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Changes in Costs Incurred by Car Users of the Local Transport System Due to the Implementation of Sunday Retail Restrictions

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Abstract: The correlation between retail trade and the transport system is clear. Shops are customer oriented, and to visit them, the shopper needs to travel by a mode of transport and find a suitable time to do so. Due to the concentration of retail outlets in large-format shopping centres, these have become among the greatest attractors and traffic generators (including car traffic). While their attraction potential and traffic generation are well established in the literature, research on disruptions to the retail market and their impact on the transport system remains sparse. The authors—wishing to extend the scope of research on this subject matter—set themselves the objective of examining the extent to which Sunday retail restrictions affect the efficiency of the local road transport system. They applied time-measured costs (queuing and delayed travel times) as a measure of efficiency. Empirical measurements of traffic volumes were employed in the study, and the measure of efficiency was calculated through microsimulation traffic modelling based on a psychophysical car-following model. However, the returned results prove to be inconclusive. A decrease in the temporal cost incurred by road users is observed in areas around shopping centres located in the city centre and the outskirts. A different pattern, however, is observed close to shopping centres located on an axis connecting the city centre to residential areas. The main conclusion from this study is that the changes in traffic density seen due to Sunday retail restrictions should induce further analyses of the changes in the spatial and temporal distribution of traffic. As a result, a more efficient traffic management that is adjusted to a given day of the week and specific situation on that day could be implemented.

Keywords: Sunday retail restrictions; psychophysical model; Wiedemann 74; urban transport system; retail market and transport system



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1. Introduction

Modern socioeconomic life involves relationships between different forces. One is the link between the performance of retail trade and the performance of the transport system. This is particularly noticeable as shopping trips are one of the most common motivations behind people's mobility [1,2]. In turn, given the ever-growing concentration of retail outlets, these trips are increasingly made to shopping centres, thereby making such places significant traffic attractors and generators. The traffic generated by these large facilities differs depending on a number of variables [3]. However, among the most common means of transport chosen by customers visiting shopping centres is private car [2,4]. This stems from the fact that customers are generally motivated to visit shopping centres by such factors as: the wide diversity of products on offer, the opportunity to buy in bulk and purchase commodities that are quite large, the ample availability of parking spaces, and even the pure pleasure of shopping derived from such places. As a result, shoppers are inclined to travel greater distances by car. While the issue of traffic generation by retail facilities is well established [5–7] and the necessary TIA reports are available for such facilities in several countries, the literature on the effects of temporal disturbances in the operation of shopping centres remains scant. In recent years, this

issue has mainly been addressed in a broader context, that is, retail restrictions as part of regulations limiting residential mobility in the face of the COVID-19 pandemic [8–10]. Such studies have proven extremely valuable, for both basic research and its applicability to scenarios that may occur only periodically. What is still poorly explored, however, is the changing impact of these traffic generators during long-term retail constraints. There are a number of studies on the impact of market regulations regarding Sunday retail, but the vast majority focus on liberalization [11–13], less frequently on increased restrictions [14,15]. The issue examined in this paper partly fits into the aforementioned research gap. An ideal country for investigating this phenomenon is Poland, where the once liberal approach to the operations of large retail facilities changed when Sunday retail restrictions were gradually implemented.

The main purpose of this study is to determine the extent to which these restrictions have affected the efficiency of the local car transport system. This efficiency is measured by the time costs for car users on the road network located in the immediate vicinity of shopping centres. The accomplishment of this objective (through microsimulation) allows for conclusions to be drawn from both cognitive and applicative perspectives. It will also enable a better adjustment of how traffic signal sequencing is operated and coordinated, especially in traffic organisation systems based on a centralised traffic management.

2. Review of the Literature

2.1. Theoretical Foundations

Shopping is among the most common motivations behind residents' mobility [1]. In the UK, around 20% of all trips from home are for shopping [2]. Polish surveys conducted prior to the implementation of Sunday retail restrictions reveal the percentage of trips to be 10.2% shopping related, with as many as 12.7% of weekend trips being for such reasons [16]. Hagberg and Holmberg [17] attribute the high percentage of shopping trips to the fact that a significant proportion of shopping activity relates to fast-moving consumer goods. For this reason, Guy [2] classifies shopping activities among residents' routine behaviour.

Wiese et al. [3] group factors that affect travel behaviour—particularly those related to the choice of transport mode—into four categories. The first three of these are: socio-demographic features (e.g., age, gender, household size, age of the family head); psychological and personal factors (e.g., awareness of the consequences behind choosing a particular mode of transport), and external factors beyond the traveller's control (weather, accessibility to transport, opening hours, etc.). The fourth class involves 'situational' factors, that is, arising from specific circumstances behind the realisation of a given travel motivation. These factors include such variables as the type of goods purchased, the day of the week and the time of day when shopping is done, or the complexity of the journey (both the number of transport modes used and the number of trips when attempting to make purchases at different locations). However, it is well worth noting that shoppers' transport behaviour is also impacted by factors related to the prominence of a given retail centre and their preference to shop in this particular facility. In this context, shoppers are prepared to cover greater distances for what they consider to be a more pleasurable shopping experience. Moreover, some researchers argue that the selection of a transport mode for shopping purposes is also affected by the catchment area of a given shopping centre [18]. The effects of the said factors that impact the modal split in shopping trips became apparent in empirical studies. Research conducted in the United Kingdom shows the leading role of the car as the mode of transport, which is used for shopping trips in over 62% of cases, with trips made to do grocery shopping at 76%. These studies demonstrate that the major factors in the selection of the car for shopping trips are the size of the 'shopping basket' (measured not by its value, but by the volume of goods) and the distance to the store [2]. The widespread reliance on the car is also evident in other countries [1,4,17,19]. For this reason, it is crucial to examine the impact of shopping trips on the car transport system.

Retail trade in free-market countries is dominated by large-format players [20]. Not only are they important trip generators, but also they can contribute to reducing the

total number of trips (a single trip to a mall enables shoppers to buy a wide range of commodities, and in bulk). This is indirectly confirmed by studies revealing the high percentage of multipurpose trips to such places [21,22]. Due to the concentration of retail facilities and the fact that many shopping trips are made to shopping malls, increased traffic is observed in their immediate vicinity [6,7,23–26]. In certain scenarios, it may amount to over 50% of the traffic—even on sections that channel large flows of urban traffic [27]. This results in adverse external effects generated by shopping centres, which are reflected in the impaired efficiency of the transport system and the associated higher costs (congestion and its environmental effects, direct costs due to extra energy consumed to pass through bottlenecks, time-related costs, etc.). The said increases in traffic congestion, when there is a high degree of operational freedom of the retail trade, are relatively simple to estimate. They have been assessed in depth for individual times of day and days of the week, based on sets of dedicated regression models. Models suitable for applicative purposes are generally those where the descriptor variables are factors defining the attractiveness of shopping centres [6,7]. The effects of the reduction in this freedom on the transport system are still little studied in the literature. One such example that proves how crucial this research gap is, is the work by Chmielewski [28]. The relevance of this subject matter is further amplified by the fact that in the European single market (the EU states), the freedom of retail trade is quite divergent [13,29,30].

Studies on changes in the freedom of retail business activity mostly revolve around two main directions—the first being market deregulation. As reported by Genakos and Danchev [13], there has been a general relaxation of Sunday retail restrictions in Europe over the past decades. Due to the fact that this trend has been the predominant one in recent years, it has been the focus of most studies in this field. Existing studies on the freedom of retail business activity primarily present the resultant economic landscape, pointing to employment benefits [11,12], greater investments in individual retail sectors [11,13], and nuanced effects on price formation [31]. However, there are few studies on the deregulation of Sunday retail with specific regard to the transport sector. De Meza [32] argues that allowing people to shop on Sundays can reduce the shopping-related costs of transport. The second trend—limiting the freedom of Sunday retail—is a less widely recognised 21st-century market direction. The brief and short-lived Hungarian experience in this respect provides insufficient data to make solid conclusions, albeit one might speculate that there was a reduction in employment in the sector due to the retail restrictions [14]. Economic analyses of the implementation of Sunday retail restrictions in Poland do not provide a comprehensive insight either since they coincided with restrictions on retail imposed during the COVID-19 pandemic [14]. There is, however, ongoing research on the impact of Sunday retail restrictions on mobility, which has been conducted on a large, citywide scale [15,33,34].

As regards the retail market and its spatial dimension, one must realise that travel costs will be incurred when shopping. For this reason, customers residing close to a particular shop will not be easily lured away by a more distant alternative. As de Meza [32] notes in his model example, shops would be generally more willing to offer price reductions to those customers who live farther away and for whom they have to compete against rivals. Obviously, market regulations make this impossible. For many customers, especially those professionally active on weekdays, the time cost of shopping happens to be lowest on Sundays. That means that, for some customers, no Sunday retail restrictions reduce costs (the time spent travelling, etc.), especially for those who live at a distance, that is, the group the retailer is trying to attract the most. Therefore, opening a shop on a Sunday becomes an effective form of competition (lying in the domain of geographical studies), one that occurs in geographical space in its full meaning, including distance decay, which is particularly salient from the perspective of transport.

2.2. Research Area

The Polish experience of changes in the transport system resulting from the Sunday retail restrictions constitutes an ideal research pretext, primarily due to the coexistence of the following two, independent, premises: Sunday retail restrictions in Poland were introduced gradually (Figure 1) [10], and the implementation period coincided with a significant expansion of the system of sensors that monitor the road network, which enabled the acquisition of considerably more precise quantitative data on urban traffic. As a result, it became possible to empirically observe residents' mobility changes following the implementation of the Sunday retail restrictions—almost in real time.

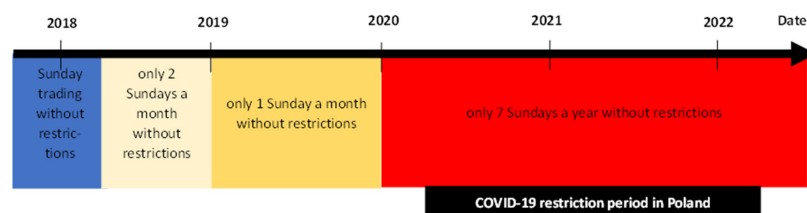


Figure 1. Progression of the restrictions on the freedom of retail operations in Poland after 2018. Source: own elaboration.

Poland is a postsocialist state where free-market processes developed rapidly after the collapse of the Iron Curtain. This boom was partly due to the large influx of capital from Western Europe, including investments in the retail market. The prolonged era of the socialist economy, which for a considerable period was marked by recurrent shortages of consumer goods, triggered a fairly rapid adoption of Western patterns and retail formats. As a result of this, and due to global processes of universal relevance, poles frequented shopping centres in droves, perceiving them as places both to shop conveniently [35] and to spend leisure time [36]. Thus, large shopping centres soon became ‘temples of consumption’ in Poland [37], regularly visited by large numbers of residents, especially on weekends [38]. In Poland, 9.6% of all weekday trips and 14.2% of weekend journeys are connected to shopping. In the Lodz Province, this percentage amounts to 9% on weekdays and 12.7% on weekends, while for the city of Lodz alone, it accounts for 8.2% (regardless of the day of the week) (37 trips per capita annually) [16]. This and the ever-increasing accessibility to cars have resulted in heavy traffic heading for shopping centres, becoming a widespread phenomenon in 21st-century Poland [26–28]. Borowska-Stefańska et al. [19] posed a retrospective question on shopping trips to facilities currently affected by Sunday retail restrictions in the period prior to their implementation. The returned results unambiguously (over 70% of responses) indicate that the car is the primary mode of transport selected for trips to shopping centres.

The heavy traffic around malls and the Sunday retail restrictions have changed Polish residents' mobility patterns, including shopping trips [33,39,40]. A study by Chmielewski [28] conducted in the Polish city of Bydgoszcz reveals an increase in traffic volumes on trading Sundays versus nontrading Sundays, although this may be impacted by seasonal weather conditions. Macroscopic analyses in this respect were also conducted in Lodz—the research area selected for this study. Again, higher overall traffic volumes are observed in the vicinity of malls on trading Sundays when compared with nontrading Sundays [15,34].

The road layout in Lodz—the city that is the case study for this paper—takes a relatively schematic shape of a grid (a framework layout) in the centre and becomes gradually less regular and more radial the farther out one goes. The efficiency of the local road transport system is quite significantly reduced, as shown by studies utilising data from intelligent transport systems [41], GPS [42], and information supplied by navigation data providers (TomTom Traffic Index reports and rankings, Korkowo website, etc.). The modal split of the means of transport used daily by Lodz residents is difficult to determine unequivocally. Some studies in this respect were conducted prior to the great investment boom (related to the expansion of infrastructure) and during the dynamic growth of the motorisation

rate, while others were performed amid the COVID-19 pandemic. Therefore, their results (Figure 2) should be viewed cautiously when attempting to circumscribe the present-day situation under normal conditions.

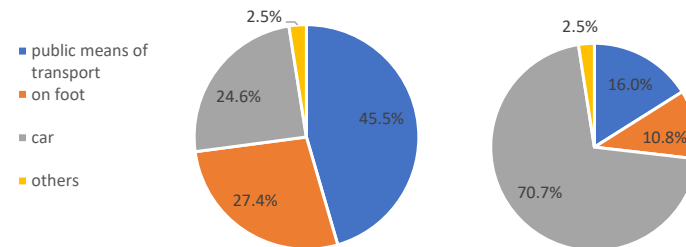


Figure 2. Modal split of total trips in Lodz in 2013 (left) and 2021 (right). Source: own elaboration based on [43,44].

For this study, three transport regions (Figure 3) were selected within the direct catchment area of three different shopping centres (Table 1). Each centre represents a different type of retail facility, following the typology of its location within the functional and spatial structure of the city and its transport accessibility. One site is located peripherally ('Port Łódź'), another along the axis of the city centre/large residential zone continuum ('Tulipan'), and the third in the very city centre ('Manufaktura') [45]. The rationale behind this selection primarily lies in the differing impact that each type of shopping centre has on the local car transport subsystem. These facilities also differ in terms of size, generation, and catchment area, which affects the nature of their commercial and noncommercial offer (Figure 4).

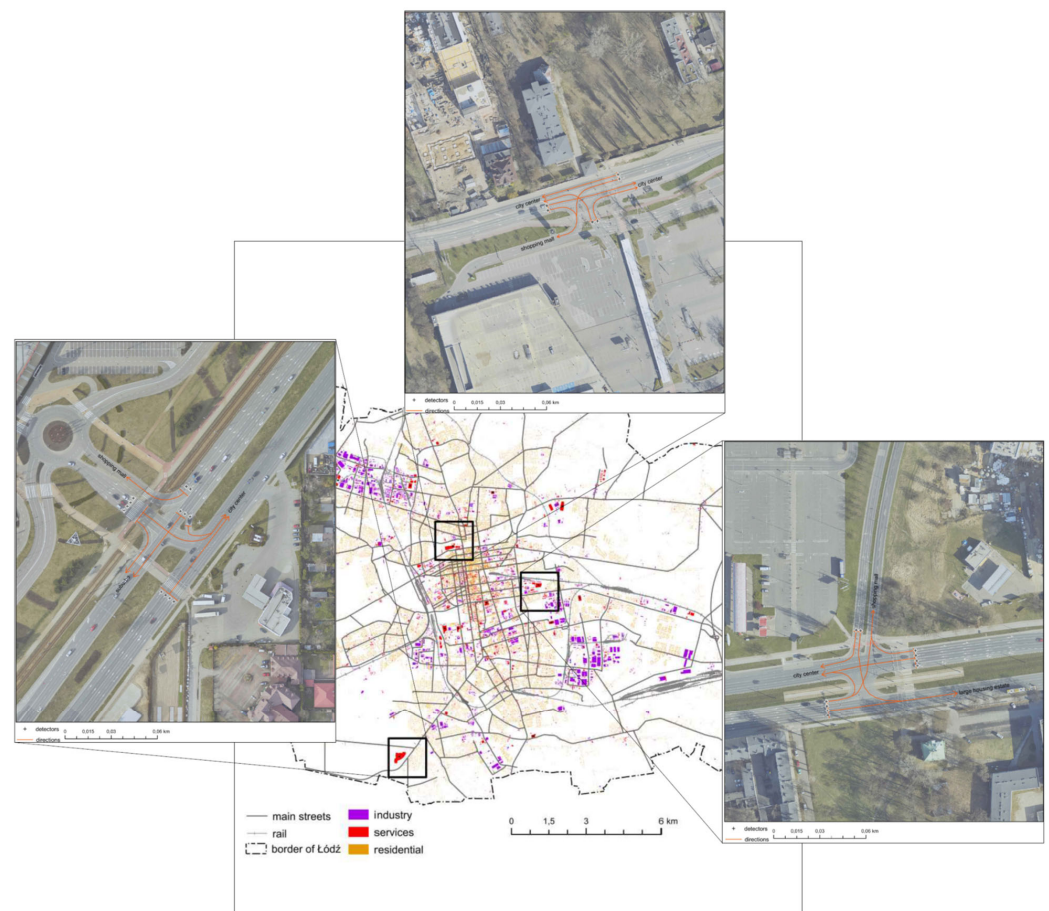


Figure 3. Location of detectors utilised in the study. Source: own elaboration.

Table 1. Key features of the shopping centres selected for the study.

Name	GLA (m ²)	Size *	Generation	Catchment Area **	Location
Manufaktura	125.7	Medium	II	Local	City centre
Port Lodz	103	Very large	III	Supraregional	Suburbia
Tulipan	33.2	Very large	IV	Supraregional	Axis: city centre—large residential area

* According to the ICSC classification (small: 5000–19,900 sq. m.; medium: 20,000–39,900 sq. m.; large: 40,000–79,900 sq. m.; very large: 80,000+ sq. m.). ** According to the ICSC classification. Source: own elaboration.

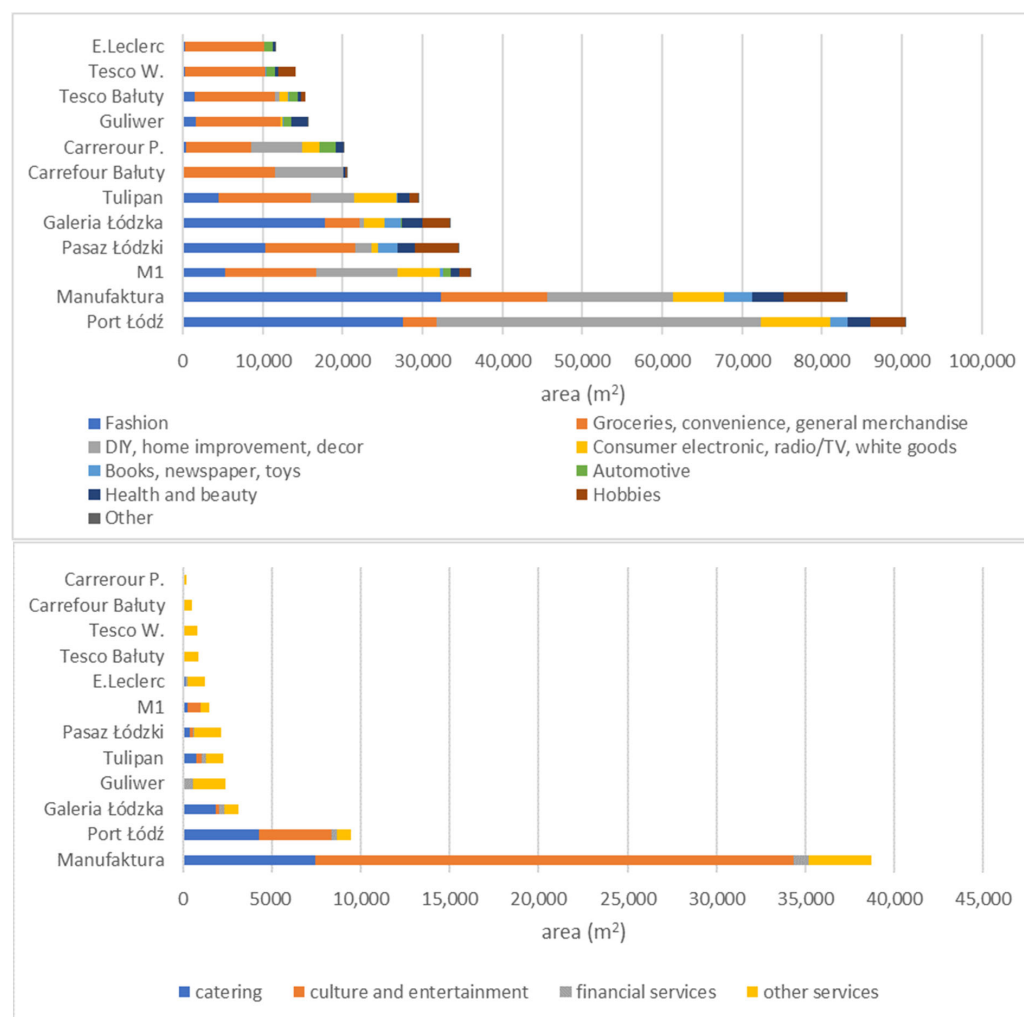


Figure 4. Commercial (top) and noncommercial (bottom) retail offerings of the shopping centres selected for the study against other shopping centres in Lodz. Source: own elaboration.

3. Source Materials and the Research Method

The analysis of the changing efficiency of the local road transport system was based on two types of data: documentation and empirical traffic measurements. Documents obtained from the local road network authority were used, including technical plans and design documentation of the analysed intersections, containing the plans of traffic signal timing. A brief explanation of this is necessary. The traffic lights management is based on a cyclic time-varying organisation, whose timing is additionally coordinated with the intersections located in their vicinity as part of the area traffic control system. For this reason, the authors relied on the examples that the system administrator made available as being most frequently applied on Sundays at a given intersection.

The second type of data is empirical measurements from induction loops that feed the local intelligent transport system with information to improve traffic management. The

measurements are performed by induction-loop sensors installed in each lane ahead of the intersections [46]. The analyses took into account measurements from the peak hour related to the shopping centre for the period prior to the implementation of retail restrictions (a Sunday in February 2018, between 3:00 and 4:00 p.m.) and when the restrictions were gradually introduced (trading and nontrading Sundays in February 2019).

Based on the dataset presented above, the authors built a model of the transport network, which included—apart from the geometrical description of the network—the existing traffic layout (speed limits, right-of-way regulations, location of stop lines, and demarcation of lanes where drivers can change lanes and directions, traffic signal timing schedules, etc.).

To demonstrate the correlation between the traffic generation of shopping centres in different analysed periods and the costs of operating the transport system, traffic microsimulation methods based on a car-following model (a technique dating back to the 1950s) were employed [47]. These solutions include the following car-following models: Helly's, Gazis–Herman–Rothery, Wiedemann 74, and intelligent driver [48]. The psychophysical Wiedemann 74 model was utilised in this study. The models in this class are based on the assumption that the driver's behaviour will vary depending on the traffic conditions they experience (e.g., moving in free-flowing traffic, having to slow due to traffic buildup, traffic moving at a crawl, braking, etc.). In other words, these models rely on the mechanism of perception of the relative flow of vehicles. The model applied falls into the class of empirical solutions, and its distinctive feature is that the vehicle follows the preceding vehicle (leader) at an average distance in an oscillatory manner. The state of motion in this model is recorded as differential equations, later to be converted into an easily readable graph [49,50].

This model was implemented into the VISSIM tool to address the main research problem. The boundary values—empirically measured traffic volumes for each period in question—were incorporated into the previously built network model. These measurements allowed the authors to construct a precise structure of traffic and were therefore implemented as static vehicle routes. All vehicles present on the network between the 120th and 600th second of the analysis were assessed, while microsimulation results were collected in 1-second time steps. The impact of the changing costs incurred by car users resulting from changes in the operation of retail businesses on Sundays was assessed based on queue time and delay time. Cars were deemed to be in a queue if, due to events on the road, their speed was reduced to less than 5 km/h and remained lower than 10 km/h, whereas delay time was an estimate of the amount of travel time lost against theoretical speed (in free-flowing traffic).

4. Results and Conclusions

The spatial and temporal changeability of traffic volumes on a citywide scale (as observed under the Sunday retail restrictions) has been the subject of a number of studies [15,19,27,34,51]. Their findings are consistent with those made on a microscale (single intersection) (Figure 5). On nontrading Sundays, the traffic connected to the analysed retail facilities decreased significantly, which seems understandable. What is less obvious, however, is the fact that lower traffic volumes were recorded in the vicinity of the shopping malls located in the city centre and on the outskirts, where traffic decreased dramatically, as opposed to an increase noted in the vicinity of the shopping centre located along the transport axis connecting the city centre to residential areas. It is difficult to determine conclusively what caused these particular shifts of the traffic flow vectors during the analysed period. Studies on a broader spatial scale and the results of social surveys indicate that at least a percentage of customers who used to shop on Sundays now choose to stay at home and eschew transport. On the other hand, many customers declare that they use the time once spent on Sunday shopping to visit family and friends [33,40]. This may explain why there is more traffic on the thoroughfare serving different districts.

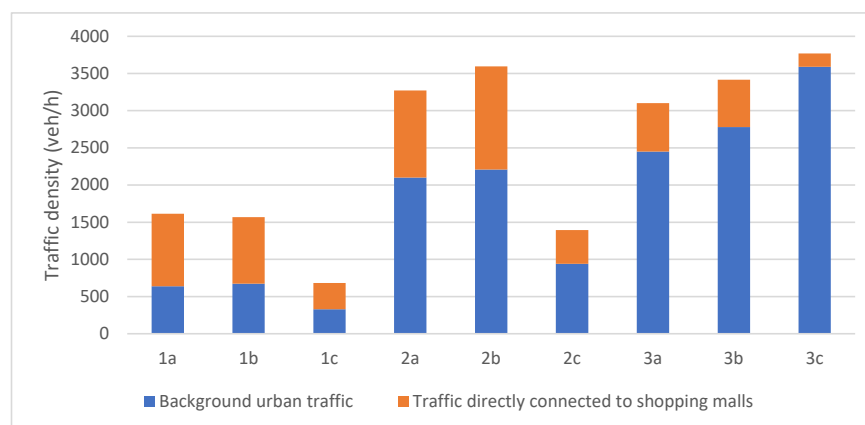


Figure 5. Traffic density at intersections with a direct slip road to the shopping centre. Legend: 1—Manufaktura; 2—Port Łódź; 3—Tulipan; a—period prior to the implementation of the restrictions; b—period of partial implementation of the restrictions for Sundays when they are not in force; c—period of partial implementation of the restrictions for Sundays when they are in force. Source: own elaboration.

The degree of vehicle traffic generated on trading Sundays is affected by the core offer of the shopping centres. This core is defined by the offer of goods and services, including anchor tenants and customer magnets [52]. This leads to increased traffic on the few remaining trading Sundays (versus the period prior to restrictions) predominantly in facilities with flagship outlets offering products that can only be purchased and viewed in a limited number of places in the region and targeted at a specific customer group. A customer magnet of this type is the IKEA store in Port Lodz [27], the only shopping centre among those in question where higher vehicle traffic was observed on trading Sundays (Table 2).

Table 2. Patterns of changes to Sunday traffic versus the period prior to the implementation of Sunday retail restrictions.

	Manufaktura	Port Lodz	Tulipan
Change in traffic density created by shopping centres for February 2019 versus February 2018 [%]			
nontrading Sundays	−64%	−61%	−72%
trading Sundays	−8%	19%	−2%
Change in traffic density unrelated to shopping centres for February 2019 versus February 2018 [%]			
nontrading Sundays	−49%	−55%	47%
trading Sundays	5%	5%	14%

Source: own elaboration.

Traffic density is closely connected to the travel time costs incurred by drivers travelling in the vicinity of shopping centres. These costs are mainly attributable to time lost in queues at intersections (Figure 6). In general, travel costs increase on trading Sundays, while the efficiency of the road system enables faster passage on nontrading days. However, on certain sections of the network, an increase in peri-urban traffic observed on nontrading days contributes to longer travel times (Figure 7).

This study may serve as a base for further research into the impact of changes in consumer behaviour as manifested by car traffic. Sudden periodic surges in the intensity of traffic generation [27] or its abrupt drops are an intriguing issue to be explored from the point of view of a number of fields: from a better understanding of the impact of legal amendments (which customarily are not directly linked to the impact on transport systems), through changes in transport costs (accessibility captured by a number of measures) and their effects on the spatial development of settlement units, to issues directly related to traffic management.

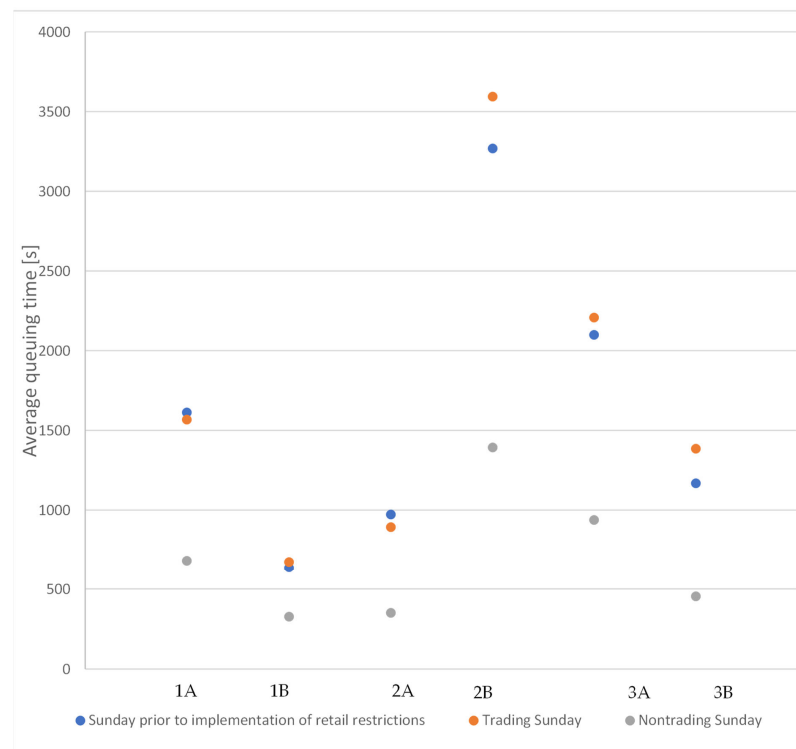


Figure 6. Waiting time in the queue at intersections in the area of shopping centres on various Sundays. Legend: 1—Manufaktura; 2—Port Łódź; 3—Tulipan; A—total traffic volume; B—traffic unrelated to the shopping centre.

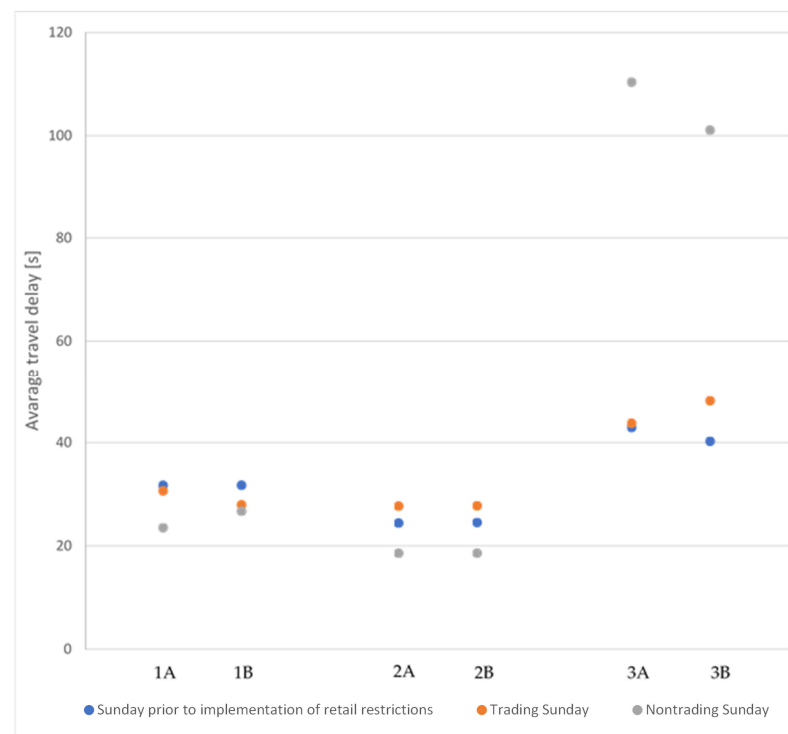


Figure 7. Delay time at intersections in the area of shopping centres on various Sundays. Legend: 1—Manufaktura; 2—Port Łódź; 3—Tulipan; A—total traffic volume; B—traffic unrelated to the shopping centre. The results clearly demonstrate that the efficiency of the area traffic control system could still be enhanced. This is particularly noticeable on interdistrict roads. In instances where there is almost no traffic travelling along the urban transport network towards the car parks adjacent to the

shopping centre, a change in the operation of the algorithms controlling traffic lights should be seriously considered. The main delays on nontrading Sundays are related to the operation of the traffic light sequencing. Even when greater priority is given to the acquired data in the traffic signal control algorithm, there are still delays and longer queues, with green light displayed for empty roads and time lost due to the unnecessary interval between green lights. To maintain the highest possible efficiency of the road transport system in the face of the changes to the operation of retail facilities of high traffic generation potential, it is vital to consider modifying the traffic management infrastructure and introducing acyclic signalling in their vicinity, that is, one with a variable sequence of signal phases. This means a fully traffic-dependent signalling system where phases can be activated based on current demand and, in addition, a variable duration, depending on traffic properties.

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