Introduction

Background

~~The~~ urban managers have long valued public transport systems. Public transport provides mobility and access to employment, community resources, health care and recreation, and it benefits those who choose to use public transport and those who have no other options (Lee and Averous, 1973; Stuart et al., 2000). It also helps to reduce road congestion and travel times, air pollution, and energy and oil consumption, from which anyone can benefit (Levine, Grengs and Merlin, 2019). In addition, public transport is vital for evacuation and shelter in emergencies (Miller, 2019).

In recent years, establishing environmentally friendly and sustainable cities has become an important goal worldwide to mitigate global warming. As a result, the importance of public transport systems is being increased and the idea of public transport oriented land use and development has become more popular. ~~In simple terms~~, this idea is known as Transit-Oriented Development (TOD) and was first proposed in 1993 by Peter Calthorpe in his book ''The next American metropolis: ecology, community, and the American dream''. This model calls for urban centres to be created by developing land within a particular area, centred on a rail or large bus station stop (Calthorpe, 1993). It refers to a dense, mixed-use, pedestrian and cycling-friendly land development oriented towards public transport and not just development alongside rail and bus stations (VTPI, 2019).

Transit-oriented development has many benefits. It has promoted nearby communities and reduced urban sprawl (Chorus and Luca Bertolini, 2011). Furthermore, development through public transport can foster a sense of community and enhance neighbourhood safety and security (Levine, Grengs and Merlin, 2019). There are already many successful examples of TOD worldwide, such as in Singapore and Canada (Jones and Ley, 2016; Tan and Yi, 2021). Moreover, many more new projects and policies are in the pipeline (Chorus and Luca Bertolini, 2011; City of Bellevue, 2018; City of Shoreline, 2016; Miller, 2019; MRSC, 2021; Zhang, Marshall and Manley, 2019).

Literature Review

Integrated transport and land use model

Assessing the extent and effectiveness of transport and land development in an area can be an essential reference for future land planning in that area. The development and use of integrated land use and transport models to assess cities can be traced back to the Lowry model of 1964 (Lowry, 1964). Depending on the type of theory on which the model is based, there are three broad types of models: integrated models based on spatial action/gravity models, models based on economic theory, and models based on micro-simulation.

The original Lowry model was based on a spatial interaction/gravity model that used classical economic theory to simulate basic urban patterns by assessing work activity and household activity (Lowry, 1964). This comprehensive model was easy to obtain data for but was too simplistic in its description of urban behaviour. Since then, many scholars have improved or built new models, such as the IRPUD model by Wegener (1982), the LILT model by Mackett (1983) and the ITLUP model by Putnman (2007).

Researchers have begun to use these models to model discrete locational distributions and travel patterns with the emergence of economic models such as discrete choice theory and consequent utility theory. The TRANUS model developed by de la Barra et al. (1984), for example, is a ~~classic~~ regional economic model that has been widely used around the world. In addition to these, the MEPLAN model developed by Echenique et al. (1990) and the PECAS model developed by Hunt and Abraham (2003).

Microscopic models are a relatively recent area of research that uses theories like cellular automata, activity-based and multi-agent systems to effectively simulate the microscopic behaviour of individual decision-makers in land use and transport development, such as MASTER, SLEUTH, CLUE-S models (Mackett, 1990; Silva and Clarke, 2002; Verburg and Overmars, 2009). The MASTER model examines population growth and changes in household structure (Mackett, 1990), while the SLEUTH model uses the principle of meta-automata to simulate urban change patterns and can model the transformation of land from non-urban use (forest, farmland) to urban land use (Silva and Clarke, 2002). Silva and Clarke, 2002).

Many Land-use and Transport models have been developed to date, based on different theories and for various purposes. Although some of these models are well developed, their purpose is not in line with the TOD concept, which encourages public transport, cycling and walking in areas where private car travel is discouraged (Calthorpe, 1993). Most of the Land-use and Transport models include a transport module that includes public transport and an assessment of private car travel, deviating from the TOD concept of 'transit orientation'.

The Node-Place Model

Bertolini (1999) first proposed the Node-Place model following the introduction of public transport-oriented development models. The Node-Place model is an analytical model that evaluates nodes in terms of both public transport and land use, based on the land-use transport feedback cycle theory (Wegener, 2004). As shown in the figure, the x and y axes of the original Node-Place model represent the transport value of a transport hub (rail station, bus station, or even bicycle sharing station) as a transport node and the human activity value as a place node. Such an approach allows multiple sites to be positioned in the same two-dimensional plane to describe and compare their development. It is worth noting that the value of a node and the value of a place are difficult to describe adequately in terms of a single indicator, and therefore these two indicators are usually expressed as a linear combination of a series of related indicators.

As defined by Bertolini (1999), the Node-Place model describes two imbalances and three balance states at different levels (see Figure 1). The three states along the diagonal are the stress zone, the balance zone and the dependency zone, which express a more balanced public transport and land use development for these sites. Conversely, the zones in the top left and bottom right corners are the imbalanced node zone and the imbalanced place zone, respectively, which have less balanced development patterns and are more oriented towards separate functions (nodes or places). In general terms, nodes located in the Balance Zone are considered successful TOD. The Dependency Zone is considered to be balanced with low levels of development. The Stress Zone indicates that the area is balanced in public transport and land development, but both are very high and maybe overdeveloped. The Imbalanced Node Zone and Imbalanced Place Zone need to be focused on, as this represents the possible development potential within them.

Based on the theoretical foundations of the Node-Place model, different frameworks based on different lists of indicators have been developed to assess the TOD around nodes based on different cases. The studies cover various cities around the world. At first, the research was mainly conducted in European and North American cities such as Amsterdam (Bertolini, 1999), Tehran (Monajem and Ekram Nosratian, 2015), Brussels (Caset et al., 2019), ~~the~~ Flanders (Caset et al., 2020), Lisbon (Vale, 2015; Vale, Viana and Pereira, 2018), London (Zhang, Marshall and Manley, 2019), and Rotterdam (Groenendijk, Rezaei and Correia, 2018). In recent years, Node-Place models have started to gain popularity in studies in Asian regions, such as ~~in~~ Tokyo (Cao, Asakura and Tan, 2020; Chorus and Luca Bertolini, 2011), Shanghai (Chen and Lin, 2015; Gui, Zhang and Wang, 2021; Li et al., 2019), Shenzhen (Su et al., 2021), and Beijing (Gui, Zhang and Wang, 2021; Lyu, Bertolini and Pfeffer, 2016). The vast majority of studies have used clustering and principal component analysis to classify a series of nodes into subcategories with different functions and levels of exploitation. Scientists argue that the analysis process is simplified by doing so, making the results more readable and facilitating subsequent planning for each type of station (Austin et al., 2010).

While applying the Node-Place model to assess the TOD, researchers have made different improvements to the model, focusing on three main areas: 1. selecting the station boundary; 2. improving the list of indicators; 3. the addition of dimensions.

Firstly, generally speaking, TOD was often studied in 400 to 800 metres around a transport node. However, most of the early studies were conducted on railway stations and more recently, the scope used by researchers has changed based on different types of transport nodes (Bernick and Cervero, 1997; Zhao et al., 2003). For example, in a study in South Korea, researchers suggested that the observation range for metro nodes should be extended to 3 km due to the popularity of bike-sharing, while the observation range for BRT nodes was suggested to be 500 m (Lee, Choi and Leem, 2015). Not only that, when assessing the TOD of the Lisbon urban metro system, Vale et al. suggest an observation range of 500 m by comparing other studies (Jun et al., 2015; Vale, 2015; Vale, Viana and Pereira, 2018).

Secondly, improvements to the list of indicators for the Node-Place Model have also been an important area of research. The original Node-Place Model has 15 normalised indicators, nine of which point to node value and six to place value, with the final node value and place value being their equally weighted mean values, respectively (Bertolini, 1999). The list of indicators has then been abridged or added to in subsequent studies due to data limitations or various other reasons (Chorus and Luca Bertolini, 2011; Monajem and Ekram Nosratian, 2015), such as proximity to city centres and public transport accessibility (PTAL) (Chorus and Luca Bertolini, 2011; Kamruzzaman et al., 2014).

Finally, the current discussion on adding a new dimension is related to 'pedestrian-oriented design', where Node and Place nodes can describe the traffic development and land development in the vicinity of a site but do not represent the 'Oriented Development' TOD well. Development (Lyu, Bertolini and Pfeffer, 2016; Vale, 2015; Vale, Viana and Pereira, 2018). For example, some poorly designed pedestrian paths may reduce people's enthusiasm to get to public transport nodes. We cannot tell whether people are well directed towards using public transport and need to measure some other indicators. ~~Therefore,~~ in his study of the Lisbon metro system, Vale (2015) proposes a new 'Design' dimension for the value of public transport orientation, looking at the public transport orientation of the area through the Ratio of pedestrian sheds on the street. Similarly, Lyu (2016), in his evaluation of TOD in

Beijing, incorporates proximity indicators into a new dimension named 'oriented' to observe the orientation.

Nevertheless, the Node-Place model has been used to evaluate TOD by focusing more on developing the surrounding area at each node but not considering the whole area's land and transport system planning. In more detail, the primary research tool currently used is cluster analysis and principal component analysis to classify a set of nodes, identify unevenly developed nodes and make recommendations for future planning (Zhang, Marshall and Manley, 2019). However, researchers have found that these initiatives are difficult to replicate and implement because administrative boundaries constrain some projects and competition for development priority occurs between TOD projects close to each other that are not part of the same local authority (America, 2007). A successful TOD project needs to go beyond the constraints of individual stations and understand the role of each neighbourhood and station area in a public transport oriented regional network, which is the conceptual basis of some of the more recent projects known as Regional TOD (Anderson, 2011). Therefore, the existing Node-Place model is not sufficient to assess TOD at the regional scale, and we need to include an assessment of the strategic value of the entire individual station to the overall network.

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