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HOW CENTRAL IS THE RAIL STATION?
Incorporating Rail Centrality with Development Potential

YOAV LERMAN
Hebrew University of Jerusalem, Jerusalem, Israel
yoavlerman@gmail.com

YONATAN LEBENDIGER
PlaNet Consultancy, Tel Aviv, Israel
yonatan.arch@gmail.com

ABSTRACT

The study presented in this paper offers a methodology for the assessment of development potential around rail stations, by taking into account the importance of each rail station in the global rail network and the local urban fabric in the rail station's vicinity. To achieve this goal this methodology incorporates intercity rail centrality along with local centrality measures relevant for non-motorized transport. The case study explored here is the Israeli railway passenger network spanning form the southern city of Beer Sheva up to the northern edge of the Haifa Metropolitan area.

Following earlier efforts for a multi-modal transit analysis using space syntax (Gil, 2012; Law et al., 2012), this study aims to combine centrality regimes at different scales, therefore providing the capability to assess a place potential for development based on its multi-modal accessibility. Combining the values of different centrality regimes allows for identification of areas that have high centrality values at different geographical scales concurrently. This methodology highlights the locations of rail stations with good local accessibility ripe for development. Moreover, this process may also be used in the planning of new rail stations and in choosing their locations.

KEYWORDS

Israel, Train Stations, Rail, Transit-Oriented-Development, Space Syntax

1. INTRODUCTION

This study addresses the central concern about how to combine expansive large-scale transport infrastructure with sustainable urban growth, by maximizing opportunities for Transit-Oriented-Development. This paper presents a specific but as of yet under-exploited contribution to this urgent issue by employing and combining the configurational approach of space syntax at different geographical scales. This configurational approach has been successfully applied in various urban planning settings (Karimi, 2012; Lerman et al., 2014), but is yet to be expanded as an evaluation tool to aid in planning of national-scale rail projects.

The central hypothesis is that space syntax methodology, through its proven ability to capture pedestrian movement (Hillier et al., 1993; Hillier and Iida, 2005) and its capacity to handle large spatial systems (Serra and Pinho, 2013; Serra et al., 2015) can contribute to a better understanding of how global and local mobility flows can be integrated. The kind of intermingling of global and local movements addressed here is especially acute in train stations (Bertolini, 1996). Therefore, this study aims to quantify the centrality of stations related to their position in the national rail network and combine it with their local centrality in the surrounding urban fabric. For this amalgamation the node-place model of Bertolini presents an excellent theoretical framework

(Bertolini, 1999). The node-place model measures rail stations by their accessibility (the node-index) and the intensity and diversity of activities in their area (the place-index). Through the combination of these measures it categorizes rail stations into balanced and unsustained stations. For balanced stations the node-index and place-index are somewhat similar (a further distinction of stressed and dependent stations is also given), while for unsustained stations there is a mismatch between the node and place indices, reflecting either high accessibility with low amount of activities or high amount of activities compared to the accessibility level. To easily assess the accessibility of rail stations (the node-index in Bertolini's model) using space syntax measures, this study relies on the directness of the rail network but does not deal with the actual frequency and speed of the trains.

Earlier work (van Nes and Stolk, 2012) assessed train stations location and potential under concurrent centrality measures at different geographical scales. Our approach aims to capture the stations' development potential with a single measure which can effectively represent the intermingling of global and local movements. Such a benchmark can help to better assess the potential development around existing and proposed train stations and support decisions makers in locating new stations and improving existing ones.

The rest of the paper is organized in the following way: the next section presents the methods and the case study on which they were applied. The section afterwards shows the results of the proposed methodology, while the final section concludes with several suggestions for further research and applications of space syntax for rail analysis and planning.

2. ANALYZING RAIL STATIONS' CENTRALITY AND IMPACT

This research focuses on Israel's national rail network. In order to assess the centralities of the rail stations the entire Israeli road network was modelled with segments adapted from a road centre line map (taken from Open Street Map). Earlier studies combining rail transit and road network analysis have differed on the exact method used to attach the rail stations and segments to the road network. Gil (2012) used axial lines and added axial connections to represent London's rail network. Another study based on segment analysis (Law et al., 2012) added direct segments between London's rail stations as well as connecting segments to represent changes from street to rail platforms. This study is based on angular segment analysis (Turner, 2007) and applies a similar approach to the one used in the latter study mentioned above. However, the method used in this study is a bit simpler. In this study, each rail station was located as a node on the end point of its nearest segment in the road system, or at the intersection of two segments which lead to the station's entrance (Israeli train stations have at most two entrances). Afterwards the rail network segments were added on top of the road network, connecting the different train stations according to the actual routes available at peak hours.

As mentioned above, this study uses segment representation of Israel's road map including its rail network. The analysis of the angular distance (least cumulative angle measure) between the segments provides a number of indices of the network, which describe the centrality of a given segment. Space syntax analysis produces several such measures, most prominent among them are integration and choice (or closeness and betweeness in graph theory). Integration indicates the closeness of a segment to all the other segments in the system. This reflects the segment centrality or to-movement potential. The Choice measure reflects the likelihood of through-movement for a given segment as it evaluates a segment usage in the shortest paths among other segments in the system. Both integration and choice measures can be calculated on a global scale for the entire system and at a local scale, limited by a specific radius. A higher radius indicates a larger extension of the network. For further information on the calculation of these measures and the relevance of angular measures for urban movement please see: Hillier and Iida, 2005.

Overall, the national road map of Israel consists of 224,657 segments covering a length of 23,544 kilometres. In addition there are 54 rail stations and 62 segments connecting them covering a passenger rail network of 621 kilometres. Since this analysis focuses on combining large scale infrastructure with local urban conditions an exact configuration of pedestrian only paths,

bridges and underpasses must be carefully represented around each station. So, while tracing the national road network, a special attention was given to the rail stations' surroundings and their exact modelling. Figure 1 shows Israel's road map with the rail segments superimposed on it.

To capture the nature of long rail distances, an angular choice measure with a very large radius was used to create a measure which quantifies the Station Power (SP). The SP value is calculated by summing the choice values for all of the rail segments meeting at a station. This calculation gives higher values to stations where multiple lines meet and where train interchanges occur.

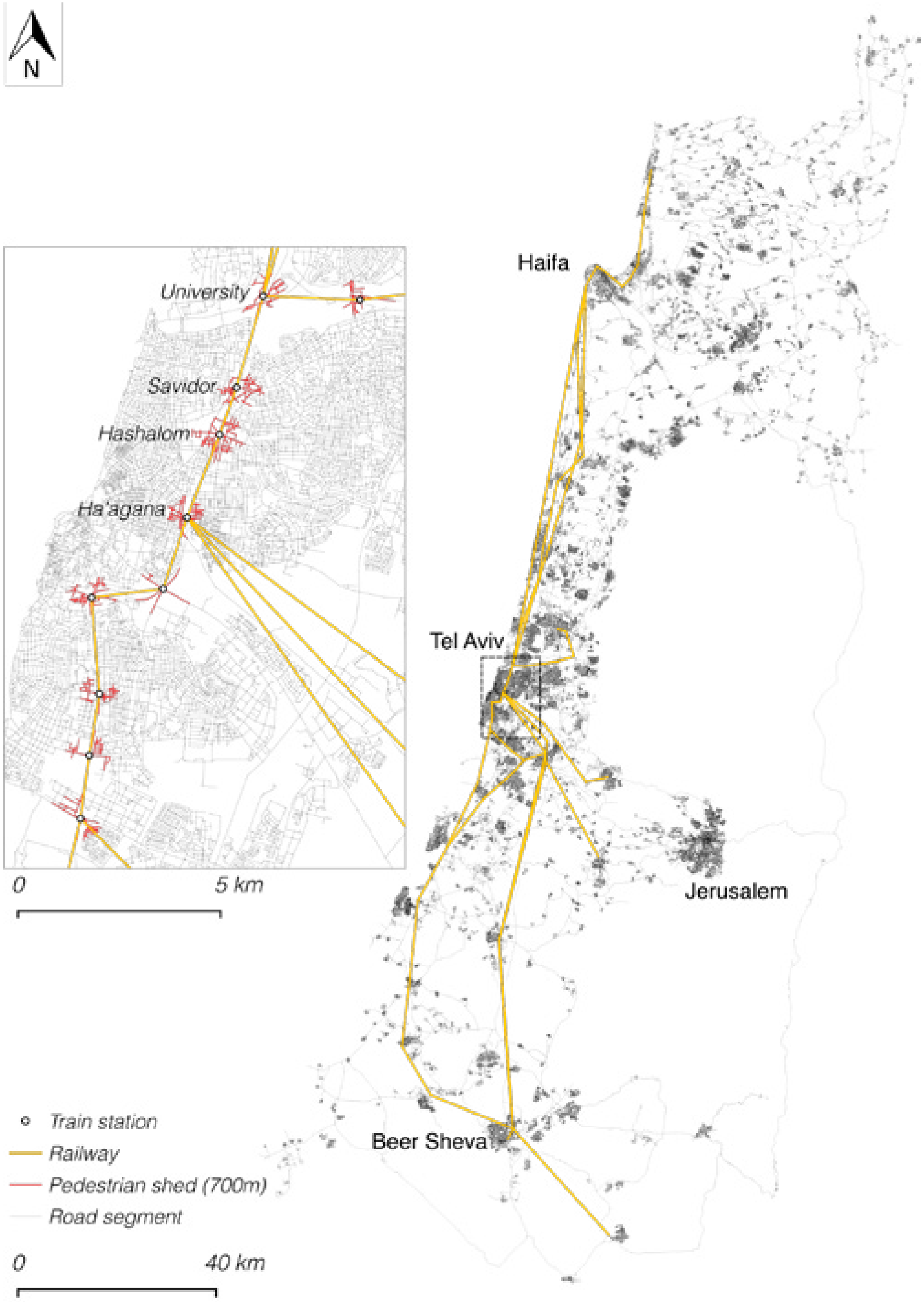

Figure 1 - The national road map of Israel with the rail segments (in yellow).

The specific radius used for the evaluation of the SP measure is derived by applying statistical correlation between the SP values of the rail stations and their corresponding total daily passenger boarding numbers. In addition, high choice values (with a large radius) tend to highlight rail segments and motorized highways. Therefore, to better reflect commuting rush hour and speed difference between rail and (clogged) highways – the calculated choice value is multiplied by a factor of three for all rail segments in the national road and rail network. This calculation is based on rail relative efficiency compared to vehicular movement during rush hour. During rush hour average rail speed in Israel may be up to ten times as much as vehicular traffic speed, depending on the specific road segment (For reports on intra-urban rail and vehicular speeds in Israel see: Ronen, 2011; Bar-Gera et al., 2015). For the purpose of this study we simplified the rail advantage by multiplying the entire rail network by the same factor, but further studies with an extended data set may multiply different rail segments by different factors (depending on the actual average difference between vehicular and rail speed along these segments).

The topmost choice values are concentrated on the segments with expected large flows of long-distance movements, including the segments that represent the rail tracks themselves. Since these segments are not available for direct urban development and do not exist in the pedestrian movement network we need to spread the impact of each station's centrality around it. For this we take the station's SP value and spread it to all the segments in the pedestrian shed of 700 metres around each station, representing the potential area for pedestrian-based development around each station (c.f. 700 metres usage in: Bertolini, 1999; Vale, 2015).

To assess the potential for development based on non-motorized movement in the vicinity of the train station we need to calculate a local angular integration value that is representative of non-motorized movement. For this we have used angular integration at the radius of 1,250 metres, which proved to have decent correlation values with pedestrian movement in several other studies in Israel (c.f. Lerman and Omer, 2016, p. 9). This integration radius value is somewhat arbitrary at this point and may be different under different conditions and areas.

To quantify the actual combination of large-radius choice measure along with the low-radius integration measure, a multiplication of the expanded choice value with the local integration value was done for all the segments in the system. The resulting multiplication values allow for locating segments that have both a high choice value, which pertains to large global scale movement flows, and a high integration at the local scale, meaning prime conditions for pedestrian movement and destinations.

To summarize, the general algorithm used to combine large scale intra-urban rail movement together with low scale local pedestrian movement, while focusing on potential development in the immediate vicinity of the rail station is as follows:

1. Calculate the sum of the angular choice measure for the rail segments at each station. The radius used should be extensive to represent rail movements probably over 50 km.
2. Correlate the choice sums at different radii versus the daily boarding numbers at each station to find the radius that has the best correlation. For each station the sum of the angular choice at the best fit radius represents the station centrality to a certain degree and we'll call this value Station Power (SP).
3. Multiply the SP value by a factor to better represent the rail advantage versus road and spread this value across a pedestrian shed around each station, encompassing the development area that has the most potential to be affected by the train station.
4. Calculate a local angular integration value that best captures local movements for the entire system. Typically, this should be done with a radius lower than 2,000 meters.
5. Now multiply the choice value with the best fit radius and the local integration value for all the segments in the system. This combined value is the Rail-Development Potential (RDP).

6. Finally, we have a map where each segment has an RDP value calculated. This map requires further analysis in order to evaluate how well this value captures real development potential and where there are gaps in the analysis or in maximizing the development potential.

3. RESULTS

In order to assess the validity of the choice measure we have calculated the correlation coefficient between the SP measure (the sum of the choice values for each station as described previously) and the passenger boarding numbers for each station. The radii range for the SP calculation was set from 50 km up to 120 km with jumps of 10 km in between. The actual boarding numbers values were supplied by Israel Railways and represent an average weekday during the first quarter of 2016. Since both the choice values and boarding numbers have heavy-tailed distributions (most stations have low values and few have very large values), we have normalized both of these variables using the natural logarithm. The highest correlation coefficient achieved was with SP based on choice measure at a radius of 100 km where the log-log bivariate correlation produced an r-square value of 0.35, which was statistically significant with $P < 0.01$.

This correlation coefficient can (probably) be improved upon with further analysis. One of the major problems with the SP calculation is related to edge effect. Major stations at the edge of the system tend to have low SP value because they have a single rail link, yet a few of them have relatively high boarding numbers. This might happen because for many people (especially those living beyond the edge of the rail system), the edge stations are the best connection to Tel Aviv CBD, which is located at the centre of the railways system. For example, Beer-Sheva central station has over 8,000 boarding passengers per day making it the 12th most use rail station in the system. Yet, in terms of SP it is third from the bottom (placed at 52 out of 54 stations). In order to test the correlation without these edge stations we removed from the dataset three stations (Beer-Sheva Centre, Modiin Centre and Nahariya) which are all edge stations with relatively large numbers of passengers. The resulting r-square value between the SP based on choice at 100 km radius and boarding numbers without these three station is markedly higher and stands at 0.46 (also statistically significant with $P < 0.01$). Therefore, further work on the SP calculation especially for edge stations can improve the validity of the method and model presented here.

Figure 2 shows the Israel road and rail map with a choice 100 km measure. The segments with high choice values tend to be either rail segments or motorized highway segments. Figure 2a shows the original values while Figure 2b shows the same map with the choice values for rail segment multiplied by three to indicate a rail advantage over road (especially during rush hour commute). Figure 3 shows a close-up of the two largest metropolitan areas in Israel – Tel Aviv and Haifa. In figure 3a the original choice values at a radius of 100km are shown, while in figure 3b the choice values for rail segments are multiplied by three, therefore allowing them higher values than the rest of the system segments. In the close-up of the Tel Aviv metropolitan area it can be seen that this multiplication lowers the relative choice values of motorways 4 and 6 compared to the rail segments.

The SP measure, which is the summation of the choice values of the rail segments that intersect it, displays a heavy-tailed distribution. Thus, in the Israeli context most stations have relatively low power values (lower than the mean of the power values for all stations) and few stations have very large power values. In order to better visualize this kind of distribution the head/tail breaks algorithm was used (Jiang, 2013). This algorithm breaks a heavy-tailed distribution in a deterministic fashion by partitioning all the data values around the mean into two parts and continuing the process recursively until the head part values do not exhibit a heavy-tailed distribution.

Accordingly, the 54 rail stations were divided into the following three categories (shown in Figure 4):

1. High power stations – five stations which account for 9% of the stations.
2. Medium power stations – ten stations which account for 19% of the stations.
3. Low power stations – thirty nine stations which account for 72% of the stations.

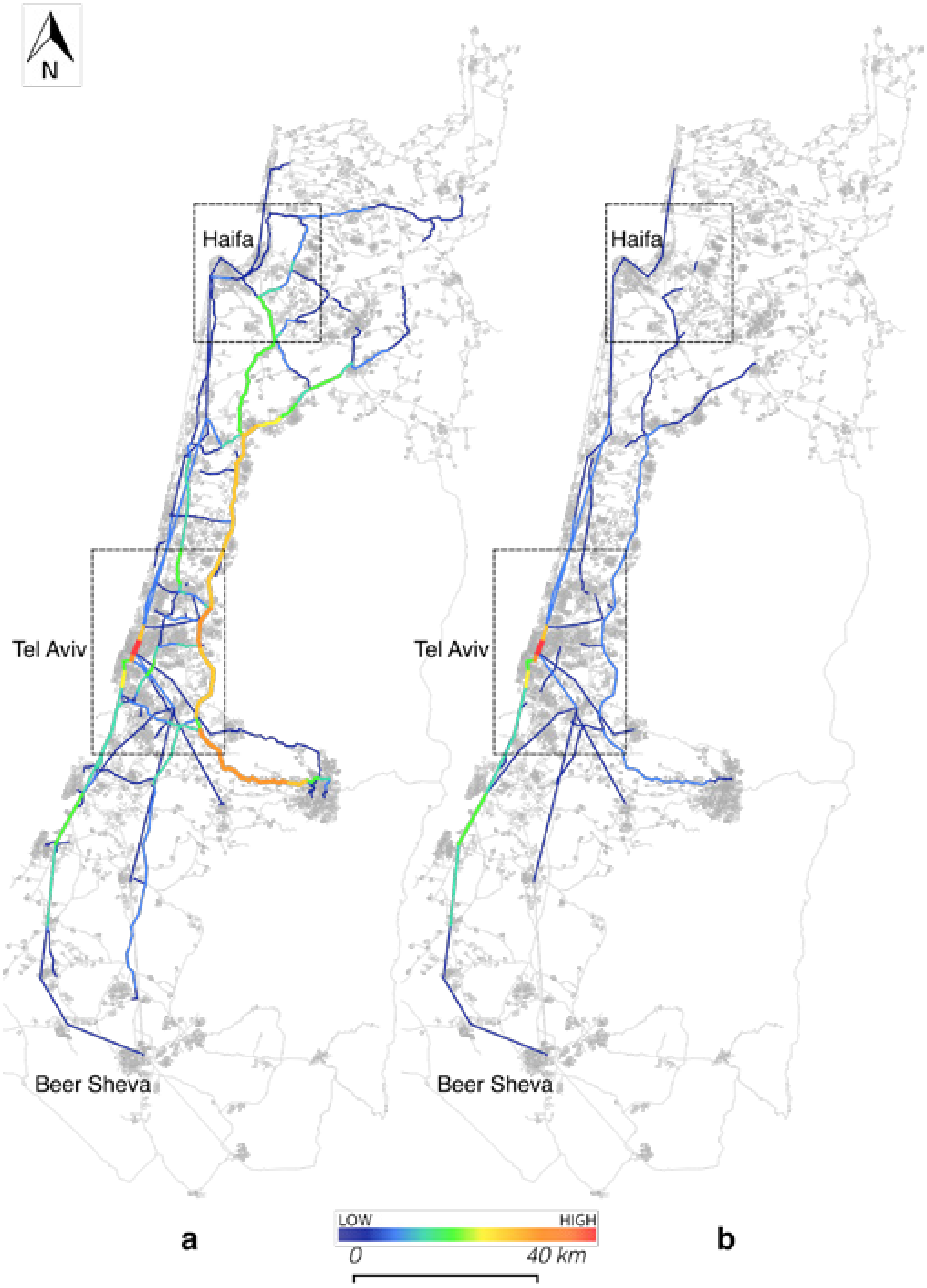

Figure 2 - Choice values at 100 kilometres radius for Israel road and rail network. (a) shows the original values, while (b) shows the same map with rail segment choice values multiplied by three.

Figure 3 - Choice values at 100 kilometres radius for Tel Aviv and Haifa metropolitan areas. (a) shows the original values, while (b) shows the same map with rail segment choice values multiplied by three.

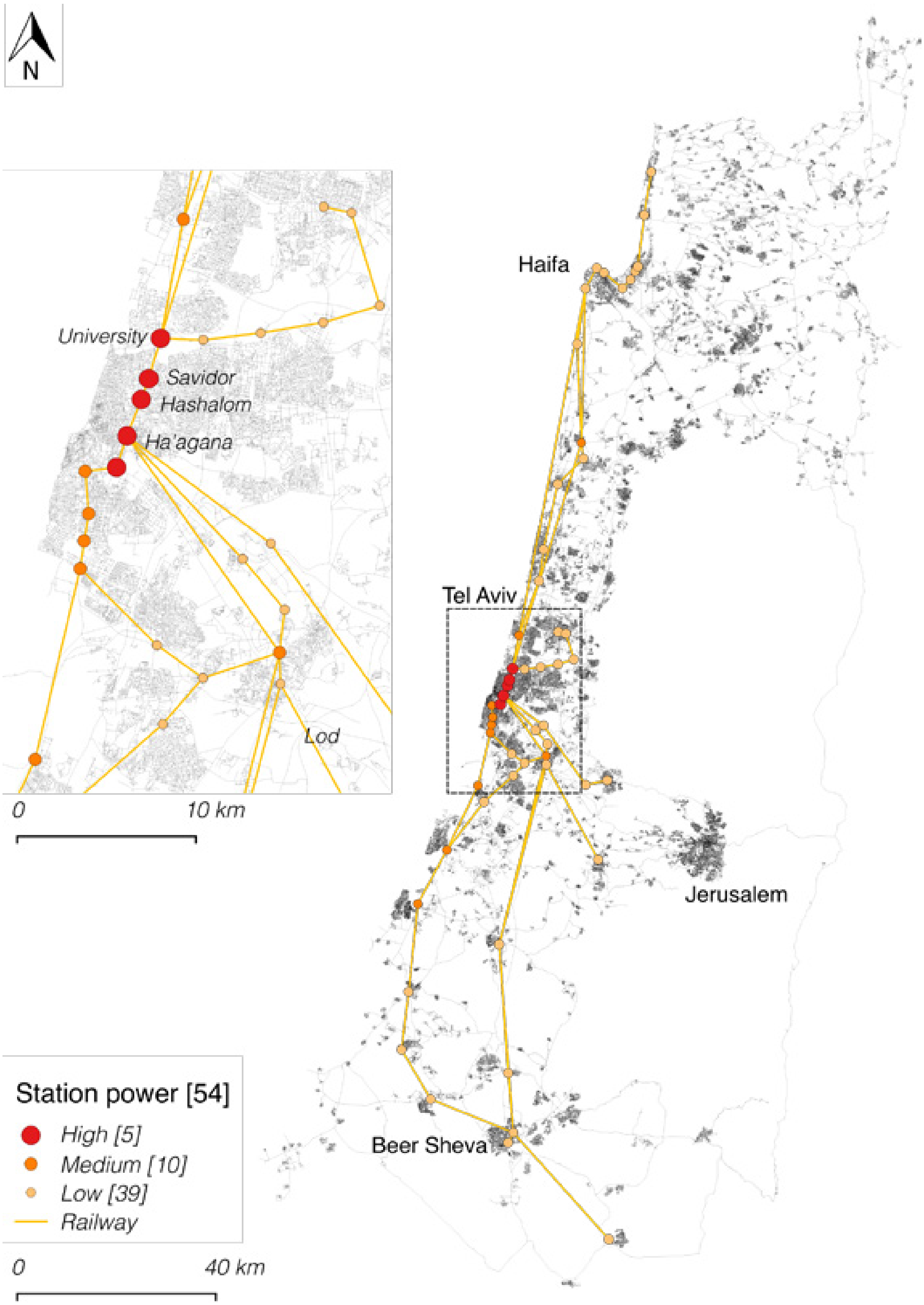

Figure 4 - A map of the Station Power (SP) measure for the entire passenger rail network of Israel. On the left is a close-up of the central rail corridor passing through Tel Aviv.

Afterwards, the SP measure of each station is spread among all the segments within its 700 meters pedestrian shed. Thus, each segment in the close vicinity of a rail station gets its value of choice at 100 km radius replaced with the SP value of that station. For the pedestrian movement potential we have used angular integration with a radius of 1,250 metres as a proxy for pedestrian movement potential and hence a proxy for intensive multi-modal development. Figure 5 shows the map of angular integration with a radius of 1,250 metres for the entire road system of Israel. Figure 5a shows the values for the entire system, while figure 5b shows close-ups of the two largest metropolitan areas – Tel Aviv and Haifa. This figure shows that the best potential for pedestrian and multi-modal oriented urban development lies at the old centre of Tel Aviv, which is indeed the case and where the financial quarter of Israel is located. This area has far more multi-modal development potential compared to the rest of the system. Figure 5 also highlights the older urban centres in Israel both in Tel Aviv suburbs and in other parts of Israel.

Finally, in order to combine large scale rail accessibility with low scale pedestrian accessibility, a multiplication of the choice value representing long movements with the integration value representing short movements and destinations is done for the entire system of Israel. Figure 6 shows the map of the RDP measure for the entire map of Israel. Figure 7 shows a bigger close-up of the central section with the stations that have the highest power values. It can be seen that the area around HaHagana station at the southern part of the city of Tel Aviv enjoys the highest RDP value, since it has a very central rail station combined with a good local urban road network around it. Another highlighted location is the area around Yoseftal station, which lies between the municipalities of Holon and Bat Yam just south of the city of Tel Aviv.

When super-imposing the SP map (Figure 4) on the pedestrian movement potential map (Figure 5), it can be seen that several of the train stations with the highest global accessibility in the entire system are located in areas with poor local accessibility and therefore low RDP value. This is especially true for Holon station (highlighted in Figure 7), where the entire surrounding area is underdeveloped, although the station enjoys high accessibility in the rail system.

This fact is also evident in the passenger boarding numbers of Holon station which has only 1,600 boarding passengers each day, a very low number when compared to the other centrally located stations (The central stations in Tel Aviv CBD handle around 50,000 boarding passengers per day, while medium size stations manage about 10,000 boarding passengers per day). This discrepancy between poor local accessibility and high global accessibility means that there is probably high potential for intense urban development around this station. Both of the stations mentioned earlier (HaHagana and Yoseftal stations) as well as the Holon station represent somewhat unsustainable station areas in Bertolini's model, where high accessibility is not accompanied by similarly high land use intensity and diversity.

In order to truly assess this model correspondence to the actual development a correlation between this calculated RDP measure and the actual land use intensity and diversity should be done. Areas where the land use development lags behind the accessibility potential should be looked into in order to understand and possibly implement steps to improve conditions for rail-oriented development at these locations.

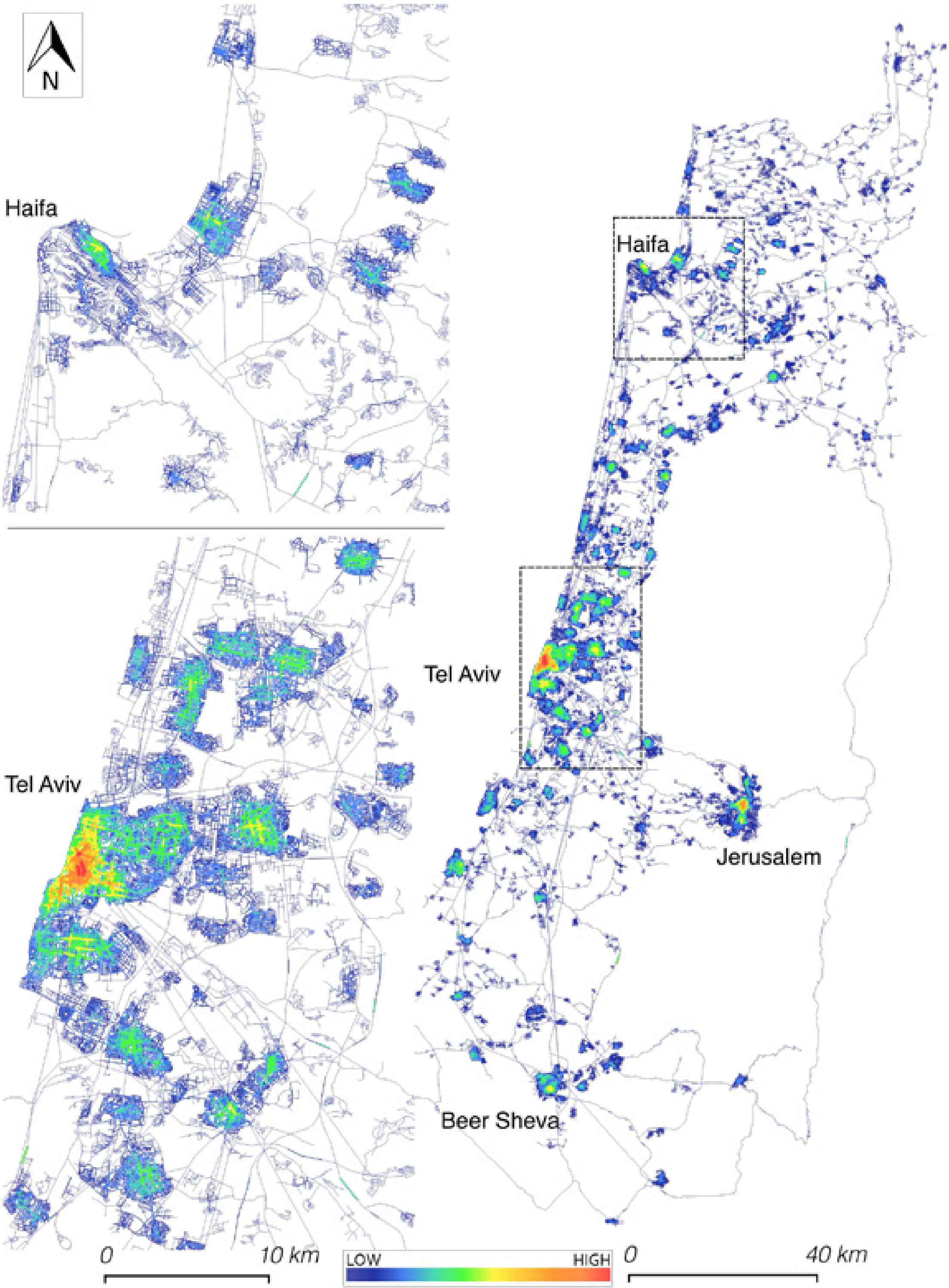

Figure 5 - The map of local level integration for the entire Israeli road network: (a) shows the entire map; (b) shows a close-up of the largest metropolitan areas – Tel Aviv and Haifa.

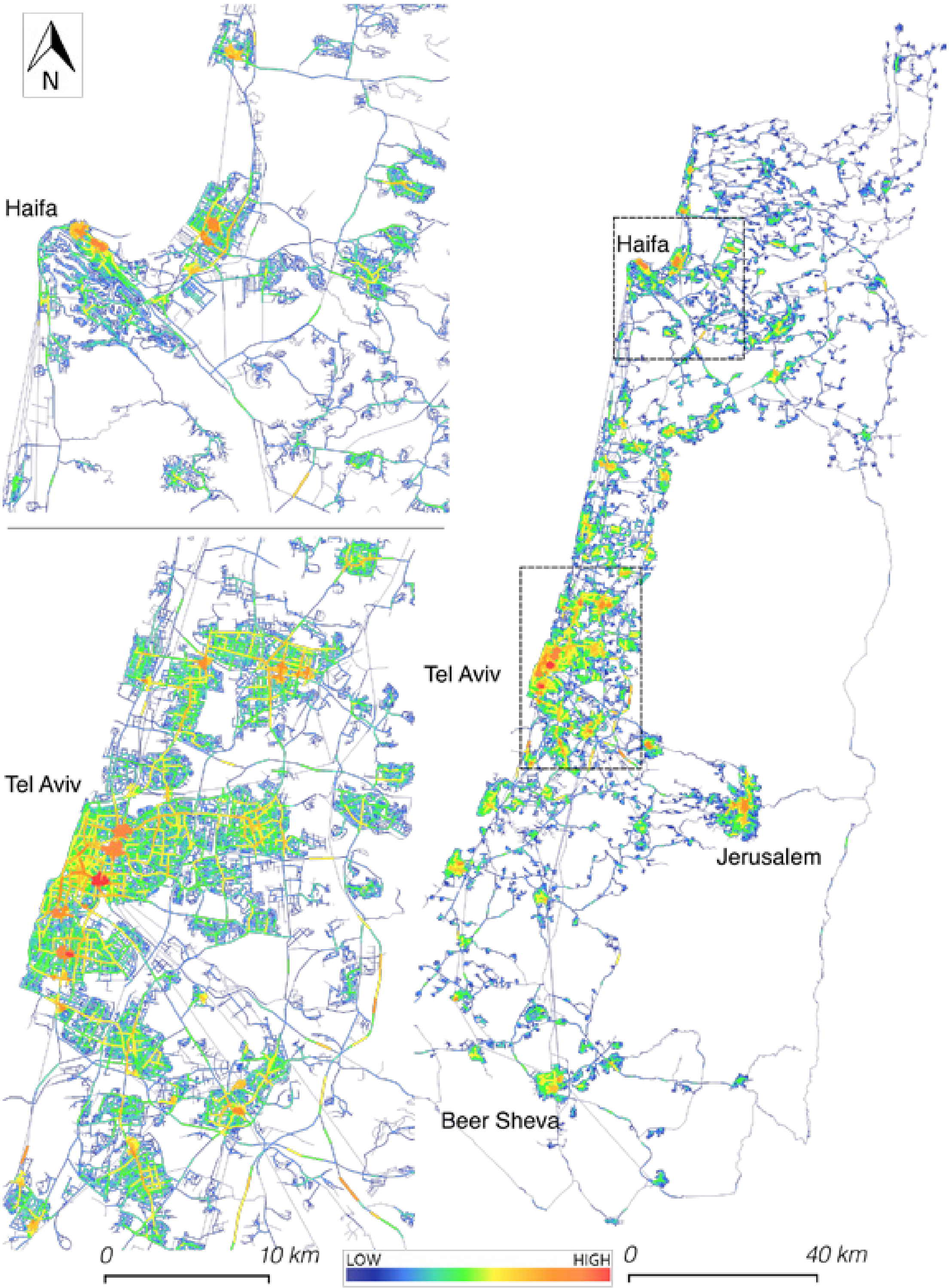

Figure 6 - The Rail-Development Potential (RDP) map for the entire Israeli rail and road network: (a) shows the entire map; (b) shows a close-up of the largest metropolitan areas – Tel Aviv and Haifa.

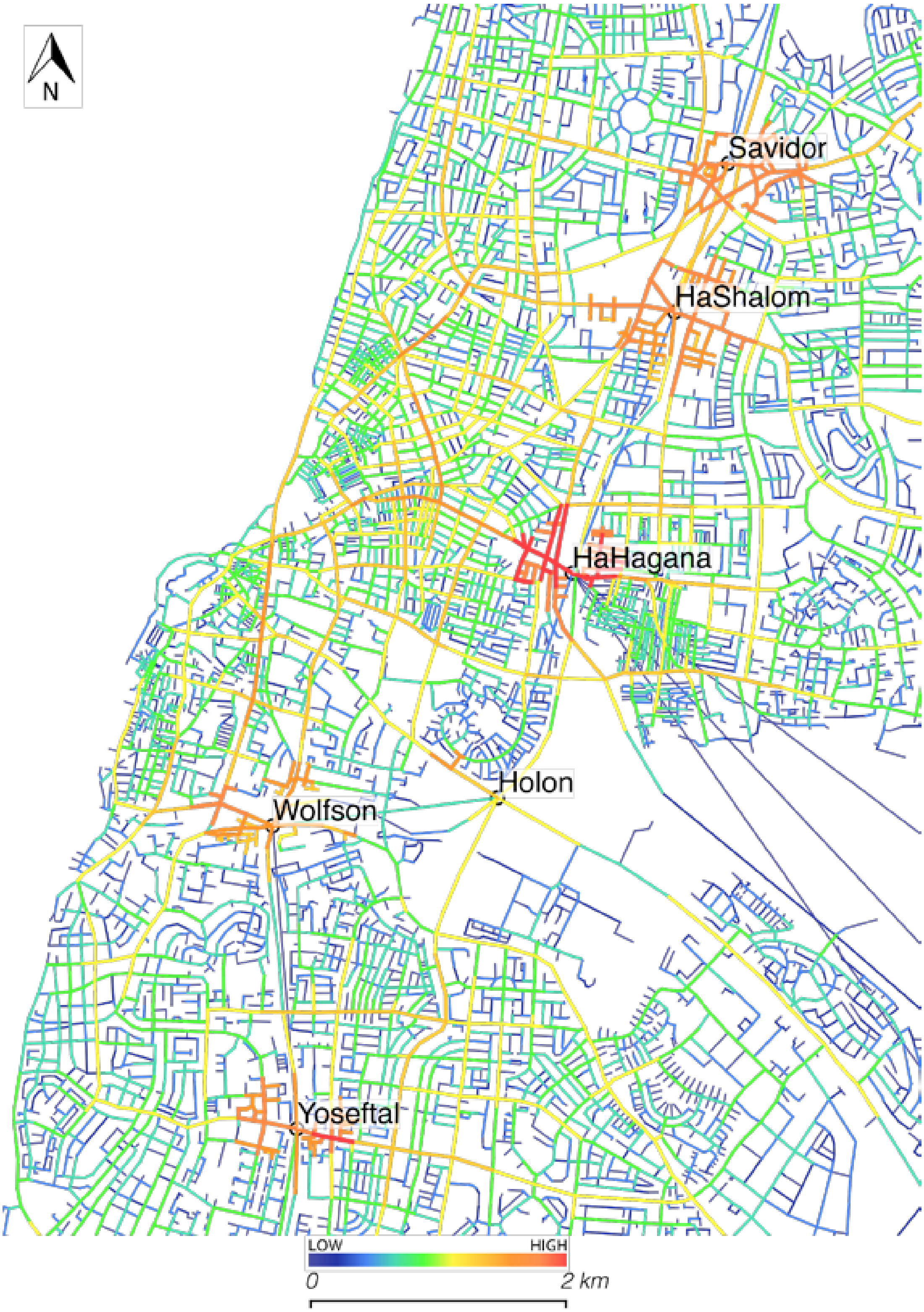

Figure 7 - The Rail-Development Potential (RDP) map for the most centrally located stations in Tel Aviv.

4. CONCLUSIONS

This paper presented a method to analyse rail station centrality and development potential using space syntax configurational approach. At the heart of the proposed method lies the combination of global flow accessibility (represented by an angular choice measure with a high radius distance) with local scale centrality (represented by an angular integration measure with a low radius distance).

Several limitations and proposed improvements to this study are put forth. This study has not used the actual frequencies and speed of the trains. To better represent rail superiority versus automobiles during rush hours, a simple multiplication by a factor of three for all of the rail segments choice values was applied. This altering of the system can be made more accurately based on real-world data with high resolution. Another incompatibility is related to the fact that several of the stations with the highest SP values have medium-level boarding numbers, yet we suspect that these stations are used heavily for train changes (especially the University and HaHagana stations in Tel Aviv where multiple lines meet and each of the stations has about 18,000 passengers boarding per day). This may mean that the stations with the highest SP measures have actually more people moving through them than reflected by the passengers boarding data, thus allowing for more retail development inside their terminals.

The case study used here was the Israeli railway network providing a relatively small national analysis. Further studies may assess larger road and rail networks, yet these assessments may be limited by the computational demands of larger systems. In addition, this study relied on the Open Street Map of Israel, which may have its own inaccuracies. Validating these results on an officially certified map would help assess their validity. As was mentioned before, this method did not take into account actual land use intensity and diversity existing around the train stations. A further step in improving the kind of analysis presented here would be to include and correlate space syntax accessibility measures (such as the SP measure and the RDP measure) to actual land use.

When revisiting Bertolini's node-place model (Bertolini, 1999) and this method's relation to it, we conclude that space syntax accessibility analysis at multiple scales can improve Bertolini's model and especially give it some kind of standardization. Furthermore, the relative quickness of space syntax analysis (the need for just one good map and not multiple databases) may shorten the time needed for this kind of analysis. Currently, accessibility analysis relies on elaborate time tables of multiple transit means, which makes the calculation needed non-standardized and cumbersome because of the amount of data required.

The real potential for the application of this kind of method in real world planning lies in its relative quickness and identification of rail stations where there might be a large potential for development, yet this potential is somewhat hidden. In the case presented in this paper, three train stations (Holon, HaHagana and Yoseftal stations) exhibited measures which imply that these stations' potential for transit-oriented-development is not fully realized. Furthermore, this kind of analysis may help in determining future stations locations or re-locations of existing stations to better capture and induce urban development potential. At times, in order to develop a station area, various infrastructure investments must take place to free the valuable land. This model can help in making these costly decisions.

In addition to rail network analysis, the method presented here applies an innovative combination of space syntax measures at different radii to make a single measure of development potential (referred to as RDP measure in this paper). In this case the combination took a choice measure at a large radius and combined it with an integration measure at a low radius. Other and more complex combinations may come to mind in order to assess alternative centrality regimes together. For example, combining motorized centrality may be achieved by adding a medium centrality radius into the mix. These kinds of combinations may improve assessment and visualization of complex transport interchanges both existing and planned. The visualization of the combined transportation means using a single measure is a powerful tool for policy making and for further integrating space syntax in actual urban and transport planning.

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