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The Emergence of Mobility Inequality in Greater Jakarta, Indonesia: A Socio-Spatial Analysis of Path Dependencies in Transport–Land Use Policies

Isti Hidayati [1], Claudia Yamu [1,*] and Wendy Tan [2]

1 Faculty of Spatial Sciences, University of Groningen, Landleven 1, 9747 AD Groningen, The Netherlands; i.hidayati@rug.nl

2 Department of Environmental Sciences, Wageningen University and Research, Droevendaalsesteeg 3, 6708 PB Wageningen, The Netherlands; wendy.tan@wur.nl

* Correspondence: claudia.yamu@rug.nl; Tel.: +315-0363-4680

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Abstract: Despite numerous studies suggesting a path-dependent relationship between transport–land use policies and urban structures, particularly on the emergence of car-oriented development, this connection has rarely been explained with spatial evidence. To address this gap, this paper investigated the historical and spatial urban transformation of Greater Jakarta from three different time periods to understand today's extensive use of and dependence on private vehicles. This study applied a multi-method approach of (1) historical literature review, (2) computational analysis of the street network using space syntax, and (3) visual analysis of video recordings to allow for a comprehensive insight into the socio-spatial aspects of urbanization as a path-dependent course. The findings indicate that Jakarta's pedestrian network has been diminishing over time against the well-connected vehicular network. Furthermore, the remaining potential for walking cannot be actualized due to walking inconveniences at the street level. This suggests mobility inequality, since access to citywide urban functions is highly dependent on the access to private vehicles. It also provides spatial evidence that previous policies have had a long-term impact on socio-spatial structures. This paper contributes not only scientific reference for transport and mobility studies in the Southeast Asia region, but also a practical reference for urban planners and policy-makers on how to achieve sustainable development goals and to provide equal access for all.

Keywords: mobility inequality; transport–land use policies; urban transformation; social-spatial structures; space syntax; path dependence; sustainability; Greater Jakarta

1. Introduction

The transport problems plaguing Southeast Asian metropolitan cities, such as the marginalization of pedestrians [1] and the tendency towards an automobile-dependent society [2], are the accumulated impacts of previous transport–land use policies that indicate a path dependency [3–5]. In this region, transport planning is heavily invested in road expansion [6,7] as evidenced, for example, through a high motorization trend in Jakarta [8,9]. This policy affects socio-spatial structures, including the street network configuration and distribution of key functions (e.g., schools, health care services), thus incentivizing motorized movement whilst simultaneously penalizing other modes of transport, such as walking and cycling. Such conditions have led to the inhabitants of most Southeast Asian cities adopting mobility behaviors through extensive use of private motorized vehicles, especially motorcycles. While the use of motorcycles could benefit the majority of the population, marginalized groups, such as those living in extreme poverty that cannot afford a private vehicle, those with disabilities, women, and children, are at a disadvantage due to a higher safety risk, especially since most urban street profiles in this region do not have properly separated pathways between motorized and non-motorized traffic.

A notable effect of this chain of consequences is mobility inequality, wherein the gap between those with and without access to private motorized vehicle is widening in terms of access to opportunities, safety, time efficiency, and monetary value. Previous studies on mobility inequality have identified that differences in mobility, or the ability to move, are both a manifestation of and contributors to socio-economic inequalities [10,11]. Mobility serves as the means to access opportunities [12]; thus, the lack of mobility can reduce access to key functions. Differences in mobility are highly associated with socio-economic attributes such as income, gender, age, or migrant status [13,14]. In Jakarta, a typical Southeast Asian city, the impact of mobility inequality is likely to be associated with marginalized groups and the urban poor, as approximately sixty per cent of Jakarta's population with an income of less than IDR 1,000,000, or around 70 dollars per month, do not have another choice besides walking [15]. For these groups, mobility inequality can further lead to transport-related social exclusion [16–18].

Mobility inequality is related to spatial patterns and structures in three different nuanced ways: (1) as a transport cost from the function of distance, (2) as a mobility barrier for a specific group in a strongly spatially segregated city where low-income and minority neighborhoods are underserved by transport services [19–21], and (3) as a factor of an automobile-dependent society [22,23]. Since spatial patterns and structures are the irreversible product of a long-term interplay between transport–land use policies and societal processes, the understanding of contingent past policies can provide insights as to the emergence of mobility inequality. This understanding, however, is often described from an institutional perspective, and is rarely supported with spatial evidence. The absence of spatial evidence makes it difficult to visualize the effect of previous policies on the present socio-spatial conditions, or to have formulate a future prognosis, which is deemed essential for urban and transport planning practice.

The aim of this paper was to understand Greater Jakarta's (hereafter Jakarta) urban transformation to identify indications of vehicle-oriented development as the manifestation of mobility inequality. Jakarta was chosen as a case study because it represents the fast urbanization of Southeast Asian cities, including a high motorization rate [24,25], that can consequently lead to severe effects of mobility inequality, especially for marginalized groups. This paper used a multi-method approach including (a) a historical literature review to understand Jakarta's urban narrative, (b) a computational analysis of Jakarta's street networks for three time periods (1940, 1959, and 2018), using space syntax to gain insight into Jakarta's spatial transformation over time, and (c) a visual analysis of video recordings applying the 'walking with video' approach [26] to illustrate the current mobility inequality in Jakarta. This combined method provided an element of novelty for our research and differentiated it from previous studies on Jakarta's urban development such as Lo's study [1] and Winarso et al.'s study [27]. This method also allowed for a better understanding of how policies and historic events influence urban transformation. The findings add to the debate around achieving a just society and sustainable cities in the urban south, as linked to the United Nations' Sustainable Development Goals (SDGs), especially SDG 11 on making cities inclusive, safe, resilient, and sustainable.

Consequently, the paper is structured as follows. In Section 2, the research methodology is described. Section 3 elaborates on the results, followed by discussions in Section 4, and Section 5 concludes with insights into practical implications and directions for future research.

2. Materials and Methods

2.1. Research Questions

In this research, we directed our focus from a policy-driven understanding of path dependence to an integrated approach, which incorporated spatial modeling and analysis. This approach allowed visualization of the emergence of mobility inequality in Jakarta as a consequence of transport–land use policies over time. More specifically, we concentrated on the following research questions:

(1) What are the transport–land use policies that have had a significant influence on Jakarta's urban development over time?
(2) How has Jakarta's urban structure changed over time in relation to changes in the transport–land use policies?
(3) What is the current state of mobility inequality in Jakarta?

2.2. Research Methods

Answering the research questions enabled the integration of transport–land use policy based on the spatial understanding of Jakarta's urban transformation, which included an exponential growth in size of around 10 times between 1940 and 2018. To answer these research questions, a multi-method approach was employed, which consisted of: (a) a historical literature review, (b) a spatio-syntactical analysis with space syntax, and (c) a visual analysis of video recordings. The mix of methods encouraged interdisciplinary discussion [28] about the complex issue of mobility inequality from the perspectives of policy analysis, spatial modeling, social sciences, and transport planning. This multi-method approach integrated the quantitative and qualitative methods of inquiry to understand the complex relations of transport–land use and urban structure within the narrative of (un)sustainable mobility.

2.2.1. Historical Literature Review

We applied an organizational pattern to a literature review [29] and focused on the historical context of the events and policies related to urban and transport development throughout a period of time. The historical literature review was conducted to identify critical junctures that significantly changed the urban development trajectory. The identification of critical junctures established a path dependence framework [4,5,30,31], which explained how past policies shaped the current urban fabric through the interplay between transport–land use and societal process. This path dependency implied that history matters, which reflects the importance of understanding the historical narrative to comprehending current transport and mobility problems. For instance, policies that encourage low-density development, road expansion, and neglect of public transport will lead to problems of automobile dependence [32]. From an institutional perspective, previous institutional values have been internalized and remain as an organizational routine in the current system [3,33]. This explains how transport and urban planners who are accustomed to road expansion strategies become reluctant to shift to more sustainable practice, such as investing more in public transit services [34,35]. On a personal level, people become more accustomed to driving a car and thus reluctant to shift to other transport modes, such as walking [36].

In this paper, critical junctures along a path-dependent trajectory were constructed from the review of published studies (n = 19) on Jakarta's urban development. The review process consisted of (1) searching for the relevant studies through Google Scholar and desk-search at the National Archives of the Republic of Indonesia, (2) content screening by applying the keywords of transport, land use, and urban development, (3) summarizing and documenting, and (4) organizing, analyzing, and synthesizing by classifying Jakarta's urban development into three periods, each defined by a different political regime: (i) the late period of Dutch colonization from 1800–1945, (ii) the post-independence period, which includes the Old Order regime from 1945–1967 and the New Order regime from 1967–1998, and (iii) the post-reformation period, from 1998 to the present. During the review process, it should be noted that Jakarta was known under different names and spelt differently: it was known as Batavia during Dutch colonization and it was spelled as Djakarta in the old Indonesian spelling, which was used from 1901 to 1947.

2.2.2. Spatio-Syntactical Analysis with Space Syntax

This paper integrated space syntax analysis into historical research to complement the narrative from the historical literature review [37,38]. Space syntax analyzes how spatial arrangement influences users' perceptions and the use of space; thus, it can be used to further infer the flow and pattern of movement [39–41]. Through applying space syntax, the street network was analyzed by measuring the relationship of one street segment to all other street segments in a system based on the concept of centrality in terms of ease of access and wayfinding. Previous space syntax studies have indicated that the relational analysis of street network configuration is correlated with actual movement and can be used to explain land use and location choices [40,42]. The interpretation of space syntax analysis, however, has to be linked to the understanding of human behavior and socio-spatial processes [42].

The added value of applying space syntax to historical research is that it helps to understand how changes in spatial structures related to culture and lifestyle in a certain time period [43–45]. Space syntax works with the concept of an axial map (street network model), which is the representation of a minimum set of sightlines of movement paths [46]. The following maps were used to model Jakarta's street network: the 1940 map (Plattegrond van Batavia by G. Kolff & Co., Amsterdam) to represent the late period of Dutch colonization, the 1959 map (Djakarta: North and Djakarta: South, both developed by the US Army Map Service) to represent the post-independence period, and the 2018 map (OpenStreetMap) to represent today's Jakarta. This dataset selection was based on map availability and reliability. For the 1940 and 1959 maps, axial lines were manually traced, while the 2018 map used road center lines. No significant differences resulted from the analysis using manually traced axial lines and road center lines [47]. All maps were scaled using the 2018 map as the base map.

Following Griffith's [43,45] framework, in this study, we compared the syntactical properties of Jakarta from three different periods by employing two measures: (1) normalized angular integration (NAIN) to identify potential destinations or activity centers (to-movement) and (2) normalized angular choice (NACH) to distinguish potential route choices (through-movement). Both measures provided insights into the structure and the ease of access of the foreground and background networks [48]. The interpretation of space syntax results was referred to the historical and policy changes in Jakarta within the narrative of the emergence of the car-oriented and pedestrian-unfriendly environment.

To trace Jakarta's citywide spatial transformation, the space syntax analyses were calculated using a 'global' or citywide radius. The global radius calculates the relation of one street segment to all other street segments in the system. Meanwhile, to represent the current conditions of urban mobility in Jakarta, a local radius analysis of 800 m, which represents approximately a 10 min walking distance, was conducted for the 2018 street network model.

2.2.3. Visual Analysis of Video Recordings

Furthermore, in this study we conducted a visual analysis of video recordings to provide visual connection and to illustrate the current state of urban mobility in Jakarta. The "walking with video" approach [26] was employed to record the sensorial elements of being mobile in Jakarta within a certain built environment context. The videos were taken by the authors while walking or riding a motorcycle (as a passenger). This approach provided the added value of recording mobility experiences, compared to the conventional method of installing a video camera in a static place to record travel behavior [49,50]. Furthermore, the recordings of the current mobility inequality conditions in Jakarta can be used in the debate of transport inequality and to inform urban and transport decision makers of this issue.

Video recordings were taken at three different times: peak hours during a weekday, off-peak hours during a weekday, and at the weekend. This process was conducted during a fieldwork survey from November to December 2018. It should be noted that during these periods there were some pilot tests for pedestrian crossing and sidewalk improvement projects in Thamrin Street, which might have slightly affected travel behavior temporarily. In total, the video recordings consisted of 615 min. These recordings were treated as visual data and saved in .mp4 format.

3. Results

3.1. Path Dependence: Transport–Land Use Policies Impact on Jakarta's Urban Development

Over the past centuries, Jakarta has undergone a significant urban transformation in terms of the urban area and population growth. In the 14th century, Jakarta was known as Sunda Kelapa, with an area of 4 km^2 and a population between 10,000–50,000 inhabitants [51]. Under Dutch rule for nearly 350 years from the early 1600s to 1945 [52], the city was known as Batavia, the capital of the Dutch East Indies. In the 17th century, the city's development was centered on the mouth of Ciliwung River and was in close proximity to the port (Figure 1). From the nineteenth century onwards, the city expanded southeast (Figure 1) to avoid the unhealthy environment caused by the silted up canals in the north [53]. Jakarta grew exponentially after Indonesia proclaimed its independence in 1945. In 2015, Jakarta had 10.2 million inhabitants in a 662 km^2 administrative area [54]. Nowadays, the urban agglomeration area of Greater Jakarta covers the neighboring cities of Bogor, Depok, Tangerang, and Bekasi, with an area of 7500 km^2, and an estimated population of 30 million inhabitants [27,55].

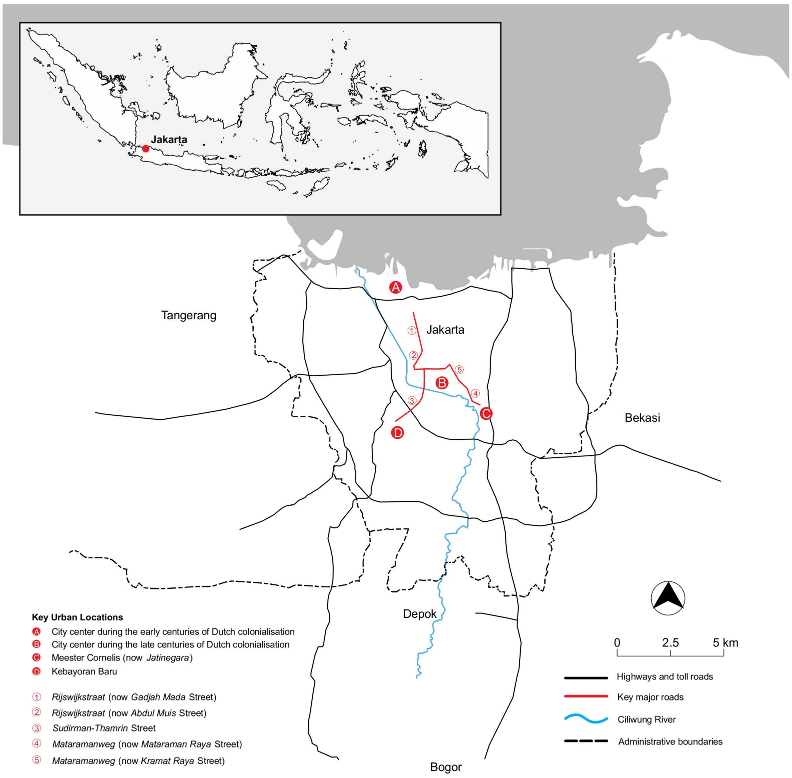

Figure 1. Overview map of Greater Jakarta (modified; original source: OpenStreetMap, 2019).

Jakarta's urban transformations have been related to significant policy changes, referred to as critical junctures or events in a path dependence context (Figure 2). An early critical juncture identified was the urban health crisis around the late 1790s to early 1800s, which caused the Dutch residential quarters and the city's administrative center to be relocated to the south. This generated a morphological change in the urban pattern as depicted on the 1940 model (Figure 3). Two major streets, namely Rijswijkstraat (now Gadjah Mada Street) and Mataramanweg (now Kramat-Mataraman Raya Street), connect offices and commercial land use areas that are mostly located in the north with residential areas in the south, such as the Meester Cornelis district (now Jatinegara). This district was a satellite town in which high-ranked officers resided, but it was later used as mercenary's quarters, thus attracted the development of informal settlements such as kampong Melayu. The Rijswijkstraat–Mataramanweg route was served by a tram [56], which applied ethnic and economic segregation when boarding the carriage. This served as an early transport-related social exclusion strategy for the poor locals.

In addition, poor local settlements, referred to as kampongs, were mostly located remote from main streets.

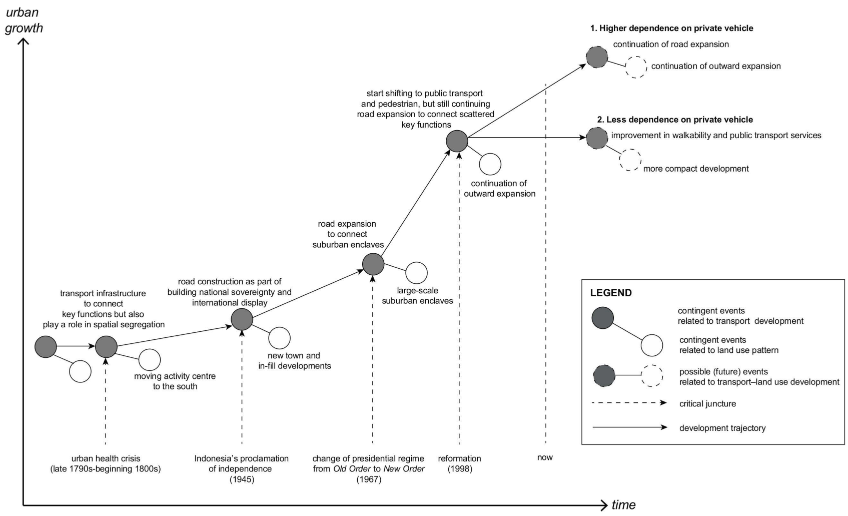

Figure 2. Path-dependent trajectory of Jakarta's urban development.

Indonesia's proclamation of independence in 1945 changed the trajectory of urban and transport development through its nationalization policies. The first presidential regime, the Old Order, urged the building of a national identity through the construction of mega infrastructure projects (e.g., highways, monuments) and the erasure of any foreign associations, which included the termination of tramline services in the early 1960s upon the accusation that the trams were the main cause of traffic jams. Massive construction in this period functioned as an international display of sovereignty [57]. It included the completion of the new town development Kebayoran Baru in 1955, which expanded Jakarta's urban area to the southwest. The new town was connected to the city center through Sudirman-Thamrin Street, as displayed on the 1959 street network model (Figure 3). These developments attracted rural immigrants, many of whom settled in urban kampongs or founded new ones by squatting vacant land next to the river or railway tracks.

During the second presidential regime, the New Order, Jakarta witnessed the soaring construction of housing enclaves in peripheral areas accompanied by road expansions. This marked a change in the path dependence course of transport development as highways were built to connect suburban enclaves. From 1980 to 1990, Jakarta's urban area doubled [58,59] as a product of an outward urban expansion. Transport–land use policies during this period introduced high dependency on private vehicles, since public transport development was stagnant [60] and pedestrian facilities were neglected [1].

Since the 1998 reformation, transport policies have started to shift. Public transport services have been improved, such as the adoption of the rapid transit bus (TransJakarta) that first began operation in 2004 and rail-based MRT (mass rapid transit), which first operated in 2019. A significant decrease in the fuel subsidy since 2013 is estimated to have lessened the traffic jams in Indonesian cities by 10% [61]. In addition, the Department of Transportation has been investing in pedestrian improvement projects on major thoroughfare streets, such as in Sudirman-Thamrin Street. However, these changes have been unable to encourage a significant shift from private vehicles to public transport or non-motorized transport. This can be attributed to an organizational routine of being accustomed to the convenience of travelling with private motorized vehicles. In this period, transport network development has served to connect key urban functions more efficiently as the city has continued expanding outwards.

These historical narratives of transport–land use policies, which indicated a path-dependent course, provide a historical context in which to understand the spatial changes, which are further elaborated in the following section.

3.2. Jakarta's Urban Transformation Over Time

Changes in transport–land use policies are manifested in the spatial structures and urban fabrics which represent the human interaction with the built environment on a daily basis. To depict this manifestation, Jakarta's street network models from three different periods were compared using normalized angular integration (NAIN) to identify changes in potential destinations and normalized angular choice (NACH) to identify changes in route choices. Due to the highly dense street network of Jakarta's 2018 model, the visual representation of the analysis was simplified by only highlighting street segments with high accessibility values (color range of red to yellow), while other street segments have been kept in grey. This has been done to provide a more comprehensible visual language. Further, NAIN and NACH measures were juxtaposed to reflect the interconnection of the foreground and background network in three discrete time periods. The foreground network represents the socio-economic dynamics that are manifested in the formation of major thoroughfare, mostly along commercial land use, while the background network represents the socio-cultural dynamics that are often found in residential areas [62]. The interpretation of these spatial analyses has been discussed in relation to the shifts in urban and transport policies.

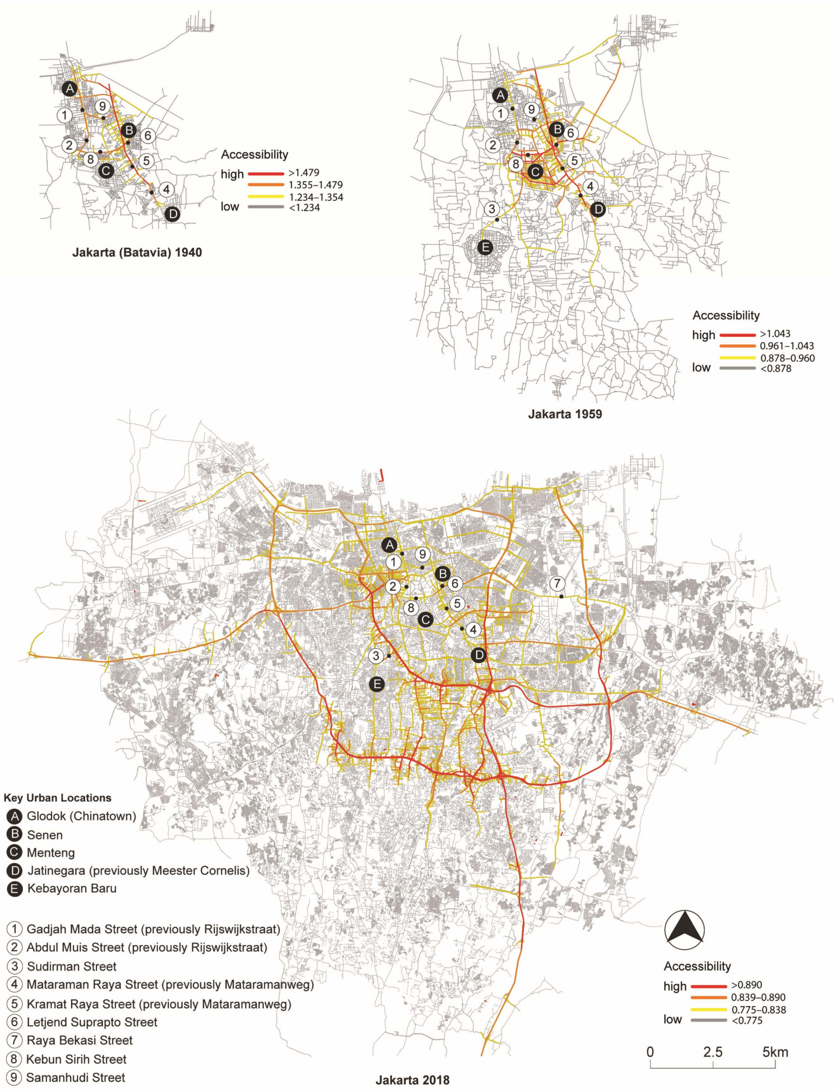

Figure 3. Normalized angular integration (NAIN) citywide analysis of Jakarta from 1940, 1959, and 2018.

The NAIN analysis (Figure 3) depicted how citywide centrality (to movement or potential destination) of Jakarta's urban space has shifted during the course of urbanization. Important economic functions that form the urban core were expanded from two major streets, namely Rijswijkstraat (now Gadjah Mada Street) and Mataramanweg (now Kramat-Mataraman Raya Street), as in the 1940 model, to the south towards Kramat-Mataraman Raya Street and branched on major streets in Menteng district in the 1959 model. In the 2018 model, the citywide centrality shifted to highways, namely the inner and outer ring roads, as the most integrated streets in the urban system. This confirms the tendency of transport–land use policy towards an automobile-dependent society, as the planned highway structures have more importance than the inner-city streets, which are more pedestrian friendly.

Over time, the previously important streets, where economic centers are located, have become less vital, as indicated by the decreased NAIN values (Table 1). These were, for instance, the decreased NAIN value of Gadjah Mada Street (previously Rijswijkstraat) from 1.466 in the 1940 model to 0.949 in the 1959 model and 0.831 in the 2018 model, and Kramat Raya Street (previously Mataramanweg) from 1.532 in the 1940 model to 1.122 in the 1959 model and 0.838 in the 2018 model. Before the 1960s, Jakarta's economic centers were mostly formed by traditional markets, which were located along the Rijkwijkstraat (such as Glodok market) and Mataramanweg (such as Senen market) (Figure 3). In the late 1960s, the economic centers in Jakarta shifted to modern shopping malls [63] and were mostly located in major thoroughfares such as Sudirman Street. In 1990, the big box supermarkets that were often located in the peripheral areas and next to the highways emerged as new economic centers in Jakarta, which explains the high NAIN value of highways in the 2018 analysis. This was in addition to the emergence of local convenience stores in the 2000s, some of which were located along major roads, providing stop-and-go services for travelers. This shift in economic centers changed Jakarta's urban fabric, as they attracted movement and reduced the importance of previous centers.

Table 1. Syntactic values of NAIN and normalized angular choice (NACH) citywide for Jakarta's central urban locations.

		1940 Model		**1959 Model**		**2018 Model**	
		NAIN	**NACH**	**NAIN**	**NACH**	**NAIN**	**NACH**
	Numbers of street segments	5783		11,335		546,282	
	Connectivity (average)	4.214		3.947		2.978	
	System minimum	0.385	0.000	0.309	0.000	0.216	0.000
	System average	0.986	0.875	0.725	0.811	0.610	0.829
	System maximum	1.599	1.602	1.124	1.522	3.377	1.974
1	Gadjah Mada Street (previously Rijswijkstraat)	1.466	1.546	0.949	1.423	0.831	1.282
2	Abdul Muis Street (previously Rijswijkstraat)	1.402	1.496	0.993	1.415	0.816	1.134
3	Sudirman Street	-	-	0.944	1.477	0.846	1.324
4	Mataraman Raya Street (previously Mataramanweg)	1.405	1.510	1.070	1.508	0.833	1.327
5	Kramat Raya Street (previously Mataramanweg)	1.532	1.596	1.122	1.517	0.838	1.312
6	Letjend Suprapto Street	1.018	1.318	0.930	1.469	0.842	1.184
7	Raya Bekasi Street	-	-	-	-	0.750	1.386
8	Kebun Sirih Street	1.410	1.427	1.102	1.470	0.811	1.257
9	Samanhudi Street	1.392	1.375	0.845	1.253	0.830	1.376

N.b.: For each street we selected the same street segments over time to ensure consistency of the data.

The NACH citywide analysis (Figure 4) represented potential through movement or route choices and therefore depicted an urban movement hierarchy connected to streets and roads, which formed the foreground network. The foreground network linked activity centers at all scales throughout the city, from local traditional markets to citywide shopping centers. In the 1940 model, the citywide

NACH analysis highlighted major streets connecting important land uses, such as the old city center in the north, markets, city square, and government offices. During this period, the foreground network formed a highly connected grid-like structure, which allowed high accessibility to all land uses. Major thoroughfares of this grid were Rijswijkstraat and Mataramanweg and the urban arterial streets such as Kebun Sirih Street and Samanhudi Street. These streets continued to have a relatively high value in the 1959 model, in addition to the new streets constructed to connect the city center with new development areas, such as Sudirman Street which led to the new town Kebayoran Baru (Figure 4, Table 1). The foreground network significantly changed in the 2018 model. Highly accessible roads formed a semi-grid like structure or a deformed wheel structure, as can be found in most European cities. This structure usually represents the main public space structure with less integrated residential areas forming the interstices of the wheel spokes, thus connecting the center to the edge [41]. Interestingly, in Jakarta's deformed wheel, the wheel spokes did not connect the center to the edge, but were instead fragmented between the inner and the outer ring roads. The deformed wheel was scattered and did not form a strong foreground network for linking all local centers in the city. In relation to the path dependence analysis, this structure can be explained as originating from the massive development of residential enclaves that took place under the New Order regime. These enclaves were developed and practically managed by private developers and had a lack of development control from the government, resulting in a housing spatial fragmentation [64,65].

Jakarta's tremendous development is implicit in the increase of the number of street segments from 5783 in the 1940 to 11,335 in the 1957 and 546,282 in the 2018 street network model (Table 1). The grid intensification of the city, which was calculated as the ratio segments over area size, changed from 39.81 street segments per km^2 in 1940 to 27.27 segments per km^2 in 1959 and 321.81 street segments per km^2 in 2018. Interestingly, both the maximum and average NACH values decreased in 1959 before they increased in 2018. This decrease can be explained by the change in the path dependence trajectory during the Old Order regime (1945–1967) where the road construction projects that were part of the nationalization policy had just started. In 1959, the grid had not yet intensified. This represented typical top-down planning of major infrastructure development.

Furthermore, streets with high values of vehicular through-movement in the 1940 model, such as Rijswijkstraat and Mataramanweg, had less value in the 1959 and the 2018 models (Figure 4), indicating that these streets have become less important in the current urban system (Table 1). Sudirman Street, which was not present in the 1940 model, appeared with the NACH value of 1.477 in the 1959 model and later decreased to 1.324 in the 2018 model. By contrast, streets connecting Jakarta's city center to the suburban enclaves gained more importance in the overall urban system. For example, Letjend Suprapto Street (Figure 4), which connects Jakarta to the east, had an increased value of NACH n-radius analysis from 1.318 in the 1940 model to 1.469 in the 1959 model. The value then decreased to 1.184 in the 2018 model as a new street segment, namely Raya Bekasi Street with the value of 1.386, was constructed, forming an outward extension to Bekasi Regency.

A detailed insight into Jakarta's urban transformation was derived by comparing the changes of the foreground and background networks and their interrelations throughout three discrete time periods (Figure 5). This was understood by creating radar diagrams, which juxtaposed the maximum and mean values of the NAIN and NACH analyses. NAIN indicates potential to-movements, thus it represents the ease of access and the depth of an overall urban system. A shallow urban system is easy to navigate since the accessibility of most street segments is high or intermediate. On the other hand, NACH depicts potential route choices and therefore represents the degree of the hierarchical structure of a street network. The foreground network, which comprises the main economic functions in an urban system, is indicated by the maximum value. These main economic hubs are often accessed through vehicular movement; thus, the foreground network can be interpreted as the vehicular network. The background network, on the other hand, is formed through socio-cultural activity that are often accessed by walking and therefore can be interpreted as the pedestrian network. The background network is represented by the mean value.

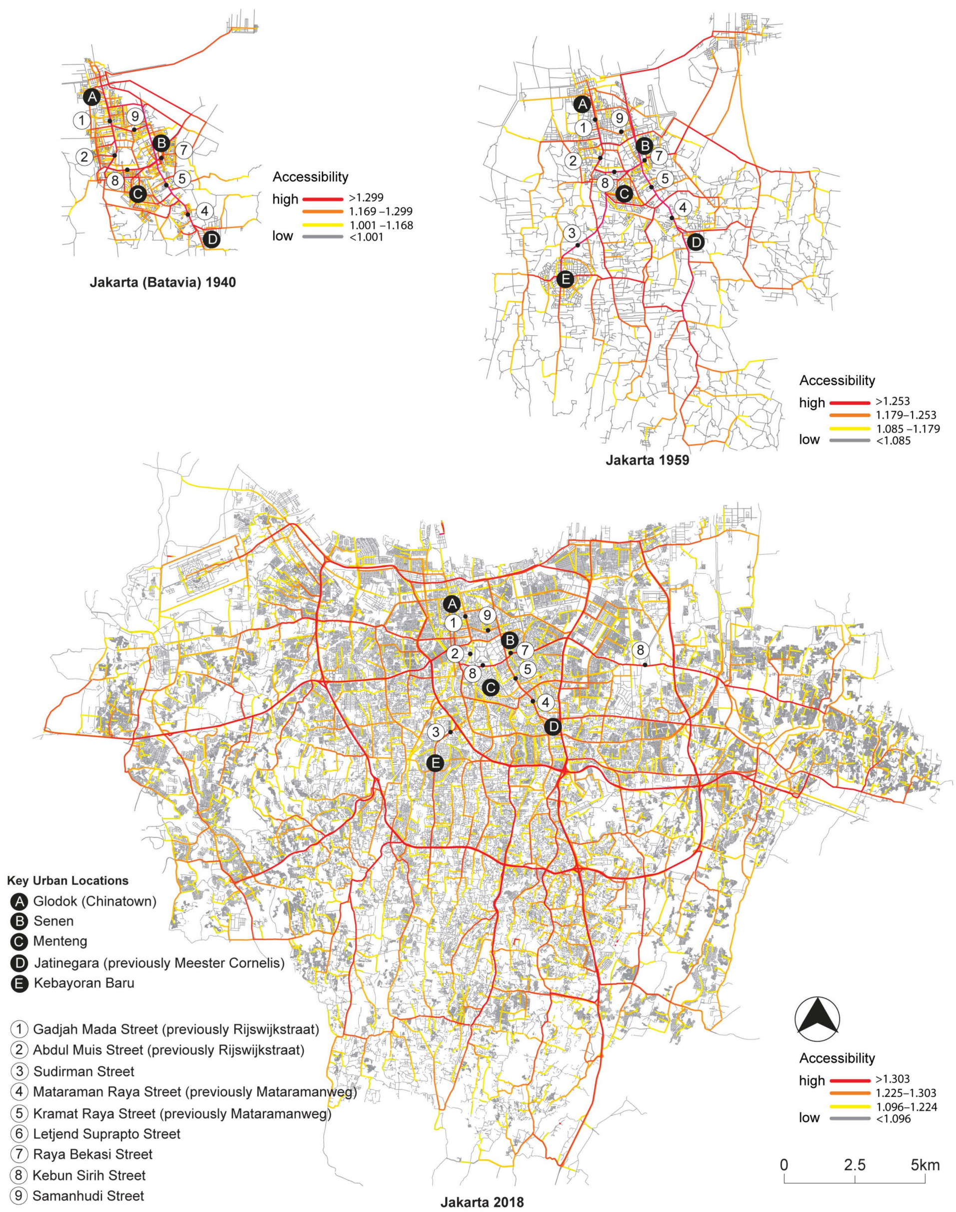

Figure 4. NACH citywide analysis of Jakarta from 1940, 1959, and 2018.

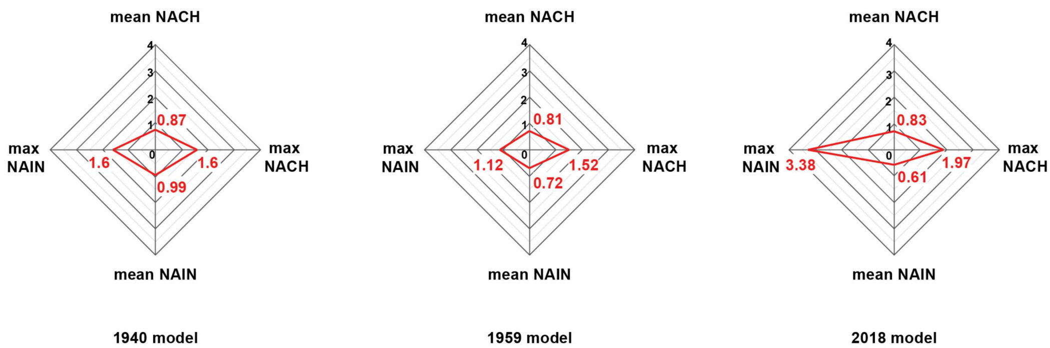

Figure 5. Diagrams of mean and maximum values of NAIN and NACH of Jakarta from three different time periods.

The diagram of Jakarta in 1940 depicted a well-balanced relation of the foreground and the background network. A similar result was depicted in 1959 model, but it significantly changed in the 2018 model, as the diagram was inclined towards the point of maximum NAIN. Changes in NAIN and NACH values represent not only how the urban system has stretched in relation to population growth, but also how the urban morphology has changed. Jakarta's population increased from 0.5 million inhabitants in 1941 to 2.8 million in 1959 [66] and 10.2 million in 2015 (only counting Jakarta's administrative area and not including the urban agglomeration part [54]). Urbanization and population influx generate the development of new settlements and the construction of new streets to connect these settlements. Along with these developments is the shift of economic centers: traditional markets that mostly formed economic activities have decreased due to the increased number of modern supermarkets and local convenience stores in present-day Jakarta. This shift changed the foreground structure of Jakarta from channeling movement towards activity centers in the city center to activity centers along major roads and peripheral enclaves using highways, which encouraged dependence on vehicular movement.

As shown in Figure 5, the mean NAIN value decreased from 0.99 in the 1940 model to 0.72 in the 1959 model and 0.61 in the 2018 model. This implies that the ease of access of Jakarta's background network has decreased over time, and the current background network is less accessible than it was in 1940. This trend is connected to spatial patches of low-income settlements or urban kampongs in Jakarta. These patches gained more prominence in Jakarta's urbanization, and thus the urban fabric entailed a non-continuous background network. Against this, a highly accessible foreground network was hinted at by the maximum NAIN values. This value decreased slightly from 1.60 in the 1940 model to 1.12 in the 1959 model, but increased significantly to 3.38 in the 2018 model. This trend can be confirmed from the distribution of economic functions in Jakarta, which are well-connected through major roads and highways. In terms of structure, Jakarta's background network has dissolved slightly over time. This is indicated from the decrease in the mean NACH value from 0.87 in the 1940 model to 0.81 in the 1959, and a slight increase to 0.83 in the 2018 model. By contrast, although the structure of Jakarta's foreground network decreased slightly from 1.60 in the 1940 model to 1.52 in the 1959 model, it increased significantly to 1.97 in the 2018 model. These trends provide a development pattern wherein the background network, often traversed by pedestrian movements, has become more fragmented in comparison to the well-connected foreground network channeling vehicular movements.

3.3. Present Conditions of Mobility Inequality in Jakarta

The historical and spatial analyses of Jakarta's urban transformation provided an understanding of the transport–land use changes and their interrelation with the socio-spatial dimension. This systemic view has implications on a very local scale, which can be observed at the street level, manifested as an inconvenient walking environment that can lead to mobility inequality.

Spatial analysis on pedestrian potential route choices by applying the NACH local radius to the 2018 street network model revealed that the current street network configuration has potential of walkability, but the video recordings indicated that this potential is not actualized. In the 2018 model, the potential pedestrian route choices highlighted major streets in densely populated areas, mostly urban kampongs such as kampong Angke and kampong Pulo (Figure 6). These urban kampongs are highly integrated locally but globally fragmented, as was also evidenced in Budiarto's [67] study on the three kampongs in Jakarta. Inhabitants of those areas have good walking accessibility for accessing local key functions such as groceries, but they are less connected to citywide functions, such as modern supermarkets, since most kampong inhabitants are low-income, and do not own a car but instead rely on motorcycles, walking, or public transport for their daily mobility. This reflects the scale discrepancy and development of imbalance between the city and neighborhood levels, as the government only focuses on road expansion strategies to connect urban functions at a citywide scale, but tends to neglect the pedestrian network on a local scale. This finding is consistent with previous studies on Jakarta's urban development [1,64].

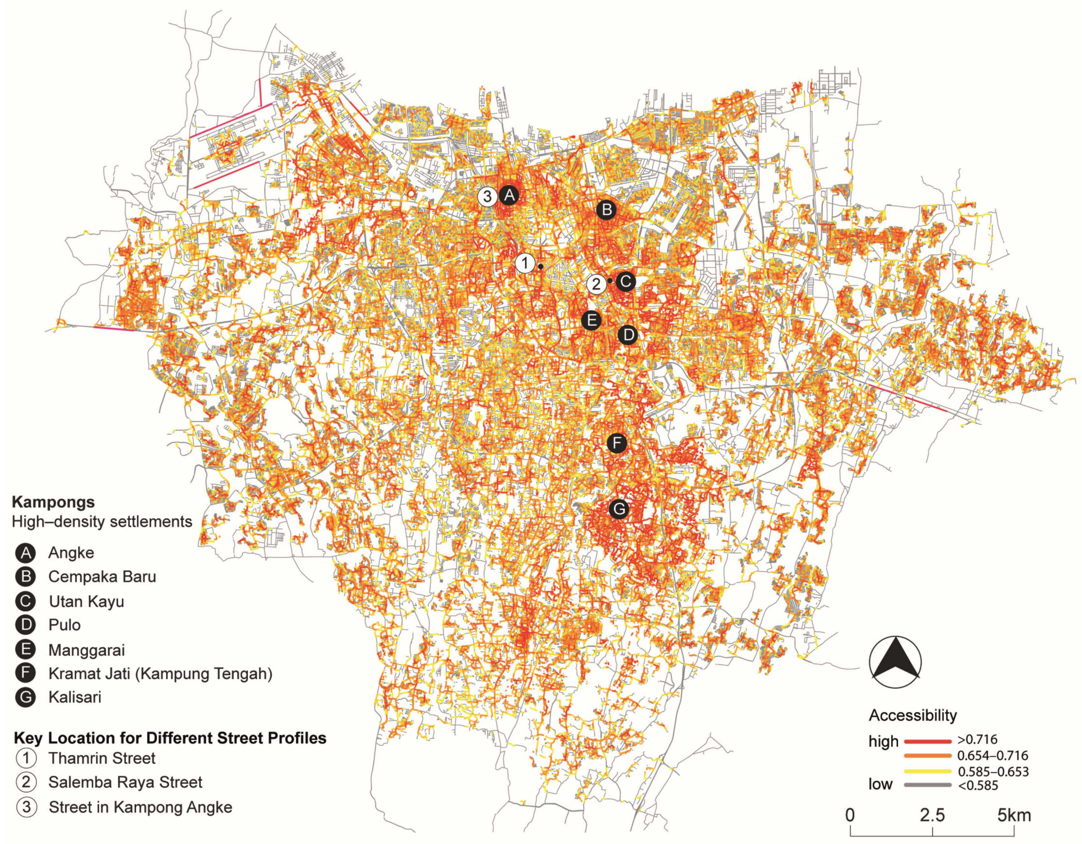

Figure 6. NACH 800 m radius analysis of Jakarta in 2018.

Visual analysis of the video recordings identified repetitive patterns in different street profiles (Figure 7), which highlighted the inconvenient walking environment at the street level. An illustration of the common patterns of street profile in Jakarta is presented in Figure 7 for selected street segments with high potential for walking, which were highlighted in the NACH 800 m radius analysis (locations for selected street segments in Figure 7 are indicated in Figure 6). Most sidewalks in major streets were interrupted with parking or street vendors, contributing to a non-continuous pedestrian network. Except for a few streets in major commercial areas (e.g., Sudirman-Thamrin Street), sidewalks often became short cuts for motorcycle while pedestrians had to give way even on their designated pathway. In a street in a densely populated area such as a kampong, motorized traffic is mixed with pedestrians, children playing, and stationary activities such as chatting with neighbors. There is therefore no proper separation on the use of the sidewalk and no clear hierarchy of which traffic users should be prioritized, which further induces wariness for potential collision with motorized traffic as opposed to the western concept of shared space [68]. This condition further leads to mobility inequality whereby captive pedestrians and marginalized groups with less access to private motorized vehicle (e.g., women, children, elderly) are at a disadvantage as they are more vulnerable to accident, in addition to risk of street crime [69,70].

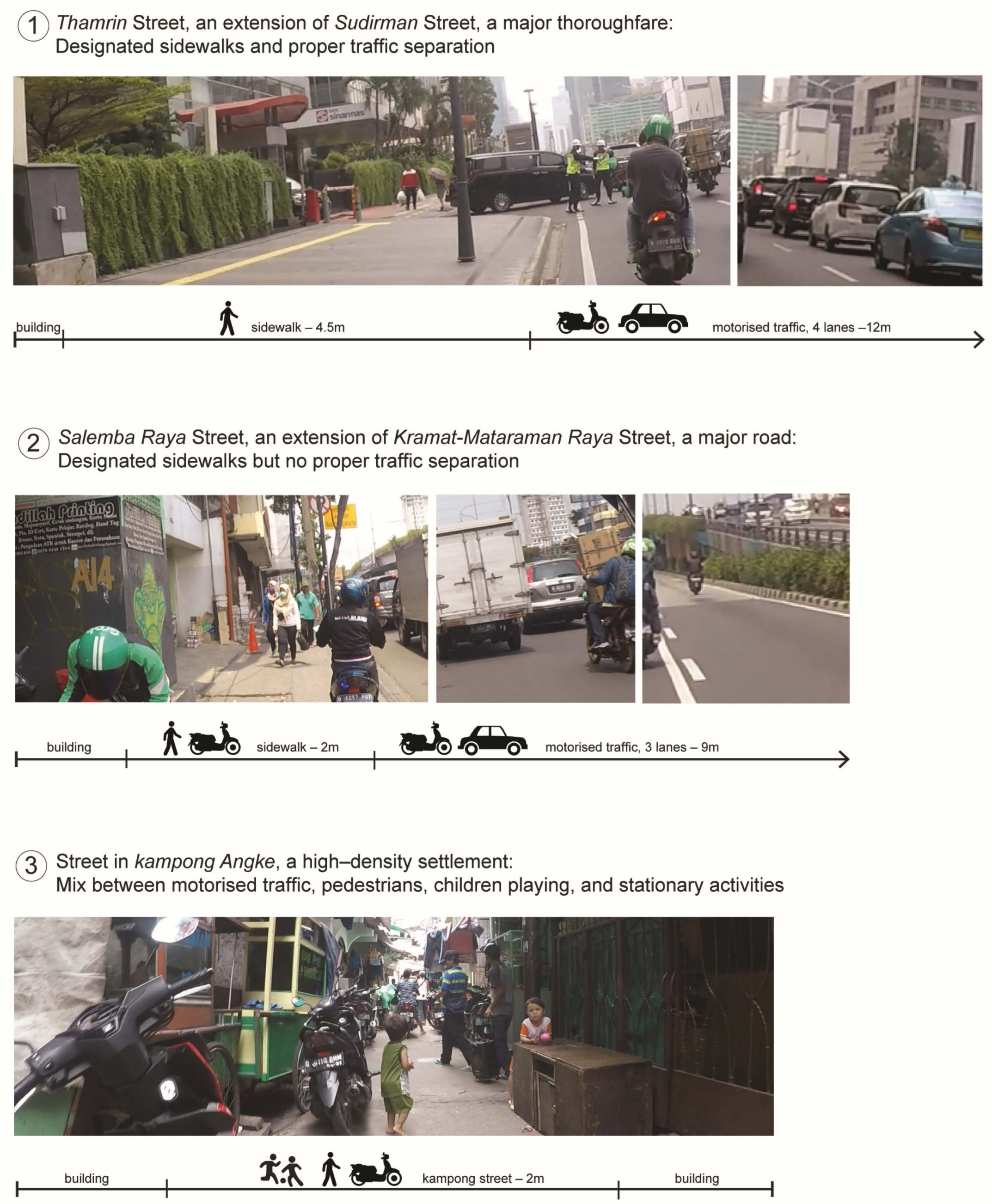

Figure 7. Different street profiles in Jakarta.

4. Discussion

The results indicate that although transport–land use policies are inseparable from political dynamics over time, such policies have had irreversible and accumulated impacts on the socio-spatial structures of the Jakarta Metropolitan Region. Following a path dependency framework [5,30], previous land-use policies of road expansion and suburbanization changed the urban structure (i.e., street network) towards a high motorization rate [8,24]. This vicious cycle of private vehicle dominance developed in tandem with rapid urban growth (see Figure 2). In line with Lo's [1] analysis on transport and land use development in Jakarta, walking is marginalized in the current urban area, although the street networks in high density settlements (i.e., kampongs) show latent potential for walking (see Figure 6). This potential has not been activated due to a lack of proper infrastructure such as continuous pavements or pedestrian crossings. The inconvenient walking environment creates barriers for the first and last mile use of public transport, while encouraging routine usage of private motorized vehicles [36]. Similar conditions have been observed in other Southeast Asia metropolitan cities, such as Bangkok, Manila, and Kuala Lumpur, leading to an automobile dependence lock-in [2].

Over time, the same transport–land use policies and urban structural changes allowed for the emergence of mobility inequalities [10,11] by providing incentives for those travelling with private motorized vehicles while inadvertently penalizing those without access to a car or motorcycle. The fragmentation of the pedestrian networks due to the dominance of vehicular networks (see Figure 5) both results in and is a result of mobility inequalities. Marginalized populations include those in extreme poverty unable to afford private motorized vehicle; women, who are often given the least access in a household with a single private vehicle; and children and the elderly who physically are unable to drive. These groups have no option other than walking and public transit, which induces a higher safety risk as they use the street in a vehicle-oriented environment. Likewise, the convenience of riding a private motorized vehicle in comparison to walking and public transit creates a vicious cycle of reinforced private vehicle ownership counterintuitive to national and regional policy initiatives on sustainable mobility and sustainable development goals [71,72].

The innovative application of this mix of methods allowed for a comprehensive depiction of the complex relation of transport–land use, urban structure, and mobility in a typical Southeast Asia metropolitan city. By combining narrative, spatial, and visual analyses, we have provided a triangulation of the results to encourage interdisciplinary discussions [28]. The historical analysis of socio-spatial structures showcased the causal relationships between land use and transport, while the spatio-syntactical approach allowed for an objective read of the network and accessibility of this metropolitan region. Our approach contributes to and complements the emerging body of literature of mobility and urban development in the region beyond, for example, descriptive or contextual analysis [1,55,57,60]. The method also demonstrated that the mathematical analysis of street network and video analysis can be used to visualize the consequences of certain policies and their impact on planning processes and practices. This can inform decision makers, who are often bounded by short-term political ambitions, about mid- to long-term consequences. The visual nature of the approach can also help bridge the communication gap between academics, practitioners, and citizens, allowing for interdisciplinary understanding and discussions [73]. This would be helpful in, for instance, urban infrastructure decision-making processes and project management, although ensuring that political dynamics do not override scientific findings will always remain a challenge. The approach is, however, limited by the level of understanding of the local context to interpret historical evidence and situate analytical results. For increased external validity, we recommend comparison with other cities and the correlation of street network analysis with access to key functions (e.g., education, health care, economic activities) to add insights into the socio-spatial consequences of transport–land use policies across time.

5. Conclusions

This paper presented findings on how transport–land use policies are connected to urbanization within a path dependence framework. The study discussed Jakarta's urban transformation from the late period of Dutch colonization to the present day in relation to the emergence of mobility inequality that is manifested in vehicle-oriented development as the product of previous transport–land use policies. The multi-method approach combining a historical literature review, analysis of mathematical street network models over time using space syntax logic, and visual analysis of video recordings allowed this study to depict the path dependence process and provide spatial evidence of the accumulated effects of urban and transport policies.

Our findings demonstrate that Jakarta's urban transformation through its spatial and policy changes have led to (1) the development of a vehicle-oriented street network that encourages a society with high dependence on private vehicles, (2) a lack of or no continuous street network to support pedestrian movement; thus, marginalized groups without access to private vehicles become captive pedestrians and are disadvantaged compared to motorcyclists and car drivers, and (3) walking inconveniences at the street level, associated with greater safety risks. It remains to be seen how changes in transport and urban planning policies of the post-reformation period (after 1998) will shape the future street network configuration and land use of Jakarta, and to what extent these changes will address inequality in mobility and accessibility. Given the path dependence context, sustainable transport policies in Jakarta will play a significant role in changing the current trajectory from the high dependence on private vehicles to a more pedestrian friendly environment.

These findings may raise awareness for urban and transport planners and policy makers of the irreversible impacts of their decisions on future socio-spatial structure. The post-diction on how transport–land use policies influence urban condition in the future could be turned into a prediction for future urban prognosis and policy testing. This could be used as a guideline for providing equitable transport services and equal access for all, especially since Jakarta and other Southeast Asian cities are increasingly focusing on the United Nations' Sustainable Development Goals, particularly Goal 11 on sustainable cities and communities [71,72]. In particular, Target 11.2 mentions the provision of access to safe, affordable, accessible, and sustainable transport systems for all. Change of the current transport development trajectory by setting priorities for pedestrians and public transport instead of private vehicles could be a way forward to the achievement of this goal. For future research, the authors intend to improve the research methodology by (1) applying experimental methods such as on-street surveys and comparing other Southeast Asian cities to validate the initial findings and establish a database for transport and urban studies in the Southeast Asian context, and (2) combining space syntax with other accessibility measures, for instance performing spatial correlations with time-based accessibility and population proximity to urban key functions such as health care services [74]. Furthermore, this will contribute to the wider discussion on urban mobility, particularly in the context of growing cities, such as the integration of smart mobility solutions [75] to reduce private vehicle dependency.

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