack of traceability in the external locations caused that in some projects there were more welding equipment than necessary, while in other projects they would be unable to comply with the production due to the lack of such equipment.

As a sequence of this problem, the loss and loss of welding equipment, positioned the company at a 77% level of reliability in its inventories. Also, the economic impact was estimated, contrasting the theoretical inventories declared in the TAM system and the physical inventories, obtaining losses calculated for about 1.4 million dollars.

3 Result and discussion

The company evaluated different solutions for asset control based on strategies for identifying procedures and software applied to inventory traceability. However, these strategies proved to be ineffective, mainly due to the uncertainty in updating databases in external locations.

Subsequently, the company evaluated alternatives with Industry 4.0 technologies. RFID was the initial proposal because this technology is one of the most prolific for traceability in the supply chain. However, due to the movements of assets in locations outside the company, GPS technology was also evaluated, which is suitable in external environments.

The alternatives with RFID and GPS were evaluated, considering in each case the positive and negative attributes, as shown in Table 2.

Table 2 Attributes of the technologies analysed

	RFID		GPS
	Passive	Active	
Indoor operation	Yes	Yes	No
Visibility in areas outside the company	No	No	Yes
Two-way communication	No	Yes	No
Tag size	3 mm - 50 mm	50 mm - 150 mm	50mm - 150 mm
Reading range	0 m - 3 m	0 - 30 m	0 m - 20,500 km
Battery life	-	Long	Long
Infrastructure cost	Medium	High	Medium
Maintenance cost	Low	Medium	Medium
Operating cost	Low	Medium	Low
Operating frequency	50 Khz - 2.5 GHz		1.5 Ghz - 2.7 Ghz

Specifically, in the configuration of the traceability information system, the organization followed a procedure based on (1) selection of network technology according to the needs of the company, (2) the development of engineering for its operation, which included aspects such as the placement of devices and sensors in welding equipment subject to traceability and (3) the evaluation of the development necessary for the data management system, including aspects such as communication infrastructure and interface of users. This study considered factors such as accuracy, accessibility, line of sight, wireless communication, data storage, and power supply.

Finally, after an agreed analysis and considering the need for visibility of assets in external locations as preponderant, the company selected GPS technology as a solution proposal. The proposal included a GPS model with the company's operating requirements, under the following characteristics: (1) two GPS check-In per day, (2) LTE-M connectivity, (3) offline storage, (4) SSL-protected Internet connectivity with 256-bit AES encryption and (5) 5-year battery life.

The implementation of these GPS-based technologies confirms that smart technologies have high potential, mainly for asset management. According to Nel and Jooste [12], it has been shown that the use of asset data analysis facilitates the management of their performance, so there is a need to create technological platforms that allow obtaining consistent and real-time information to Informed decision making. By implementing the proposal with GPS systems for external locations, the control and monitoring of the company's welding equipment were improved. Automatic updating of locations was also achieved, through the use of this technology. The company estimates that with this implementation you can obtain levels of reliability in the inventory close to 99%, which would lead to decrease equipment losses, generating savings on an annual average of 553, 634 USD.

Other particular benefits achieved with this proposal were: (1) improvement in the efficiency for data collection of equipment (quantity and location), (2) increase in the reliability of the inventory of welding equipment and (3) improvements in access of the complete history of the movements of the teams, such as dates, times, locations among others.

The integration of GPS technology with the RFID-based TAM system allows traceability in locations inside and outside the company, in addition to ensuring real-time inventory reliability. Keeping asset locations updated was also one of the benefits achieved through this proposal.

4 Conclusions

Considering that "it can only be understood, what can be measured", technology-based traceability is a key tool that supports and provides a global vision throughout the processes of the supply chain. Currently, Industry 4.0 demands a higher priority for traceability even among the most conventional companies. CPS in industrial operations requires innovative technologies that allow efficient production, in a sustained supply chain, and completely connected to its different processes, from supply to the final customer.

Industry 4.0 also requires the identification and location of assets within the supply chain instantaneously to obtain information on their origin, storage**,** and status. Monitoring the current status of an asset through traceability technology allows **us to** provide the necessary tools for operational analysis, proposing more efficient routes and production processes. The balance in the use of technologies, for the traceability with the systems of administration of supplies, inventories**,** and finished products, arise**s** as a response to the constant variations in customer demands. RFID, GPS**,** and RTLS are tools that are used in logistics, affecting the improvement in visibility, security**,** and risk reduction throughout the supply chain.

As was shown in the case study studied in this article, through the implementation of traceability technology such as GPS, it is possible to ensure the reliability of inventories and at the same time reduce the losses associated with the lack of visibility of assets along the supply chain. The use of massive data of GPS positions, in the assets of the company, also allowed to detect bottlenecks, achieving greater efficiency in logistics operations.

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AUTONOMOUS MOBILE ROBOT TECHNOLOGY FOR SUPPLYING ASSEMBLY LINES IN THE AUTOMOTIVE INDUSTRY

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Keywords: autonomous mobile robot, automated guided vehicle, assembly line supply, automotive industry, material handling

Abstract: The ever-increasing customization and differentiation of the product portfolio and the shorter life cycle of products and technologies in the automotive industry lead to the development of flexible and convertible manufacturing and logistics technologies and systems at all stages of car production. In the field of supplying assembly lines in the automotive industry, such technologies are based on Autonomous Mobile Robots (AMRs). The aim of this paper is to create a comprehensive knowledge base for design, selection and implementation of AMR technology in the form of unit load carriers for supplying assembly line in the automotive industry. The outputs of the article are based on a case study aimed at assessing the feasibility of introducing AMR technology for supplying car assembly line parts with irregular consumption. The article presents a general procedure for feasibility study of the project of AMR assembly line supply and a comprehensive set of recommendations divided into five key categories: Technology, Management, Economics, Capacity, and Vendors.

1 Introduction

The trend in the current automotive industry is the increasing customization and differentiation of the product portfolio as well as the ever-shorter life cycle of products and technologies. This is a consequence of growing customer demands in a globalized and highly competitive automotive market. It can be assumed that this trend will continue through the implementation of alternative concepts of car use, new materials and technologies, changes in consumer behaviour and further individualization and personalization of cars. For this reason, it is necessary to fundamentally change the principles and technologies of production and logistics systems used by car manufacturers. It is necessary to change classical systems based on the principles of stable and mass production. For that purpose, flexible and convertible production and logistics systems are being developed at all stages of car production.

At present, automated logistics systems based on Automated Guided Vehicle (AGV) technology are used in automotive assembly. They help car manufacturers to increase the efficiency and quality of logistics processes. However, the traditional AGVs are particularly popular for the regular and stable loading of assembly lines, as they are generally based on a limited number of pre-defined paths. This would make their use for irregularly loaded parts highly inefficient (low degree of utilization considering the purchase price of AGVs).

Recently, however, AGVs have seen rapid technological development. AGVs are becoming more sophisticated, flexible and cheaper. Autonomous Mobile Robots (AMRs) are now considered the highest AGV level. Their high degree of autonomy does not require the creation of pre-defined paths and AMRs can also be deployed to supply assembly lines with irregularly loaded parts, the number of which is constantly increasing due to customization and differentiation of cars.

Unfortunately, a systematic literature review has shown that there is still no comprehensive knowledge base (a comprehensive set of recommendations) to design, select and implement AMR technology for supplying an assembly line in the automotive industry. The aim of this article is to create this knowledge base. One of the following types of AMR technology can be used to supply assembly lines autonomously: towing vehicles, forklifts, and unit load carriers. The article focuses on the implementation of unit load carriers.

2 Literature review

2.1 AGV classification

Overall, AGV is a vehicle which can move in predetermined and specific direction automatically without human interference [1]. More specifically, AGV is a device for moving unit loads of materials from one place to another, within a facility, with no accompanying human operator. Vehicles are battery powered and an on-board computer controls the movement [2].

Gul and Rahiman [3] divide AGVs according to a path guidance principle into static and dynamic path vehicles. The static path vehicle uses pre-defined path between its origin and destination point. The dynamic path vehicle behaves autonomously to determine path by detecting and avoiding obstacle. Wang, Tao a Liu [4] states that traditional AGV plans routes by electromagnetic path-following system, and avoids barriers by simple sensors, thus ensuring automatic driving along preset routes. On the contrary, modern AGVs are based on combination of RFID automatic recognition technology, laser guiding technology, wireless communication technology and model feature matching technology. They also state that the efficiency of route planning and group scheduling is increased significantly by combining with big data, the internet of things (IOT) technology and intelligence algorithms.

Gul, Rahiman a Nazli Alhady [5] divide AGVs according to technology of navigation into: (1) wired type, (2) guide type, (3) laser type, (4) gyro based, and (5) vision based. Vision based AGVs that use camera to acquire environment features and made decision based on those features to navigate the vehicle can be considered the highest level of technology.

2.2 AMRs in industrial logistics

In this study, AMRs are considered to be a subgroup of AGVs with a high degree of autonomous control by intelligence algorithms, dynamic path system, wireless communication technology, model matching technology, and primarily the vision-based navigation technology. A number of other AMR designations appear in scientific publications: Mobile Autonomous Robots (MAR), Autonomously Moving Vehicles (AMV), or Mobile Autonomous Units (MAU). The authors consider these names synonymous.

Unger, Markert and Müller [6] state that AMRs are "mobile robots that can perceive their surroundings via various sensors and are able to react to changes in their environment" whereas "mobile robots are a special form of robots that consist of at least the components drive, control and manipulator and are able to move and navigate freely in a given area to fulfil various tasks". At the same time, these authors define the basic characteristics of AMRs: "They are capable of solving tasks with higher complexity without every single process step being explicitly taught. Programming of such devices is in general more task oriented and rule based (higher level of abstraction) than jobs of conventional robots. Solutions to problems are generated by algorithms in real time to cope with variations in processes.".

Scientific literature examines the benefits of AMR implementation in logistics systems. Zhang, Hu and Guan [7] define the following benefits: (1) Autonomous path planning, high level of flexibility, (2) The system operates steadily and safely, (3) High degree of intelligence and fewer staff members, and (4) Battery driven, green and environmentally friendly. Similarly, Unger, Markert and Müller [6] state the following benefits: (1) Higher flexibility in processes, (2) Improved ergonomic scorings of close by workstations, (3) Improved degree of capacity utilization for robots, (4) Higher economic efficiency and process stability, and (5) Automation of currently not automatable processes.

2.3 AMRs for supplying the automotive assembly lines and workplaces

Several studies dealing with the implementation of AMR technology in the automotive industry were found during the systematic literature review. Several of these studies dealt specifically with the use of AMR technology to supply the assembly line.

In their study, Koo, Yang and Suh [8] addressed the issue of determining the size of the AMR fleet needed for trouble-free operation of given production system. When determining the number of AMRs deployed, they took into account, in particular, the total vehicle travel time that includes empty vehicle travel time, loading time, loaded vehicle travel time, and unloading time. They defined an algorithm to determine the optimal fleet size based on the knowledge of travel time and frequency between locations.

Fathi et al. [9] developed an optimization model for material supply scheduling at missed-model assembly lines. The aim of the study was to optimally schedule the delivery of raw material at assembly lines while using the minimum number of vehicles. This model also provides accurate information on the planned deliveries, material type and quantity in a given cycle and the type of handling technology used.

Kern, Lämmermann and Bauernhansl [10] proposed an integrated logistics concept for a modular assembly system. They describe a case study of the implementation of the integrated production logistics concept using AMR on the case of a pre-assembly line in a German car manufacturer. The subject of the case study was a pre-assembly line with manufacturing cells. In designing the concept, they considered consumed parts, logistics area, material flow, assembly sequences, and rules for assigning to workstations. The proposed concept made it possible to reduce the number of buffers, storage areas, handling units and parts inventory.

Zhang, Hu and Guan [7] proposed a hybrid-load AMR dispatching model, which allocates different types of AMR for different sizes of materials, for mixed-model car assembly line. The model is based on a combining the single-load and multi-load dispatching system. They used a genetic algorithm to solve the problem. The criterion of optimization is minimization of the total cost of logistics system.

Kousi et al. [11] designed a service oriented, web-based control system that would enable the monitoring of the shop floor status and the dynamic scheduling of material supply operations in a car assembly system using AMR technology. The control system is based on time and inventory data. Next, Kousi et al. [12] proposed a decision-making method for plan generation of part supply operations undertaken by AMR. The results of this study indicated that the method can provide high quality solutions, in terms of production volume and minimization of the line stoppages.

All the above studies proposed optimization models for selected AMR implementation and control problems for supplying automotive assembly lines, especially AMR fleet size determination, material supply planning and scheduling optimization, and selecting the AMR dispatching model. However, no study dealt with the issue comprehensively and in terms of managerial implications. The literature lacks a comprehensive set of recommendations that can serve as a knowledge base for the design, selection and implementation of AMR technology for supplying assembly lines in the automotive industry.

3 Research methodology

The basic research tool was a case study aimed at assessing the feasibility of introducing AMR technology for supplying car assembly line with parts with irregular consumption in a leading passenger car manufacturer.

Case study have often been considered as one of the basic methods of qualitative research, although it may also be quantitative or contain a combination of qualitative and quantitative approaches [13]. It is a research method involving an up-close, in-depth, and detailed examination of a subject of study (the case), as well as its related contextual conditions. There are various case study categorizations. For the needs of the presented research explanatory [14], intrinsic [15], and evaluative [16] case study was chosen.

At the beginning of the research, there was the requirement of the car manufacturer to assess replacing the current method of supplying the assembly line using human operated tow trains with vision based AMR supplying system. One of the following types of AMR technology could be used to supply assembly lines autonomously: towing vehicles, forklifts, and unit load carriers. The case study focuses on assessing the implementation of unit load carriers.

The study analysed the current state of supplying of the assembly line. The subject of the analysis was 88 workstations of the assembly line supplied with irregularly consumed parts, because regularly supplied parts are supplied by standard AGVs (with pre-defined paths). The parts are loaded in pallet containers which are placed on rolling racks. The containers and racks represent a handling unit.

The researched process was characterized by a high number of different combinations of supplied workstations, i.e. paths. The frequency of parts deliveries to workstations was on average 46 per hour, at peak times up to 80 per hour. Process of supplying workstations with parts begins with the emergence of need and call-of the parts from a particular workstation by an operator using a button and continues by picking the required parts from the warehouse at train station where the handling units are loaded onto the tow train. The process then continues with parts delivery to each workstation, whereas one tow train usually transports three handling units to three different workstations. Routing is based on the experience of tow train drivers. The full handling unit is unloaded and handled by the driver to a predetermined location at the target workstation. Next, the driver handles and loads an empty handling unit on the tow train. After performing the above operations at all three workstations, the tow train returns to the train station where empty handling units are unloaded on the designated area and the tow train is ready for another mission.

In the case study, research of currently available technologies was carried out and 76 vendors of potentially suitable technologies were identified. Based on a more detailed analysis of the technologies offered, 17 vendors were shortlisted, among whom a tender procedure was carried out. Benchmarking with other plants and external industrial companies was also carried out during the study. However, no case with a larger AMR fleet was found. Based on the information obtained, the proposal of the concept of AMR supplying the assembly line and the proposal of technological solution were carried out in three variants. A capacity calculation indicating the number of required AMRs was performed for each variant. Subsequently, three proposed variants were economically evaluated.

4 Results and discussion

Based on the performed research and case study, the general procedure for feasibility study of the project of AMR assembly line supply can be proposed. The procedure includes eight steps in recommended sequence, while some of the steps can be carried out in parallel as shown in Figure 1.

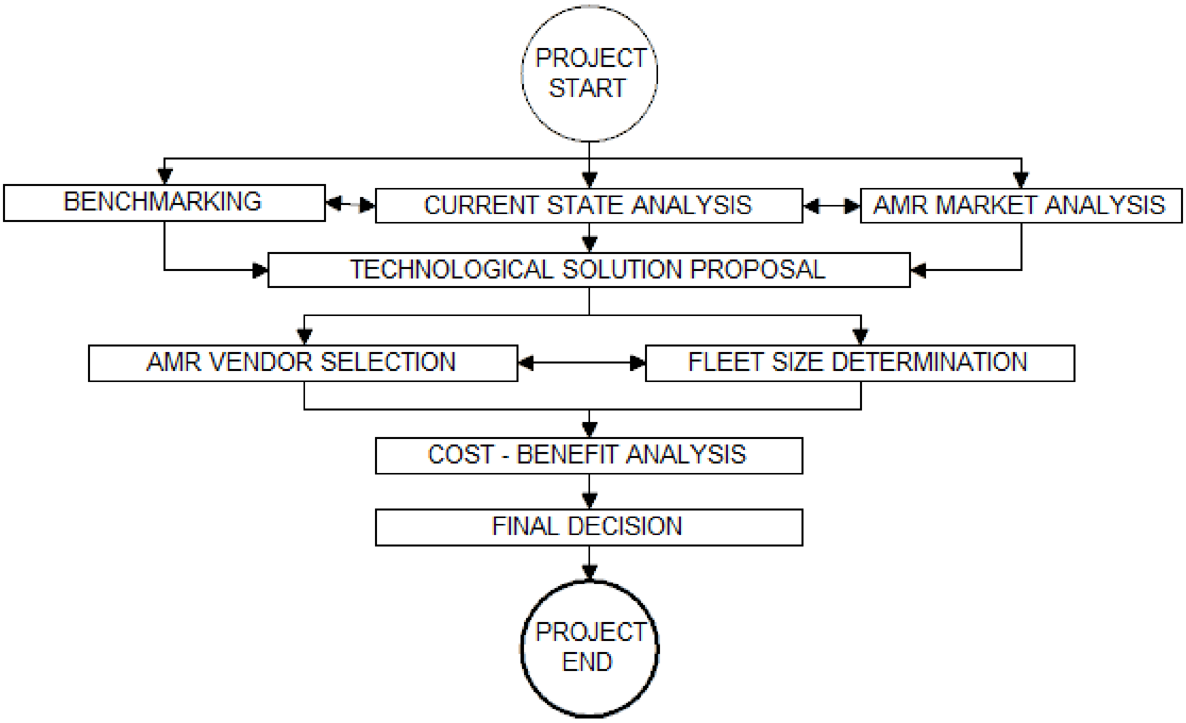

Figure 1 General procedure for feasibility study of the project of AMR assembly line supply

1. Benchmarking – internal and external (competitive and functional) benchmarking of existing implementations.
2. Current state analysis – analysis of supplied workplaces, supplied parts, process of loading and unloading, frequency of supplying, manipulation units and packages, weight of supplied units, principles of supplying.
3. AMR market analysis – search for available vendors and technologies, rough evaluation and selection of suitable vendors and technologies.
4. Technological solution proposal – narrow selection of the most suitable technologies, proposal of supplying concept.
5. AMR vendor selection – requirements specification, contacting suitable vendors, evaluation of business offers, final selection of the most relevant vendors.
6. Fleet size determination – calculation considering the supply needs, capacity, speed, manipulation times and other parameters of selected technology.
7. Cost-benefit analysis – calculation considering initial investments, operation costs, savings and return on investment, comparison of selected technologies and vendors.
8. Final decision – final selection of specific technology and vendor.

The following subchapters present generalized conclusions formulated based on the findings of the case study. The conclusions are structured into five categories and represent a set of recommendations that can serve as a knowledge base for designing, selecting and implementing unit load carriers type of AMR technology for supplying assembly lines in the automotive industry.

4.1 Technology

This category focuses on the technical aspects of AMR implementation, particularly in terms of additional technologies and accessories:

- The use of AMR technology to supply assembly lines usually requires their customization by purchasing special top modules (e.g. lift, hook, roller conveyor). Their choice depends on the type of handling operation and unit.
- It is important to decide whether the task of AMR system is only to transport (handling at the station and workstation is carried out by workers) or also to exchange the handling units (full/empty) and place them in a precisely defined location. For autonomous loading and unloading of handling units, it is necessary to select special accessories

again. For example, racks and docks are commonly used for this purpose. However, their use increases space requirements at the assembly line (setting up an additional exchanging space). It is better to look for solutions that do not require additional space.

- Most AMRs in the basic version are unable to identify the parts being transported. This is important so that the AMR recognizes the target workstation at the train station. For automatic identification of transported parts, it is necessary to equip the AMR with additional technology, e.g. a camera enabling recognition of QR codes, which will be used to mark the handling units.
- An important criterion for the selection of technology is the range of load-bearing capacity of individual types. Some vendors specialize only in a certain load capacity (e.g. up to 100 kg or over 1000 kg). In order to select the appropriate technology, it is necessary to perform an analysis of the weight of the loaded handling units. Based on it, AMR fleet with appropriate ratios of load capacities should be selected.
- It is necessary to count on the allocation of the AMR charging area, which should be located in the immediate vicinity of the station.

4.2 *Management*

This category is oriented on the managerial and control aspects of AMR implementation:

- The handling operations performed by AMR at the workstations are so time consuming that basically a single-pallet system cannot be used. However, the two-pallet system is the standard in the automotive industry.
- The use of AMR to supply assembly line with irregularly consumed parts requires an advanced fleet management system based on advanced technologies (artificial intelligence) that allow efficient AMR collaboration and the whole fleet control. The importance of using this system grows with the number of AMRs in the fleet.
- In a classic automotive plant, several handling technologies (e.g. human operated or automated guided trains and forklifts), including pedestrians, are combined and they meet on the roads, which should be taken into account when designing the implementation, mainly to maintain road throughput.
- A preferred solution should be to introduce AMR and/or AGV technology from a single vendor. The simultaneous use of technologies from different vendors raises problems resulting from the reluctance of vendors to cooperate. This makes it difficult to implement an integrated control system. Managing technologies and systems from different vendors also increases the administrative and financial resources requirements.
- The implementation of AMR technology enables increased road safety compared to human-operated tow trains. AMRs are equipped with advanced safety systems and move at a lower speed.
- There is little experience to date with the quality and reliability of AMR systems. The technology has not been proven on a larger scale in the automotive industry. It is therefore necessary to take into account the need to eliminate a relatively large number of errors during the start-up of the technology.
- It is convenient to select a technology that allows the user to manage the entire system. Many systems cannot work without close cooperation with the vendor both during the implementation and the operation phase, which reduces the flexibility of setting up and managing the entire system and also increases the implementation and operation costs.

4.3 *Economics*

This category presents conclusions and insights on the cost of the technology and the return on investment:

- Features and functionality (navigation method, charging time, dimensions, fleet management, ability to bypass an obstacle, solution of crossroads, etc.) of AMRs available on the market is very diverse for a relatively similar price. Thus, the most advanced AMR technologies can be almost as affordable as standard AGV technologies.
- Depending on the chosen type of AMR, additional costs for top modules and accessories (e.g. racks, docks) allowing loading and unloading, identification of handling units, as well as for the modification or purchase of new rolling racks have to be expected.
- The return on investment of AMR technology implementation as a substitute for human operated supply depends mainly on personnel costs. Faster returns can be achieved especially in locations with expensive labour. However, the total elimination of personnel costs cannot be expected, as it will be necessary to establish the position of the AMR fleet dispatcher.

4.4 *Capacity*

This category focuses on the conclusions and findings regarding the calculation of the appropriate number of AMRs, i.e. the fleet size needed to supply the assembly line:

- AMR moves slower than human-operated tow train. In order to secure the supply of the assembly line, there will be more AMRs in operation, which may overload selected roads and create traffic bottlenecks.
- The fact that the AMR real average speed differs significantly from the maximum speed indicated by the vendors must be taken into account in the capacity calculation. This depends mainly on the nature of the loaded handling units and the road traffic density.
- The calculation of the required number of AMRs is based on the determination of the AMRs total travel and handling time. The total time depends on the assembly line requirements in a specific period. The travel time is a multiple of AMR speed and the total distance travelled by AMRs in the given period. The handling time is a multiple of the time of one handling operation (unloading or loading of one manipulation unit) and the number of handling operations in the given period. Other times, which should be taken into account when determining the required number of AMRs are the charging time and a time reserve for other scheduled or unexpected events (e.g. maintenance, breakdowns, collisions).
- Supplying the irregularly consumed parts will result in peaks in real operation. These peaks cannot be fully covered by increasing number of AMRs. Their number would be so high that there would be a significant decrease in the average AMRs utilization and overall system inefficiency. It is therefore advisable to operate an alternative supply system for the peaks.

4.5 Vendors

This category presents the conclusions and findings of the AMR market analysis:

- The generally available public information on AMR technologies and the specifications published by the vendors are problematic, vague and often misleading and cannot lead to a relevant selection. Direct communication with vendors is essential for the initial selection of suitable technologies.
- Vendors come from different countries of the world, but regional support is needed for AMR technology selection, implementation, and operation. Unfortunately, the support is not available for all vendors or can be very problematic if they are located far from the implementation site.
- To date, there are very few applications with a larger fleet of AMRs in the field of assembly manufacturing, which makes it impossible to obtain relevant references and practical experience with a particular technology.
- Many vendors are specialized. They develop tailor-made AMRs for special purposes and do not provide standard ready to use solutions.

5 Conclusion

The use of AMR technology for supplying assembly lines in the automotive industry, especially for supplying irregularly consumable parts, represents a great potential for companies' efficiency improvement. However, its implementation is also a major challenge. Although technology and the AMR market are evolving rapidly, there is still a lack of experience in deploying a larger fleet of AMRs. Since its implementation requires relatively large investments, the decision and the subsequent implementation project must be based on a comprehensive and high-quality knowledge base. For this purpose, the article presents a comprehensive set of recommendations that address the technological, managerial and control, economics, capacity and vendors aspects of the design, selection and implementation of AMR technology for supplying assembly lines in the automotive industry. Based on the performed research, it is not possible to unambiguously recommend a specific AMR technology for supplying the assembly line in the automotive industry. When considering the implementation of the AMR fleet, each company should responsibly approach the research and assessment of the suitability of currently available technologies. The criteria for selecting the appropriate technology must always be based on the specific needs and capabilities of a particular company. In addition to the technical and economic parameters of individual technologies, it is necessary to take into account factors concerning, for example, the possibilities of self-government of the entire system, compatibility with technologies operated in parallel or supplier support. An important factor for the design of the assembly line supply system in the automotive system and the selection of a suitable technology is also the capacity calculation, resp. fleet size and traffic load. The issue of the implementation of AMR for supplying the assembly lines in the automotive industry is complex and the assessment of the suitability of a particular technology depends primarily on setting the significance of the individual criteria assessed. In general, given the dynamics of development of this field, it is possible to recommend an orientation to the most advanced technologies and user-friendliness of the entire solution, which plays an important role in real operation.

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OPTIMIZATION OF TECHNOLOGICAL JIGS FLOW IN AUTOMOTIVE USING SOFTWARE MODULE TECNOMATIX PLANT SIMULATION

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Keywords: material flow, jigs, automobile body, optimization, simulation

Abstract: Production must be adapted to the needs of the product structure while meeting the economic requirements of low cost. As processes will be monitored, managed and optimized in near real-time, decentralization of decision-making processes will also increase. Due to the heterogeneous structure of the value chain, its complexity is increasing, reorganized, causing changes to the system as a whole and will require the creation of appropriate infrastructures. Mastering the value chain dynamics is largely translated into logistics. This paper deals with the optimization of the flow of technological jigs at the workplace of the paint shop in a company that is oriented to the automotive industry. The design of an optimal solution will be verified using the selected software module Tecnomatix Plant simulation. Description and analysis of monitored flows of technological preparations are realized in the workplace Painting. The simulation model of the original state was created and by testing alternative solutions the solution of inter-operational transport was chosen, which is optimal. The use of software support in the analysis of variant solutions is of great importance especially in terms of speed of verification and achievement of results from the tested variants.

1 Introduction

The authors [1] in their study “Industry 4.0 and the Current Status and Future Prospects on Logistics” focuses on clarifying the impact of the Industry 4.0 concept on logistics. Under Industry 4.0 they understand the introduction of CPS, IoT, IoS and Smart Factory. Although the concept of Industry 4.0 is only at the beginning of its development and it is not known how it will be reflected in practice, its impact on logistics is still uncertain, the authors note its enormous importance and potential of use especially in the field of logistics. Regarding the introduction of these technologies, the authors argue that "Industry 4.0 can, by its very nature, become a reality only if logistics can provide production systems with the required inputs at the right time, quality and in the right place" [1].

Logistics in large halls must be precisely planned to save time, increase efficiency and thus reduce costs and increase production. The whole material flow must, therefore, be one perfectly functioning system. The growing competitive environment, which forces companies to reduce production times, inter alia, leads to continuous improvement in inter-operational transport [2,3].

The goal by making the logistics model is to simplify the mapping of complex logistics systems in order to gain knowledge, that can be transferred back to real system without interrupting current flows. In general, the simulation model of real logistics system is simplified through abstraction and idealization. The abstraction allows the real elements, relationships, and attributes omitted in order to concentrate on the essential system components. The idealization, however, allows you to view these components in the created simulation model, but in a simplified form [4-6].

For example, as stated in the case study, when simulating a assembly line in automotive, not all part positions that are installed in the vehicle are shown. This abstraction leads to that the simulation model used remains manageable and controllable. At the same time, the real component is represented by idealization in a software-specific component without, for example, displaying the geometric dimensions more precisely in the model. With both approaches, it is first necessary to decide which system components are mapped or how they are simplified. Which specific selection decision is made can, however, only be made in individual cases and always goal-oriented [7-9]. The higher level is the direction to the digital enterprise, i.e. through the creation of a digital twin, it would be possible to create a fully valuable system in a virtual environment with the possibility of virtual set-up and process optimization without interfering with the real system, and through digital twin, technologies to implement them directly into the real system [10-14].

Currently, there are programs to solve such problems that save time in designing workplaces and logistics. TX Plant Simulation is a software tool that allows engineers to create digital models and simulations of both logistics and manufacturing systems. It offers a wide range of modules to monitor the individual production process [15-18].

It is these software programs, automation, and robotization of production processes that represent the fourth industrial revolution. Companies, as well as individuals, are constantly striving to design, develop and implement new ways of production, simplification, optimization, and rationalization. In the world we know today, it is unimaginable that simulation programs, models, robots and other advanced technologies are not used in pre-production phases such as planning, design, and production. Robots and production automation itself are slowly replacing human activity, thus avoiding errors in the production process. All of this takes human society to the next level and creates a world of technology [19-26].

The case study below analyzes the workplace painting in a company focused on the automotive industry, simulates the current state and concludes with a proposal for a solution for inter-operational transport. Tx Plant Simulation was used to create a simulation model of current material flows in the workplace painting.

2 Material and Methods

2.1 Description of used software Tecnomatix Plant Simulation

Tecnomatix Plant Simulation support discrete-event simulation. It shows the state changes of the model components at certain points in time, not continually over time. When certain events take place, certain model components change their state and thus control the simulation. This software considers these events in a discrete way, step-by-step. The main advantage is that TX Plant Simulation skips the time between the events. In addition, TX Plant Simulation is an object-oriented application, that allows child objects to inherit properties from a parent object [15]. Different and very complex systems and business processes can be represented realistically and with high accuracy. The object-oriented, graphic and integrated work environment has increased user acceptance. Working with objects that are inherited has great advantages:

- adjustments are made much faster,
- parameter changes are made more securely in the entire model.

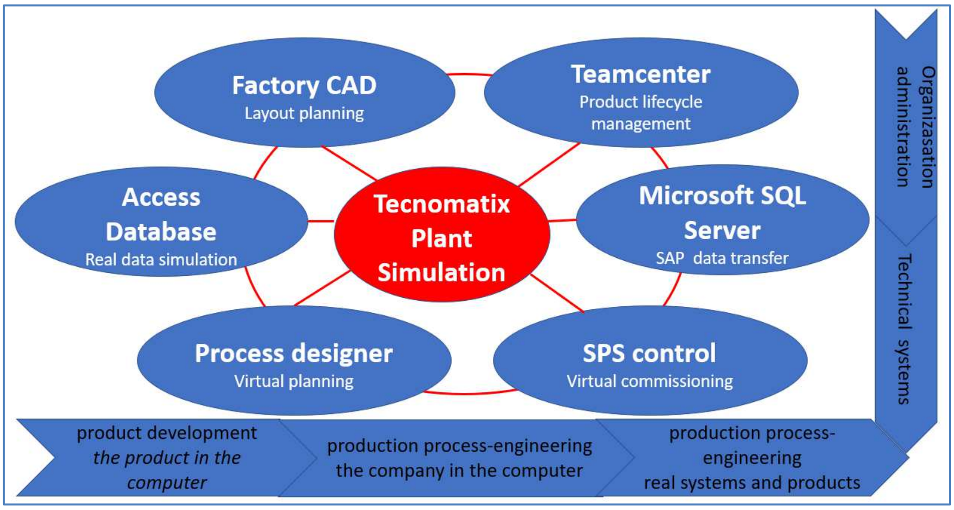

Figure 1 Company-wide simulation with TX Plant simulation and integration example [7]

The extraordinary functionality in the creation of models, as well as the easy modification and maintenance of created models in TX Plant Simulation have made the universal and productive use this tool possible. The data exchange during the simulation run and the complete control of TX Plant Simulation by other programs (e.g. PPS, ERP system, etc.) are important for integrated solutions. Via the existing interfaces, TX Plant Simulation is open for individual extensions and fulfils all practical integration requirements. TX Plant Simulation integrates with many other software systems, (Figure 1).

Throughout the automotive manufacturing process, processes in the paint shop are among the most technologically demanding, as they include various processes based on the chemical, thermochemical, physical and technological properties of the materials used, such as: paint, paint, putty, bodywork, chemicals used in individual processes, etc.

2.2 Layout Workplace Position Painting Module

Throughout the automotive manufacturing process, processes in the paint shop are among the most technologically demanding, as they include various processes based on the chemical, thermochemical, physical and technological properties of the materials used, such as: paint, paint, putty, bodywork, chemicals used in individual processes, etc.

The workplace of the paint removal process consists of two parts. This is from an enclosed and ventilated area, where there are three paint removers, a sump for working with a high-pressure device, and a place for blowing with compressed air. In this part of the workplace, the operator inserts resp. removes rotary baskets from paint removers. Here, the paints are removed after each painting process. This workstation is closed in order to prevent the odor spread of the chemical varnish medium present in the varnish modules during the varnishing process. Therefore, during insertion respectively. When removing the rotary basket from the machine, the worker must use personal protective equipment (face mask for respiratory protection, protective shield, chemical gloves, rubber boots, chemical coat, protective headphones).

In the case study, an analysis of the flow of auxiliary technological products and an analysis of the current working positions that perform the manipulation with the given technological auxiliaries was created. The bodywork in the painting process passes through specific workplaces to obtain a final look. Bodies move along the conveyor system with a length of 7.5 km. This system also includes a 360 ° rotary immersion system, which is used in degreasing and pretreatment processes. By means of these processes, the body is free of dirt and grease, and at the same time in the subsequent cataphoresis process a protective layer is applied. There are 80 robots integrated in the entire painting process, which are used to apply sealant and paint. The paints used in the coating process are water-dilutable and therefore do not significantly pollute or damage the environment. The process of applying paint and varnish is flexible, so the company offers several colors for each model. The amount of color shades for each model is described in Table 1.

Table 1 Quantity of colors for individual models in the company

Model	Number of shades
A	13
B	14
C	10

Analysis of the current state is focused on the flow of auxiliary technological jigs, which are not part of the final form of the automobile body, as parts or components, so that they do not create the added value of the product. These preparations are designed to facilitate the work of operators, but also robots in robotized workplaces. The types of preparations analyzed have a fixation, support, and auxiliary function.

The fixatives are mainly used to fix the front and rear doors and the front and rear bonnets during degreasing, pretreatment and cataphoresis processes. Thanks to these products, the opening of the individual body parts is prevented since 360 ° rotation occurs during these processes.

Supporting products are used mainly during the movement of car bodies between individual workplaces of the paint shop, but also in production halls (from the welding shop to the paint shop, from the paint shop to assembly). Supporting agents are also important during the process of applying the sealant to the inner body. These pro Auxiliaries perform various functions. Whether they simplify opening the front resp. hold the door open while moving between workstations, or help keep the door open during the process of applying the sealant to the inner part. Some of these formulations also undergo a coating process. Jigs that pass through this process must, after removal from the manufacturing process, be removed by stripping in the stripping module operated by the operator at position no. 1.

The work positions analyzed in this chapter are handled by external company workers who carry out the transport and supply of individual workpieces with preparations, operate the stripping module and perform other work and handling activities described in the workflows.

2.3 Process Flow on workplace painting

In Table 2, the individual preparations which enter the production are described. The table shows in which workplaces the products enter and exit the production. The last column of this table shows which operator is in charge of transporting the product to the workplace.

Table 2 Overview of jigs at the workplace painting

No.	Jigs' name	IN	OUT	Notice	Operator ´s manipulation	
1.	front hood support (from welding)	Welding area	Preclean	-	Op.3 **Preclean - Welding area**	
2.	rubber stop rear bonnet	Welding area	Preclean	-	Op.3 Preclean - Welding area	
3.	door fixation	Welding area	JIG Station	paint removing the preparation over the weekend	Op.3 JIG Station - Welding area	
4.	door hinge screws	Welding area	Assembly	ASSY-Paint removing module	Op.2 Paint removing module - Welding area	
5.	fixing the front and rear bonnet	Preclean	JIG Station	Washing the jigs over the weekend	Op.3 JIG Station - Preclean	
6.	magnet into the door	JIG Station	Sealer	-	Op.3 Sealer - JIG Station	
7.	long bonnet support (front and rear bonnet)	JIG Station	Deadener Pad	-	Op.2 Deadener Pad - JIG Station	
8.	artificial roof preparation	JIG Station	WAX	-	Op.2 WAX - JIG Station	
9.	plastic door stop	JIG Station	Assembly	Single use	-	
10.	tailgate opening jig	Sealer	WAX	WAX - Paint removing module	Op.1 Paint removing module - Sealer	Op.2 WAX - Paint removing module
11.	fuel tank cap holder	Deadener Pad	WAX	WAX - Paint removing module	Op.1 Paint removing module - Deadener Pad	Op.2 WAX - Paint removing module
12.	front bonnet opener	Deadener Pad	WAX	WAX - Paint removing module	Op.1 Paint removing module - Deadener Pad	Op.2 WAX - Paint removing module
13.	front bonnet support	Deadener Pad	WAX	Outsourcing	Op.2 WAX - Deadener Pad	
14.	fixation strip	WAX	Assembly-Door off	-	Op.1 Assembly -WAX	
15.	pin under the front bonnet	WAX	Assembly-T220	-	Op.1 Assembly -WAX	
16.	panoramic roof pin	Sunroof	Assembly-Door off	-	Op.1 Assembly -Sunroof	

In the following Figure 2 is a schematic diagram of the input resp. input circuit output of preparations to/from production. The solid circle marks the mounting of the fixture on the automobile body. Removing the jig from the automobile body is indicated by an empty circle. The full arrow is characterized by the transport resp. moving the mounted fixture on the body during the manufacturing process. Dashed arrows indicate routes of jig which after disassembly continue to the paint removing module for the paint removing process.

Color differentiation of individual arrows is created for the transparency of entry and exit of individual jigs according to workplaces where the jigs are mounted respectively. removed from the automobile body. Numbers by the full and empty circles are denominations of individual jigs from the Table 2.

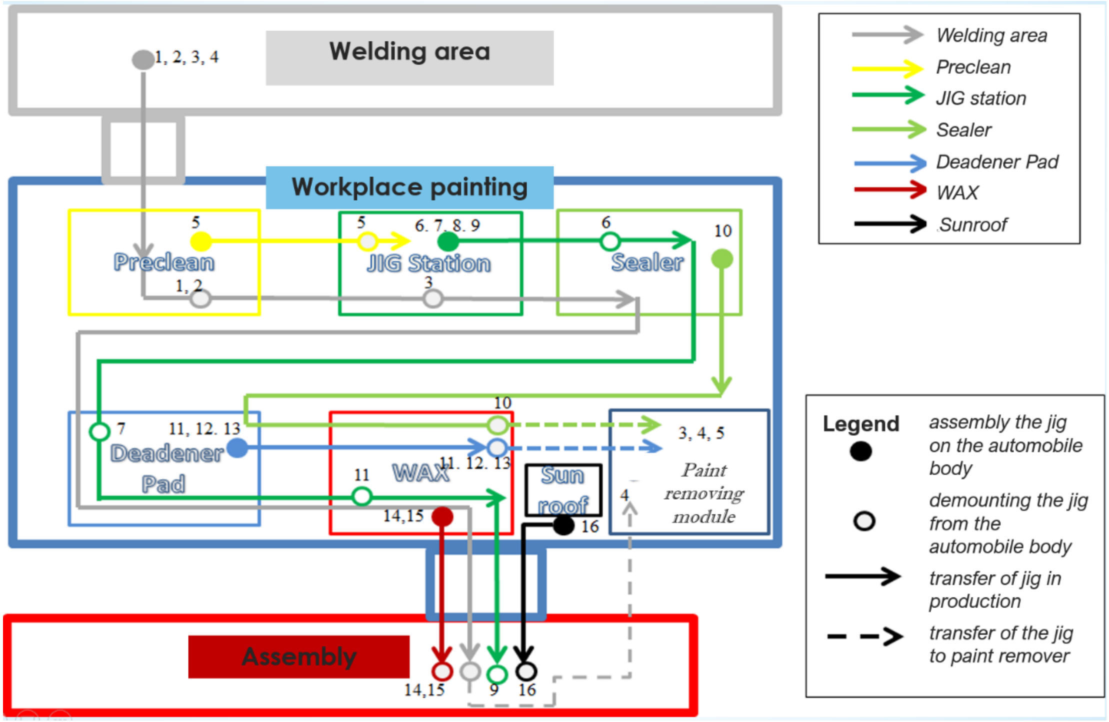

Figure 2 Scheme of jigs cycle

In Figure 3 are show the automobile body and the individual jigs whose color differentiation serves to illustrate the entry of the jigs into the individual workplaces. The locations where the jigs are mounted on the automobile body are indicated by arrows.

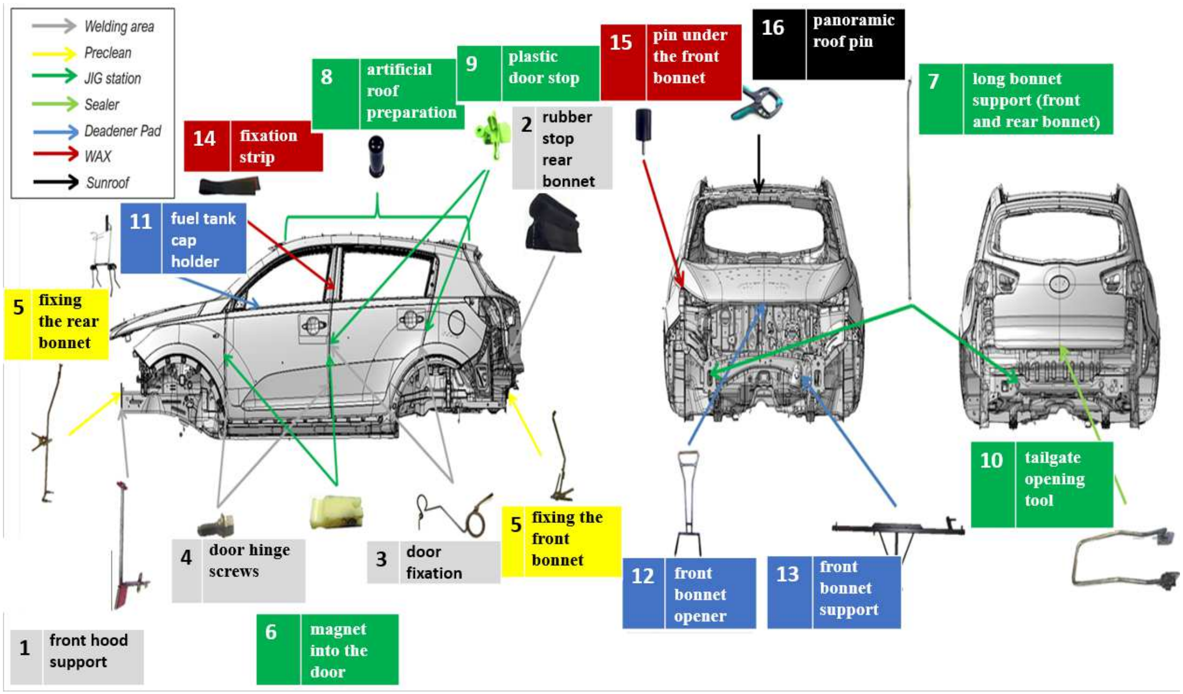

Figure 3 Placing the jigs on the automobile body

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2.4 Creation of simulation model of material flow of technological jigs on position: Paint removal module

The worker in this position carries out the preparation of supporting and fixation products for production, their removal or the operation of the removal equipment of the products and their subsequent logistics for individual workplaces. At the same time, he is in charge of transporting some types of jigs from assembly to paint shop.

Paint removal of the formulations is carried out in rotary baskets into which the formulations are stored according to the prescribed procedure. After the stripping process has been completed, the operator must subsequently rinse the preparations with water using a high-pressure device. After rinsing the cleaning medium, the worker must remove the residual water preparations by blowing with compressed air to ensure their dryness. The final rinse and blow-off process of the formulations is performed to remove residual amounts of cleaning medium that can cause contamination of the body surface and hence quality problems.

In addition to the preparation of support and fixation products for paint removal and for the operation of the paint module, this work is also in charge of the product logistics. The varnished, rinsed and dried preparations are sorted and stored by the worker and are prepared to handle trolleys according to the type of preparation. It then delivers these product trolleys to Deadener Pad and Sealer. During the varnishing process, this worker also takes care of the logistics of some types of fixtures (fixation tapes, pegs under the front hood and pegs on the panoramic roof) from assembly workplaces to paint shops workplaces.

Movement worker on position: Paint removal module

The job description of the employee in this position is not only the operation of the workplaces of the Paint removal modules but also the transport of individual products to the workplaces. The routes along which the worker transports the individual jigs are mapped in Figure 4.

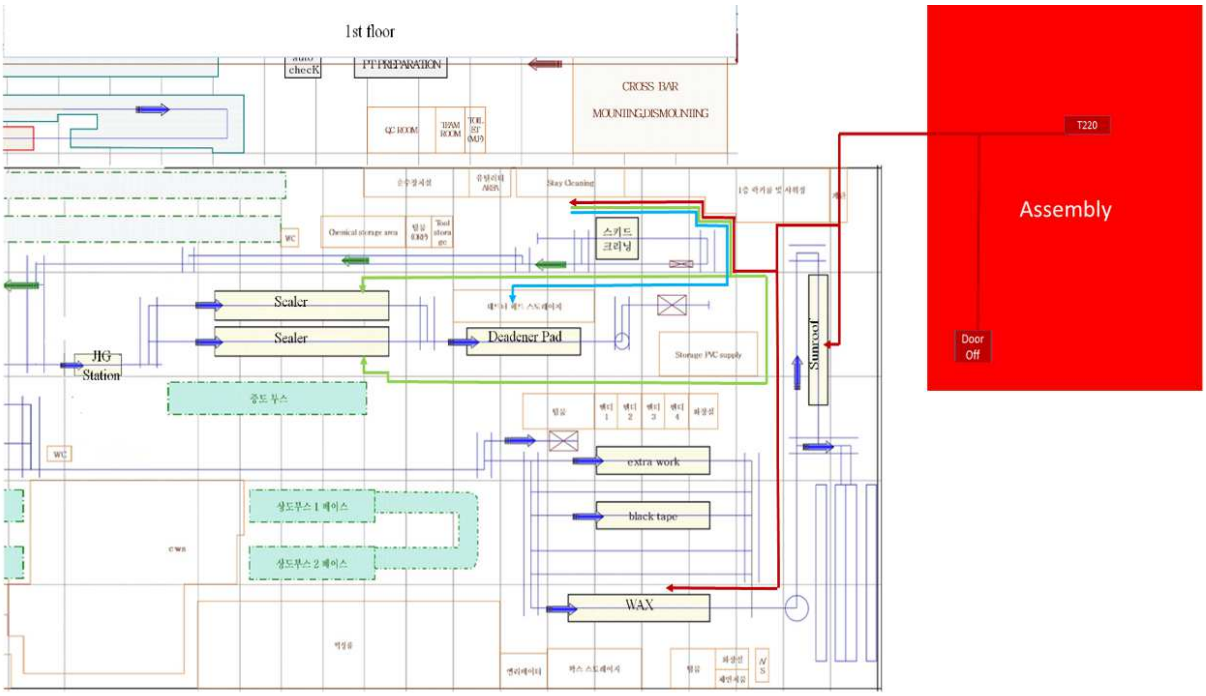

Figure 4 Motion map of worker on position: Paint removal module

After completing the preparatory work, inserting the fixtures and operating the paint remover, the worker collects and transports the fixtures (panoramic roof pin, fixation strip and pin under the front hood) from the Assembly Offices (Door off, T220) to the workplace Painting, first to Sunroof and then to WAX. After unloading at the WAX site, the worker returns to the paint module. The worker's movement along this route is marked in red.

After the removal process has been completed and the painting preparations are sorted into prepared handling trolleys. The transport route for the Deadener Pad is marked in blue. The transport route to Sealer is indicated in green.

2.5 Suggestion of optimal solution of the flow of technological jigs in the examined company.

From the results of observation, data collection and analysis of logistics workers in the workplace painting about and subsequent creation of simulation models of individual manipulation workplaces, re-design of these workplaces was created. This solution is based mainly on observation and analysis.

The re-design of the workstation relates to position no.1 of the painting module and position no.2 of the WAX. The proposed change and optimization are to move the operation:

- Transfer of painting jigs (tailgate opening jig) to Sealer.

This process is removed from the workflow for position no. 1, and is assigned to the worker of position no. 2 WAX. This operation will be a worker at position no. 2 can be carried out after the transport of the preparations from the WAX workplace, which then proceed to the paint removal process. After completion of the previous paint stripping cycle, when the compositions are painted, depleted of the cleaning medium by a high-pressure device, blow-dried and sorted into ready-to-carry carts. Subsequently, the worker at position no. 2 transports the tailgate jigs to Sealer.

The reason for this proposal and optimization of the occupancy worker at position no. 1, which is responsible for operating the paint remover work module, which includes three paint removal device.

At the same time, it is responsible for the correct storage of the products in the baskets. An important activity is also the proper cleaning of paintings products, their drying with compressed air and subsequent sorting into handling trolleys and their distribution to workplaces, according to the working procedure. Between these operations, he must also transport the jigs from assembly to the workplace painting

When the worker at position no. 2 WAX was observed short downtimes were detected. Assignment of the above operation does not burden the worker at position 2 significantly, because the operation is performed every two hours.

Table 3 Comparing the current and proposed state after simulation

Current status		*Proposed state*	
Traveled Distance		Traveled Distance	
	Traveled Distance		Traveled Distance
.MUs.Pozicia1:1	5294.55m	.MUs.Pozicia1:1	4631.05m
Object	Number of Entries	Object	Number of Entries
.MUs.Pozicia1:1	39	.MUs.Pozicia1:1	36

The proposed change for position no. 1 of the painting module and position 2 of the WAX is shown in Figure. 5. In Figure. 5 is a red highlighted route to the Sealer site that the worker had not previously performed in that position. At the same time in Figure 6 is shown a 3D model of the proposed optimization.

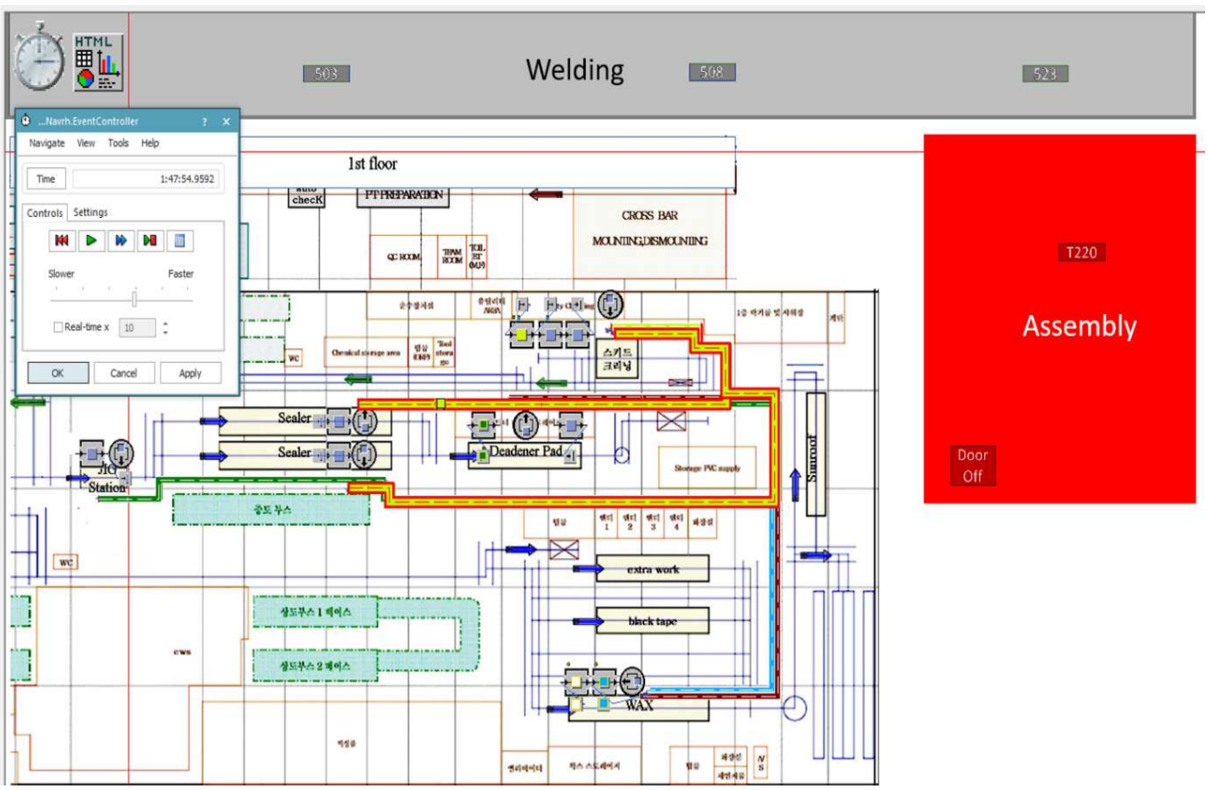

Figure 5 Optimization Proposal - Position no. 2 WAX

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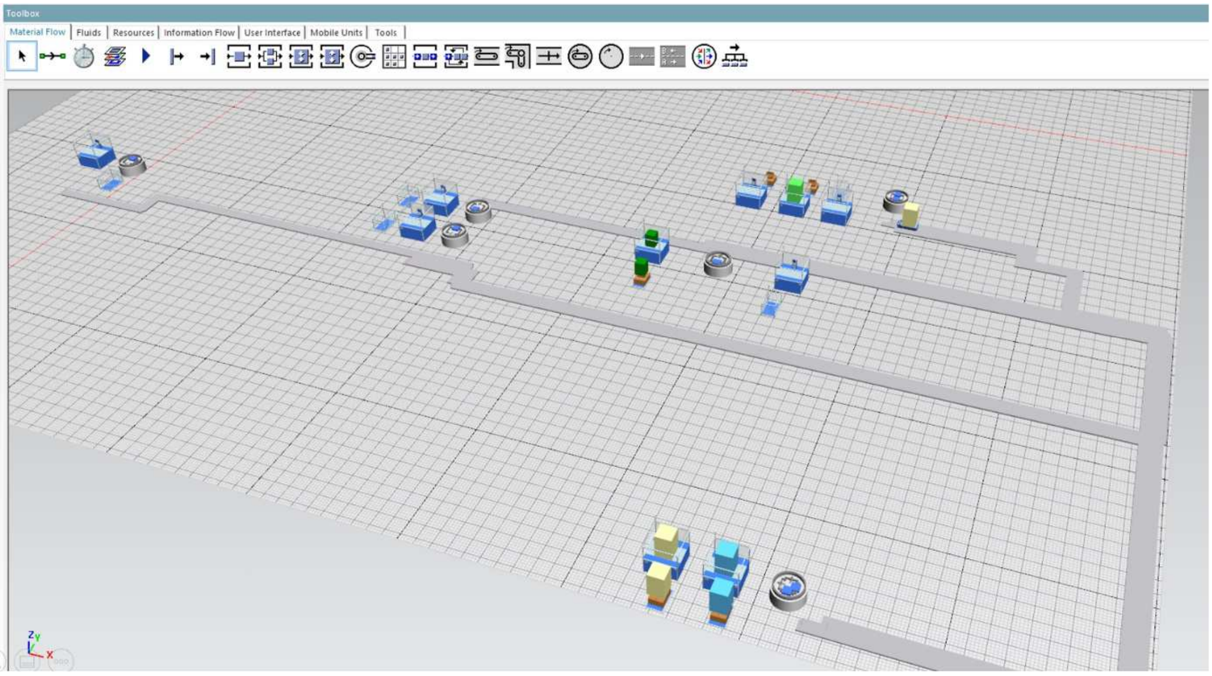

Figure 6 3D model of the proposed optimization

After elaboration of the optimization proposal and subsequent simulation of this proposal are shown in Tab. 3 taken into account and compared two indicators of the current and proposed state, namely the distance traveled by the worker in position no. 1 during a 12-hour change and the number of inputs to workplaces. The current system will pass 5294.55 meters and the proposed is 4631.05 meters. The difference between these distances is 663.5 meters. The distance that has been shortened to the worker at position no. 1, when transporting the preparations to the workplace, Sealer creates a time reserve. Thanks to this time reserve, the worker can focus on the processes related to the painting process, in particular the processes of rinsing off the painting jigs with a high-pressure device and the subsequent blowing off of the cleaning medium residues. Focusing on this process is very important as this process avoids the possible contamination of the automobile body and hence quality problems.

The second indicator that points to an increase in the necessary time reserve is the number of inputs to workplaces. When comparing the current and the proposed situation, we can point to a reduction in the number of inputs to 36 compared to the original 39.

• Transfer of painting jigs (tailgate opening jig) to Sealer.

3 Result and discussion

The use of simulations and the creation of simulation models is nowadays an essential part of modern enterprises for maintaining but also increasing their competitiveness in the market. The use of simulation software facilitates but mainly speeds up the pre-production phase of the process. In this phase, when planning, designing, resp. re-designing both production and non-production processes is an important factor in time. Simulation programs significantly reduce this time compared to mathematical models resp. experiment during operation. Along with the reduction of time, the costs of introducing new or changes to the original system are also reduced. These two variables can be characterized as important indicators in the introduction of new resp. changes to legacy systems. Before developing a simulation model in this case study, it was necessary to develop an in-depth analysis of the system with a focus on logistics staff. Workers in these positions are responsible for transporting a group of products between the individual workplaces of the painting.

The analysis was created from the results of observation and data collection, in a workplace painting in a company focused on the automotive industry. Part of the analysis is the characteristics of the monitored job positions. The next part of the analysis was the workflow, which is processed in the tables. Subsequently, a table was drawn up of the jigs that the worker transported between workplaces. The next section describes the routes, layouts of workplaces and handling trucks on which the worker transports the jigs. The simulation model of the current system was developed from the knowledge from analysis and observation. The final part is a proposal for the optimization of the current system. Optimization related to position no. 1 Paint removing module from which the process Movement of the painting jigs (tailgate opening jigs) was taken away to the Sealer position. This operation has been assigned to the worker of position no. 2 WAX, thereby reducing the time and physical intensity of position no. 1. This proposal is based on observation and in-depth analysis of the current system directly in the company.

The results of the simulation of the current and proposed status were compared based on two indicators, namely the distance travelled by the worker during the change and the number of entrances to the workplaces. When comparing the distance indicator between the current and the proposed condition, a difference of 663.5 meters was made. The difference in the two indicators results in a new time pool that the worker can use to focus on rinsing and blowing processes, which are very important in preventing automobile body surface contamination that results in qualitative errors.

4 Conclusions

Current tools for modeling and simulation of logistic processes enable the creation of models, simulation experiments, statistical analyzes, and have a library of predefined entities that can be extended. However, they are not flexible enough to increase the agility of individual entities through the introduction of technological innovation. However, the increasing degree of autonomy of individual elements of the system requires the solution of new problems related to modeling and implementation of autonomous Logistics 4.0. There is a need to apply sophisticated simulation tools that have computational and communication capabilities and can create a digitized image of a real system. This leads to a significant transformation of the so-called hardware logistics to software logistics.

Technological innovations, particular CFS and IoT, create an integration element between decision-making and performance processes that increases the efficiency of bidirectional information flows. There is a need to ensure active and individual communication capability between individual elements of the system. This leads to optimal production adapted to the specific product. The products themselves are looking for their production flow as the distribution of available capacities is subject to a dynamic solution of the products themselves.

Acknowledgement
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CHOSEN ASPECTS OF A SPATIALLY FUNCTIONAL ACCESSIBILITY BY PUBLIC TRANSPORT: THE CASE OF TRNAVA SELF-GOVERNING REGION (SLOVAKIA)

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Keywords: rural area, public transport, accessibility, Trnava Self - Governing Region, Slovak Republic
Abstract: The aim of the paper is to analyze transport possibilities of Trnava Self-Governing Region (TTSK) municipalities residents to its center (regional capital) by public transport. The authors of the paper have reviewed the current trends of public transport and discussed the optimization of their capacity and timetable scheduling in terms of continuity and parallelism of bus and train transport. The research methods included GIS tools, complex accessibility calculations based on the journeys published on slovakrail.sk and www.cp.sk on a Tuesday, February 6, 2018 at four key times (4:00, 7:30, 14:00, 24:00), which were compared by four aspects: distance traveled, travel time, number of transfers, comprehensive route accessibility by three types of transport: train, bus and combined transport. The results of the research have showed that there is a certain threshold value for travel distance, time and number of transfers, which affects the commuters to either not visit the regional capital or choose to travel by a car. It was confirmed, that every type of public transport in the territory of TTSK has areas where it is currently the main way for commuting to the regional city. The authors of the paper have provided a comprehensive picture of selected aspects of spatially functional accessibility by public transport and the characteristics of individual types of transport in terms of following the scheduled route timetables in the TTSK region during the selected key times.

1 Introduction

Different types of transport are key accelerators for the development of population mobility. According to the European Commission White Paper "Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system", transport is a key element of the economy and society [1,2]. The European transport policy emphasizes on an increased use of more environmentally friendly types of transport, in particular rail transport.

During the first decade of the political transformation in Slovakia (after 1989), the reverse development of public transport services (road and rail) was observed, while the role of individual transport (cars) in society has increased significantly. Until 2014, the share of public transport for passenger transportation in the Slovak Republic was decreasing. This decadent state is more noticeable in rural areas, where transport routes have been reduced or canceled. The cancelation of bus and rail routes and the creation of a “more efficient” (inconvenient for passengers) transportation system in the municipalities of the Slovak Republic was caused by several factors. The most important [3] are considered to be: i) questionable demarcation of higher territorial units, driven by political (not geographical) criteria; ii) the growing significance of individual car transport in both the commercial and private spheres; iii) structurally spatial changes in the labor market, which have caused considerable number of people to work from home or commute home on weekends only, as well people not working during typical work shifts (06:00-14:00, 14:00-22:00, 22:00-06:00, or 08:00-16:00).

Since 17 November 2014, public rail transport services in Slovakia have become a specific phenomenon with zero tariffs for selected groups of passengers, which contributed to the growing share of railways in passenger transportation. While bus transport is in the competence of 8 self-governing regions, railways are still the responsibility of the state [1].

The aim of the paper is to analyze transport possibilities of Trnava Self-Governing Region (TTSK) municipalities residents by public transport, review the current trends in a qualitative dominance of various types of public transport and discuss the optimization of their capacity and timetable scheduling in terms of continuity and parallelism of bus and train transport.

Dealing with these action poses a new question: "Which of these types of transport should be a priority for ensuring transport to the regional capital of TTSK?"

On the basis of new methodology presented by the authors of the paper the complex availability equation based on the comprehensive route accessibility proposed by the authors of the paper, the most convenient way has been suggested for transporting each municipality residents belonging to TTSK towards the regional capital Trnava at four key times has been suggested.

2 Theoretical background

Public passenger transport, understood as transport operated with – pre-determined and publish transport and tariff conditions, is accessible to any interested party-transport participant, regardless of their gender, age, nationality, ethnicity, etc. It is especially importana as ecologically friendly alternative to individual car transport, for citizens who are unable to use a car [4,29]. Accessibility is, according to [5], a measure of the strength and extent of geographical relationships between citizens and their socio-economic activities. [6] in his work defines the spatial accessibility of regions as "the ease of reaching a region from other cities or regions.

The accessibility of Slovak cities in terms of correlations between settlement, transport network configuration and territorial division has been given more attention in the geographical community [7-10] than the availability of rural municipalities towards their natural centers [11] and [12]. Even in Czech geography, public transport and its spatial connections are mainly addressed in regional cities [13-16], and not in its regions [17].

The Polish literature [18] has been an inspirational publication for the aim of this study, where an example of canceled passenger rail routes in a transforming Poland highlighted the importance of public transport in connecting cities and settlements. The traffic congestion in Poland and other developed countries [19] and [20] is considered to be one of the most significant issues influencing living conditions of urban and regional residents.

It is noted, that this situation was caused not only due to the increase in the population's wealth, but also to the chaotically progressing suburbanization. The chaotic suburbanization and the related deterioration in accessibility by public transport is based on research in the Olcztyna region [21] and Krakow [22]. Another inspirational publication from a non-European environment has been [23].

3 Research methodology, data and research area

While [13] calculates the accessibility of public transport in terms of frequency (the sum of 3x long-distance trains per standard Wednesday, which stop in a given municipality + 1x regional trains per standard Wednesday, which stop in a given municipality + 2x the long haul buses per standard Wednesday, which stop in a given municipality + 1x regional coaches per standard Wednesday, which stop in a given municipality), the authors propose a calculation based on speed and reliability of passenger transport (the ratio of traveled distance and time multiplied by the number of routes). The proposed calculation procedure was named complex accessibility (kd) calculation and was applied in [11] and [12].

$$kd = \frac{s}{t \times p} \qquad (1)$$

kd - complex accessibility,
s - distance traveled,
t - time traveled,
p - number of transfers.

For the purpose of complex accessibility calculation in this paper a standard Tuesday (February 6, 2018) was considered, thus eliminating the increasing trend of traffic before and after the holidays, but also the decreasing trend of traffic during them.

Transport journeys at four key times were selected: i) journeys leaving at 04:00 from municipalities with the earliest arrival in Trnava (important for tourists, long-distance travelers and commuters to work for morning shift); ii) journeys with the latest departure from municipalities arriving at 07:30 in Trnava (important for commuters to school, work, doctor office etc.); iii) journeys with the earliest arrival in municipalities leaving from Trnava at 14:00 (important for commuters from school, work, doctor office etc.); iv) journeys with the latest departure from Trnava arriving in municipalities by 24:00 (important for tourists, long-distance travelers, commuters from afternoon shift). In the case of time equality during the calculation, the number of transfers and a traveled distance was taken into account (lower is better).

Data used for railway journeys calculations were acquired only for municipalities with at least one tariff point – a railway station or a stop from the scheduled timetable published on [24]. The difference between a railway/bus station and stop has not been considered for the calculation purposes.

Data used for bus and combined transport services were with attention to the number of lines, routes, and bus operating companies acquired through a search engine at [25]. The default filter setting of the search engine was used to generate search results, the only exception was filtering out inner city transport buses. Combined transport combines the usage of both bus and train transport during journeys.

4 Research results

Trnava Self-Governing Region (TTSK) is located in the west part of the Slovak Republic and consists of 7 districts: Dunajská Streda (DS), Galanta (GA), Hlohovec (HC), Piešťany (PN), Senica (SE), Skalica (SI) and Trnava (TT). In the west it borders with the Bratislava self-governing region and Austria, in the north-west with the Czech Republic, in the north with the Trenčín self-governing region, in the east with the Nitra self-governing region and in the south with Hungary.

Trnava city, with a population of 65,382 (31.12.2017), as the regional capital of TTSK, concentrates important institutions such as faculty hospital basic secondary and university educational institutions, cultural institutions, public administration typical for the regional city, the state administration - police, jurisdiction and other services resulting from the nodal position of the regional city in relation to its background. There is a high concentration of industrial enterprises represented e. g. by car manufacturer Peugeot-Citroën, increased concentration of progressive activities and it is also an important bus and train hub of Slovakia. TTSK is a higher-level service center for seven districts with 491,904 residents (31.12.2017).

The TTSK route network has a convergent shape and consists of a dense network of roads in total length of 1951.041 km [26]. According to collected data [27], TTSK contains 67.24 km of motorways, 22.93 km of expressways, 268.084 km of I class roads, 535.873 km of II class roads and 1056,912 km of III class roads. Currently, TTSK has agreed on a framework contract with three bus operating companies providing services in public interest (suburban bus service on the territory of TTSK) operating 93 routes. Specifically, ARRIVA Trnava, a. s. operates 31 routes, Slovenská autobusová doprava Dunajská Streda, a. s. covers 45 routes and SKAND Skalica, s. r. o. manages 17 routes. Ten railway lines run through the territory of TTSK. They create a 347 km long rail network with 62 tariff points, composed of 30 stations and 32 stops. The railway lines run through 55 municipalities of TTSK, which is 21.9 % of the total of 251 municipalities. Railway lines on the territory of TTSK create an odotropic type of network [11].

4.1 Spatially functional analysis of TTSK residents transport accessibility by public transport

Early in the morning, the results confirmed the priority position of bus transport. In the Fig 1, several areas can be identified: Záhorie, north of the TT, PN and HC districts, the area around the town Sereď and the west of the DS district. Main reasons for the obtained results within the area of Záhorie are: i) train transport is not available as only few municipalities have train station/stop, ii) combined transport is not convenient as the first morning buses from the surrounding municipalities are not synchronized with the train departures, and iii) at the same time, the quality of road infrastructure is better in comparison with the railway infrastructure on lines 114 and 116. In the northern part of the TTSK region (i. e. districts TT, HC and PN), good road infrastructure leading primarily to Trnava and small number of functional train tariff points accessible by buses (for combined transport) contributed to the major usage of bus transport. The surrounding of the town Sereď is typical by frequent and convenient train and combined journeys. Most municipalities in this area have a direct journeys with Trnava in the morning. On the other hand, the train is only available in Gáň, Sereď and Križovany nad Dudváhom, where bus and train journeys do not follow each other. This situation creates complications and makes combined transport impossible.

The west of the Dunajská Streda district is a typical gravitational area of bus routes to Šamorín and Bratislava. These bus stations are not in close proximity to the railway stations. For this reason, from Bratislava bus station, the journey to Trnava is better by long haul bus than by train, to which travelers need to move by using Bratislava public transport.

On the other hand, the quality of the journeys in the early morning is brought by the railways due to the arrival of their employees. In most municipalities with a train tariff point, the train route was more favorable or equivalent to the bus. The exceptions are: i) Pusté Úľany with more convenient bus lines as the road is more direct, ii) Buková with a remote train stop and the fact that the first train to Trnava does not stop there, iii) municipalities between Leopoldov and Piešťany, which are offered only one complicated journey with Trnava through Piešťany, iv) line 114 from which surroundings leads better road infrastructure. In addition, the Figure 1 also shows some areas where combined transport is preferred. Especially the surroundings of Galanta with a built transfer terminal with short transfer times and relatively well-timed train and bus timetables, while the direct bus journey with Trnava is poor. Similar parameters were observed in the south from Dunajská Streda, with the integrated transport terminal in Dunajská Streda, as well as near Piešťany with the integrated transport terminal in Piešťany.

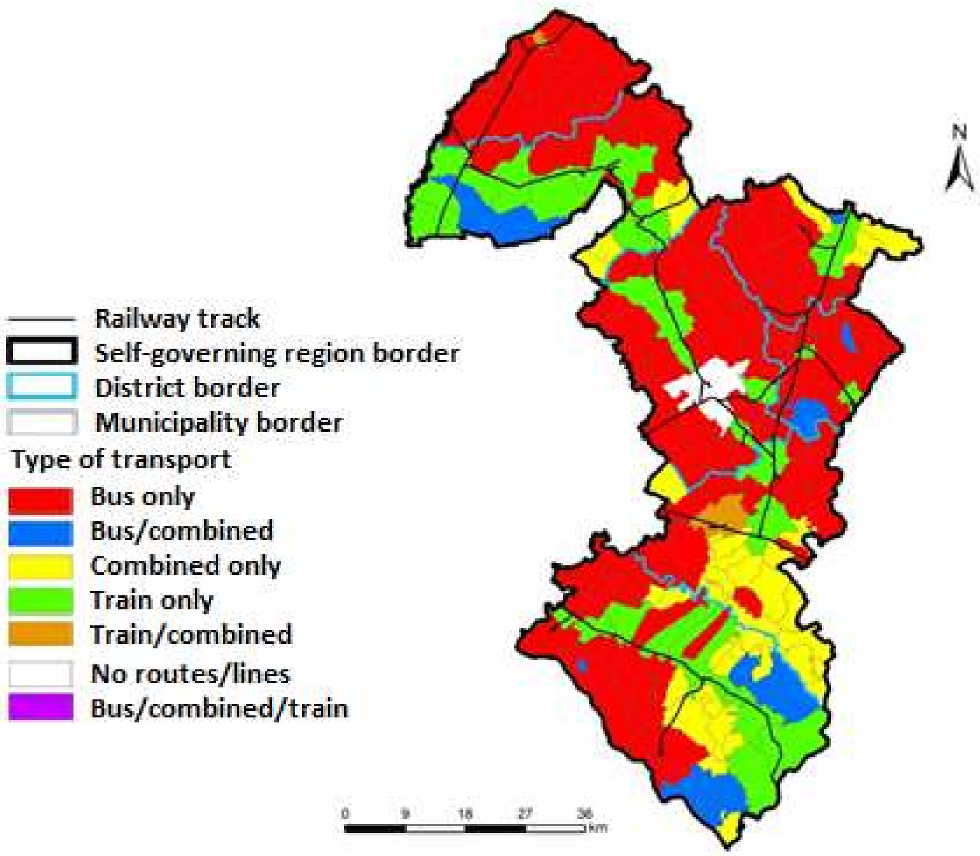

Figure 1 The best journeys to the regional capital Trnava from the municipalities of TTSK at the time 4:00

The Figure 2 shows a few changes in comparison with the previous figure. First of all, the surroundings of Gbely are more oriented towards train and combined transport. This is due to the situation (at around 6:00) in municipalities with a railway point, where it is already worthwhile for bus operating companies to transport people from places where it was pointless at 4:00. Thereafter, these people are transported by a train that arrives in Trnava at 7:21. This way, trains can compete significantly with buses, which are slower due to poor road infrastructure in the section from Gbely to Senica.

Thanks to the alternative route through Galanta, a significant part of the municipalities of the Dunajská Streda district, which had a favorable rail or combined transport at 4:00, was reoriented to bus or combined transport. A similar process occurred in Sereď and Gáň, where the bus arrival time in Trnava (7:30) is more convenient, rather than train arrival time (7:21), which result in higher complex accessibility.

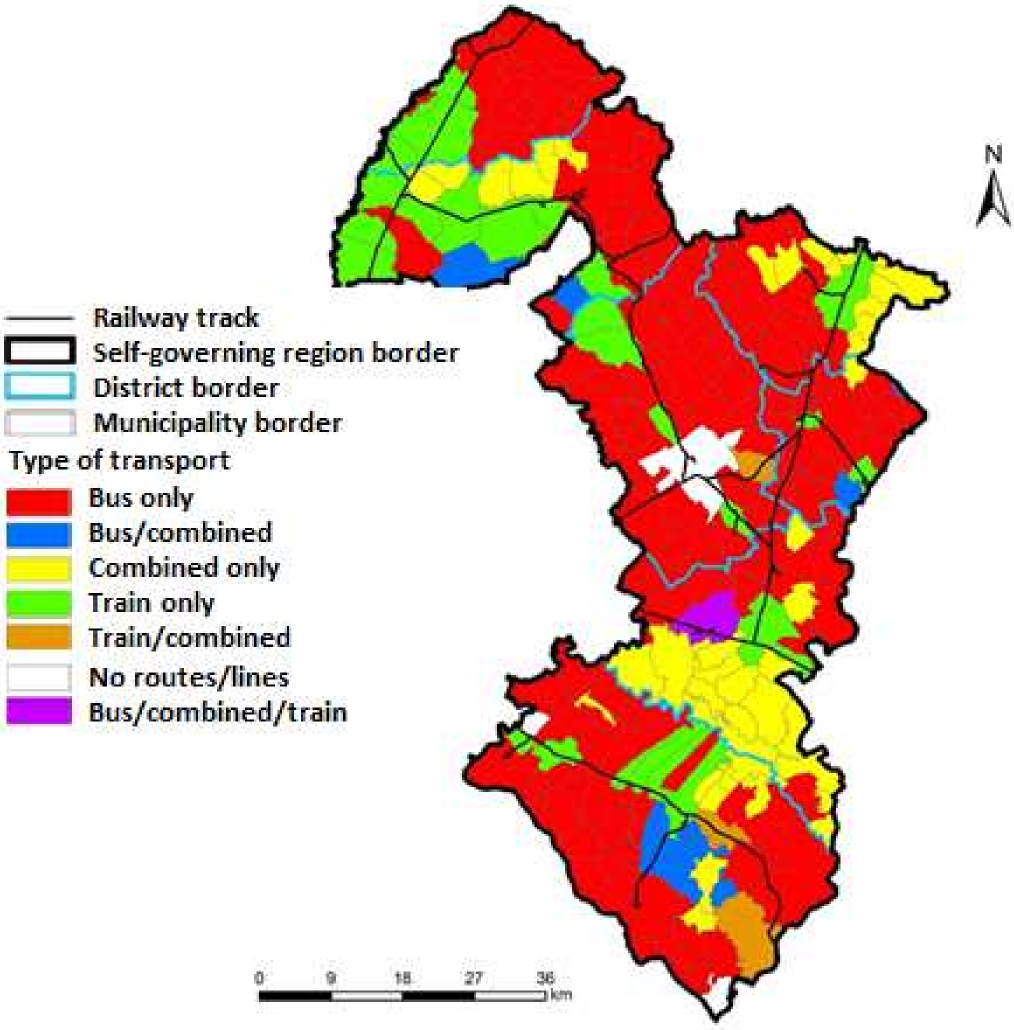

Figure 2 The best journeys to the regional capital Trnava from the municipalities of TTSK with the arrival time before 7:30

The Figure 3 shows a significant change in comparison with the maps of morning journeys, especially in two aspects: i) almost complete orientation of the districts of Dunajská Streda and Galanta to the bus transport, ii) a strong orientation of Záhorie region to combined or train transport. In the district of Dunajská Streda, this change was caused by the time-consuming regional train to Bratislava with 22 minutes break to following train to Trnava. In the case of Záhorie region, the significant factor is that trains from Trnava to the mentioned direction depart at 14:06 following shortly after the arrival of other regional trains from surrounding municipalities. Buses leave Trnava usually around 14:30, due to the shifts in the Zavar logistics park, which creates long break within the journey. The bus transfers in Cerová-Lieskové, Šajdíkove Humence, Borský Mikuláš and Šaštín-Stráže that follow the train from Trnava have simple, unequipped bus stops (sometimes even without shelters), but the timing of the buses is well-planned, thus creating an easy distribution to municipalities which are far from the tariff points.

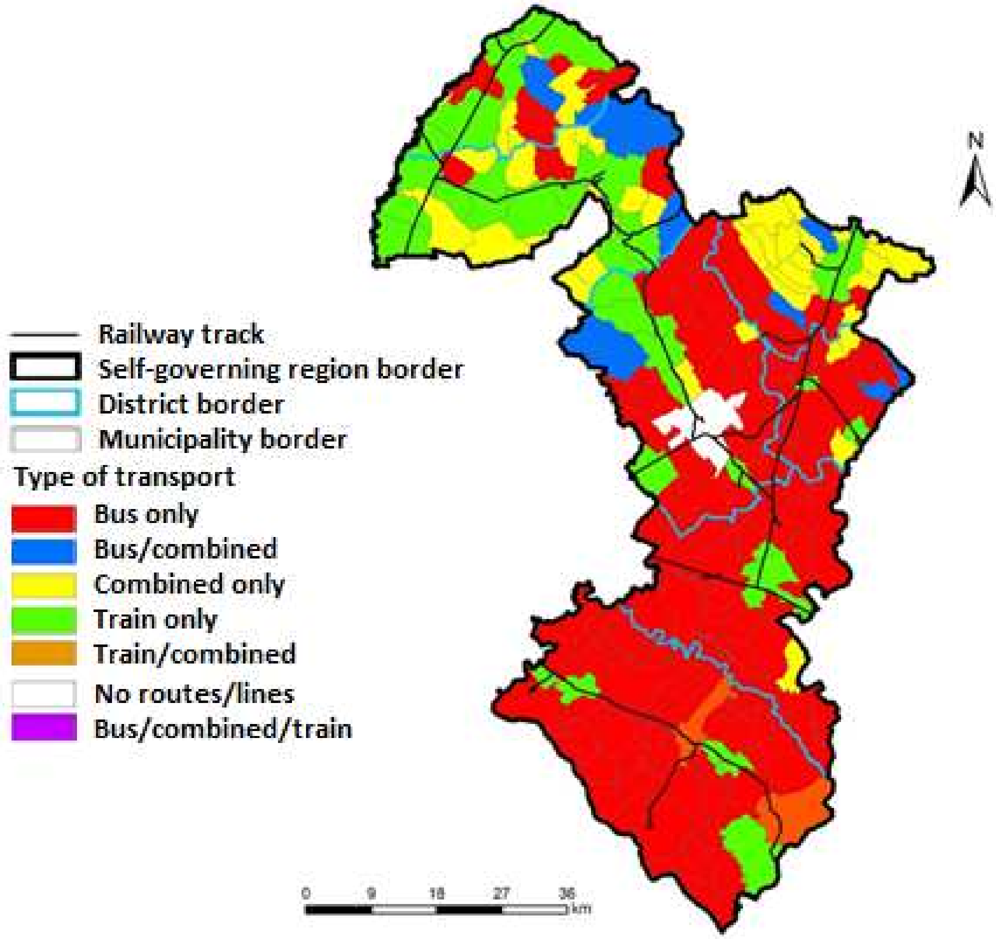

Figure 3 The best journeys from the regional capital Trnava to the municipalities of TTSK at the time 14:00

The map of the journeys from Trnava with the latest departure (Figure 4) brings a completely different result. The usage of train transport is preferable only in the south-east of the district of Dunajská Streda, the towns of Galanta and Sládkovičovo and several municipalities along lines 116 and 110. The reason is that the last buses have later departure time than the last trains. On the other hand, a large part of the districts of Senica, Skalica and Dunajská Streda residents chose combined transport, as direct bus transport from Trnava was not provided to municipalities situated away from the main roads from Trnava past 22:30. The later journeys by combined transport were more preferable. Passengers chose combined transport despite the long distance between the train station and bus station in Bratislava and Senica, which was inconvenient at peak times. Combined transport proved to be advantageous in the vicinity of Galanta again.

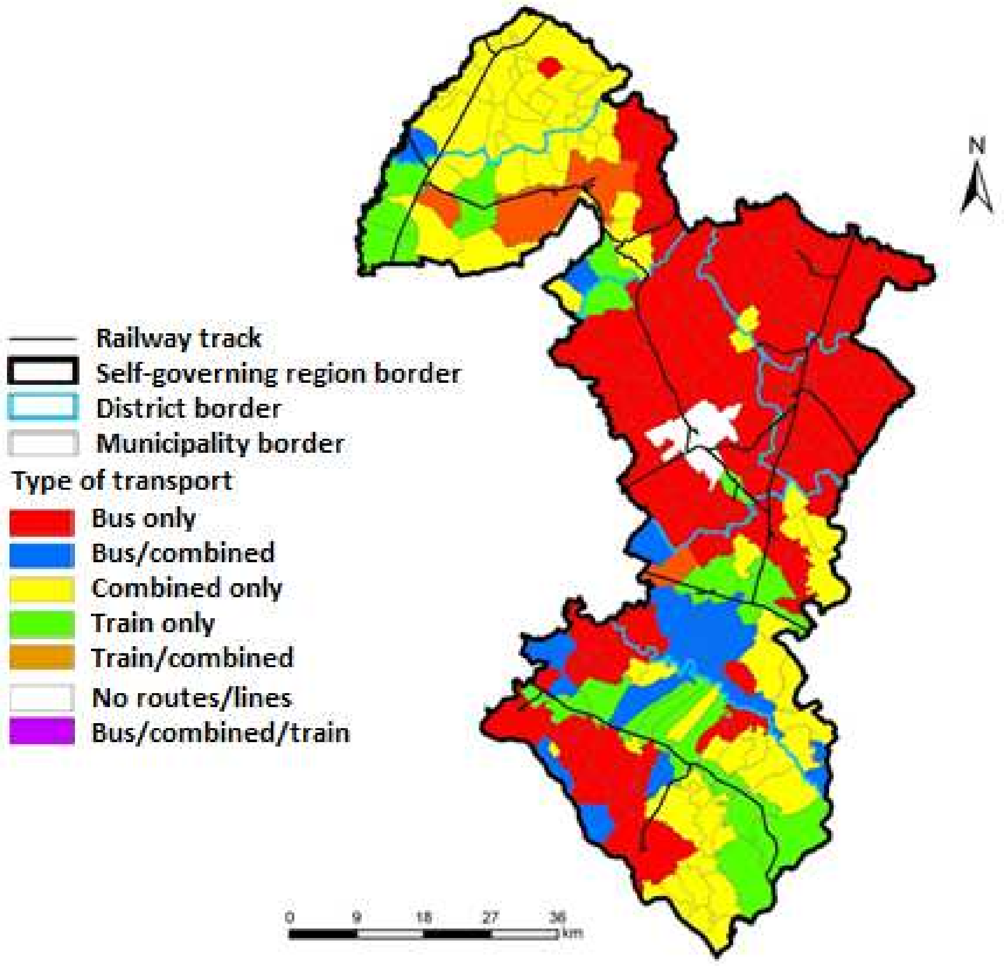

Figure 4 The best journeys from the regional capital Trnava to the municipalities of TTSK with the latest departure

The authors of this paper conclude from the results of the investigation that the bus was the most efficient type of transport within the Trnava Self-Governing Region. In the first morning journeys, 53.36 % of TTSK residents and almost 70 % of municipalities considered bus transport as the most advantageous way of transport; 62.47 % of residents and 71.32 % of municipalities preferred bus transport to travel to Trnava at 7:30; 56.91 % of residents and 65.33 % of municipalities preferred bus transport at the 14:00 departure time and 56.68 % of residents and 62.55 % of municipalities preferred bus transport for the latest journey from Trnava in comparison with the train and combined transport. According to the calculations, the bus was convenient especially for smaller municipalities.

The train transport reached the highest efficiency according to the number of residents (36.69 %) at the first morning journey to Trnava. However, according to the amount of percentage points of TTSK municipalities (17.93 %) the highest value was obtained at the 14:00 departure time. This means, that the morning train transport was more efficient for larger municipalities and train transport at 14:00 was more efficient for smaller municipalities.

Combined transport showed the highest values at the latest departure time from Trnava with 20.38 % for the TTSK population and 26.9 % for the municipalities, specifically the smaller municipalities of TTSK (Table 1).

Another important aspect related to the quality of public transport services was direct lines. The direct lines without transfers have the best chance to compete with individual transport. According to the collected data, 101 municipalities within TTSK had direct bus journeys (40.3 %) with Trnava (both directions, within 24 hours), in total 1327 journeys. Most frequent lines are with the Trakovice village with 111 direct journeys. On average, there were 13 direct bus journeys per 24 hours per municipality. On the other hand, 24 municipalities of TTSK (9.6%) had direct train routes with the regional capital with total 428 journeys, which is almost 18 journeys per 24 hours per municipality. The village of Leopoldov had the most frequent direct train journeys with Trnava, 76 journeys in 24 hours. Final evaluation of the accessibility of the regional capital by direct line was that the train transport had 38 % higher number of journeys than bus transport.

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Table 1 The most effective way of transport provided by public transport between the regional capital Trnava and the TTSK municipalities at four key times

The most effective way of transport		**Number of TTSK municipalities**		**Number of TTSK residents**	
Bus, Train, Combined		**Abs.**	**%**	**Abs.**	**%**
The first morning arrival to TT	Bus	174	69.33	265 495	53.36
	Train	40	15,93	**182 538**	**36.69**
	Combined	37	14,74	49 542	9.95
Arrival to TT at 7:30	Bus	**179**	**71.32**	**309 656**	**62.47**
	Train	26	10,36	118 159	23.84
	Combined	46	18,32	67 846	13.69
Departure from TT at 14:00	Bus	164	65,33	277 899	56.91
	Train	**45**	**17.93**	145 713	29.84
	Combined	42	16.74	64 722	13.25
The latest departure from TT	Bus	157	62.55	285 990	56.68
	Train	29	11.55	115 738	22.94
	Combined	**65**	**26.9**	**102 847**	**20.38**

5 Conclusions

According to [1], the organization of the public transport should reflect changes in the spatial organization of society and country systems. The most important changes are suburbanisation in the proximity of the largest cities and towns [22], changes in economic positions of centers, etc. The big differentiation in the availability and density of spatial links of the functional region (the so-called low availability of region) causes negative consequences for the overall region development [21]. Poor accessibility may result in low level of education, unemployment and low level of social capital [21,28-30].

The authors of the paper have reviewed the current trends in a qualitative dominance of various types of public transport in TTSK. Comprehensive picture of the transport individual types characteristics in terms of following the scheduled route timetables in the TTSK region during the selected key times was provided. The main sorting element for the accessibility evaluation of TTSK municipalities was the presence of railways on their territory or the distance from it. The disadvantage of the train transport is that the lines are linked to existing railway infrastructure (lines and stations). The train routes order within the territory of Slovakia is subject to approval at the level of the Ministry of Transport, Construction and Regional Development of the Slovak Republic (the relevant departments [3]) [3] points out that this system is not optimal in terms of coordination among various types of transport. Regional bus transport brings both advantages and disadvantages. On the one hand, the bus can get almost anywhere, serves usually 2-3 more stops in the municipality than train, is less limited to the capacity of the infrastructure and the loss of profits due to black passengers is lower. On the other hand, the bus transport is slower, more endangered to traffic jams, accidents and has less passenger capacity per one vehicle driver. Combined transport by using both bus and train combines the advantages and disadvantages of the two above-mentioned types of transport. Its advantage is that combined transport enables to avoid routes that are problematic in terms of traffic jams and increases the frequency of the journeys, and at the same time, the combined transport helps to bring the advantages of the train transport to municipalities that are positioned further from the railway station. The disadvantage is required space for bus turnovers near the train station and on the willingness of bus operating companies to adjust their timetables to the departure of trains and to modify their routes to closer proximity of the train station.

The authors of this paper have realized that not all four solved times are equally necessary for passengers and that people do not travel only to a regional capital. The number of transfers is also important factor. There exists a certain threshold value for travel distance, time and number of transfers, which affects the commuters to either not visit the regional capital or choose to travel by a car. From the collected data can be concluded that these limits are at a distance of 150 km, with a time interval of 2 ½ hours, at a maximum of 3 transfers. However, the number of direct journeys is important factor, where, on average, train transport achieved a better result.

Generally, it was predicted, that every type of public transport in the territory of TTSK has areas where it is currently the main way for commuting to the regional capital.

It is difficult to judge which type of public transport should be promoted primarily for the most efficient route. However, in Slovakia, several bus operating companies complain about the introduction of free train services for certain population groups, causing them loss of customers. As a result, they cancelled journeys, sometimes whole routes, even in places where passengers do not have an option to use train. The authors have realized that the lines need to be optimized in terms of continuity and parallelism but no limited to the minimum necessary journeys.

This paper ought to inspire other experts to explore the quality of transport in other regions of the Slovak Republic. At the same time, it may be an impulse for improvement of the public transport operating companies' services and timetable scheduling.

Public transport is also recording changes after the covid crisis. Predicting future developments in this sector is rather compolicated. However, already at present is monitored and felt an obvious decline in transport with this form of transport and the strengthening of individual transport. At the expense of public transport, there is strong pressure to create cycle paths in cities such as Paris, where they plan to reduce the number of passenger parking spaces by 20% by 2024, when the Summer Olympics will take place, but not to encourage public transport but to create cycle paths and new infrastructure for safe bicycle transport in city. Such projects will again slow down the development of public transport, seriously affect its functioning and it is possible that even in the TTSK region, the situation of transport will return to the years of the first decade of the 21st century.

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IMPLEMENTING CIRCULAR ECONOMY CONCEPTS FOR SUSTAINABLE URBAN FREIGHT TRANSPORT: CASE OF TEXTILE MANUFACTURING SUPPLY CHAIN

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Abstract: Rapid industrialization and mass urbanization have generated a challenging situation for the city's planners and managers to maintain a balance between economic development and a sustainable environment for its inhabitants. Circular economy concepts can offer a unique opportunity to decouple growth from resource requirements. At the core of the circular economy, is the proposition of complete elimination of waste – i.e. waste not in its traditional sense, but any form of underutilization of assets and resources. A case study of the textile manufacturing industry in Surat, India is taken to compare the performances of traditional supply chain processes and the advantages of adopting circular economy concepts. Temporal sprawl of the textile industry is used to find the changes in trip lengths of urban freight trips over the last two decades. For estimating freight trips volume and patterns, roadside interviews of freight vehicles and establishment surveys of manufacturing and trading units were conducted. Overall urban freight transport contribution from the textile industry is estimated by modelling field data. Organized trip planning and optimized utilization of payload capacities can reduce vehicular emission generated from commercial goods movement in the textile industry to 2/3rd of its current levels. The paper asserts reinforces that the integration of circular economy principles with supply chain processes is beneficial from sustainability as well as a business point of view. The congestion mitigation due to the reduced number of trips offers a further reduction in the overall traffic emissions due to better traffic flows on the city's road network.

1 Introduction

Circular economy (CE) is the representation of a continuous cycle that cautiously utilizes natural capital, optimizes resource yields, and minimizes system risks by managing stocks and renewable flows. According to CE Principles, any kind of limited resources should follow 3Rs, i.e. reduce, reuse and renew [1], while renewable resources should follow the 6Rs, i.e. reuse, recycle, redesign, remanufacture, reduce, recover [2]. Building a CE environment needs coherent change in consumer behaviour, governmental policies, and business practices. Such a transition is complex and requires simultaneous changes in various sub-systems, such as energy, logistics, and financial sub-systems. In different parts of the world, the concept of CE has evolved differently based on their cultural, social, and political systems [3]. For instance, in the United States and Canada, corporations apply the CE concept to conduct product-level life cycle studies [4], in Europe CE is applied for addressing issues associated with the use of natural resources for sustained economic growth as well as for effective waste management [5]. Some CE related initiatives in South Korea and Japan aims to increase consumers' responsibility for material use and waste [6,7]. In China, the concept of CE is used as a mechanism for profitable product development, technology development, and improving industry management [8].

Post economic liberalization in 1991, India has been experiencing environmental degradation in extreme measures. As the economy struggles with supply-demand issues, faster urbanization is leading to a greater generation of waste. On one hand, there is a need to sustain the industrial growth in our desire to become a developed economy; and on the other hand, it is critical to identify innovative growth models that do not aggravate the existing resource constraints in India. It is estimated that in India, the transport sector emits 258.10 million metric tons of carbon dioxide (CO_2), out of which 94.5% was contributed by road transport alone [9]. The present case study is of Surat city, which is located on the western coast of India in Gujarat state. The city is the 8th most populous with around 4.6 million people [10]. With the decadal growth of over 55%-60% since the last four decades, it is one of the most sought destinations for employment and business opportunities. The city has a very vibrant economy as it is a hub to the diamond and textile industry. Globally, 63% of the textiles produced is through synthetic fibres [11], which are derived from petrochemicals and its production leads to the generation of CO_2 [12]. Surat, located on the western coast of India is also a big manufacturing hub of synthetic textiles. The city is popularly known as the “Synthetic capital of India” for its scale and expertise in the manufacturing of synthetic textiles. Textile manufacturing processes in Surat have a fragmented industry structure leading to several goods movement trips in the city. According to a study, the internal goods movement generated by the textile industry makes around 40% of the total internal goods movement by light commercial vehicles (LCV) [13]. In the present study freight trip generation from the textile industry is estimated and the emission impact of these trips is found.

The city has a very high level of vehicular emissions, especially particulate matter (PM) levels in the areas having industry presence. Almost 38,000 LCV trips made for transport of textile goods are found to be empty due to non-optimized operation generating more than 190 tonnes of CO_2 every day. Empty vehicle trips are also causing unnecessary traffic on city roads thereby reducing the overall efficiency of the network. If the estimated empty LCV trips are optimized by planning complete utilization of payload capacities, 370 thousand vehicle kilometres travel (VKT) can be reduced from the city roads. With reduced use of LCVs owing to optimization, the congestion situation is predicted to mitigate. Vehicular emission, especially Particulate Matter (PM) are found to be in a very high amount in the textile industry clusters, for some areas it is twice the national average and exceeds the permissible limits for a healthy life. The current state of affairs is not sustainable for years to come even after the optimization of empty trips. The use of alternate fuel sources has been extensively promoted in several countries of the world already. In India too, a new policy is taken up by the government to replace petroleum fuel-based vehicles with electric battery vehicles by the year 2030. This initiative can also be implemented for LCV used for short freight trips in cities. Textile freight being lightweight and average trip length under 10 km, diesel engine LCVs can conveniently be replaced by electric LCVs (e-LCV). Also, the use of e-LCV would provide relief to alarming levels of vehicular emission in the highly affected area. The overall ideology is to make the entire goods movement cleaner and eco-friendly for the industry and the city as well. Cleaner urban freight transport would reduce the overall vehicular emission in the form of GHG and CO_2 emitted for every kilometre travelled.

2 Literature review

The circular economy concept has been important, relevant, and applicable for a long time in the manufacturing industry. With depleting levels of natural resources and increasing levels of man-made pollution, the focus of the academic and research community is gradually shifting from the predominant linear growth model of produce, use, and dispose of, to a sustainable and eco-friendly growth model which CE offers. The CE concepts are implemented in several ways by various industries at different times, and hence evidence for the origin of the CE concept is unclear [14]. CE is not a standalone concept, but it is interwoven with various other concepts like industrial symbiosis [15-17]. Some conceptual frameworks for CE proposed by different researchers and institutions are given in Table 1.

Table 1 Concept of circular economy given by different researchers

Year	Conceptual framework for circular economy
2007	Revamping the material flow from linear flow to circular flow; thereby increasing the efficiency of resource utilization and reducing the amount or intensity of emissions [18].
2008	Materials flow in a closed loop of activities with feedback processes, the basic process in which natural resources get transformed into manufactured products thereby generating by-products that can be fed as resources for other industries [19].
2011	Develop a closed system of resource-product-renewed resource, which involves reducing, reusing, and recycling of resources, against a unidirectional system of resource-product-waste [20].
2013	It brings a paradigm shift, used products (waste) used will be repaired, reused, and recycled for other purposes [21].
2014	Shift towards the use of renewable energy sources; eliminate the use of toxic substances and minimization of waste through the superior design of materials, products, systems, and business models. Replacement of the end-of-life concept with restoration [22].
2015	Maximization of in-use resources throughout its life cycle, from sourcing to supply chain, to consumption, to the remaining unusable parts for one function and converted back into a new source for another purpose, thereby reducing the extraction of resources from nature [23].
2016	Decoupling of economic growth from the extraction and consumption of scarce resources with negative footprints and making existing resources productive for as long as possible [24].

Though after a much delay, gradually there is a universal realization that the earth is fragile with its carefully balanced ecosystem and natural resources [25]. There is a fundamental shift in the socio-economic and environmental landscape, technology evolution, population growth, and global awareness regarding the finite nature and rapid depletion of resources. The consumption model, i.e. cradle-to-grave model which involves exploiting the finite resources to create new products and eventually disposing of the used products non-systematically into landfill sites, which lacks sustainability for the future. There is a lot of risks associated with the increasing demand-supply gap due to the growing population, increasing demand for resources, finite nature of resources, and take-make-dispose oriented linear economic model that has led to an interest in the adoption of the cradle-to-cradle model. This cradle-to-cradle approach forms the central idea of the CE model [26,27]. Though a considerable amount of research work is carried out in the area of CE, the majority of it is focusing on the manufacturing and operations phase of any product/ service development. From the 3Rs of CE i.e. reduce, recycle, and renew, [28]; reduce is the components applicable to efficient logistics or supply chain management systems. According to the Circularity Gap Report [29], about 26% of the global carbon dioxide emission is due to transport processes. It is not necessary to recycle or renew the waste or by-products to successfully apply the principles of CE. Reduction in the available resources is also a very way of making the environment sustainable wherever recycle or renew is difficult. There are very limited studies carried out which explore the application of CE in city logistics or freight management.

Urban freight transport (UFT) is a very crucial area for the sustainable existence of cities. Research in UFT has come a long way from early effort started in the 1980s in the US and European Union. Recently, a multistage modelling approach is used that points out the relations existing among city logistics measures, actors, and choice dimensions. It comprises three model sub-systems to estimate the quantity origin-destination (O-D) matrices by transport service type (i.e. retailer driven or wholesaler driven or by a third party carrier), the delivery O-D matrices by delivery period, and the vehicle O-D matrices according to delivery tour departure time and vehicle type [30]. A similar analysis of freight trip attraction (FTA) and its relationship with key features using spatial econometric techniques to assess the role of spatial effects among establishments and the urban environment, where the results show that FTA is better modelled as a non-linear function of employment and other location based variables like floor area and width of connecting road [31]. Bringing urban analysis and spatial studies closer to urban logistics appears to be relevant to tackle last mile issues. A spatial analysis coupled with a logistical approach provide a relevant diagnosis for urban logistics practitioners and local authorities, before the settlement of logistics organizations or new regulations that suit cities' characteristics, assets and constraints carried out comparison of constant freight trip generation (FTG) estimations for three different aggregation levels of activity-based categories to derive different functional forms [32,33]. It is observed that suitable functional form can reduce the need for more disaggregated data, which can reduce the overall cost of collecting data.

From the relevant studies reviewed it has been found that the majority of the researchers have focused only on the freight trip generation aspect in their work, freight distribution and trip assignment is not explored much in research, probably due to the complexity of the supply chain of innumerable goods and service offered. Studies are primarily carried out from the data obtained from transporters dairy, industries, or vehicle surveys. Also, studies have focused on aggregate data of all the freight intensive activities of the city. An exclusive study focusing on trip generation characteristics of the industry and its traffic impact on the city network has probably been an unexplored dimension in the city logistics.

3 Supply chain analysis: Textile industry

Textile is the largest industry in the city employing a million people directly and indirectly. The city has its production facilities specialized in synthetic textiles, having 21 industrial clusters in different parts of the city having more than 25,000 manufacturing (weaving) units, and 513 processing units. Surat exports its textile products to various corners of the country and abroad regularly. The textile industry in the city is highly fragmented with clusters of small production units set up in different corners of the city. Details of production, processing, and trading facilities of the textiles industry are given in Table 2.

Table 2 Details of Textile Industry, Surat

Type of units	Activity	Number of units	Number of Clusters	Approximate area occupied
Powerloom and shuttle-less looms	Weaving of raw fabric	25,000	20	3 million sq. m.
Processing house	Dyeing, printing	400	5	7.43 lacs sq. m.
Value addition works	Embroidery, jari works, lace work etc	11,000	12	1.2 million sq. m.
Trading	Wholesale and retail trading	160 trading complexes	2	3.3 million sq. m.

The fundamental textiles manufacturing process involves several stages like weaving, dyeing, printing, etc, and requiring goods flow from one place to another for different activities. From the various interactions with industry experts and trading unions, it is observed that the entire textile manufacturing process can be divided into four phases. A diagrammatical representation of the various processes (Figure 1).

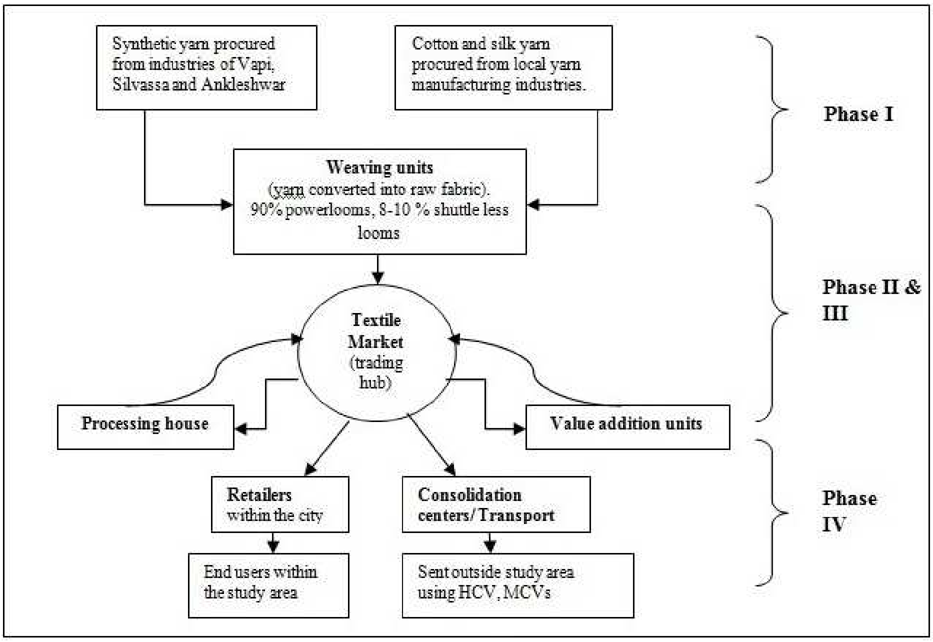

Figure 1 Supply chain of textile manufacturing industry

***Phase 1**:* Raw material procured locally or nearby industrial towns (Vapi, Ankleshwar) reaches Surat in the form of yarn reaches the weaving units (powerlooms)., which is then sent to the textile market for trading or further processing. In this stage, the predominant modes of transport are heavy commercial vehicles (HCV) and medium commercial vehicles (MCV).

Phase 2: The yarn is weaved to produce raw fabric or grey cloth which is sent to the textile market, it undergoes various initial quality checks there. Here the transportation of the processed fabric takes place through LCVs.

***Phase 3**:* Raw fabric is then sent to the processors for dyeing and printing activities. Then again, the processed fabric is sent to the textile market for final quality checks. Freight is moved using LCVs here. The processed fabric from the textile market is sent to various small-scale value addition units. Since the value addition units have a very small quantity of goods transactions, it is generally carried using two-wheelers or passenger three-wheelers also.

Phase 4: In this stage, the processed and value-added fabric, after undergoing physical quality checks at the textile market, is dispatched to the consolidation centre. From the consolidation centre, the finished textile is distributed outside the study area via HCVs and MCVs. As there are a large number of units for each phase of production and traders involved, a lot of trading activity of goods takes place in the city leading to frequent traffic jams and congestion (Figure 2).


Figure 2 Traffic condition at Surat's textile market area

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The city has a very well developed market along with it major arterial road (ring road) for trading in textile goods, the market covers an approximate area of 3 square kilometres and has more than 140 building complexes housing approximately 60,000 traders engaged in the textile business. The textile industry of the city is witnessing continuous sprawl in its manufacturing and market facilities over the last three decades. Figure 3 shows the expansion of the textile market area of the city from the year 2000 to 2018.

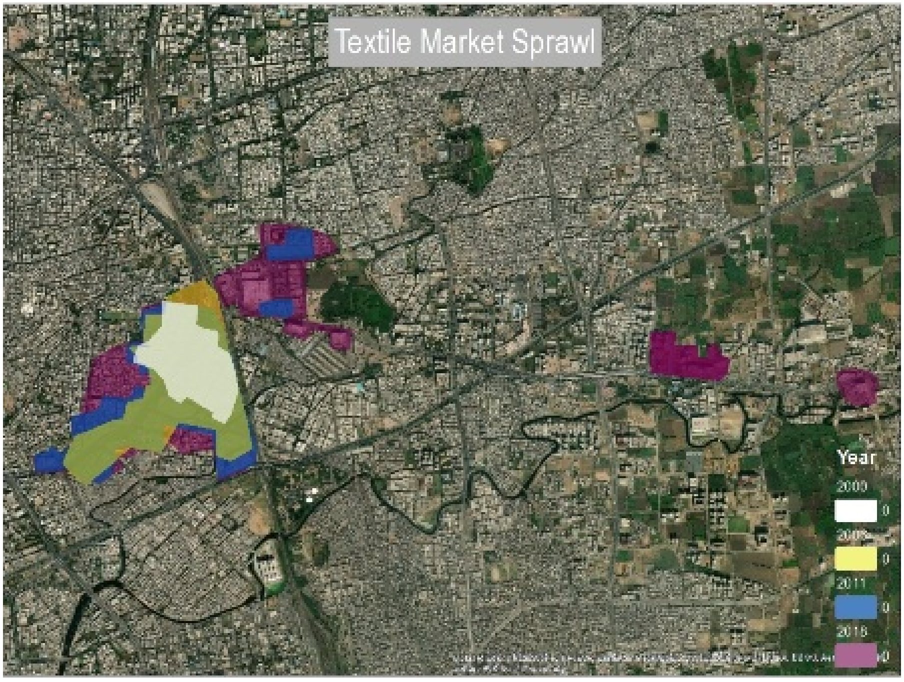

Figure 3 Temporal sprawl of textile market area, Surat

Similarly, the production units also have gradually sprawled out to newer outskirts of the city owing to higher land prices and traffic congestion in the city centre (Figure 4). The sprawl of the textile industry is more towards the eastern side whereby the national dedicated freight corridor (DFC) would be coming up soon.

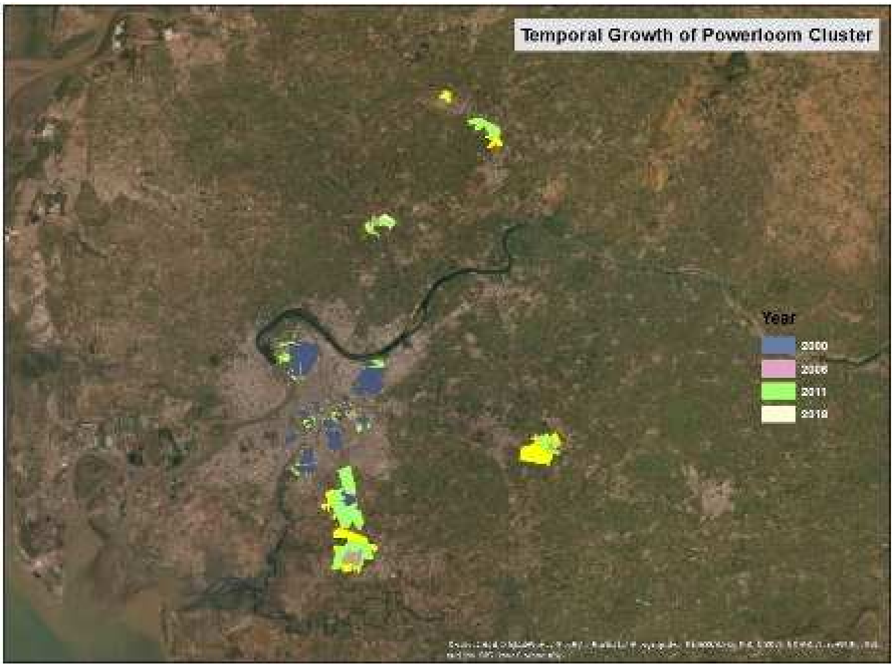

Figure 4 Temporal sprawl of textile powerloom (weaving) units

For both, the maps shown in Figure 3 and Figure 4 colour coding is used to show the expansion of market area and clusters' growth over the years. The textile industry has grown considerably over time. As per recent data, textile production in Surat has grown by 10% in the last 5 years [34]. LCVs having diesel-run engines also have higher emissions than their petrol or natural gas counterpart. The sprawl of textile activities increases pollution in the newly developed area gradually. Environmentalists have carried out studies to measure pollution levels in different parts of the city and the results found and not very encouraging. The city is already facing serious health problems from the high levels of particulate matter (PM) in the atmosphere due to the industrial emissions and noxious fumes of vehicles, particularly in the last two years. Annual PM10 data of the Gujarat Pollution Control Board [35] shows that the particle pollution recorded from 10 locations in the city was much higher than the national average (Table 3).

Table 3 Air quality at different location in Surat

Name of location	PM10 level	PM2.5 level	Activity pattern
Udhana	167	53	Textiles (Weaving)
Bhagal	130	42	Oils and chemicals
Palsana	147	48	Chemicals
Pandesara	171	54	Textiles (Weaving)
Pandesara GIDC	184	55	Textiles (Mills), Chemicals
Chalthan	173	50	Heavy industry, Pipes
Sachin GIDC	188	55	Textiles, Oils
Jolva	184	53	Textiles, Freight Transport
Ring Road (Delhi Gate)	164	54	Public and Private transport

Source: GPCB Data, 2018

Pandesara GIDC which has most of the textile processing houses in the city is having a mean of particulate matter (PM10) at 184 per micrograms per cubic meter of air (μg/m^3) per annum as against the national average of 100μg/m^3. In the ring road (Delhi Gate), where the textile markets are located, at 164μg/m^3 the PM10 levels are exceedingly high. Air Quality Life Index (AQLI) reveals that an increase of 10 micrograms of PM10 (particulate matter that is 10 micrometers or less in diameter) per cubic meter of air (μg/m^3) reduces life expectancy by 0.64 years [36]. World Health Organization has suggested the levels of PM 2.5 at 10 μg/m^3 annual mean and keeping these levels in check may help increase the lifespan in cities [37]. While Surat's annual average PM 2.5 level at 50μg/m^3 is an alarming situation. With the growth of the industry and population growth prospects, it is going to be very tough for city officials to provide room for both the healthy lifestyle and sustainable growth of the city.

4 Estimation of textile industry freight trips

For collecting data related to freight flow patterns in the textile industry, roadside interviews (RSI) of freight vehicles and establishment surveys (ES) of various manufacturing and trading clusters were conducted. Some surveys were also conducted with transport providers to understand the inflows and outflows of freight from the city. The RSI provided the data regarding the type of vehicles, loading capacities, origin-destinations, route, and timings of freight movement in the textile industry. While the ES provided information regarding the daily output and thereby daily trips per unit area of the establishment, number of employees, production capacity, and capacity utilization. The textile industry has cauterization of production units with similar activities based on the availability of labour and other ancillary support. There are clusters of different production phases and trading developed in different areas of the city which is represented on the map of Surat (Figure 5).

It also shows the location of important public transport locations like railway and bus stations. This location is bound to have excessive passenger movement along the road. As per the data obtained from the traffic control cell of the city municipal office, movement of HCV is restricted within the city limits from 7:00 am to 12:00 pm and 05:00 pm to 11:00 pm; also movement of MCV is restricted along the ring road encompassing the central zone of the city. Due to these restrictions majority of the textile goods transportation within the city is carried out using LCVs only. From the roadside interviews of 1137 freight vehicles carried out for 24 hours on a typical working day along with the ring road trip, destinations have been mapped (Figure 6).

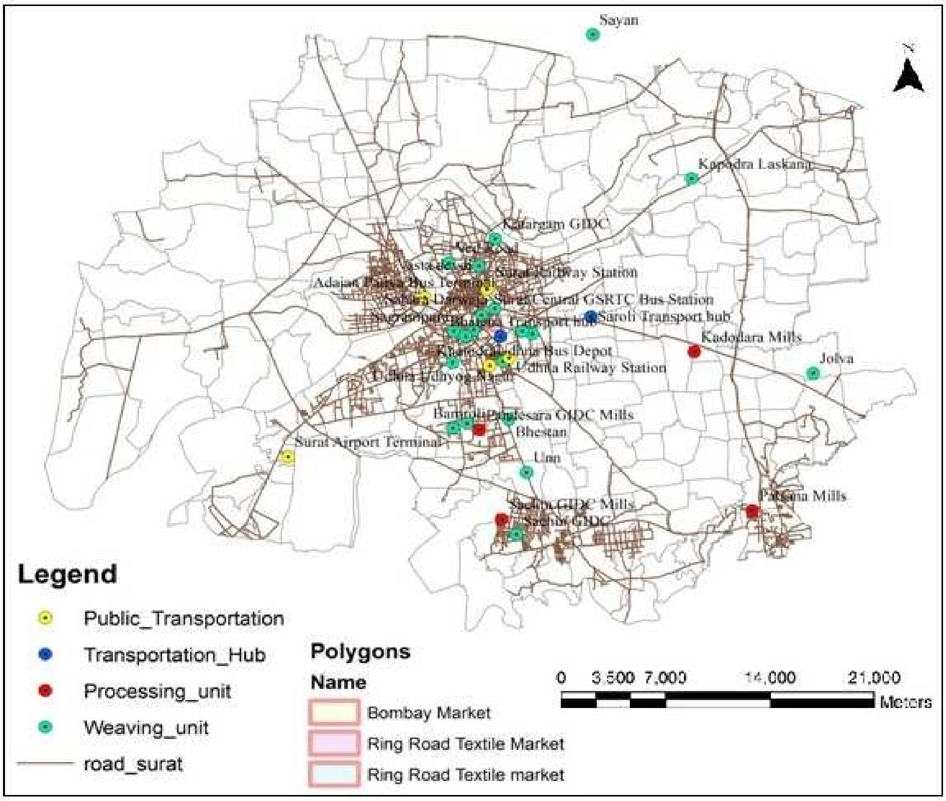

Figure 5 Location of textile industry (production units and market), Surat

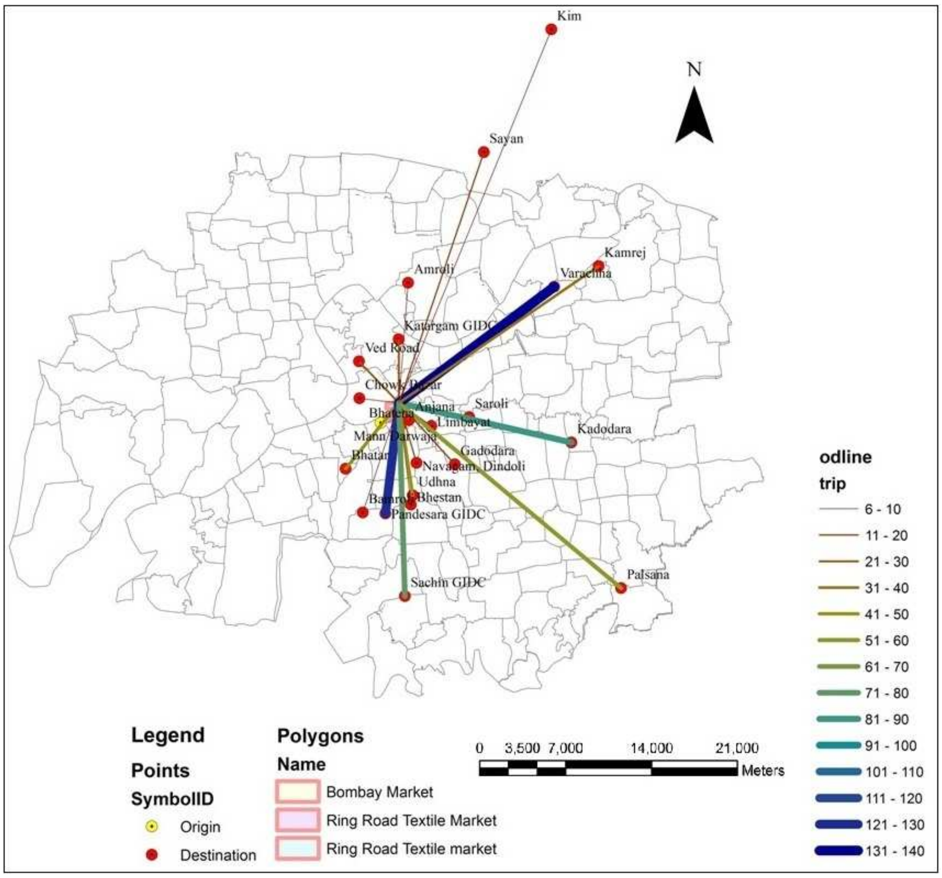

Figure 6 Mapping of LCV trips in textile industry

During the survey, it is also observed that around 20% of the trips originating in the market area and getting completed within the market area itself. It is also observed from the survey that around 35% of the LCVs trips are empty. During the drivers' survey, willingness to electric LCVs (e-LCV) was asked and it was found that approximately 60% of the drivers were willing to shift to e-LCV if they were provided proper facilities (Figure 7).

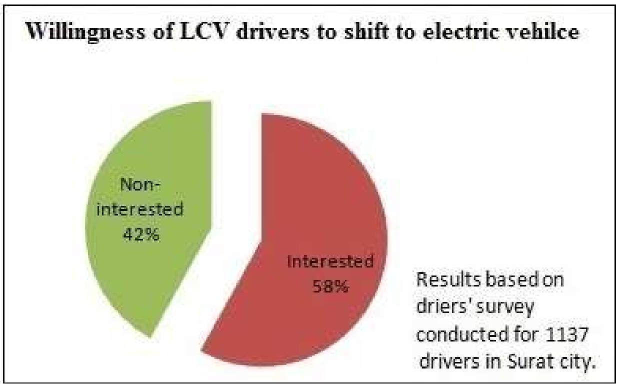

Figure 7 Percentage of LCV drivers willing to shift to electric LCV

Details of the emission standards of the vehicles used were recorded during the survey. It is observed that not all the LCVs used in the city are having the latest emission norms i.e. Bharat Stage IV (BS-IV), on the contrary majority of the LCVs are of the models of previous emission norms. Figure 8 shows the percentage of share of vehicles based on the emission norms.

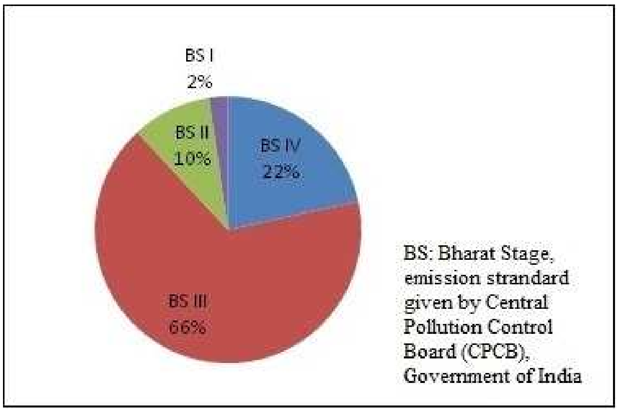

Figure 8 Distribution of LCVs based on emission standards

Also, the trips from the various textile clusters have been estimated using the ES data. The majority of the trips carrying the semi-finished goods within the industry are carried out using LCVs from the manufacturing clusters also. When the map of trips originating from manufacturing clusters was compared with that of the ring road market area, it is observed that similar clusters have been mapped as the destination locations from the RSI of freight vehicles. Figure 6 shows the directional movement of LCVs from various clusters of textile manufacturing. Here clusters from Katargam, Varachha, Udhna, Pandesara are having very high numbers of freight trips, as these clusters are quite old and have a large number of textile manufacturing units (up to 1800 units in a single cluster), while Sachin, Palsana, Kamrej and Jolva which are on the outskirts of the city showing lesser number of freight trips in the map as the number of units in these clusters are less. Also, clusters located in the outskirts do not prefer frequent trips as the distance is more. Establishment survey of production units and trading units enabled designing a trip attraction and production models based on the parameters used in several works of literature on freight trip generation (FTG) (Equation 1).

Multi-linear Regression model for trip generation for goods movement in textile industry is:

$$FTG = 9.686 + [(\underset{(0.0264)}{0.0055} * Q) + (\underset{(0.0031)}{0.0480} * Npm) + (\underset{(0.0037)}{0.0074} * A) + (\underset{(0.0013)}{0.1485} * Ne) - (\underset{(0.0781)}{0.0167} * D)] \quad (1)$$

$R^2 = 0.78$

Where,

Q	is the quantity of goods produced (kilograms),
N_{pm}	is the number of weaving machines at the establishment,
A	is the floor area of the establishment (square meters),
N_e	is the number of employees at the establishment,
D	is the average distance between industrial cluster and distribution centre.

Values given in parenthesis are the p-values for each of the parameters of the multi-linear regression; here the values are statistically significant for each of the parameters. From the multi-linear regression model developed for production units, it is found that though the number of units largely depends on the factors like floor area of the unit, number of machines and labour employed, on an average 15 LCV trips produced per month, also a unit attracts at least 4.5 HCV/MCV trips per month for the supply of raw materials. For the trading units, the number of trips is largely fluctuating based on seasonal variation and overall business trends in the industry. Trading units are not trip generators, but they are trips regulators for different phases of production based on the demand and supply of a particular type of textile goods.

From the details shared 50 major transport service providers, it was understood that mining materials, construction materials, chemicals and oils, consumer goods and are the most important commodities from the tonnage of export and import point of view. Textiles goods contribute about 15% of the total commodities tonnage transported to and from the city. While the intra-city movement of goods within the industry is carried out using LCVs. For the export of goods outside the city HCVs and MCVs are preferred. Textile goods are exported to major cities in the country as well as to major ports for international exports. The major entry points for textile freight in the city are Navsari, Palsana, Kadodara, Pipodara, and Olpad. Traffic coming from/going towards Pipodara and Palsana have very high interaction with Sahara Darwaja where the major textile markets are located. There are 140 market complexes here, which enable business operations of more than 45000 textile traders. During business hours, the entire area of three square kilometres along the stretch between Mann Darwaja to Sahara Darwaja becomes extremely congested due to local goods trips and loading/unloading of the goods simultaneously.

Considering all the stages of the manufacturing process, the textile industry alone contributes around 38–40% of the total urban freight trips (CMP, 2018). Also, most of the chemical and engineering industries within Surat are indirectly associated with the textile manufacturing process. Textile goods movement contributes 32% of the total truck movement and 40% of the total LCV movement in the city (Table 4).

Table 4 Freight trips in Surat and its textile industry

Type of movement in urban area	**Number of HCVs and MCVs trips**	**Number of LCV trips**	**Total trips**
Total goods movement	8041	261,081	269,122
Textile goods movement	3487	105,108	108,595

According to RSI, 35% of the trips are empty, and as per ES of trading and production unit's average trip length of the freight, the trip is 9.8 km. Therefore approximately 370 thousand VKT of LCVs is wasted in the city every day. The economic concern in the terms of financial loss due to wastage of man-hours, fuel, and operational life of vehicles is not the only loss incurred here. There is also a continuous addition of CO_2 and other GHG gases due to this empty movement which is adding an unwanted burden on the city's atmosphere. Table 5 below gives describes the impact of empty vehicle trips on the city's economy in brief.

Table 5 Details of LCV freight trips and its emissions

Description	**Reference**	**Quantity**
Total number of textile freight trips	ES & RSI	108,595
Average freight trip length in textile production	ES & RSI	9.8 km
Total vehicle kilometers travel (VKT)	ES & RSI	1,064,231 kms
Carbon dioxide emission (CO2)	[38]	548.3 tonnes
Sulphur oxides emission (SOx)	[39]	1.51 tonnes
Nitrous oxide emissions (NOx)	[40]	1.36 tonnes
Methane gas emission (CH4)	[41]	95.78 kgs
Approximate empty trips by textile industry	ES & RSI	35%
Empty freight trips (daily)	ES & RSI	38,008
Total empty daily VKT induced by textile industry	ES & RSI	3,72,481 kms

The emissions mentioned above can be reduced if the number of empty trips is avoided by proper planning measures. The LCV trips are short distance trips carrying lesser loads, the possibility of using electric vehicles as a replacement of conventional diesel LCVs would reduce the emission impact largely.

5 Results

The textile industry is generating more than a hundred thousand LCV trips for the internal movement of goods. It is observed that as compared to other industries, textiles are generating far more intra-city trips than that of intercity trips due to the back and forth movement of textile goods during its various phases of production and intervention of textile market at each phase for quality checks. Analysis of the data collected in the RSI and ES survey can be summarized as follows.

The 3 sq. km of the textile market area near Sahara Darwaja is a highly congested becoming bottleneck to the entire road network of that zone. HCV/MCV trips consist only of 8 percent of the total trips, which are also quite organized and efficiently managed. Urban freight trips generated from the textile business is one of the major polluting factors in the study area. From the analysis of the surveys carried out it is derived that approximately 190 tonnes of CO2 can be reduced by strategizing land use and freight trips to eliminate empty freight trips that currently comprise 1/3rd of the total LCV trips generated on daily basis. The GHG emissions basically in the form of sulphur oxides and nitrous oxides gases which are harmful to the health of residents of the city as well as contributing towards warming of the city's temperature can be reduced by 500 kg/day and 450 kg/day approximately. As per the survey, approximately 60% of the LCV drivers are willing to shift to cleaner fuel option (i.e. e-LCV), if gradually the use of fossil fuel-based vehicles are replaced by this innovative option, 60% of the total emission can be simply eliminated, which would be a great relief for the alarming levels of PM and GHG at major industrial zones in the city. Reduction of 38,000 empty trips and replacement of 60% of LCV by e-LCVs can together bring a complete change in the existing situation of urban goods movement in the study area.

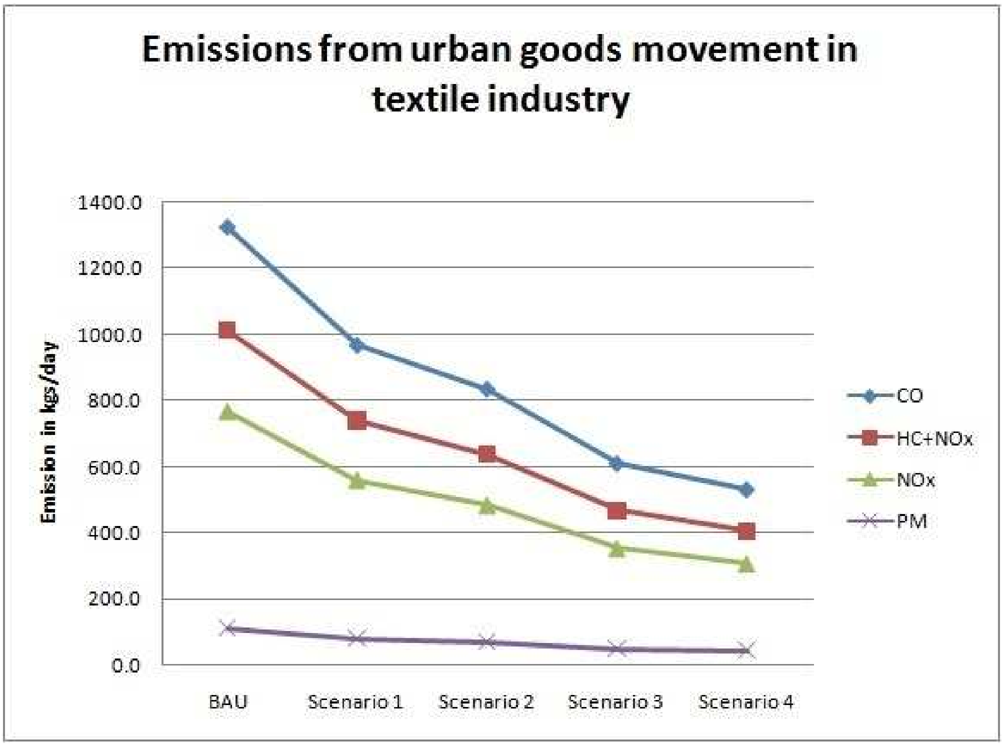

Figure 9 Emissions from urban freight movement in textile industry

Figure 9 shows a graph of different scenarios of the estimated reduction in pollution gases under different solutions sought here. Business as usual (BAU) refers to a current condition with vehicle composition and trip lengths estimated from surveys carried out. Reduction in the emission from LCV trips is considered in four different scenarios. Scenario 1 refers to complete utilization of unused or underutilized payload of LCV trips, scenario 2 refers to the removal of all empty trips (35%) by sharing of freight trips, scenario 3 refers to both removal of the unutilized payload as well as the removal of empty freight trips by sharing of freight trips and the last scenario refers to the replacement of 58% of LCVs with e-LCVs. Scenarios are avoiding empty trips by proper land use planning and management, replacement of conventional LCV with electric LCVs based on the response from the driver's surveys. Here solutions for both the problems i.e. traffic congestion and vehicular emission, arising from the textile industry can have a sustainable solution. Traffic congestion can be reduced by one-third reductions in the overall number of trips or VKT of LCV, while the emissions can be kept in check by replacing the conventional LCVs with e-LCVs.

6 Conclusions

Based on the several recommendations made by GPCB and the prevailing standards of atmospheric emissions recommended by the WHO (Table 3 & 5), it is very certain that cleaner ways of transportation which would have a less negative impact on the environment. From the study, it can be concluded that for reducing vehicular emission and mitigating the traffic situation following strategies can be adopted by city planners and transport planners.

- Textile production houses should be convoked to shift their delivery times to a suitable off-peak hour, which would reduce the overall logistics and parking congestion.

- Local freight transport service providers should be permitted to operate only for a limited area/ zones, to reduce the haphazard movement of LCVs over the entire city.
- Freight depots can be developed at critical locations enabling sharing of freight trips and multi-modal trips, thereby reducing the overall kilometres travel.
- Long term planning for providing electric commercial vehicles and related infrastructure initially in a dense commercial area and later covering the entire city can be carried out by public-private partnership, for example charging ports facility at parking locations

As discussed in the results section, it is possible to reduce the total emissions from urban freight movement in the textile industry by 60%, which is a very progressive move in the direction of cleaner city logistics. The oldest of the industrial clusters which are dense and surrounded by residential properties need to be targeted first for the alleviation of the vehicular emissions. Cleaner production does not necessarily mean to reduce the polluting factors from the production cycles alone, environmental impact due to the freight movement during and after the production cycles of the goods is equally important. Targeting freight intensive industries for cleaner logistics measures gives double benefits to the city, reduction in the overall emissions from these vehicles, and alleviation in the overall congestion which is caused due to these slow-moving freight vehicles. These concepts can also be replicated on other industries like FMCG, dairy, and bakery supplies where the use of LCVs is high A similar concept can be applied to other cities in the country where the textile manufacturing is an important industry in the city. Also with modifications based on industry parameters these models can also be used for other small scale industries in the city and other cities of the country.

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