
Using Six Sigma in the Management of City Logistics Processes: A Case Study on the Impact Assessment of Transport Infrastructure on Fuel Consumption in Szczecin

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Justyna Lemke¹, Roma Strulak-Wójcikiewicz²

Abstract:

Purpose: The objective of this paper is to present the possibilities of using the Six Sigma (SS) methodology in the management of city logistics processes in the Polish city of Szczecin.

Design/Methodology/Approach: The Six Sigma methodology is used in this study. We discuss the possibility of managing city logistics based on the Six Sigma methodology. In the first stage, the city logistics processes are analysed, and the customer of this process and their needs are defined. For this purpose, a SIPOC (Suppliers Inputs Process Outputs Clients) diagram is used, as well as a CTQ (Critical to Quality) tree. Subsequently, an overall concept for the management of city logistics processes is developed.

Findings: Based on the literature review, possible process evaluation indicators are proposed. Finally, an example of a Six Sigma project is presented, to improve the city logistics process in the city of Szczecin in Poland.

Practical Implications: The presented research results show the possibility of using the Six Sigma (SS) methodology in the management of city logistics processes.

Originality/value: The Six Sigma management concept in city logistics presented in the article is the first study of this type according to the authors' knowledge. The in-depth analysis of the literature on the subject, presented in the article provides for a possibility of applying the Six Sigma methodology in logistics processes and in city management. The management concept according to Six Sigma has not been previously applied to the management of city logistics processes to the authors' knowledge.

Keywords: City logistics, sustainable development, urban transport, city infrastructure, Six Sigma, DMAIC, Design of Experiment (DOE).

JEL classification: R40, O18, Q01.

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¹Maritime University of Szczecin, Faculty of Economics and Transport Engineering, ORCID ID: 0000-0003-1269-1956, e-mail: j.lemke@am.szczecin.pl

²Maritime University of Szczecin, Faculty of Economics and Transport Engineering, ORCID ID: 0000-0002-9702-7554, e-mail: r.strulak@am.szczecin.pl

1. Introduction

Six Sigma arose in the 1980s, when Bob Galvin and Bill Smith implemented it at Motorola (Vivekanathamoothy and Ankar, 2011). It belongs to the so-called concept of quality management, in which great emphasis has been placed on process management. At present, Six Sigma is believed to be one of the best concepts for management. Management based on Six Sigma was initially focused on the manufacturing industry (Prabu *et al.*, 2013), however, the methodology has been successfully used in other industrial branches, such as the hotel industry (Kumar and Singh, 2015), services (Chakraborty and Tan, 2012), and finance (Ansari *et al.*, 2010).

There are also examples in the literature of the use of Six Sigma in logistics processes (Tjahjipno *et al.*, 2010; de Carvalho *et al.*, 2017). For example, Staniviuk *et al.* (2020) have shown the possibility of implementing Six Sigma for vehicle fleet management. Quality Digest describes Fort Wayne city, which was the first to successfully implement Six Sigma for city management (Quality Digest, 2007), completing a total of 60 Six Sigma projects (Smith, 2005). Examples of good practices for the application of the Six Sigma methodology in the field of logistics process management or city management, as described in the literature, prompted the authors to consider the possibility of using Six Sigma for the management of city logistics processes in Szczecin, Poland. At this point, it should be emphasized that, despite an extensive literature review, no study was found that directly presents the management of city logistics processes using Six Sigma.

There are many definitions of city logistics in the literature, with each one putting a different emphasis on different factors. Numerous areas related to city logistics have been highlighted, directly or indirectly. These include freight transport, passenger transport or quality-of-life, and sustainable development (Benjelloun *et al.*, 2008; Crainic, 2008; Dablanc, 2007; Russo and Comi, 2004). City logistics has been defined as "*the process of totally optimizing the logistics and transport activities by private companies in urban areas, while considering the traffic environment, the traffic congestion, and energy consumption within the framework of a market economy*" (Taniguchi *et al.*, 2001). According to the proposal of the Council of Logistics Management (CLM), city logistics can be defined as a process of planning, executing, and controlling flows (Pasternak and Sadowski, 2014). The mentioned flows can be initiated both inside and outside the city.

Furthermore, a city can only have a transit function for transported goods. At the same time, the stream of goods is accompanied by an information flow. While the CLM stressed the orientation of flows, pointing to the possible variants of goods flow processes within a city, Taniguchi emphasized the aspect of flow management and the optimization of flows. However, it can easily be seen, in any case, that city logistics is a term used to denote the specific logistic concepts and practices involved in deliveries in congested urban areas—the so-called "last mile"

transport—with specific problems, such as delays caused by congestion, lack of parking spaces, close interactions with other road users, and so on.

City logistics is closely related to the development of cities. The smooth functioning of cities without efficient logistics is currently impossible (Kauf, 2016). The growing number of city residents has increased the demand for freight traffic (e.g., supply of goods, transportation of materials, disposal of urban waste, and so on). The intensifying increase in freight traffic has significantly impacted upon the quality-of-life of city residents. Increases in traffic density have negative impacts on the environment, as well as the health and quality-of-life of city residents (Łatuszyńska and Strulak-Wójcikiewicz, 2014). The negative effects of increases in traffic density mainly include congestion, air pollution, deterioration of the acoustic climate and vibrations, accidents, and landscape degradation (Cisowski and Szymanek, 2006).

The negative aspects of transport also include the use of non-renewable fossil fuels, the loss of green spaces and open spaces (due to the development of transport infrastructure), and an increase in the amount of waste, such as tires, oil, and other materials (Iwan, 2014). Urban mobility accounts for 32% of energy consumption and 40% of all road transport CO₂ emissions and up to 70% of other transport-related pollutants (Russo and Comi, 2012). The congestion of urban roads is responsible not only for the increase in environmental pollution and energy consumption, but also for the increased length of journeys. Every year, due to this phenomenon, the European economy loses approximately 1% of its Gross Domestic Product (GDP) (Russo and Comi, 2012). These facts are directly related to public health, as traffic emissions are responsible for 70% of cancerous agents and other dangerous substances (Silva and Ribiero, 2009). Despite the negative effects, numerous limitations, and high costs of freight transport implementation in urban areas, it is impossible to eradicate it, due to the function it holds in everyday life (Kijewska, 2014a). Nevertheless, city logistics professionals should strive to optimize these flows and reduce their harmful impacts on the urban environment (Taniguchi *et al.*, 2001; Zajac *et al.*, 2018). The importance of sustainable urban development should be emphasized here.

The literature consists of numerous publications raising the topic of sustainable development related to cities, agglomerations, and metropolises (Jurczak, 2019). The works (Arkin and Crenshaw, 1992; Blassingame, 1998; Næss, 2001; Sneddon *et al.*, 2006; Egger, 2006; Mitchell and Casalegno, 2008; Jenks and Jones, 2010) are worth mentioning here. Therefore, the increasing requirements from the city residents—in particular, those regarding quality-of-life—predispose the aspect of sustainable development as decisive in city logistics management (Jaroszyński and Chład, 2015). Developing a balance between social, economic, technological, and environmental growth is essential for the effective development of cities. It has been estimated that, in 2025, more than 75% of Europe's population will live in cities, and in 2050 this number will probably increase to 84%. This is expected to translate

into an increase in freight transport. Forecasts have shown that freight transport intensity within urban areas will increase by 40% by 2030 and by more than 80% by 2050, when compared to 2005 (Kiba-Janiak, 2016). Thus, in just a few decades, cities will become dominated by road transport, which is one of the essential results of the spatial expansion of cities, with all its consequences (Mantey, 2009).

Due to the fast development of cities, combined with the growing needs of city residents, the problem of the efficient functioning of transport and distribution of freight in urban areas has gained more importance (Iwan, 2014). Excessive urbanization and growing urban populations pose a serious challenge for sustainable urban management (Rześny-Cieplińska, 2018). The effective implementation of city logistics strategies, which are compliant with the principles of sustainable development, poses a significant challenge for cities around the world (Taniguchi and Van Der Heijden 2000; Taniguchi *et al.*, 2001). Considering the above considerations, it can be concluded that developing city logistics (i.e., the organization of transport services provided in urbanized areas) in a way that meets the postulates of sustainable development is a highly complex and particularly difficult task (Kijewska, 2014b). The complexity of the issues related to sustainable development, along with the changing and growing requirements of city logistics stakeholders, make managing its processes a challenge for city authorities. To ensure the effective, sustainable, and ecological development of urban areas, it is necessary to consider different aspects in urban transport systems, including city logistics (Korneć, 2018).

Our literature review indicates that the Six Sigma methodology can be successfully used to solve problems related to the quality of logistics processes and city management. As city logistics also affects quality problems—in this case, it is the quality-of-life of city residents—and is a strategic area of city management, the Six Sigma methodology should be used for the management of city logistics processes. This paper proposes the use of the Six Sigma (SS) methodology in the management of city logistics processes in the Polish city of Szczecin.

2. Materials and Methods

The Six Sigma methodology is used in this study. We discuss the possibility of managing city logistics based on the Six Sigma methodology. In the first stage, the city logistics processes are analysed, and the customer of this process and their needs are defined. For this purpose, a SIPOC (Suppliers Inputs Process Outputs Clients) diagram is used, as well as a CTQ (Critical to Quality) tree. Subsequently, an overall concept for the management of city logistics processes is developed. Based on the literature review, possible process evaluation indicators are proposed. Finally, an example of a Six Sigma project is presented, to improve the city logistics process in the city of Szczecin in Poland. The necessary research cycle is performed for the first three phases of the DMAIC cycle (Define Measure Analyse Improve Control), that is, for the phases Define, Measure, and Analysis. For phases four (Improve) and

five (Control), only possible actions are recommended. The aim of the Six Sigma project proposed in the case study is to improve urban logistics processes in Szczecin. The Define phase describes the problem, identified in the city logistics process in Szczecin, which is fuel consumption.

A literature review is carried out, based on the defined problem. Subsequently, air pollution data for Szczecin from 2016 to 2019 are analysed in the Measure phase. A list of root causes and potential reasons for increasing fuel consumption is drawn up in the Analyse phase of the DMAIC cycle. The results are presented in the form of an Ishikawy diagram. In order to select only one factor from a wide list of potential factors influencing fuel consumption for further analysis, consultations were conducted among the residents of Szczecin and experts. We decided to assess the impact of transport infrastructure on fuel consumption.

Next, the verification of three factors related to infrastructure was carried out. Here, it must be noted that this study should be treated as a pilot study and the construction of a wider list of root causes, verified by more in-depth expert revision, is advised. The methodology DOE (Design of Experiment) for the city logistics process was used in the next step of the research. Four test rides were carried out in the city of Szczecin, in accordance with the mono-factorial experiment OFAT (One-Factor-at-a-Time) method. The rides took place in February 2020, between 11 and 12 a.m. At that time, there were no restrictions related to COVID-19 in Szczecin. Traffic on the streets was comparable to that in other corresponding periods. The same car, a Citroen C3 Aircross with petrol engine of 81 kW and 1199 cm³ capacity was used for each test. Furthermore, the vehicle load was the same every time and the same driver was used. This treatment allowed us to minimize the impact of other factors on fuel consumption. The exclusion of other factors was the condition for conducting the experiments in accordance with the DOE methodology.

All diagrams were made using Microsoft Visio 2016, with measurements such as drive time, route length, or fuel consumption read from the car's onboard computer.

2.1 Assumptions and Tools of Six Sigma

One of the main assumptions of Six Sigma is that quality can cost nothing. It should be added, here, that this is a general settlement between the costs of maintaining quality and the costs of poor quality. Expenditure on the former will level the loss that arises from the latter. For this to happen, the processes must be designed adequately. Furthermore, a process should be carried out correctly the first time, and any potential errors should be captured and eliminated at the earliest possible stage. Any actions in Six Sigma are focused on increasing the ability of the process to meet client needs. A process that generates a maximum of 3.4 defects per million possibilities of defect is considered perfect (Banuleas and Antony, 2004), where a defect is understood as a value of the process output meter that goes beyond the client's specification. It should be noted that this refers to both the external client

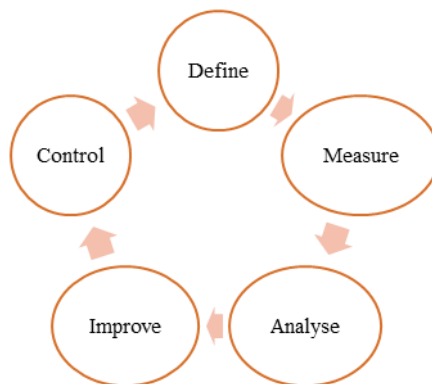
and the internal process. A process with a DPMO (Defect per Million Opportunities) of 3.4 is defined at the Six Sigma level. For each process, 1 to 2 indicators of customer satisfaction should be defined.

The process should also be monitored in terms of suppliers (from 2 to 3 indicators) and process efficiency (one key indicator). Managers should constantly monitor the selected indicators. If any of the assessment indicators are not satisfactory, the process should be improved. For this purpose, an improvement project—called the Six Sigma project—is carried out. Any decisions regarding the process quality improvement, elimination of defects or flaws, or the implementation of improvements must be based only on facts.

2.1.1 DMAIC Cycle

Process management within Six Sigma is based on the DMAIC cycle, which allows for integrating three areas that are crucial for this concept; namely, the client, the process, and the staff (Antony *et al.*, 2005). DMAIC is a five-stage implementation cycle for the improvement of Six Sigma projects (see Figure 1).

Figure 1. DMAIC cycle



Source: Own study.

During the first phase—Define—the problem and objective of the project should be identified (Schanzez and Valles-Chavez, 2011). Projects most often aim at reducing costs and improving client satisfaction, efficiency, or eliminating waste. Initially, Six Sigma projects were associated with the improvement of processes that take place within production (Prabu *et al.*, 2013). At present, however, they have come to be successfully used in other areas, such as the hotel industry (Kumar and Singh, 2015), services (Chakraborty and Tan, 2012), and finances (Ansari *et al.*, 2010). At this stage, a process map is developed, and the clients and their needs are identified. In the next step—Measure—the process output is measured. This stage should end with an answer to the question of how often the defects occur. While the final result of the Analyse phase is to determine the source cause of the problem that was identified in the Define stage, the Improve phase consists of finding and implementing concepts

and solutions that eliminate the problem. It can be stated that a Six Sigma project is completed at this stage. The last phase of the DMAIC cycle—Control—consists of systematic process measurement. Whether the implemented solution has brought a permanent result or not is assessed. If any deviations from the desired outcome are noticed, the problem identification phase is restarted, and the cycle starts from the beginning. In each DMAIC cycle stage, the design team has several tools at their disposal; selected tools are presented in Table 1.

Table 1. *Sample tools in DMAIC*

Step	Tools
Define	CTQ (Critical to Quality), VoC (Voice of Consumer), SIPOC (Supplier Input Output Customer), 5W2H (5 Why 2 How)
Measure	Data collection plan, histogram, Pareto chart, Cp (Potential Capability), Cpk (Real capability Index), DPMO (Defect per million Opportunities)
Analyze	Ishikawa diagram, 5Why, DoE (Design of Experiment), correlation analysis
Improve	Poka Yoke, FMEA (Failure Mode and Effect Analysis), SMED (Single Minute Exchange Die), 5S
Control	Histogram, Shewhart control charts, process audit

Source: Own study.

The next part of the paper presents the concept of a Six Sigma project which improves city logistics processes.

2.1.2 Design of Experiments (DOE)

Design of Experiment (DOE) is a branch of Applied Statistics. As it allows for determination of the influence of independent variables on the dependent variable, this method has found a place in Six Sigma (Zondo, 2018; Tanco, 2009). In this case, the root cause of the problem is sought. Experiments within the DOE methodology can be carried out according to different plans. Among others, OFAT (one-factor-at-a-time) (Tanco, 2007), full-factor (Glitsau, 2008), or fractional plans (El-Haik, 2005) can be used. The choice of a specific plan is a compromise between the number of experiments needed and knowledge of the interactions between factors.

For the purposes of this paper, we decided to conduct an OFAT experiment (i.e., one-factor-at-a-time), where the conducted experiments provide results of marginal costs and impacts on the accuracy of the results (Cox and Reid, 2020). For the described case study, a single-factor OFAT experiment was decided on. This plan requires fewer experiments and, therefore, requires less time. The estimation of the impact of each of the factors is more precise. There is no chance to correlate analysed factors with each other.

Arranging the plan of experiments as OFAT requires that, for each of the analysed factors, the so-called low and high levels must be determined. A basic experiment is conducting at first, in which all factors are minimal. In the following experiments, the maximum level changes for only one of the tested factors at a time.

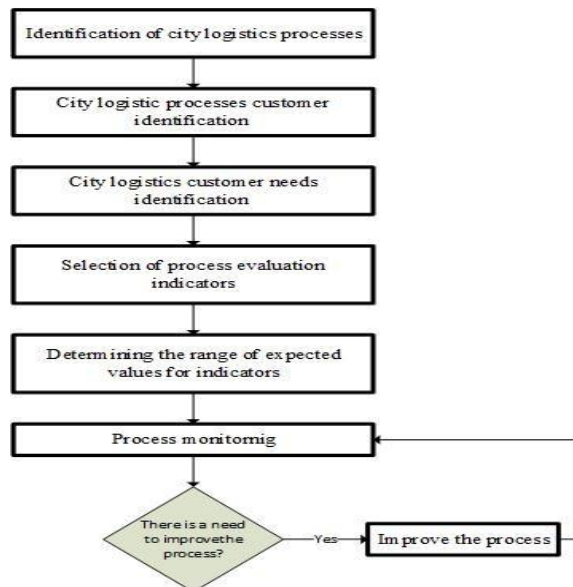
3. Results

3.1 The Concept of Management of City Logistics Processes According to the Six Sigma Methodology

As is apparent from the above considerations, Six Sigma can be implemented in a particular business entity or local government unit. City logistics, in this regard, is specific. It is impossible to unequivocally define the owners of the processes taking place within city logistics. Decisions determining the shape of city logistics processes are made by associated stakeholders (carriers, local governments, or private investors) (Pasternak and Sadowski, 2014). Kijewska (2015) proposed to appoint a city logistics manager within the city structure, whose task would be to coordinate the (often conflicting) interests of stakeholders and activities aimed at the proper functioning of freight transport in the city. In particular, the manager's responsibilities should include meeting customer needs, increasing the efficiency of the goods distribution system, improving the availability of goods in the city and diagnosing the current situation of freight transport in the city.

In this article, we take it a step further. The city logistics manager can carry out these activities in accordance with the Six Sigma methodology. Therefore, it is recommended that a person with skills at the Six Sigma Green Belt certification level be appointed as the City Logistics Manager. This certificate confirms that a person is qualified to run Six Sigma projects. City logistics management should follow the scheme shown in Figure 2.

Figure 2. Model of city logistics processes management, according to the Six Sigma concept



Source: Own study.

According to the Six Sigma methodology, the processes should meet the client's expectations. Therefore, in the first place, the city logistics manager should become acquainted with the city logistics processes in the city, the customers of these processes, and their expectations. After process mapping, identification of its clients, and their requirements, the process can be measured and assessed. Assessment indicators should be established for each process. The literature has proposed dividing the indicators into three groups: economic, environmental, and social (Joëlle and Gonzales-Felia, 2014).

According to Six Sigma, the indicators should be sorted, according to three evaluation categories: process inputs, process outputs, and the process itself. The process input assessment indicators should provide information about process suppliers. In the case of city logistics, these are carriers, producers, or local authorities. The indicators belonging to the group of process output assessment should present the view of the process client, while the indicators of the assessment of the city logistics process itself are designed to assess the effectiveness of the process. Examples of indicators for city logistics processes, along with their assignment to the three assessment groups described above, are shown in Table 2.

Table 2. *Examples of indicators for the assessment of city logistics processes*

process input assessment	process assessment	process assessment	output assessment
capacity of the means of transport	lay time		NO _x level
number of suppliers	delivery time		CO ₂ level
weight of loads	cost of the service	transport	CH ₄ , CO levels
the quantity (number) of deliveries	number of services	transport	noise level
number of means of transport			number of accidents
loading time			infrastructure capacity
			completeness of supplies
			waiting time for delivery
			number of unloading bays
			km of roads
			time of travel
			number of unloading places
			unloading time
			time of possible unloading
			number of VMS (Variable Message Signs)
			number of freight transport management applications
			area of the paid parking zone
			parking fees

Source: *Own study.*

Table 2 shows only examples of city logistics assessment indicators; it is not a closed catalogue. Each city should choose its own set of indicators, which should be regularly assessed. It is assumed that 2–3 process input assessment indicators, 2–3 process output assessment indicators, and one key process performance assessment indicator should be monitored. When selecting indicators for city logistics assessment, the manager should take into account the strategic goals of the region. In this context, it is advisable to place particular emphasis on the ecological aspect of city logistics.

For each selected assessment indicator, the city logistics manager should establish a tolerance range. If the value of a given indicator exceeds the set limit, it should be considered that the process has experienced a defect. Any symptoms of irregularities in the process may become a signal to start the Six Sigma improvement project. The dispersion of the monitored index values may coincide with the adopted tolerance range. This process has a level, known as Three Sigma. If the city logistics manager does not notice defects in the analysed processes, they can also (and even should) initiate a Six Sigma improvement project aimed at increasing the Sigma level of the process.

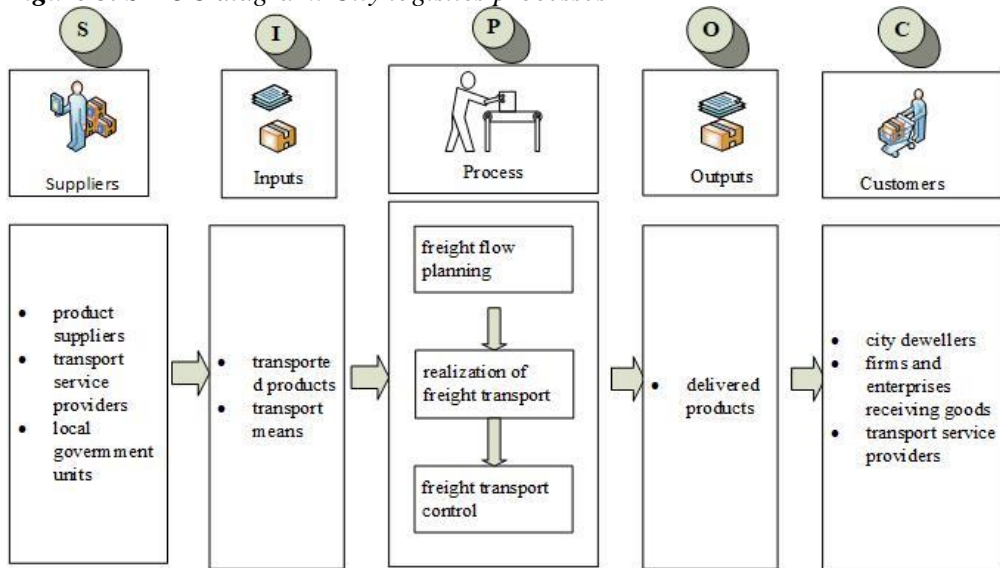
Therefore, projects to improve city logistics processes should, on one hand, reduce the negative impact of transport and, on the other hand, develop transport possibilities in the city. Examples of goals of the projects from the first group are to reduce congestion in the city, reduce the negative impact of transport on the environment (Kijewska, 2017), or reduce the number of accidents. Examples of the objectives of projects to improve city logistics processes from the second group are to shorten the transport time, adapt the city to the operation of alternative means of freight transport (Kołakowski, 2015; Deja *et al.*, 2019), or improve the possibilities for unloading and loading.

3.2 Define Processes of City Logistics

As mentioned above, the most basic part of process management is recognizing them. The Six Sigma methodology uses a SIPOC (Suppliers, Inputs, Process, Outputs, Clients) diagram for this purpose. Figure 3 presents the SIPOC diagram for city logistics processes in Szczecin.

The SIPOC model shows only the most important processes, without determining the means of their implementation. The proposed model may pose a basis for further consideration of city logistics processes. If it is noted that the objective of city logistics processes is to fulfil the needs of an urban agglomeration, in terms of management, life, and growth quality, then its clients will be all the stakeholders of its processes; that is, we cannot limit ourselves to the end-client receiving the goods. For example, transport service providers are beneficiaries of decisions on infrastructure made by local governments, which impacts on the management quality.

Figure 3. SIPOC diagram: City logistics processes

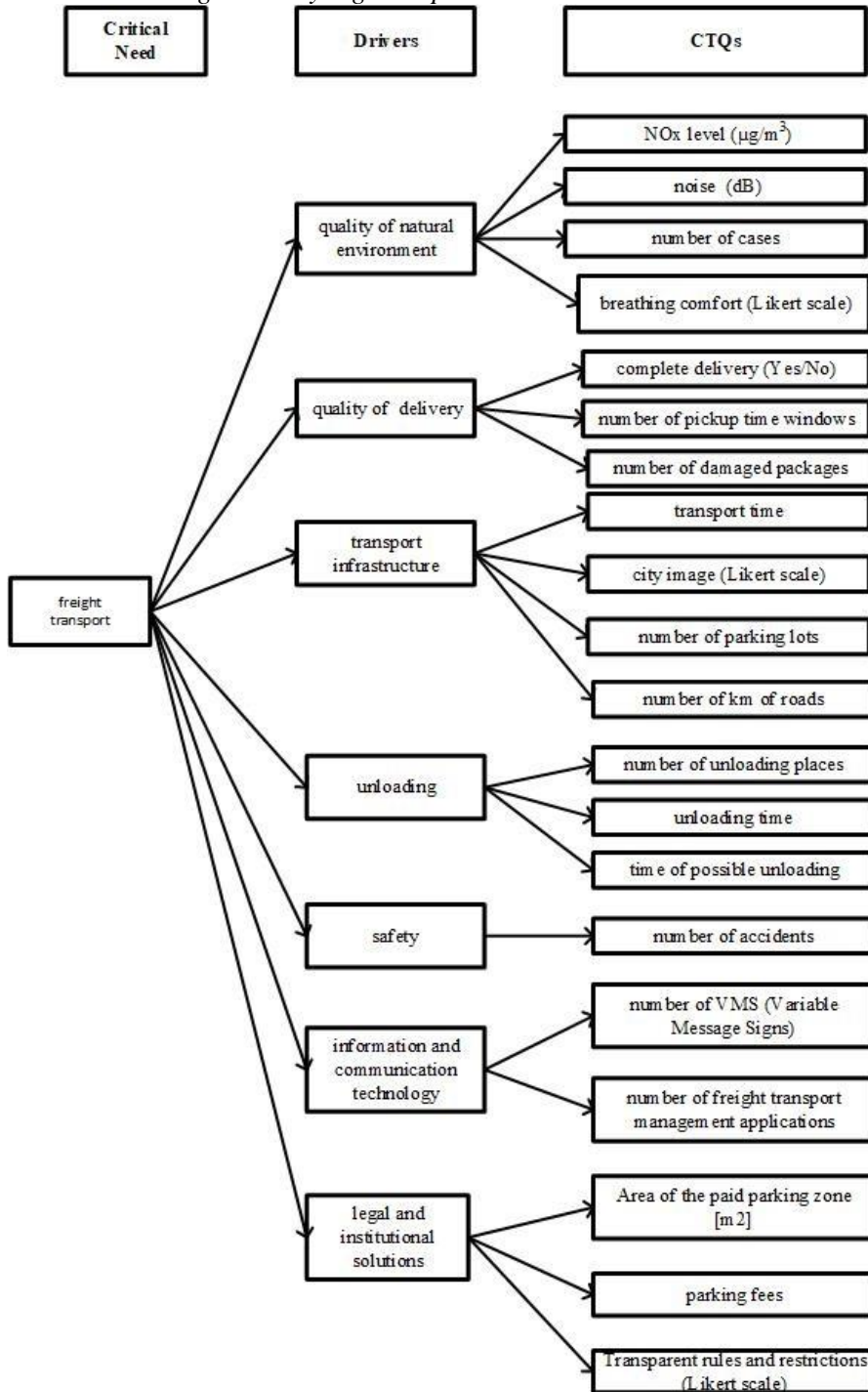


Source: Own study.

The basis of Six Sigma management is the identification of the needs of clients. The needs of the recipients of city logistics processes for Szczecin were determined on the basis of interviews with Szczecin residents, as well as through a literature review (Kiba-Janiak, 2011; Witkowski and Kiba-Janiak, 2012). In this study, a CTQ (Critical to Quality) tree was adopted to show the needs of a city logistics client (Figure 4).

At this stage, it is important to focus on the feelings of the process recipients, not on the idea of the outcome of the process that its performers have. Therefore, the group of proposed measures includes such positions as breathing comfort and city image. An average city resident should not be expected to be able to state the NO_x level that would be satisfactory for them or provide its current concentration in the air. However, everyone can relate to some subjective feelings, such as scratching in the throat or the sense of a “full” breath. Some measures, which can be characterized by measurable units—as the name itself suggests—must be proposed for the provided indicators. Where no direct measurement of the value can be made, a five-stage Likert scale is proposed. City residents, as recipients of parcels, view freight transport from the perspective of quality of their life in the city. As can be read in the work of Dąbrowska (2017), the quality of their lives can be assessed through the prism of such factors as subjective well-being, material living conditions, the main type of activity, work, health, education, leisure time and social relations, economic and physical security, state rights and civic activity, and the quality of the environment in the place of residence. In the context of sustainable development processes, particular attention should be paid to environmental quality. On the other hand, the residents also expect adequate infrastructure.

Figure 4. SIPOC diagram: City logistics processes



Source: Own study.

Such infrastructure is equally important to a city resident as it is to the enterprises engaged in freight transport. Here, the transport time may seem particularly important. However, due to the frequently raised problem of urban unloading possibilities, we decided to provide a separate indicator. At the same time, attention should be paid to the dependencies among the indicators themselves. Like the environmental impact of infrastructure, the route parameters, along with the shape and development of the surrounding terrain, affect the atmosphere. The emission of air pollutants depends, among other things, on the route height above ground level (i.e., trench, embankment, bridge, or flyover, or at ground level) and types of buildings (i.e., low, medium, or high).

These parameters influence the possibility, direction, and range of the pollution emissions "movement". This happens as the air turbulence created by uneven terrain, buildings, and green belts of high compactness leads to intensified dissipation of the pollution cloud. Air movement over a barrier takes place with increased speed, while the air velocity decreases behind that barrier (a barrier should be understood as the terrain, water bodies, or buildings).

3.3 Problem Definition and Measure of Pollution

A case study was used to demonstrate the idea and concept of running a Six Sigma project in the city logistics context. The project described should be treated as a pilot study. The first step of a Six Sigma project is to define the problem. Analysis of the literature, the experiences of the authors, the interviews conducted among the residents of Szczecin, and the opinions of experts revealed that the residents of Szczecin expect clean air. Analysis of data on quality-of-life of city residents revealed the problem described in Table 3, namely, the increase in pollution.

Table 2. Problem Definition (5W2H)

Question	Question description	Problem description
What?	What is the problem	Pollution increase
Where?	Where was the problem noticed	in Szczecin
When?	When was the problem noticed or when it occurred	in 2016–2019
Who?	Who noticed the problem (who is the problem)	City residents
Why?	Why is this a problem	Increases in the incidence of disease, the greenhouse effect
How?	How was the problem detected	Analysis of data from the Provincial Inspectorate of Environmental Protection
How many?	What is the scale of the problem	Maximum exceeding the NO _x standard by 12 µg/m ³

Source: Own study.

Air quality depends on many factors but, in Szczecin, attention was paid to a relatively high level of NO_x, which comes from vehicle exhaust. According to the

Provincial Inspectorate of Environmental Protection in Szczecin (SMJP, 2020), the permissible annual level of NO_x was exceeded in Szczecin in 2016–2019. As shown by the results of the Provincial Inspectorate for Environmental Protection in 2016, the share of linear emissions (from transport) in the total emissions of dust pollutants was 22% and, in the case of gaseous pollutants, contributed to over 40% of emitted nitrogen oxides (NO_x) (POŚMS, 2017). Table 4 summarizes the results of the annual average NO_x concentration values in 2016–2019 in Szczecin from two measuring stations.

Table 4. Average annual concentration nitrogen oxide in the years 2016–2019 in Szczecin

Year	Station number	Average [µg/m ³]	Min [µg/m ³]	Max [µg/m ³]
2016	station 1	27.1	0.1	854.5
	station 2	46.4	0.2	738.1
2017	station 1	21	0.5	532.5
	station 2	38.2	0.5	794.7
2018	station 1	25.2	1.7	574.7
	station 2	41.6	0.5	649.4
2019	station 1	17.9	0	589.2
	station 2	32.2	0.5	417.4

Source: Own study.

Measuring station 1 was located at Andrzejewski street (on the right side of the Odra River), while measuring station 2 was located at Pilsudski street, practically in the very centre of the city (on the left side of the Odra River). The routes included in the experiments described in Section 3.3 were located on the left side of the Odra River, which was the location corresponding to measuring station 2. The positions of the measuring stations are illustrated in Figure 5.

Figure 5. Location of two main measurement stations in Szczecin



Source: Own study based on www.google.com/maps.

Taking into consideration of the admissible average annual nitrogen oxide concentration of $30 \mu\text{g}/\text{m}^3$, station 2 recorded higher concentration levels, mainly because the location of station 2 was in the centre of the city, which experiences a much higher traffic volume than station 1.

This is important, as Poland is a member state of the European Union and, as such, it must comply with certain air quality standards. Failure to comply with these standards may result in specific financial penalties. However, from the perspective of the client of the city logistics processes, the relationship between an increase in air pollution and health seems to be more important and more noticeable. Nitrogen oxides are atmospheric pollutants responsible for the formation of smog, which hinders human functioning and is particularly dangerous for their life and health. Gasoline combustion products, including NO_x , have been claimed to be one of the causes of lung diseases. It should be noted that an increase in the incidence of asthma (by 28% in children and 67% in adults) has been recorded within the recent 20 years (Kobalińska and Antczak, 2018). At the same time, the combustion of fossil fuel products, including oil and gas, release CO_2 which, in turn has a negative impact on climate change.

According to the WHO, about 88% of the existing global burden of disease due to climate change also falls on children (Perera, 2016). It should be added that the European Commission has introduced a requirement to achieve at least a 60% reduction in greenhouse gas emissions from transport before 2050 (White Paper, 2011). If the districts and other local and central self-government units cannot calculate and monitor their carbon footprint changes in the future, they will not be able to develop and implement effective strategies for this task in practice. Identification and monitoring of the carbon footprint provides valuable information about undertaken activities related to the transport and logistics and their environmental impact, therefore providing a basis for the setting of objectives related to sustainable transport. The methodology used to calculate the carbon footprint should ideally be suited to accounting for the ecological effects of single investment projects (Sharmina *et al.*, 2020; Piecyk and McKinnon, 2010).

Having defined the problem, another step in the DMIC cycle is to measure the process output. Here, we refer to the SIPOC diagram (Figure 3). Loads are transported at the process output. According to the research conducted by the Szczecin Statistical Office in 2018, 15,404 thousand tons of cargo were assigned in Szczecin and the transport performance of the cargo was 2252 million ton-kilometres (Dmitrowicz- Życka, 2019). In the same year, 14,596 thousand tons of cargo were accepted, the transport performance of which amounted to 1838 million ton-kilometres.

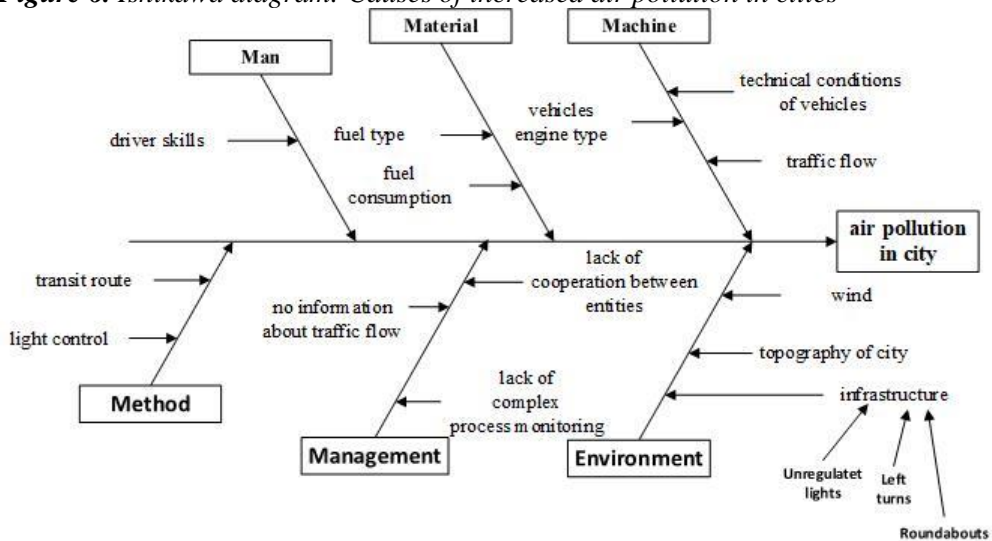
It should be noted that this picture of cargo transportation is incomplete. The statistics of the Central Statistical Office (GUS) take into account commercial transport. In the meantime, plenty of companies perform transport for their use.

Furthermore, the transport of goods can also take place using a passenger car (e.g., in the case of pizza places) or bikes (e.g., Glovo). Although the latter does not generate exhaust fumes, they can affect road capacity. Additionally, data on cargo transport should be supplemented with those goods that are transported through Szczecin, for which their loading and unloading take place outside the city. At the same time, to solve the problem of pollution generated by city logistics processes, an in-depth analysis of pollution—in particular, of NO_x—should be carried out.

3.4 Identifying the Root Cause of the Problem

After a detailed analysis of the process output, we moved on to the “Analyse” phase; that is, searching for the root cause of the problem. The overall state of the polluted air was influenced by numerous factors, such as the size and structure of emissions and the location of emitters, topography and land-use, and meteorological factors (Figure 6).

Figure 6. Ishikawa diagram: Causes of increased air pollution in cities



Source: Own study.

The level of contamination is affected by air movement. On one hand, it is related to climatic conditions and meteorological factors, such as atmospheric diffusion, the vertical temperature gradient, wind speed and direction, the thickness of the mixing layer, precipitation, and the transformation of pollutants in the atmosphere, on the other hand, it is also affected by the topography and the way the land is shaped and developed. The presence of pits or elevations allows or impedes the mixing and flow of air or its stagnation. The potential causes for pollution increase in cities have been defined, considering city logistics processes. Therefore, the presented Ishikawa diagram does not include passenger transport or private cars, as well as the emissions of pollutants generated by, for example, households.

Our focus was only on freight transport. In this context, numerous potential causes of pollution are related to the vehicle itself. It should be noted that there is a positive correlation between an increase in pollution and the fuel consumed while driving. The combustion rate and, consequently, the range of pollutants emitted by a vehicle into the atmosphere and the general condition of the polluted air is influenced by such vehicle-related factors as engine parameters (its capacity and power), along with the design solutions adopted in the engine and exhaust system (a catalyst), vehicle weight, body type, number of axles, type and design of transmission components, type of tires, or additional equipment (e.g., A/C, parking heater). The weight of the cargo should not be forgotten, either. The type of fuel burned, and the technical condition of the vehicle are not without significance for the level of exhaust emissions (Edroga, 2014). Another important issue is the choice of the route and the associated travel times at certain speeds (Merkisz *et al.*, 2013).

It should be noted that shortening the driving time by choosing a different route is not always tantamount to reducing fuel consumption or emissions of individual exhaust components (Ahn and Rakha, 2008). Apart from the length of the journey itself, the intensity or obstruction of traffic, as well as elements of road infrastructure along the route, such as the number and type of intersections, length of straight sections, or speed limits, are important (Filipczyk, 2014). At the same time, it should be stressed that the vehicles are operated by humans. A human—and their driving technique, in particular—can decrease or increase the fuel consumption of a vehicle.

One of the basic principles for proper operations of a car is striving for the lowest possible fuel consumption while, at the same time, limiting the intensity of wear and tear on the vehicle components (i.e., engine, transmission, chassis), this is the so-called economic driving principle. A driver should adjust their speed to traffic volume, trying to keep their driving as smooth as possible. Furthermore, it is important to match the gear to the engine load and to properly accelerate and brake.

From a wide list of selected factors influencing the level of pollution, road infrastructure was selected for further analysis. The authors decided to select elements of transport infrastructure as factors verified in the experiments, as infrastructure was indicated (by experts and road users with whom the interviews were conducted) as the factor worth checking first. This was confirmed by our literature research. Forced stops or difficulties in the traffic flow have been mentioned as one of the main factors influencing fuel consumption in cities (Lorenc, 2012), having a huge impact on sustainable development (Wang *et al.*, 2018).

As one of the main urban elements, transportation infrastructure such as roads, highways, railways, airports, bridges, waterways, canals, and terminals play important roles in the transmission of materials and the flow of the population during urban agglomeration and diffusion (Holl, 2004; Correia *et al.*, 2016). Transportation infrastructure, as a complex network, connects cities and accommodates human activities, combining social, economic, and environmental

systems with urbanization and population growth. Additionally, the transportation network contributes to socio-economic development and increased quality-of-life, by generating inter- or intra-city connections during urbanization (Rodrigue *et al.*, 2016; Liu *et al.*, 2015). However, the irrational planning of transportation infrastructure may generate negative effects, such as ecological destruction, increased traffic accidents, climate change, CO₂ emissions, and lower transport efficiency (Doyle and Havlick, 2009; Tasic and Porter, 2016; Camp *et al.*, 2013).

In view of the above, it should be assumed that a decrease in pollution in Szczecin can be achieved through infrastructural improvements. The proposed solutions in Six Sigma projects must be specific and usually low-cost (e.g., reconstruction of one traffic light intersection into circular traffic or the development of software for route planning). Streamlining the process should be treated as an evolution, not a revolution, in the process. Otherwise, it will not be possible to tell what has had a positive effect and what has made the problem even worse. For this purpose, an experiment was carried out to identify the infrastructure factor with the greatest impact on car fuel consumption.

The experiment was planned according to the DOE (Design of Experiment) planning methodology (Durakovic, 2017). An OFAT (One-Factor-At-a-Time) experiment was planned. An OFAT plan is conceptually simple, requiring less experimentation than other plans, and does not take into account the inter-relationships between factors. In the case of the OFAT experiment, one more experiment should be performed than the number of tested factors; for example, with three factors in the OFAT plan, four experiments should be carried out. In comparison, a full-factors plan would require eight experiments. It is important to indicate a specific solution to improve the city logistics process. As mentioned above, the improvement should be related to one element of the infrastructure. The number of experiments in DOE depends on the number of analysed factors. Each experiment has a cost.

Therefore, taking into account the number of factors in the study was a compromise between the cost of the experiments and the information that could be obtained during the study. In the presented case study, we decided to select three elements of the transport infrastructure in Szczecin (roundabouts, traffic lights, and left-turns) for further analysis. Fuel consumption was assumed to increase if flow of traffic was lost. Inadequately regulated lights may be such a slowing-down element of the infrastructure. In the study by Filipczyk (2014), traffic lights were found to be one of the most influential factors on fuel consumption, under the impression that the light regulations did not keep up with other regulatory changes, such as when the speed in the city was reduced from 60 to 50 km/h. The UPS courier company considers that left-hand turns are dangerous and less economical, in terms of fuel consumption, in right-hand traffic (Proscio, 2017). In accordance with the OFAT plan methodology, minimum and maximum values had to be established for each factor. Table 5 shows the assumed low and the high values of individual infrastructural elements.

Table 5. Factors analysed in the experiments

Factor	Minimum (number of infrastructure elements)	Maximum (number of infrastructure elements)
Factor A: Lights	1	2
Factor B: Roundabouts	1	2
Factor C: Left turns	1	2

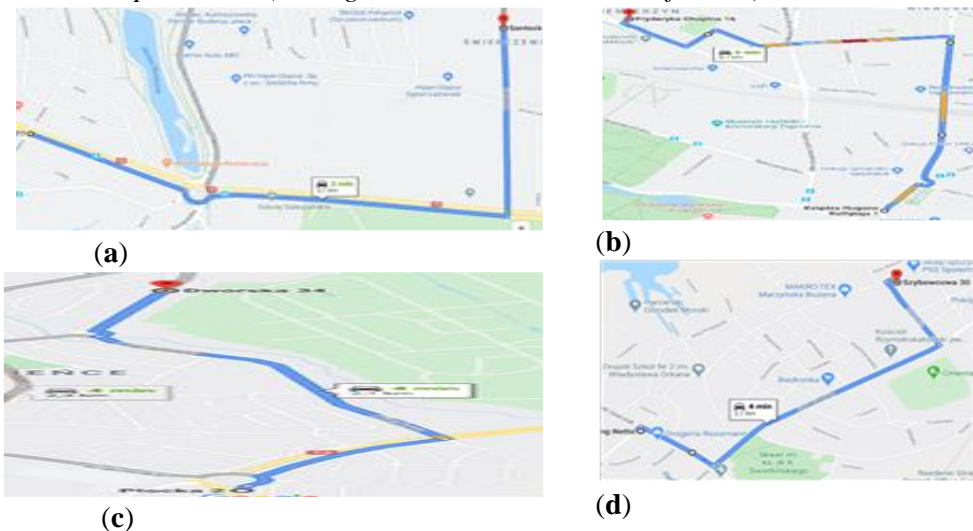
Source: Own study.

In order to carry out the experiments, it was necessary to select the routes to be tested. The routes were selected based on the following assumptions:

- routes of equal length;
- the base route (experiment 1) had to have all three factors at the lowest level (i.e., 1 roundabout, 1 traffic light, 1 left turn);
- each of the following routes should differ in the number of one of the factors, while the other factors are kept the same:
 - the route in experiment 2 had 2 lights,
 - the route in experiment 3 had 2 roundabouts, while
 - the route in experiment 4 had 2 left turns.

Routes meeting the above requirements were found using Google Maps. The courses of individual routes are presented in Figure 7.

Figure 7. Experimental routes: (a) Experiment 1 (one light, one roundabout, one left turn); (b) Experiment 2 (two lights, one roundabout, one left turn); (c) Experiment 3 (one light, two roundabouts, one left turn); and (d) Experiment 4 (one light, one roundabout, two left turns)



Source: Own study based on www.google.com/maps.

The first experiment carried out was the one in which all the analysed factors were at the minimum level. In subsequent experiments, the value of only one factor was changed to its maximum. When carrying out individual experiments, it was necessary to ensure that other factors, on which fuel consumption may depend, did not affect the result of the experiment. Therefore, driving took place in the same time period and the car was driven by the same driver. The car and its load were not changed. In this way, the impacts of other factors on fuel consumption, such as traffic intensity, driving technique, or car engine parameters, were minimized.

A passenger car was selected for the tests, as the type of the car in this experiment had no influence. Furthermore, as mentioned above, plenty of transport is carried out using passenger cars. The experiment did not seek to determine the actual fuel consumption of the used car but, instead, to discern the impacts of particular elements of the infrastructure on the fuel consumption level. Four experiments were necessary for the three factors considered. The results of the experiments are shown in Table 6.

Table 6. *Results of experiments*

Experiment no.	Factor A (Number of lights)	Factor B (Number of roundabouts)	Factor C of (Number of left turns)	Fuel consumption (l/100 km)
1	-	-	-	6.4
2	+	-	-	8.0
3	-	+	-	8.1
4	-	-	+	8.3

Source: Own study.

A minus sign means an experiment was carried out with a low level of a given factor, while a plus symbol represents a high level of the factor. Test runs were made in Szczecin. The length of each route was 2.1 km and the driving time was between 3.15 and 6.24 minutes. The car's computer, which the average fuel consumption values were taken from, was reset each time. For comparison, a plan with all factors would have required eight experiments. In the next step of experimental analysis, the differences in fuel consumption between routes characterized by a high level of a given infrastructure element and the base route (with the low value of all factors; Experiment 1) were determined. The above-mentioned differences suggest how the studied element of infrastructure influences the fuel consumption level. The results are shown in Table 7.

Table 7. *Impacts of the factors on fuel consumption*

Factor	Fuel consumption increase (l/100 km)
Factor A: Lights	1.6
Factor B: Roundabouts	1.7
Factor C: Left turns	1.9

Source: Own study.

The left turn was found to be the infrastructure element with the highest impact on fuel consumption of the three considered. The average fuel consumption, with respect to the base route, was increased by 1.9 l/100 km.

Therefore, the improvement of city logistics processes to reduce fuel consumption should focus on reducing left-hand traffic. In the "Improve" phase of the DMAIC cycle, the placement of lights at existing or new intersections can therefore be proposed. Besides, process improvements, in the context of fuel consumption reduction, can be achieved by planning supply routes accordingly. Unless the alternative route results in a significant increase in the number of kilometers to be covered, suppliers should choose one with fewer left-handed turns. The journey time should be noted here. The route with the highest combustion value did not turn out to be the one with the longest journey time. On the contrary, the 4.33 minute journey time achieved proved to be the second-shortest, immediately after the base route.

On the other hand, it took more than 6 minutes to complete the route with the lowest level of fuel consumption from among the routes with one high value factor (with two lights), which was the longest time to drive. Carriers wishing to be "eco" should accept the possibility of extending their transport time. At the same time, it should be remembered that the travel time at intersections with lights can be reduced if they are properly correlated in time. After implementation of the improvement in the case of city logistics, an FMEA analysis can be performed. In the last stage of the DMAIC cycle—"Control"—Shewhart cards can be used for continuous data, such as NO_x levels. It is also advisable to regularly assess the actual and potential capacity of the process (i.e., determination of the Cp and Cpk indicators). If the NO_x levels continue to exceed the customer-expected values, another Six Sigma project should be initiated. At the same time, as mentioned above, the remaining key indicators for the evaluation of urban logistics processes should be monitored.

4. Discussion and Conclusions

Due to the scope of the paper and the fact that it is only a presentation of a concept, only selected steps of the DMAIC cycle were discussed in detail. Thus, the conducted study should be treated as a pilot study. Based on the conducted experiments, only three factors from the infrastructure group (lights, roundabouts, and left-turns) were verified. The specificity of the city of Szczecin allowed us to find four routes that each differed in only one factor, which was a requirement for conducting the DoE experiment. Each route was only completed once. It is recommended to carry out several tests within a single experiment, in order to improve the reliability of the results. The experiments can be also carried out using the plan including all factors; however, finding eight routes which are adequate for the plan considering all factors in a single city may turn out to be impossible. Here, attention should be also paid to the fact that the experiments were carried out in a real environment: The city of Szczecin, Poland. On one hand, this is the value of this study but, on the other, it made the selection of routes more difficult.

Consequently, while selecting the routes, the roundabout diameter or the number of lanes were not taken into consideration. Also, the number of pedestrian crossings and deceleration thresholds on the route were not accounted for.

Szczecin is a city with a lot of roundabouts, compared to other cities in Poland. The road infrastructure redevelopment in the city is still aimed at rebuilding intersections and replacing them with roundabouts. Our study demonstrated that this is a justified action, considering the results obtained during the experiments. The conducted research showed that left-turns had the greatest influence on fuel consumption. On the basis of our experiments, it is difficult to draw far-reaching conclusions; even more so, when considering that the Six Sigma methodology has not yet been implemented in the management of city logistics processes. The presented case study only shows the possibility of implementing Six Sigma in city logistics. It is only possible to define the expected results. In the case of city logistics processes management according to the Six Sigma concept, the expected results may be a reduction of city logistics management costs, a reduction of freight transport costs, and promoting the attractiveness of the city to its residents. However, it is necessary to conduct further in-depth research, including studies focused on other factors influencing fuel consumption during city transport. As a note of caution, Six Sigma projects are always dedicated to particular processes. Therefore, results and solutions that work in one city do not necessarily work in another.

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