Journal of Transportation Technologies, 2023, 13, 262-281
https://www.scirp.org/journal/jtts
ISSN Online: 2160-0481
ISSN Print: 2160-0473

Delivering Tram-Based Boulevards: Learning from Opportunities and Challenges in Three European City Case Studies

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How to cite this paper: Scheurer, J., Verschuer, M., Newman, P. and Desha, C. (2023) Delivering Tram-Based Boulevards: Learning from Opportunities and Challenges in Three European City Case Studies. *Journal of Transportation Technologies*, **13**, 262-281.
https://doi.org/10.4236/jtts.2023.132013

Received: January 10, 2023
Accepted: April 10, 2023
Published: April 13, 2023

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Abstract

Increasing calls for zero-carbon cities invite transformative solutions for people and places within our cities around the world. Key to the transformation is cities and regions shifting in mobility away from fossil-fuel based car-oriented solutions. The paper investigates a range of case studies where "tram-based boulevards" have been planned or implemented to provide such opportunities. The case studies share a common broader policy objective: to transform the car-oriented or car-saturated areas to an intensified urban template based on a critical presence of dedicated mid-tier transit infrastructure and active transport. "Trams", or mid-tier, mid-capacity transit when combined with Transit oriented development (TOD) along whole corridors can provide transformative pathways towards zero-carbon outcomes as well as multiple, strong urban benefits. However, many successful or instructive examples of this practice from non-English speaking countries, particularly in Europe, are underdocumented in the international literature. The paper addresses this gap by investigating opportunities and challenges evident in a range of European case studies. These are explored for insight towards policy learning particularly in New World cities seeking to transform into a zero-carbon and more transit-oriented template: How can decision-makers avoid repeating the identified pitfalls, and instead focus on emulating the successful approaches and outcomes? We conclude the need for recognition of the inherent synergies between transport and land use settings in any endeavour, and their translation into policy priorities in both fields of planning. We also conclude the importance of decision makers proactively identifying and critically appraising specific opportunities for change, concerning funding, technology, public opinion, stakeholder alliances or market dynamics,

and capitalising on them at suitable moments in time.

Keywords

Transit Oriented Development (TOD), Transit Activated Corridors (TAC), Zero-Carbon Cities, Transit Diversity, Urban Corridor Intensification, Trams, Boulevards, European Case Studies

1. Introduction

European city regions and their New World counterparts all experience the challenges of directing urban growth around existing or new public transport infrastructure, to produce an urban fabric that enables low rates of car use and high spatial amenity. In the paper we call this kind of transit-oriented urban transformation "tram-based boulevards"[1]. Since the 1990s a sizeable body of literature and practical experience has accumulated around the concept of "Transit Oriented Development" (TOD) in North America and Australia, where the terminology was first coined [1] [2] [3] [4]. In contrast, comparatively little research (in the English language) has been published on similar planning practices in Europe [5].

The lack of documented European TOD research is an intriguing reality, given the generally greater existing role of public and active transport in the mobility mix of European cities over North American and Australian cities [6]. The relative absence of European academic literature about TOD may be partly due to language barriers. It may also be due to the relative continuity of transit-oriented planning in many European cities during the automobile era, which diminished the novelty value of TOD compared to the situation in North America and Australia [7]. Furthermore, the prevalence of New World TOD literature is also not representative of progress. For most city-regions in North America and Australia, TOD continues to represent a relatively small "niche market" compared to the much greater magnitude of conventional suburban development [5].

The automobile era has left a global legacy of activity corridors along arterial roads, surrounded by low-density land uses configured around ease of access by car. This is readily observable in New World cities, many of which experienced their most significant growth period during the second half of the 20th century. It is also observable in European cities, often associated with the "patchwork" of land uses in peri-urban areas and/or the spaces between neighbouring metropolitan centres [8] [9] [10].

In pursuit of transforming urban and regional settlements around the world towards a zero-carbon future (*i.e.*, minimizing—towards eliminating—carbon

[1]The mid-tier modes are higher in capacity than a bus mode and lower than a train mode. In the past they have been Light Rail Transit and Bus Rapid Transit and in recent times these have included Trackless Trams; they are summarised as "trams" in the paper for ease of communication.

emissions), we had been considering, "*What kind of policy could facilitate TOD patterns that absorb a more sizeable proportion—perhaps the majority—of population and job growth in the next* 30 *years*?". Observing successful TOD examples in Europe and realising this knowledge gap in the literature, we then asked, "*What lessons can we extract from European cities*, *regarding policy and implementation*?". We posited that case study exploration of successful TOD examples—in Europe and elsewhere—could elicit specific opportunities and conflicts that could inform decision-making for zero-carbon outcomes in cities around the world.

In the paper, to help define tram-based boulevards, we introduce the concepts of "urban corridor intensification" and "transit diversity" in the context of transforming a city's development trajectory towards net-zero carbon outcomes. We then use case studies to explore whether and how the scope and character of such transformation depends on the presence of particular transit modes, or a particular mix of transit modes. Synthesising the case study insights, we argue for a transit diversity approach analogous to the richness experienced through species diversity in natural ecosystems. We intend to illuminate the policy and implementation conditions in which hybrid mid-tier, medium-capacity transit technologies can have maximum benefit in terms of city building and reducing car dependence, while minimising stakeholder conflict about their implementation.

2. Introducing Three Concepts for Zero-Carbon Outcomes

There have been many rationales for overcoming automobile dependence over the years [3] [9] [11] but the most cogent in the days of climate change policy is the need for net zero cities [12]. Net Zero Cities are designed to contribute to reducing greenhouse emissions to less than 50% of the 2005 level by 2030 and by 100% by 2050. These targets become very stark when cities are the focus of attention as infrastructure built now must start this transition rather than being business-as-usual and they must cover the whole city by 2050. This is a powerful agenda for cities [12]. In the quest for zero-carbon outcomes, city-regions around the world are considering or embarking on programs to convert automobile-urban fabric towards a spatial template more amenable to the needs of public and active travel users as well as shifting to renewables-based electromobility [9] [13]. The paper sets out some key ideas about how this can be done in practical urban programs that enable the transition to net zero to begin whilst enabling multiple improvements to happen at the same time.

2.1. Tram-Based Boulevards

The need to intensify land development along main roads and enable a more comprehensive transit system, is something that has happened in the past as cities began to spread out after the industrial revolution. The streets were often called boulevards and this has become a core concept in transport planning that tries to do more than just increase traffic flow down a corridor. Invariably such extra qualities are about local place and amenity with a big emphasis on landscaping and walkability. This paper will suggest that a new approach to boulevards is needed on main roads where a combination of urban regeneration and improved transit is required: tram-based boulevards. In today's world of net zero cities this tram-based boulevard needs to use renewable electricity for both the transit and the station precincts, creating net zero corridors that can expand into their surrounding suburbs [14]. The details of how this technology can be implemented in established urban areas need to be demonstrated but the core of this paper is how older European cities are beginning to rediscover the value in tram-based boulevards.

2.2. Urban Corridor Intensification

An increasingly popular template for these new boulevards involves what we refer to as "urban corridor intensification", which is the intensification of land uses around urban and suburban arterial roads, and the retrofit of those roads with low-cost transit infrastructure that represents a significant upgrade from the limited capacity and speed of conventional buses. The intensification process is inherently needed to be a place-based approach that creates outcomes from the many groups of people committed to the corridor. This has become known as Movement and Place strategies and developed out of corridor planning in Transport for London [14].

2.3. Transit Diversity

We have previously argued that of all public transport modes, the tram delivers the greatest impetus to reshape the urban fabric at a human (pedestrian) scale (https://sbenrc.com.au/research-programs/1-62/). For heavy rail routes, fully exclusive right-of-way is required, usually underground, elevated or otherwise grade-separated—this achieves the highest passenger capacity for public transport and is inherently suited for autonomous operation, but also creates inevitable spatial barriers between the station infrastructure and the pedestrian realm. Light rail—both in its conventional form and the rubber-tyred varieties discussed in the context of French cities below—restores a more fine-grained integration between transit and the streetscape, but depends on design solutions having to be found along the entire length of the route, potentially driving up both costs and political conflicts over the use or road space. In contrast, high-quality electric buses, bus rapid transit or trackless trams can operate in mixed traffic along segments of route that have not received the traditional tram treatment, though allowing this can lead to reduced performance and legibility of the transit system. These varying characteristics do not imply that particular modes must necessarily be considered inferior to others in rolling out their own specific city-building benefits—rather, each needs to be seen for their own inherent value. Lavadinho and Lensel [15] suggest in this context to consider the urban modal mix as a kind of "biodiversity", an ecosystem where each species is allowed to thrive in its specific niche to mutual benefit. This also means a city should build on its historical transit systems. Lavadinho and Lensel [15] see this ideally as a process of "sedimentation", allowing each generation to set its own priorities in the synergy of transport infrastructure development and city building and, rather than attempting to erase the legacy of previous eras, allowing them to develop complementary to each other as a helpful antidote against path dependency.

In France, twenty-six cities introduced new tram systems since the mid-1980s. In most cases this was combined with a fundamental reconfiguration of the urban space along the new transport corridors. According to Lavadinho and Lensel [15] (p436), these city-building capacities associated with tram systems rest on three key promises that represent a step-change to conventional bus systems:

- *Cognitive reassurance*: The network is simple and readily absorbed into users' mental geography.
- *Temporal reassurance*: The network is operated at consistent high frequencies and service spans.
- *Spatial reassurance*: There is progressive improvement of urban space quality and intensity/mix.

Lavadinho and Lensel [15] note that the construction cost and space-take of trams in an urban environment can sometimes jeopardise these very goals: for example, in the German city of Karlsruhe the success of ever-increasing tram operations created a spatial conflict in the city's central pedestrianised corridor, necessitating a costly undergrounding of the infrastructure in 2021. Such adverse effects, however, contrast with the superior ability of tram-oriented urban fabric to offer amenity to non-motorised modes (thus spatially expanding its reach up to 1 - 2 km beyond the immediate tram corridor; see also [16]), the better design integration of tram stops in public spaces compared to underground metro stations or bus stops, and the ability of trams to expand into a geographically "complete" network comprising both radial and orbital routes within the reasonable time horizon of one generation.

In many practical cases, the process of transforming cities towards a transit-oriented urban fabric alongside the installation of new transit infrastructure has proved anything but straightforward. Lavadinho and Lensel [15] recount that as far back as the 1980s in France, tensions developed between moves to expand or introduce new trams and their associated city-structuring capacities, and those that attempted to continue with the previous paradigm of prioritising the accommodation of private cars. Such resistance occurred either because (typically in the case of smaller cities) it proved problematic to mobilise the resources, critical mass of users or political will to take the leap into redesigning the urban fabric around tram corridors, or (typically in the case of larger cities) because they relied or continued to rely on expanding sub-surface public transport (metro) while attempting to maintain automobile privileges at street level.

Transit diversity is thus an approach that finds key roles for all kinds of transit from high capacity urban region metros, mid capacity corridor trams, and low capacity local buses, as well as transit integrators like shuttles, bikes and walking. The paper shows that tram corridors which aim to be boulevards are emerging as a critical element to remake cities in a future that needs net zero in its emissions outcomes.

2.4. Tram-TOD Pitfalls

Within this context of considering tram technologies and associated tram-based boulevards for urban corridor intensification, Lavadinho and Lensel [15] identify a range of challenges that frame the dilemma of the decision making process. We have consolidated these here into three key "Tram-TOD pitfalls":

1) *Focussing excessively on economic cost-benefit analysis and other quantifiable indicators of success for transport projects*. This includes for example prioritising passenger numbers or operational costs while neglecting or failing to consider useful indicators for wider, less tangible benefits such as the common good, socio-spatial justice, long-term or external effects in the decision-making process.

2) *Using transport infrastructure initiatives to placate broader*, *but undeclared or understated policy conflicts*. This includes economic development rivalries between adjacent municipalities, and/or excessive confidence that transport policy initiatives may compensate for underachievement in other public policy areas, such as housing or employment market challenges. It could also refer to regulatory regimes that continue to promote excessive spatial segregation of urban activities, in a decision-making environment where these complementary goals are not meaningfully integrated.

3) *Regarding transport investment solely in mobility terms*; thus failing to appreciate the wider impact of corridor intensification on urban liveability, particularly facilitation of social exchange and the enhancement of the urban fabric.

In summary, the concept of tram-based boulevards helps us to evaluate successful examples of such urban development with regard to their cognitive, temporal and spatial attributes. We can also learn from how the successful examples avoided or dealt with these key policy pitfalls, towards supporting decision-making processes that can now deliver zero-carbon outcomes.

3. Methodology

This study adopted a qualitative mixed-methods approach, including literature review and case study. We looked for examples in Europe that we could learn from regarding the pitfalls for lessons to be learned.

It is plausible that such goals of upscaling of tram-based boulevards are dependent on an accelerated rollout both of specific forms of urban fabric and of the associated transit infrastructure. This affects both greenfield land and interventions in established urban areas, upgrades and extensions of existing transit technologies and the introduction of new ones. Medium-capacity mid-tier modes (Light Rail Transit (LRT), Bus Rapid Transit (BRT) or the new Trackless Tram technologies), operating at surface level, are considered to provide the passenger capacity required along high-density urban corridors while significantly reducing the high capital costs and long construction periods associated with underground rail or metro routes.

The compilation of case studies in European cities was subsequently selected with the following criteria in mind:

1) Information is available regarding the decision-making context surrounding the joint pursuit of: a) urban intensification corridor strategies to accommodate regional growth, and/or b) boulevards.

2) In the case study, decision-makers were aiming to introduce or upgrade their medium-capacity public transport modes, wherein Trams were part of the solution proposed and/or implemented.

3) The case studies include one or more contexts that are relevant and/or similar to Australian and North American experiences.

The resultant three case studies are summarised in **Table 1**, comprising four policy process narratives from Scandinavia and France.

The two Scandinavian examples from Finland and Sweden included a legacy of lower-density urbanism and sparse settlement patterns that are more comparable to Australian and North American experiences than that of their central and southern European counterparts. They were examined for opportunities and drivers that favour the emergence of a contrasting, higher-density template of urban growth and its relationship to/implications for urban movement patterns and infrastructure requirements. We also explored the planning conflicts accompanying this shift, and the varying conceptual approaches of different stakeholders towards corridor-based urban intensification.

The French example included substantial experiences with new tram and other medium-density transit systems introduced over the past 40 years. They were examined for their experiences in technological diversification away from conventional trams and buses. We explored the opportunities and constraints that guided the emergence of hybrid medium-capacity transit systems such as rubber-tyred trams and bus systems at high levels of service (BHLS). This included asking, "*What motivated cities to opt for pioneering new transport technologies*?", and "*What is the post-implementation experience with such innovations*?".

Table 1. Summary of case studies.

Case study location	Feature/s of interest	Criteria addressed
Helsinki, Finland	Boulevards	1, 2, 3
Skåne, Sweden	Transforming public transport networks with medium capacity modes	1, 2, 3
Paris and Caen, France	Technological choices between rubber-tyred and conventional trams	1, 2, 3

4. Results: Case Study Narratives

4.1. Case Study 1: Tram-Based Boulevards in Helsinki (Finland)

The Finnish capital of Helsinki, in 2016, adapted an urban strategy (Helsinki City Plan) envisioning a future development direction as a polycentric, rail-based agglomeration. A prominent element of this vision included the conversion of the inner sections of radial, arterial multi-lane roads and expressways into multimodal boulevards including tram or light rail extensions, bicycle infrastructure and significant urban intensification [17] [18].

According to Granqvist *et al.* [18], the overall goal of a polycentric agglomeration was shared between the core city (Helsinki) and the 13 surrounding suburban municipalities. While there is no statutory body for the metropolitan area as such and inter-municipal collaboration remains largely voluntary, the polycentric vision had also been enshrined in strategic planning documents by the larger regional administration (Helsinki-Uusimaa) as well as non-statutory plans by an alliance of local governments [19]. However, interpretations of what exactly was meant by polycentricity differed between planning actors/tiers of government and led to policy controversy that, in 2018, was resolved by a court decision removing four of the original seven "boulevard" corridors from the urban strategy [18].

In this process, the concept of polycentricity had thus become what Granqvist *et al.* [18] (p 741) describe as a "pacifying spatial imaginary" that planning actors could galvanise around in discursive terms while concealing its inherent ambiguity and the weakness of institutions tasked with its operationalisation, but fell short of an "integrated planning strategy" that could guide the resolution of practical disagreements on detail and implementation [18].

The key issue of contention over the boulevards scheme between national/regional and local government (as opponents in the court case) revolved around the city's intention to devise these spaces as multimodal urban growth zones, accommodating space for expanding core city functional mix and densities (about one third of population growth until 2050 was to occur around the seven boulevards) and servicing them with better public transport and non-motorised infrastructure while accepting a reduction in speed and capacity for road traffic (following the strategic goal of "sustainable transport"). This clashed with the regional strategy's categorisation of some of these roads as critical links, and the interpretation of a polycentric metropolitan structure as requiring optimal road connections between its disparate centres to pursue the strategic goal of "spatial balance".

Thus the intent of the City of Helsinki to accommodate growth along while traffic-calming its arterial roads was understood to represent an attempt to make the core city more polycentric internally (by offering more spaces for dense urban living and walkable employment clusters away from the CBD). Simultaneously however, it was interpreted to weaken polycentricity at the metropolitan/regional scale, as it facilitated the consolidation of the core city at the expense of centres in suburban municipalities by reducing road accessibility between core city and suburbs. Critically, the court case emphasised that the drop in road accessibility would also affect bus-based public transport, with radial express buses between suburban areas and central Helsinki having a relatively significant role in the public transport network [18].

The tram-based boulevards scheme still looks set to go ahead at a reduced scale (see **Figure 1**), and in the context of a revised regional plan as a new attempt to build policy consensus following the court decision [19]. Meanwhile, an orbital light rail line (Jokeri 1) is under construction for a 2024 opening, which will not follow any of the boulevards but intersect them in critical centres, though mostly still on the territory of the core city of Helsinki at about 7 - 8 km distance from the CBD [20].

4.2. Case Study 2: Transforming Public Transport Networks in Skåne

The agglomeration of Skåne in southern Sweden, of which Malmö (340,000 inhabitants), Helsingborg (150,000 inhabitants) and Lund (120,000 inhabitants) are the principal urban centres, has traditionally been serviced by a public transport network consisting of regional rail and buses, planned and managed by a regional transport association (Skånetrafiken) [21]. In recent years, network reorganisations and simplifications culminated in a comprehensive rollout of BHLS (Malmö) and the introduction of a light rail route (Lund).

Lund's 5.2-km tram route opened in December 2020 after a three-year construction period that involved the conversion and extension of a former busway

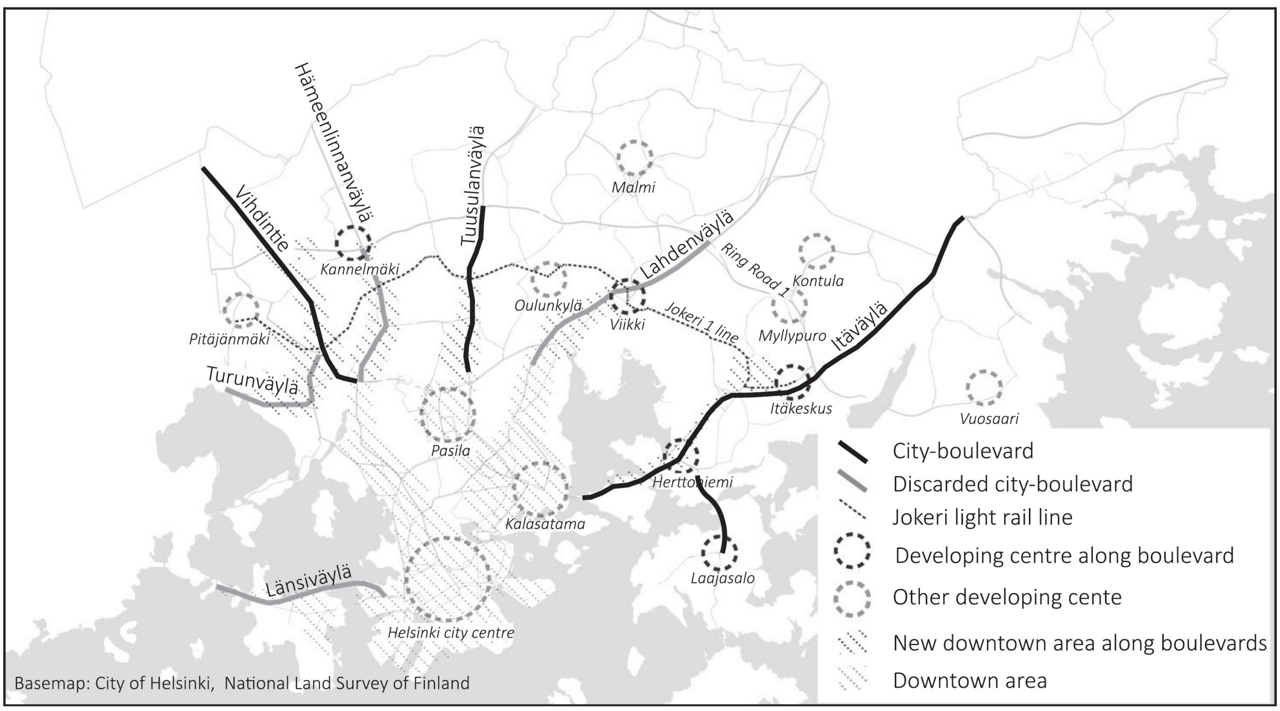

Figure 1. Helsinki boulevards or corridors and urban growth centres. Source: Granqvist *et al.* [18] (p 747).

along the same corridor, built in 2003 with later upgrading to LRT already considered in the original design [22] [23]. Total investment costs amounted to EUR 148 m, of which EUR 88 m (approximately EUR 16 m/km) was spent on corridor infrastructure and about EUR 30 m each on a fleet of 7 vehicles and the depot. The route has its own right-of-way throughout, full tram priority at traffic lights, features 9 stops (average stop spacing 650 m) and has a scheduled operating time of 15 minutes (average commercial speed: 21 km/h).

The tram corridor links the city's railway station (located near the historic centre) with a number of university and health facilities, a major Greenfield development area and the European Spallation Source (ESS) at its outer terminus, a prestigious EUR 1.8 bn international research facility that is expected to attract 2000 - 3000 visiting researchers annually when fully operational in the mid-2020s [22]. Thus the rationale to supply this relatively small urban centre (which never had a first-generation tramway) with an LRT route can be understood as a combination of foreseeable future capacity constraints on the existing BRT route, the intention to maximise the proportion of Lund's projected urban growth until 2050 around this particular corridor (30% or up to 40,000 residents and jobs) with the aid of a high-profile, fixed and green (grassed tracks) piece of public transport infrastructure, and perhaps the desire to match the prestigiousness of the ESS (that the region appears to be quite proud about having attracted in a Europe-wide competitive process in 2009) with a similarly high-profile transport mode [22] [24].

Linné [23] describes this combination of public transport capacity, directed urban growth and modal prestige arguments as an isomorphic discourse: it is based on several assumptions that represent contemporary international transport planning best practice, which may or may not provide a "best-fit" to the specific conditions found in Lund. Within the decision-making process, Linné [23] identifies elements of coercive pressure (embodied by the prestige case for LRT, or the conditions applied to national and European funding contributions that favoured this solution), mimetic learning (the abundance of national and international examples that link LRT projects and urban intensification, and the relative absence of such evidence for bus projects—see also [5]), and normative involvement (the state-of-the-art knowledge propagated by international consultancies and other global expert groups or institutions in the sector, making up for the common insufficiency of relevant local knowledge available prior to cities embarking on projects of this kind). While political majority support in Lund held up to see the LRT project to implementation, controversy developed around the lack of rigorous assessment of technological or policy alternatives other than a comparative "no-action" scenario, effectively presenting LRT in the public discourse as the only available solution to address the planning challenge [23].

In nearby and significantly larger Malmö, an LRT project initially developed jointly with Lund in a regional planning context was suspended in the 2010s in favour of a bus at high levels of service (BHLS) project. Viitanen [21] describes a disconnect between public transport planners who promoted an LRT solution following modelling and operational experience pointing at severe capacity constraints on parts of the existing bus system as the city and public transport use continue to grow, and political actors at local and regional level whose disunity proved unable to effectively moderate public concerns about the associated redistribution of street space and urban transformation. The lack of political consensus over the most suitable type of public transport upgrades also put practical limits to the amount of funding that could be mobilised for such measures. As a result, a scaled-down BHLS project, which initially had no corridor-specific urban intensification component, has been pursued as a short to medium-term solution in lieu of a more ambitious and expensive LRT project.

Viitanen [21] critiques that the associated detachment of transport and land use planning as well as the circumvention of controversial elements concerning future traffic management and road space allocation carries a double risk. First, there is a risk of overreliance on technocratic solutions that alienate citizen involvement (*i.e.* lacking a visionary dimension and arguing for design solutions solely along technical imperatives). Second, there is a risk of promoting projects that inadequately address existing public transport challenges particularly in terms of capacity (smaller buses in place of larger trams) and performance (avoiding public transport right-of-way or traffic priority measures just where they matter most; [21] p 69).

Both cities thus appeared to suffer from a degree of co-option of the transport mode decision-making process by political actors who, in Lund's case, favoured LRT to the exclusion of possible alternatives even though the capacity of buses would perhaps not be exceeded if the anticipated urban growth were less focussed on the LRT corridor. In Malmö's case, the political process appears to have placed LRT in the "too-hard" basket due to the associated controversial impacts on traffic management and streetscapes, and used this diversion to distract from a debate about public transport capacity despite it representing a more pressing and present concern than in neighbouring Lund.

4.3. Case Study 3: Integrating Rubber-Tyred and Conventional Trams in France

During the 1990s-2000s, two types of rubber-tyred tram technologies (*tramways sur pneus*) were developed by Bombardier (*Transport sur Voie Réservée* or TVR; also referred to as Guided Light Transit or GLT in an English-speaking context) and Translohr (later acquired by Alstom), respectively. Both technologies are based on electric vehicles using overhead catenary and a central guide rail for power supply, though TVR (and in one case, Translohr) also offered the option of battery and hybrid diesel-electric propulsion, combined with the ability to leave the guideway. TVR systems were put in place in the medium-sized cities of Nancy (2000) and Caen (2002); Translohr systems emerged in Clermont-Ferrand (2006) and on two geographically separated lines in the Paris metropolitan region (2013/2014), as well as in the Italian cities of Padua and Venice-Mestre (2007/2010), in China (Shanghai and Tiangjin) and in Colombia (Medellín).

Villamos [25] attributes the conceptualisation of rubber-wheeled trams to the disposition of many post-war French transport planners to deflect from the implications of the conversion of first-generation tram systems to bus operation they had implemented between the 1930s and 1960s, by promoting a medium-capacity public transport technology that represents a break from rather than a modern version of the conventional tram. Foot [26] reports on a French government research and development program into hybrids between tram and bus in the early 2000s, designed to facilitate the implementation of medium-capacity transit in smaller cities or lower-density areas surrounding larger cities where procuring the funding for conventional trams may be problematic.

However, Foot [26] describes the evolution of rubber-tyred intermediate modes in France as a history of crises. A magnetic guidance system for buses pioneered in Douai (and in Eindhoven) was built but never operated in that mode. Nancy's and Caen's TVR system were beset with significant maintenance cost blowouts, high accident rates and poor service reliability, leading to Bombardier discontinuing production and to the two systems undergoing conversion to conventional tram (Caen) and conventional bus (Nancy).

4.3.1. Caen (TVR)

Fournier [27] describes how the Caen TVR project was subject to multiple controversies during its conception phase in the late 1990s, including a referendum where the project was comprehensively rejected but whose results were overridden in the light of low turnout and its limitation on the core municipality (excluding the 16 suburban municipalities from having their say). Unlikely alliances between centre and periphery and across the political spectrum pulled the project through, but the supporting council majority was voted out before completion in 2002.

The tram project became a major change agent for urban life and urban development in Caen, arguably the most significant transformation since WWII destruction in 1944 [27]. However, major operational problems related to the TVR technology particularly during the first two years caused significant public disenchantment and led to operating and maintenance costs in excess of a conventional tram. After Bombardier discontinued the TVR product only a few years after opening, it became clear that viable operation, let alone future capacity increases, were unlikely for the originally anticipated 30-year lifespan of the system [28]. Regular changes of local government led to shifting policy priorities about how to resolve this dilemma, but a decision to convert the system to a conventional tram was eventually made in 2012 [27]. Greater public participation occurred compared to the initial project, though another change of government led to the abandonment of a proposed major network extension. The cost of the conversion, completed in 2019, was comparable to that of constructing the original system: apart from rebuilding the guideway, the measures required some gradient reductions and also included a short realignment to better service a university campus, and a short branch line to access an emerging inner-city redevelopment area [28].

The introduction of rubber-tyred tram infrastructure based on the premise of reduced cost and flexibility proved to be unsuccessful in this instance. During the 2010s, however, iterations of the electric tram-bus such as the Van Hool Exquicity introduced in Metz in France in 2015 and Malmö in Sweden in 2016 (see case study 2 above) resulted in most major vehicle manufacturers offering versions of a stylised tram-bus as part of their fleet offering. Available in 18 m and 24 m length, the passenger capacity these vehicles offer sits between that typical for conventional buses (12 - 18 metres) and trams (24 metres and above). Propulsion systems include fully electric, hydrogen fuel cell, hybrid electric with either diesel, biofuel or LPG. These vehicles provide affordable mid-tier transit capable of utilising existing road infrastructure and depots, and are now running on over 200 routes worldwide.

4.3.2. Clermont-Ferrand and Paris (Translohr)

Between 1992 and 2014, eight new tram lines were opened in the previously tram-free metropolitan area of Paris. Four of these are conventional trams (T1, T3, T7 and T8), two started as heavy rail conversions (tram-train) that were later extended on-street (T2 and T4), and two use the rubber-tyred Translohr technology (T5 and T6). With the exception of conventional lines T1 and T8, there are no physical track connections between these lines (yet), though T2/T3 and T1/T5 respectively share a point of interchange (otherwise the lines are also geographically separated).

According to the planning approval documents, the initial sections of conventional tram lines T3A, T3B, T4, T7, T8 and T9 (opened between 2006 and 2021) taken together required capital funding of nearly €2.5 bn for just over 60 km of track, amounting to an average per-km cost of €41.5 m/km (including vehicles and depots/maintenance facilities). The two rubber-tyred tram lines (T5 and T6, both opened in 2013-14) between them had a comparative cost of €766 m for just over 20 km of route length, or €37.2 m/km. These figures are documented on the relevant French-language Wikipedia pages, refer to time of planning approval for each project (no adjustment for inflation) and come with obvious caveats concerning data reliability and compatibility. But overall, they do not suggest that the choice of Translohr over conventional tram technology made the provision of medium-capacity transit significantly cheaper in a Paris context. Rather, Translohr technology might have been selected in order to enable greater alignment flexibility (the vehicles are narrower and capable of negotiating steeper gradients than conventional trams) as well as resulting from effective industry lobbying, which as recounted by Ferri [29] also played a critical role in the case of the first French Translohr system in Clermont-Ferrand. This smaller city is home to tyre manufacturer Michelin, perhaps leading to easy stakeholder support for the provision of a medium-capacity transport system that requires new sets of tyres at the rate of twice per year.

In the Paris metropolitan region, there are currently a number of proposals for conventional tram extensions and two additional routes in various stages of planning and construction, as well as three further tram-train orbitals (TramExpress; first section opened in 2017). There are no apparent plans for extensions of or additional Translohr routes (see **Figure 2** below).

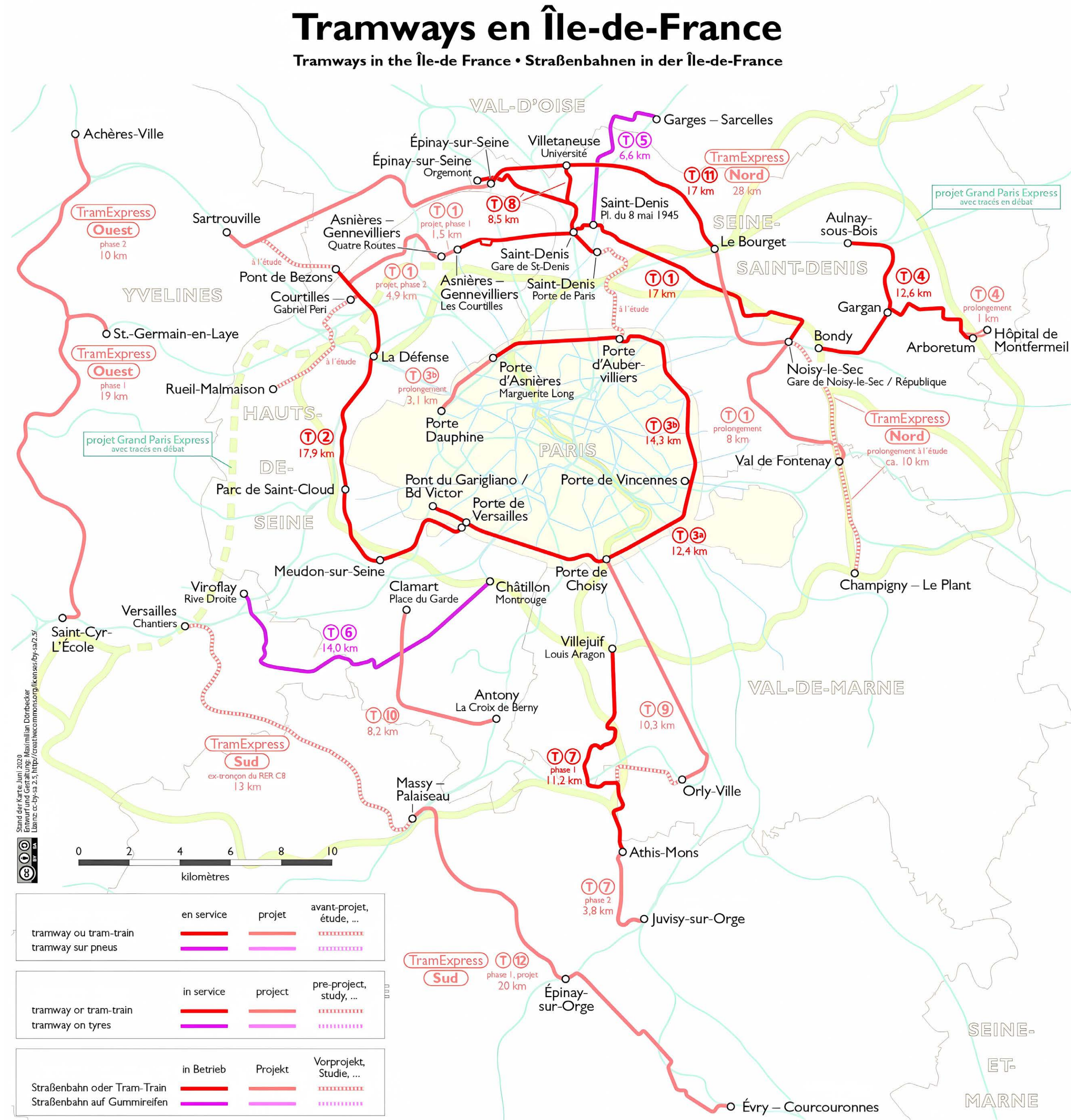

Figure 2. Existing and proposed tram routes in the Paris metropolitan region in 2020. Source: Maximilian Dörrbecker (https://commons.wikimedia.org/wiki/File:%C3%8Ele-de-France_-_plan_des_tramways.png).

5. Discussion

The case studies discussed in this paper share a common overarching policy objective, to transform car-oriented or car-saturated urban areas into an intensified urban template with a critical presence of dedicated public transport infrastructure and active transport. In other words, they aim at rolling back the legacy of automobile urban fabric in favour of a spatial expansion of contemporary versions of transit and walking urban fabric [30] [31]. This is the precursor to progress the zero-carbon cities agenda as it is not only reducing their dependence on individual road transport: it is enabling urban renewal that will now be able to include all the necessary design and technology for net zero cities [12]. While many jurisdictions in New World countries now subscribe to this objective in principle, a number of challenges emerge on the pathway to implementation of the associated transformation of the land use-transport system.

The experience of Malmö, where the introduction of a medium-capacity transport mode was resisted in favour of incremental improvements to the existing bus system forming the backbone of intraurban transit, serves to illustrate the first challenge in the "Tram-TOD pitfalls" discussed earlier. The city's policy debate surrounding the transformation appeared focussed on technical details while failing to effectively communicate, build alliances for and mobilise funding for a broader vision of future land use-transport integration. Consequently, the public transport capacity problems identified by transport agencies remain under-addressed while the land use transformation, most recently concentrated on former port areas adjacent to the central city, occurs without the critical guidance of a high-profile public transport infrastructure element other than the relative proximity to Malmö's long-established central railway station. As overcrowded bus services limit the share of trips that public transport is capable of serving, this lack of integration between different stakeholders will also make net zero outcomes in the urban transformation process harder to achieve.

The experience of Helsinki, where an ambitious program for the urban intensification and transit retrofit to middle suburban arterial road corridors was scaled down in a policy conflict between core city and surrounding jurisdictions, illustrates the second "pitfall" challenge. Here, a transformative vision attracting broad support in principle ran the risk of placating the different interests of different players in the process: namely, the varying interpretations of what constitutes spatial balance across a multi-centred metropolitan region (should the core city be allowed to grow at the expense of suburban hubs, or should it be the other way around?) and what constitutes sustainable transport (is it acceptable for the performance of express bus routes to be reduced as their roadways morph into multimodal, lower-speed environments?). Greater deliberation and mediation of such competing visions was required to build a deeper, more resilient policy consensus, a process that arguably delayed the implementation of Helsinki's boulevards scheme and possibly led to a permanent reduction in its scope, which in turn may result in a greater proportion of urban growth occurring in areas away from the target corridors and less suitable for the desired integration of land use intensification and medium-capacity transit. Similar pitfalls can occur when net zero planning is incorporated, as the whole exercise needs to optimise land use for multiple outcomes including new factors such as recharge hubs for electric vehicles that are likely to be needed in station precincts for the e-micromobility as well as the e-transit.

The experience of Lund, where an LRT system was introduced in a relatively small conurbation, almost represents a reversal of the third "pitfall" challenge. Rather than mobility considerations delivering the rationale for a transport project to the exclusion of wider aspects of city building, in this case it was arguably the scale of the urban expansion and intensification program and its character (internationally prestigious research centres) that determined the choice for a medium-capacity transit mode. This is despite the capacity of buses probably being sufficient if the land use vision for the corridor were less ambitious (or if the projected rate of growth should fail to eventuate), and the lack of operational economics of scale for a relatively short LRT line without prospects to grow into a larger network in the foreseeable future.

While the choice of transport mode may not immediately affect net zero outcomes—eventually all public transport will need to be electrically powered from renewables-based grids—the Swedish examples illustrate that such choices do not always follow a spatial or economic logic as they navigate the political and policy-making sphere, and may not necessarily follow a net zero logic either. They are strongly influenced by the presence or absence of a transformative vision, underscoring the importance of this factor for net zero urban development outcomes. The paper has attempted to show that tram-based boulevards can be a major mechanism for establishing such a vision. The ability of decision makers and other stakeholders to communicate and build consensus for such visions will therefore be assisted by a net zero rationale. However, as the French case studies in this paper demonstrate, they can also themselves provide a distraction on the journey from policy to implementation.

The French experiments of diversifying medium-capacity transport away from conventional trams and buses by developing hybrid technology during the 2000s and 2010s appear to have stalled. Not only did these systems largely fail to deliver on the promise of lower infrastructure and/or operational/maintenance costs in comparison to conventional trams. They also failed to provide a long-term modal alternative in an uncompetitive marketplace where the future prospects of unconventional medium-capacity transit hinged on the short-lived proprietary technologies of particular manufacturers, necessitating costly infrastructure retrofits with each new generation of rolling stock or wave of network expansion.

While the public transport system in the large metropolitan area of Paris appears capable of absorbing the impact (including potential inefficiencies) of the resulting diversity of transport technologies without significant adverse effects on the pace of network expansion, it is arguable that in smaller cities such as

Caen (where a rubber-tyred tram was converted to a conventional one after only 15 years) and Nancy (where the rubber-tyred tram was abandoned in favour of conventional buses) the discontinuity of medium-capacity transit technologies contributed to the partisan contestation of policy settings and resulted in severe disruptions and delays on the journey towards a more transit-oriented urban template.

6. Conclusions

The journey of a city to reduce its automobile dependence and at the same time create a transition to a net zero city requires both knowledge exchange with other cities, and finding the policy paths and appropriate technologies best adapted to the local context. The paper has set out how tram-based boulevards may provide one approach that has worked over a long period of urban history and is being re-invented in European cities as outlined in the case studies.

There are however pitfalls that cities can fall into. Ultimately, as argued poignantly by Bertolini [31], the development of urban corridors with increasing densities and functional mix anchored by medium or high-capacity public transport infrastructure not only depends on the recognition of the inherent synergies between transport and land use settings in such environments, but it must impact on their translation into policy priorities in both fields of planning. This will become even more evident when cities begin the transition to net zero outcomes and seek to make tram-based boulevards a key mechanism in how this can be achieved efficiently and with multiple benefits. It also depends on decision makers proactively identifying and critically appraising specific opportunities for change, whether that concerns funding, technology, public opinion, stakeholder alliances or market dynamics, and capitalising on them at suitable moments in time. It is critical that such policy learning on multiple levels informs the net zero transformation process in North American and Australian cities, while accounting for the inevitable social and cultural differences experienced in these generally more car-dependent environment and whose detailed analysis is beyond the scope of this paper. The same is true for the "leap-frogging" opportunities in emerging cities where most urban development is currently occurring at a global scale, and where the need for net zero with SDG benefits will be even more important [32].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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